Index to the Tube Amp FAQ

Back to the GEO Home Page

Musical Instrument Tube Amp Building, Maintaining and Modifying FAQ

Much of this material applies to building or re-building hi-fi equipment, as well but it was originally intended for musical instrument crazies.

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Contributors

Thanks to the contributors who helped and taught me:

Hundreds of folks who taught ME stuff when I didn't know a triode from a Tri-Axis; I can't remember all of your names, and it all comes out as general knowledge now, but I appreciate it. A few names in that category stand out:

- Tom Balon David Mourning Mark Hammer

And people who have contributed things that I have included as part of the actual text:

- Dennis O'Neill
- Nathan Stewart
- George Kaschner
- David Kohn
- Michael Edelman
- Len Moskowitz
- John Stokes
- Brian Carling
- Eric Barbour

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Back to the GEO Home Page

Index

Contributors

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10. Can I convert an amplifier with an ultralinear connected OT to normal use?
11. Can I substitute two single ended transformers for a single plate-to-plate transformer?
12. How do reverse biased diodes act as "transient spike preventers"?
13. Can I use an ordinary pushpull output transformer as a single ended ultralinear output transformer?
14. What does the "impedance" of my output transformer mean?
15. Why do I have to match speakers to the output impedance of the amp?
16. Will it hurt my amp/output transformer/tubes to use a mismatched speaker load?
17. Can I use two single ended output transformers in a push-pull circuit and then parallel the outputs?
18. What are the things about output transformer that cause the differences in tone?
19. How can I tell if my output transformer is live or dead?
20. Where can I get a good replacement output transformer?
21. I want to make my own power and output transformers. How do I do this?/ Where can I find information about this?
22. Should I replace my stock transformer with a new/old/vintage/purple one for better clean/grunge/grit/etc. sound?
23. Are potted / impregnated transformers better? Is potting / impregnation necessary?

Power Transformers

3. What is the easiest way to get tube sound at a good price?
4. How can I modify my tube amp to ... ? (also see recommended mods, below)

   - get lower hum?
   - have higher gain/more distortion?
   - have a smoother, less buzzy distortion?

1. When should I bias my amp and how do I do this?

   - What is "bias"?
   - When should I bias my amp?
   - How do I bias my amp?
   - Matched output tubes - do you need them?

1. Amplifier Modifications

   - OK/Recommended amp modifications
   - NOT Recommended amp modifications

Back to the GEO Home Page

Basics of Tube Amps for First Timers

- Why use a tube amp?

  Tube amps have always been the amplifier of choice for the working musician. Musical myth has ascribed almost magical tone to them. While the results may not be entirely magic, tubes do have a sound that is different from solid state amplifiers, and one that happens to make amplified music sound better to the human ears and brain. There are lots of technical and psuedo-technical explanations for why this should be true, but there is enough solid evidence that it is a real effect to trust it. The real reason to use tube amps is simply that they sound better. For that advantage, we put up with the poor supply of parts, high prices, fragility and excess heat that they produce.

- Are Tube Amps louder than solid state amps of the same power?
  No. However they do SOUND louder. Let me explain.

  Some excellent scientific work on tube preamplifiers and their distortion products has turned up the mechanism for this. When tubes are driven outside their linear region, for the first 12db or so of overdrive the harmonics that they produce trick the human ear into thinking that the sounds are getting louder, when in fact the sound is getting progressively more distorted.

  It is this acoustic trick that can make tube amps sound up to 12db louder than they actually are compared to a perfect, undistorted amplifier. A solid state amplifier of the same power as a tube amp may distort at the same signal level as the tube amp, but the distortions are not subtle, and we hear them as distortion, not as a slightly louder sound. A solid state amplifier of much greater power would remain undistorted at higher levels, and the tube amp would sound comparably loud to the larger solid state amp.

They sound larger than they are.

What is "Standby" for?
Standby is used to make sure the amplifier is quiet and lower the power dissipation inside the amplifier during times when you will not need it for some period of time. Breaks in song sets are the ideal illustration. If you'll be coming back to the amp within a short period of time (under an hour, say), flip it to standby.

Standby also serves as a softer power up switch. To get the most possible life from a set of tubes, the tube heaters should really be hot before the main power supply is applied to the tubes. When tube rectifiers are used, the rectifiers do this almost automatically. However, when solid state rectifiers are used in an amp, the main power supply comes up almost instantly, and this can shorten tube life by the somewhat-esoteric means of cathode stripping. The standby switch can be used to prevent this.

- How should I turn it on and off?
  If it has a standby switch, flip this to standby, and then turn the power switch on if it is separate, or if the power switch is simply ON-OFF-Standby, turn it to standby. Leave it this way for 15-30 seconds, then turn it to normal operation. This gets the heaters hot before the main power supply comes up.

  To turn it off, simply flip the power switch to "off", don't use standby. This lets the still-conducting tubes bring down the high voltages in the power supply.

- How long do tubes last? When should I replace my tubes?
  It depends heavily on use. In a closet, the tubes will last forever, of course. For practice in a bedroom a couple of times a week at modest volumes, you'll probably get five to ten years out of them. If you practice twice a week for a couple of hours at full volume and play two gigs a weekend, count on one to two years out of a set of output tubes. Note that this assumes that you got good ones to begin with and that you had them properly biased when they were put in.

  Tubes wear out by sheer hours of being turned on, by how hard they're worked, how hot they get from just the heat in the box, by the number of times they're turned on and off (thermal shock). Notice that being played at maximum warp into a dummy load (or power brake, or attenuator, etc.) counts as being played hard, and that because you can't hear all the sound, you may not think that you're working them hard.

Your ears tell you when to replace them. When they no longer sound quite as punch and sweet as they used to, start thinking about changing them.

I have a somewhat more extreme approach, myself. The best time to get new tubes is when you DON'T need them. You get the chance to find the best tubes at the best price without time pressure. I prefer to keep a whole spare set ready. That way, a sudden burn out will not cripple the amp, and I can readily tell when one of them is just not sounding right by subbing in a replacement that I already have. Be prepared!

- Can I replace my own tubes?

  Preamp tubes - sure! They're in sockets, any replacement tube of the same type will at least not damage the amp.

  Even preamp tubes that are not exactly the same type can often be substituted as long as they have the same pin connections. For the commonest type, 12AX7, there are many types that have the same pinout and can be put in the same socket for different gains and tone. For instance, you might be able to use 12AU7, 12AT7, 12AY7, ECC82, ECC83, 7025, 5751, 6201, 6072A, 5814A, 12BH7 and others. See the section on tube substitutions for more info.

  Output tubes are more problematical. You really should have a tech check and if necessary adjust the bias on your output tubes whenever they are replaced. This keeps them from getting too hot. Power tubes are much more finicky than preamp tubes in this way, as preamp tubes do not in general need bias adjustment.

  You will undoubtedly have heard that you can substitute in other types of output tubes for better tone as well. This is getting into really tricky areas if you don't have the capability to open up the amp and rebias. You can imagine that if you have to rebias when replacing output tubes of the same type, you certainly have to with different tube types. That being said, there are a number of output tubes that have the same pinout. You should consult a competent tech befor doing this, as some of the "compatible" tubes may need minor rewiring or may use more heater current than your amp can supply. It's not a good idea to just swap in different types of output tubes unless you understand the different requirements they have.
- What things will damage my tube amp, what's safe and what's not?
  We'll assume that you don't need guidance about the obvious: don't drop it in a lake, or from a helicopter, don't pour it full of soda or beer, and so on.

A few more pointed do not's:

- Never, never, never run the amp with no speaker plugged in. This can cause major damage.
- Do not flip the power switch off, then back on rapidly. This can cause power supply damage.
- Never replace a burned out fuse with a bigger-amperage one. Remember - there was a reason the first one burned out, usually protecting something more expensive. Putting a bigger fuse in will just rachet up the power level until something really vital burns out. If the second equal-rating fuse pops, turn it off and get a tech to look at it.
- Never ignore signs of high heat inside - a wisp of smoke or a burning smell is NOT normal.
- Your amp produces lots of heat, and will continue to do so even if you block the fresh air vents. Blocking the vents will just allow the amp to heat to the point that you get to buy some very expensive repairs.
- Never ignore a red glow other than the small orange ends of the filaments. A red glow over a large part of the internal plates of the output tubes means they're about to melt (yes, really melt - heat is our enemy). If you notice this, shut it down and get a tech to help you find out what it wrong.

Correspondingly, you can do the following without too much worry:

- Add another speaker into the "external speaker" jack; a mismatched speaker load won't kill it, while an open circuit (disconnected speakers) may do so.
- Overdrive the stuffings out of it. Tubes are very forgiving of massive overdrives, unlike solid state stuff. As long as they tubes don't overheat or stay overdriven for long periods, it's not fatal.

Back to the GEO Home Page

*** SAFETY WARNING *** READ THIS FIRST!!!!!

Working inside a tube amplifier can be dangerous if you don't know the basic safety practices for this kind of work. If you aren't prepared to take the time to learn and apply the right precautions to keep yourself safe, don't work on your own amp. You can seriously injure yourself or get yourself killed. This section is not intended to be a complete guide to safety in tube equipment, just to hit the high points as refresher for those of you who have some experience. The best way to learn the requirements and practices for safety in tube equipment is to find someone who will teach you one on one.

BASIC REQUIREMENTS

- **UNPLUG IT FIRST** Pretty self explanatory. Do not, ever, ever, leave the equipment plugged in and start work on it unless you specifically intend to make some live-voltage measurement. Leaving it plugged in guarantees that you will have hazardous voltages inside the chassis where you are about to work. This is like setting a trap for yourself.
- **LET IT DRAIN** If the amp has been turned on recently, the caps will still have some high voltage left in them after the switch is turned off. Let it sit for five minutes after you turn it off.
- **SUCK IT DRY** When you open up an amp, you need to find a way to drain off any residual high voltage. A handy way to do this is to connect a shorting jumper between the plate of a preamp tube and ground. This jumper will drain any high voltage to ground through the 50k to 100K plate resistor on the tube. To do this successfully, you will need to know which pins are the plate pins. Look it up for the amp you're going to be working on. You'll need to know this for the work anyway. Leave the jumper in place while you do your work (high voltage electrolytics caps can "regrow" voltage like a battery sometimes. Really.) Remember to remove it when you finish your work.
- **TEST IT** Take your multimeter and ground the (-) lead. Probe the high voltage caps and be sure the voltage across them is down, preferably to less than 10V.
- **BUTTON IT BACK UP FIRST** Take the shorting jumper out. Put the chassis back in the cabinet, making sure all of your tools, stray bits of solder, wire, etc. are out of it. You don't have to actually put all the screws and so forth back in if you believe more work might be needed, but make sure that the chassis is sitting stably in the cabinet and won't fall out. At the end of a listening test, either continue buttoning up if you're done, or go back to UNPLUG IT FIRST.

Basics of Tube Amps for Beginning Users

Back to the GEO Home Page

Where can I learn about building tube amps?

Get one or more of the following references (note that these books are mostly old, and highly sought after, and so may be expensive and hard to find):

- "The Ultimate Tone" by Kevin O'Connor. This the best book on guitar amps I've found. It assumes you know some electronics to start with, so is not a beginner's book. Published by Power Press, which now has a web page at http://www.wwdc.com/~power/ .
- "The Tube Amp Book" by Aspen Pittman, now in its fourth edition. This contains the majority of guitar amp schematics ever made. Don't believe all the "technical information" as gospel, though.
- "Electric Guitar Amplifier Repair Handbook" (?) By Jack Darr. Good intro to actually making repairs as well as many schematics.
- "ARRL Handbook", preferably a late 60's or early 70's edition. Read the sections on construction practice, safety, and tube info.
- Guitar Player Magazine's article on tube types and operation from a year or so ago
- Glass Audio magazine, Old Colony Sound in Peterboro NH
- Mesa/Boogie will send schematics of their amps, call 1-707-778-6565; note however, that these schematics are known to be inaccurate.
- "Vacuum Tube Amplifiers" by G.E. Valley, Jr. Part of the MIT radiation lab series, originally published by Boston Technical 1964. Reprints are currently available from Antique Radio Classified (P.O. Box @, Carlisle, MA 01741, 508-371-0512)
- Amplifiers, H. Lewis York. (Evidently part of the Encyclopedia of High Fidelity). Good basic technical ref. Simple math, good explanations. Includes a couple of designs (several use hard to find tubes) and tips on physical construction as well.

- Radiotron Designer's Handbook, Langford-Smith. Heavy theory, heavy technical. Not coffee table reading, but if you want to know, it's probably in there. This book is perhaps the most highly sought after tube related book, and commonly goes for $75-$100 in good shape. You want the 4th edition.

Old Colony Sound just announced a CD ROM version of this book, apparently indexed, illustrations and all, for $69.95.

- RCA Receiving Tube Manual. Reprints available from several sources, including Antique Electronic Supply & others (Old Colony?) Mostly tube spec sheets & some characteristics charts. The intro is a pretty good technical primer.

- Electron Tubes, R.G. Kloeffler. little application, but a good easy to digest explanation of characteristics of diodes, triodes, beam power & true pentodes, with the math to go along. Worth reading if you're trying to do modeling.

- The Audio Designer's Tube Register. Tom Mitchel. 1993, Media Concepts. Volume 1 - Common Low Power Triodes. 144 pages of freshly compiled tube data, some of which was not previously published. Kinda pricey ($18 from Antique Electronic Supply) unless you need the data. Included are plate characteristics, transfer characteristics, constant current curves, mu as a function of grid potential and plate potential, transconductance as a function of plate current and grid potential, and dynamic and static plate resistance as a function of plate potential and plate current.

(Tom mentions a 2nd and 3rd volume in the distant future - covering low power pentodes & oddball tubes, and Power & Beam Power pentodes respectively.)

- Learn about the manual and safety aspects of working on tube amplifier circuits. Read the ARRL handbook, or better yet, get to know a ham radio operator who will give you some guidance and teaching. Do not skimp on the safety aspects. Tube circuits contain deadly voltages. You can - * DIE * - if you mess up or are careless. It is your personal responsibility to learn how to do this safely.

- Get to know a guitar repair technician, perhaps do some free apprentice grunt work for them in return for some teaching.

Back to the GEO Home Page

Where can I find parts to build/repair amplifiers?

When I first wrote the Tube Amp FAQ almost ten years ago, tubes were a dying breed. In that decade, the tube world has turned around. Today, there are major sources for tubes and parts. The list is long enough that I'm severely cutting back this section.

New tube parts and supplies were steadily getting harder to find in the 80's, but in the last decade this has turned around radically. There are now many companies offering new parts, especially power and output transformers. It is still true that used parts are often nominal cost or free. The hard parts to find in high quality are the transformers.

If you're building, I recommend getting your transformers first. If you are getting vintage parts, they are likely to be one-of-a-kind. If you've just ordered new ones, the transformers will have a massive effect on your chassis's mechanical layout.

The easiest but most expensive source for parts is at your retail musical instrument store as "repair" parts. Other sources:

- Musical instrument repair shops will sometimes order parts or sell you parts out of their stock.
- Amp makers' repair parts departments. Many manufacturers will sell their parts to "repair shops" to fix their amps. Some of them are better than others about this, so be polite and businesslike.
- old, broken, or unloved equipment. This may be free, or units-of-dollars. You get transformers, sockets, tubes, and chassis in the deal. May require cruising garage sales or diving in dumpsters. Trash every part except the tubes, transformers, sockets and chassis. I got a 15 Watt mono amp/preamp intended for mono hi-fi music for $20 at a local garage sale. Needs only some tweaking to be a Studio .22 or an AC-15.

Are Carbon Comps really magic tone mojo?

Maybe. Like everything else, there's the hype, and then there's the real world. A good maxim to remember about electronics is that if you can't express it in numbers (that are also measurable by someone else, not just made-up numbers) then you really don't know the thing at all, you're only believing the myth.

The vintage amps we all love had CC's in them, and they certainly have their share of mojo, but the makers of those amps in the 50's and 60's used them because that's what was available. Today we have lots of resistor options. What's different about carbon comp, and can we express it in numbers so we don't keep being superstitious?

So I went to the internet and searched for manufacturer's info on CC's. The makers themselves admit that carbon comps have excess noise, high drift, high pulse power, and high variability. They also have a high voltage coefficient of resistance. Voltage coefficient of resistance?? What's that?

That means that the resistance actually varies with the voltage across the resistor. The resistance is actually different if you put 100V across the resistance than if it's got 0V across it. What that means to us is that if you put a 50V DC level across a CC resistor and a 100V sine wave superimposed on that, the sine wave will be measurably distorted by the resistor itself. We have ***resistor*** distortion.

The distortion is pretty much pure second harmonic. In small amounts, you can't hear second harmonic as distortion, only a certain amount of "sweetening" or liquidity to the tone. That's what carbon comp resistor mojo really is - the resistors are distorting, but in a way our ears like.

The manufacturers also document that CC's have excess noise and bad drift with temperature and aging. That makes them a two-edged sword. Put everywhere in an amp, and they'll both sweeten the tone, and at the same time induce hiss. A little thought leads us to the following guidelines for using carbon comps for tone mojo:

1. high voltage across the resistor is necessary, in the range of 100V on up
2. large signal swings across the resistor are needed - ideally, a large fraction of the static DC voltage so you have signal swings of 50 to 100V too.
3. only positions in the amp that have both high DC voltage and wide signal swings as in 1 and 2 will give you enough resistor distortion to benefit from; other places should be chosen for low noise and/or economy.
4. resistor power rating should be the minimum needed to work for a reasonable life in the circuit to maximize resistor distortion. Maybe a good guideline is that the dissipation should be selected to be as close to two times the average dissipation as possible.
5. as a corollary to the power guideline, we should be prepared to replace CC's every few years as the life at high temp makes them drift and get noisy (-er).

Guidelines 1 and 2 are simply the recognition that the voltage coefficient of resistance is not very big. In fact, although the coefficient is small, it was specified to be small by the makers and controlled tightly, indicating that it was a recognized problem. In the Radiotron Designer's Handbook (4th edition, pg. 1345) they list the JAN-R-11 specification for CC resistors as less than 0.035% per volt for 1/4 and 1/2W resistors, and 0.02% per volt for higher power ratings. Given that the max voltages for these parts was 1/4W-200V; 1/2W - 350V; 1W and 2W - 500V, that works out to a 7% change in resistance for a 1/4 W part used at its max voltage, a 12.3 % change for a 1/2W, and a 10% change for bigger resistors. That's one of the thrusts of guideline 4 - pick the smallest dissipation resistor you can, to maximize the coefficient.

Of course, that's as big as the effect can get, and you would have to carefully set up the situation to get that much resistor distortion. In an amp, you probably won't be able to get that close to max voltages or signal levels. Realistic levels might be 200V across a 1/2W resistor, and a 75V signal swing. That would give you a 2.6% distortion - enough to be audible as sweetening. That's the point of guideline 3 - you have to have a big enough signal swing across the resistor to have the signal distorted significantly by the voltage coefficient.

But with a 10V signal, you only get 0.35% distortion, and it starts down the slippery slope to inaudibility. More importantly, these percentages represent the maximum beyond which a resistor would have been rejected in the 1950's. Today's CC resistors are much lower distortion. From IRC's web site, we find some numbers. A typical resistor voltage coefficient can be seen at http://www.irctt.com/pdf_files/IBT.pdf - which shows carbon comp at 0.005%/volt for that company's products. Another was 0.008%/V. These are smaller than the max allowed under the JAN military spec.

So where do they work best? Where can we use CC's for their soft distortion, and where can we sidestep them to lower noise?

First, they do no good and lots of noisy bad where the signal level is small and the following amplification is high - a classical description of an input stage. The input to an amp should probably have a metal film plate resistor to minimize noise. Grid resistors in all but output stages also do no good, because the signal level is typically too low. A 12AX7 can be driven from cutoff to positive grid voltage with a couple of volts of signal, so the grid resistor never has a big enough signal to be distorted appreciably.

Cathode resistors are another poor use of CC. They typically only have a few volts across them, and they're often decoupled with a capacitor, both of which would minimize the resistor distortion. In cathode followers, there can be substantial DC and signal voltage across a cathode resistor, but in this case, the resistor is driven by the low impedance of the cathode, and the voltage across the resistor is controlled by the grid voltage very tightly, so the exact resistor value doesn't matter much - there won't be significant distortion.

The place to use CC's is where there's big signal - plate resistors, and ideally the stage just before the phase inverter. The phase inverter would otherwise be ideal, with plate resistors carrying the highest signal voltage in the amp, but phase inverters are often enclosed in a feedback loop. The feedback minimizes the distortion the resistor generates.

Use CC's sparingly - only where your personal ears tell you that they make a difference.

I'm always amused at people who advertise putting carbon comp resistors in their 9V powered effects to give them some kind of magical vintage sound. Urban legend is tough to kill, though - and magic mojo always makes for dynamite advertising copy.

So now you know what's happening, and something of the numbers involved. The effect is real, though slight.

Back to GEO!

How can I modify my Blender Tweety Bird amp to be as loud as a Marshall Major/AC30/Tweed Bassman/SVT/ etc.?

(Alternatively, how can I make my amp twice as loud/more power/ etc.?)

You can't do this in a low power amp, at least not electronically. To put out the power the big amps put out, you need the entire power train to be as beefy as the big amps. This means bigger power transformer, rectifiers, filter capacitors, output transformer, more power tubes, bigger chassis, more ventilation to carry off the heat, lots of things. You can't just add a couple of tubes.

An amplifier is properly thought of as primarily a big power supply that has some extra junk tacked onto it to carefully let a little of the power out to the speakers under special, controlled circumstances.

You might be able to just pull a couple of tubes OUT of a high power amp to make it quieter, under some conditions. O'Connor discusses this in "The Ultimate Tone".

Back to the GEO Home Page

How can I extend my tube life?

- Modify the power on switching to heat the filaments first, let them warm up for 30 seconds, then switch on the high voltage plate supply.
- Add more ventilation to the amp chassis, perhaps with a small fan.
- Modify the tube operating conditions so the maximum cathode current is not exceeded under even maximum warp drive conditions. Exceeding max cathode current causes cumulative emission losses and early tube death. This requires a somewhat deep understanding of the design of tube amps to do, unfortunately.

Back to the GEO Home Page

How do I get...

- Blues distortion? Made by overdriving preamp and power tubes a little, enough to just start compressing the peaks of the waveforms, and not very much high frequency content, by electronically cutting highs or running the signal into a speaker cab that acoustically cuts highs.

Guitar Player magazine ran a construction article on this very topic, modifying a Fender Bassman to be the "Ultimate Blues Machine". The article ran in 1995, authored by John McIntyre.

A recently voiced although intuitively applied idea in distortion is that tube distortion sounds best when each successive distortion stage is overdriven by less than about 12db. This has the effect of keeping the tubes inside the area where the signal is more compression-distorted than clipped. That is what those resistive divider chains between distortion stages are for inside those distortion preamp schematics. Mesa's distortion preamps are another good example.

Overdriving a tube stage too much gives you harsher clipping, not the singing, sweet distortion we want. To really get sweet, crunchy distortion, keep each stage that goes into distortion no more than 6-9db into distortion.

- Marshall/metal/Boogie/etc. distortion? Made by massively overdriving preamp tubes until the original waveform is massively compressed and clipped. Usually followed with a moderate amount of high frequency cut to remove some of the "insect attracting" overtones generated in the clipping process. There is commonly some output tube overdrive in this process, too.
- Good distortion at low(er) volumes? overdrive preamp tubes until you get the clipping you want, then feed a limited amount of this to a power amp stage to get the loudness you want. This is how master volume controls work.

Back to the GEO Home Page

Where can I find plans for a Belchfire/Maximo/etc. speaker cabinet?

- ElectroVoice sells (?) makes available (?) plans for cabinets for their speakers.
- Copy an existing cab.
- Some cabinet fitting suppliers have example plans.
- -- (addresses in a future posting) ---

Back to the GEO Home Page

Output transformer questions:

Q: Do output transformers sound different from one another? If so, why do they sound different? Can you for instance wind a transformer to get an intentional frequency response? Like, you think your Marshall has too much midrange, so you put a new OT in that has like a 6-9dB cut around 800hz to get a natural "scooped" sound?

A: These things cause transformers to sound different:

- High and low frequency roll-offs caused by the details of the iron, copper, winding and manufacturing processing.
- Inherent distortion caused by the magnetic properties of the iron and the driving impedance
- Excess distortion caused by lack of coupling between sections of the windings - literally where all the windings are in relationship to one another - in a Class AB or B biased

amplifier.

High and Low Frequency Roll-offs: Transformers all by themselves have a high end rolloff point and a low end rolloff point, and a broad flat region between the two. The exact frequencies where the highs and lows roll off are a characteristic of the iron, copper, and how they're wound and stacked together and treated or mis-treated.

It is possible to get a resonance or two between the two ends, but most often there is only a self-resonance point above the high frequency end. Usually any reasonably well-made output transformer has no oddities within the high and low frequency roll-off points.

Given enough info about the transformer and the use (power through it, temperature, DC bias current, etc,) you can use the parasitic parts of the transformer's response, the unavoidable self capacitances and leakage inductances, with other components outside the transformer to shape the frequency response inside the relatively flat pass band; this is more like shaping it externally than designing the response into the transformer, though. The parasitics are largely what cause the high and low frequency cutoffs, so it's not easy to move their effects out into the passband with simple circuits.

You can design in a high and/or low frequency response point, and you may be able to tinker inside the passband a little, but even an experienced designer can't easily just design in a scoop of arbitrary depth at a given frequency with only the transformer windings to work with.

Inherent (or Iron) Distortion: It's not widely understood, but transformers have their own distortion generating mechanism. The iron in a transformer has to be driven to a certain magnetic flux level to couple signals to the secondaries. The output tubes must supply this magnetizing power as well as the power to the secondaries. A well designed transformer can make this power very small. However, the nature of the iron itself is that the magnetizing power is non-linear. It takes proportionately more or less magnetizing power at different magnetization levels, so the iron siphons off more or less of the signal.

This depends on the core material linearity and magnetic softness, and how close the transformer is driven to saturation. The amount of distortion depends, among other things, on the source impedance driving it, as the distortion comes from the nonlinear shunting effect of the transformer's primary inductance. A voltage source driving a transformer will be able to be distortion free on the secondary. A high impedance drive source (like a pentode plate, unfortunately) will not be able to provide all the current the core needs to keep the voltage linear, and so some distortion will show up on the secondary as a result. This distoriton is relatively small, probably 2-

5% below the beginning of saturation, and is primarily third harmonic.

Excess Distortion: Only in push-pull Class AB or B amplifiers (that is, most guitar amps) when the crossover point where one tube turns off and the other tube carries all of the power load, EVEN IF THE BIAS FOR THE TUBES PROPERLY ELIMINATED TUBE CROSSOVER DISTORTION the sudden change from two half-primary windings conducting all of the power to the the secondaries to only one tube supplying the secondaries, if the magnetic coupling from both half-primaries to the entire secondary is not excellent, there will be a glitch in the output waveform caused by the change in current in the leakage inductance in both the half-primary that is turning off and the one turning on. This crossover distortion can not be biased away. Cheap, non-interleaved output transformers often have this kind of distortion and sound "harsh".

Q: Obviously, output transformers have tolerances. Are the impedance tolerances the reason one OT may sound better than another?

A: The impedance ratio(s) of a transformer are fixed by the number of turns on each winding, and it's unusual for modern winding machines to forget or miss a turn. Can happen, but it's rare; so the impedance ratios are not what are the biggest contributors to tone differences.

Q: Are paper bobbins really superior to plastic bobbins in output transformers? How about power transformers?

A: No. Both paper and plastic are non-magnetic and non-conductive. The only way they can affect a magnetic field is by taking up space and therefore excluding either a conductor or a magnetic material from that space. As long as the winding window is reasonably filled with turns of copper wire, the effect of one bobbin material versus another is essentially impossible to find even with sensitive lab instruments designed for work on such things. The business about paper bobbins being thinner and letting the copper wires be nearer the core is nonsense. The entire iron core "conducts" the magnetic flux. Moving a turn of copper a tiny fraction of an inch closer to the center leg moves it that same fraction further from the outer leg. As long as the dimensions for paper and plastic bobbins are not grossly different (and the differences between old paper -actually glued-up cardboard- bobbins and plastic bobbins are tiny) then there is no reason that the magnetics should be affected at all.

There is some reason for this myth being started, though. The output transformers from the "golden age" were pretty much all hi-fi output trannys. This meant they were, among other things, carefully interleaved and wound. The earliest plastic bobbins were wound not to get good sound, but because the MBA's that had infiltrated the guitar companies were trying to save a buck. A quick and dirty, lowest-bidder transformer wound without interleaving on a plastic bobbin and laminated with cheap, thick iron costs less than a good on from an old-line hifi maker, so that's what they started making. The plastic was not the problem, but it was all that the uneducated user could see, so plastic got an undeserved bad rep.

Let me be clear - IT'S NOT THE BOBBIN, IT'S THE DESIGN AND ASSEMBLY.

Q:Are differences in transformer sound in the pattern of the windings? Or something else?

A:Having pooh-poohed the idea of paper bobbins being better with the "a turn's a turn" argument, I hesitate to get into this, but I guess I should. The thing that makes for an OT tone is the sum total of the contributions of all those parasitic elements in the transformer - the series wire resistance, the leakage inductance in the magnetic path, the turn-to-turn capacitance, the layering and distribution of layers in the window, the depth of the core stack, the thickness of the iron in the laminations the -*magnetic softness*- of the iron in the laminations and how carefully they have been interleaved and butted together, and how free the laminations are from electrical contacts.

Paper bobbins are one of the few things that DON'T affect a transformer's tone, all other things being equal.

It is really a no-brainer to copy a transformer, but you have to know about and be able to copy all of the details about how it's made. Once you do that, you get fairly repeatable results, with the exception of the handling of the iron. Transformer iron is annealed to be physically and magnetically soft (which go together), and an oxide layer is grown on it to prevent the layers from electrical contact, which affects how much core loss happens. If the iron is roughly handled, it gets hardened and has more core losses and higher distortion, as well as having the oxide scraped and or punctured, which increases eddy current losses. These will have an effect. You can detect the changes in magnetic characteristics of transformer iron by testing the iron into a test coil, then striking it sharply EVEN ONCE. I've performed this test myself on occasion.

Care in stacking the iron and jogging it together also has an audible effect. If the laminations are carefully jogged together so the joints are as tightly fitted as possible, it runs the primary inductance up and the low frequency rolloff down, making for a better bass response.

All this sounds obscure, but is really much easier than learning to play guitar on an intellectual scale. It's just another special language to learn. Most people just don't go there, so it gets shrouded in myth.

Q: I remember reading Matchless's (or others...) ad stating they copied the OT of an incredible sounding amp and that was the key ingredient of their sound. What was it they copied, impedance or winding pattern?

A: They had to do both to get a good copy - as well as having to duplicate or approximate iron composition, thickness, and stacking.

Q: Is hand winding superior to machine winding for output transformers? When a known "good sounding" vintage or modern transformer is duplicated, will modern equipment should be able to consistently reproduce them without varying results? Is hand winding being superior to machine winding is a myth?

A: The devil is in the details. Machines can produce goods with a consistency that a human hand/eye/brain simply can't, so where pure replication is required, bet on the machine. Whenever the materials/ situation/adjustments, etc. require judgement and on-the-spot compensation, bet on the human - IF the human is an expert at whatever the situation is.

I would say that historically, the real situation is that cheaply produced and poorly designed (for instance, non-interleaved) machine wound transformers were accurately reproduced, and sure enough, the sound was reliably bad. A good hand winder repro-ing a carefully stacked interleaved OT could, in spite of the inevitable slight variations and flaws produce a much better sounding transformers - at a much higher price - in low quantities. A myth gets started - "I used so-and-so's hand wound OT, and it ran rings around the machine-wound replacements," which is demonstrably true, but then the leap to myth is made "therefore only hand wound transformers are good." This train of reasoning is so seductive in the "vintage-is-god" environment that it almost instantly becomes common wisdom, putting the merit on hand winding when in fact the differences were in different designs.

For duplicating windings, a well made, well adjusted and well maintained machine will produce more consistently identical windings than a human. Note that I put a number of caveats on that statement.

An expert human with little or no equipment will produce better, more consistent goods than a bored, ill-trained, poorly paid operator coping with the wrong wire size on a poorly adjusted forty year old machine, which is how some (especially the cheaper) transformers get made.

So - is the notion that handwound transformers are ALWAYS superior BECAUSE they're hand-wound a myth? Yes.

Are hand-wound transformers SOMETIMES superior to machine wound?

Yes, especially where the hand-winder is producing a different design from the machine.

I'd call the quality pretty much the same for hand-wound and machine wound transformers where the hand-wound ones are produced in low quantity by experts (a caveat that excludes fatigue and skills flaws) and the machine wound ones are made on modern equipment with skilled operators in large quantity (which allows adjusting the machines for consistency).

Q: I've read references to modifying PP OTs, adding a mysterious "gap" (mysterious to me at least) for SE use. What does that mean?

A:Probably this: process of adding a gap means carefully unstacking an interleaved PP transformer, restacking the E's and I's into non-interleaved chunks and reinserting the bobbin with a spacer. This gets you a transformer that has a lower primary inductance, but that won't saturate as easily. It's probably not what you would originally have designed for any given SE circuit, as the primary inductance is now lower, but it might work. And it REALLY appeals to the home-handyman tube hacker crafstman instinct.

Q: What are "gaps" in output transformers, and why are they good?

A: The "gap" in single ended transformers is just that - a space where there is no iron. The way this is done with E-I cores is to stack all the e's together and insert them into the bobbin in one chunk, then put a paper or fiber spacer across the end of the "E"'s, and then the I's are laid on in a chunk. The point of this is that there is now a gap where there is no iron bridging it that makes the magnetic field jump across. This linearizes the magnetic properties of the structure as a whole, as the properties of the gap are so different from iron that they dominate, and the gap cannot saturate like the iron can.

The overall primary inductance is much lower now than if you had interleaved the laminations, alternating the direction of the E's in the center of the transformer, though, so you must use much more iron and copper to get as much primary inductance and low frequency response as you would have had if you'd interleaved the laminations, so the transformer gets big expensive, and can support much less output power for its size than it might otherwise. Ten watt gapped single ended OT's for instance may be four to six times as heavy as Class AB transformers designed for fifty watts out.

Q: Can I use a push-pull OT in my single ended amp? How about if I re-stackit to have a gap?

A: The use of PP OPTs for SE is cautionary. The problem is that you must run the bias current through the primary as DC, and this offsets the core magnetically. A transformer which uses interleaved laminations (almost all PP OPT's) has a much higher primary inductance, but is easy to offset and make the iron saturate. Introducing a gap makes the primary inductance lower, but makes the transformer much more resistant to saturation, good for SE OPT's. Using an interleaved PP OPT in SE use necessarily limits the amount of DC bias that can be used without saturation and the corresponding distortion. It works if you keep the DC bias current low enough to not saturate the core, but that limits the amount of power you can use. So in general it probably works if you use a BIG PP OPT for a much smaller SE amp. As a tube hacker, I can understand the urge to just hook up whatever you have that might be a good output, but as a former transformer designer, there are going to be cases where it will not work or won't work well. Experiment if you like, but be prepared to toss the transformer and/or output tubes if they fry, or tear it all down if it just doesn't sound good.

Q: What is an "ultralinear" output transformer?
A: It's a transformer with a tap at about halfway between the B+ connection and the plate connection to which you can attach the output tube's screen grid. This connection provides some feedback to the screen grid as well as a bias voltage and has been found to act like a connection halfway between pure pentode modes and pure triode mode, with lower distortion than either. It's almost a requirement for tube hifi ampliers. Bass amplifiers use it to get large amounts of clean power. It usually sounds too "sterile" or clean for guitar players' tastes.

Q: Can I convert an amplifier with an ultralinear connected OT to normal use?

A: Yes. Just disconnect the ultralinear taps and make sure they don't short to something, then connect the screen grids to a screen voltage supply. This is a common mod to UL connected amplifiers for guitar use.

Q: Can I substitute two single ended transformers for a single plate-to-plate transformer?

A: If you have two single ended transformers, these are running effectively in parallel. It makes no difference whether you are driving them from a phase inverter or not, because the phase on the two (independent) output windings can be changed either way by reversing the leads. This is not going to give you the same operation of either the transformers or the tubes as a true plate to plate transformer. The real plate to plate transformer actually combines the tube power in the flux in the iron, which can never happen in two separate transformers.

Hooking two transformers together to combine the output power is always tricky, series or parallel, because if you combine them wrong, there can be large circulating currents, which can kill the transformers. How did you determine the proper phasing on the outputs when you connected them up? It is coneptually possible to series two outputs and have everything work, but in practice, it's hard to do this well.

For a series connection, you MUST get the secondary voltages to add. If you get the secondary voltages offsetting each other, the series connection is effectively open circuited, no matter what load is on the series combination no current flows because the secondary voltages cancel out. In this connectio, you probably kill the primaries by arcing over the internal insulation, possibly followed by burning the winding open when a turn or two shorted from the puncture in the insulation and the B+ caps dumped through that short.

The safe way to find out the phasing is to use two resistor-loads, one per secondary, and then to connect one end of each secondary together; drive the amp with a signal generator and measure the AC voltage across the free ends. If the voltage is 2X the voltage on either secondary, you're phased correctly, and you can leave the center connection where it is, remove the resistor loads, and put one speaker across the free ends.

If the voltage across the free ends is smaller than the voltage across either secondary, they're phased wrong, and you need to swap the ends of one secondary. Combining the powers of two SE transformers is best done acoustically. Drive a second speaker.

Q: I've seen circuits that use reverse biased diodes connected from ground to the plates of output tubes as "transient spike preventers". How does this work?

A:The 1N4007's serve mainly as an amulets against the voltage gods in this case. An inductive flyback pulse will go to literally ANY voltage until it finds a discharge path. Ideally, transients that would cause very high positive voltages on one push-pull plate would cause high negative voltages on the other plate, and the diodes on the negative going plate would clamp the voltages on the positive going plate through the output transformer. This does indeed happen for small, extremely-tightly coupled transformers. However, any leakage inductance between the two primaries prevents the tight coupling that would let the negative going diodes protect, and worse yet, it's the leakage inductances that cause the spikes on transients anyways.

What really happens is that the first few flyback pulses that occur will break over the 1N4007's rather than than arcing the plates on the positive side, so there really is some protection, it's not just where it looks like it is. If you're lucky, the 1N4007's break over before the transformer insulation punches through, and all is well until the 1N4007's go leaky or short. Probably better than nothing, but not a whole lot of additional protection, either. Heck, amulets are not harmful, I guess.

Q: Can I use an ordinary pushpull output transformer as a single ended ultralinear output transformer?

A: Maybe. It's cheaper than getting one originally designed for that use, but you do have to consider it as experimental - it may or may not return good results, and you may have irretrievably damaged a working OPT, which may or may not be a tragedy, depending which transformer it was and whether you paid real dollars for it and how many. You can try it, but consider the transformer expendable.

Q: What does the "impedance" of my output transformer mean?

A: Transformers don't have impedances, they have impedance RATIOs. This is an important distinction.

Transformers transform impedances as a pure ratio. That is, a 4400 PP to 8 ohm transformer makes any load on its secondary look like it's 550 times bigger to a tube at the primary. An 8 ohm secondary load then looks like a 4400 ohm load at the primary. It also makes a 16 ohm load look like an 8800 ohm load if you hook 16 to it, 2200 if you hook a 4 ohm load to it, and similarly for all values in between. Power tubes have a power output that depends on matching - that is, they have sweet spot load that they do best on, most power out, and other loads will get less power because the tube itself limits how much power it will transfer out. [Actually there are two sweet spots, one for highest power, one for lowest distortion; the two spots are not the same for any known tube. From zero ohms loading up to some ill-defined number of ohms higher than the optimum power load, power tubes do not destroy themselves, they merely change how much they transfer to the load. So - if you have a tube amp with a tap for 8 ohms, you will get the nominal power of the amp only with a "matched" 8 ohm load. If you hook 16 ohms there, the power tubes "see" a proportionately higher ohmage on their plates, and can only put out about half the nominal power. If you hook up a 4 ohm load to the 8 ohm tap, the power tubes "see" a load about half of the matched one, and again will put out only about half of the nominal power. This "half the nominal" power is not fixed because of the 2:1 change in load, but varies from amp to amp and tube to tube, and may not be exactly 2:1. In addition, speakers are NOT single impedance loads. It is convenient to think of "8-ohm" speakers, but the plain fact is that the speaker's impedance varies with frequency and also with the acoustic loading (cabinet and other things) that the speaker sees. That impedance meter is not going to be a huge help, because you have to specify the frequency being tested as well as the impedance to have something meaningful.

Q: Why do I have to match speakers to the output impedance of the amp?
A: You'll get the most power out of the amp if the load is matched.

Q:Will it hurt my amp/output transformer/tubes to use a mismatched speaker load?
Simple A: Within reason, no.
Say for example you have two eight ohm speakers, and you want to hook them up to an amp with 4, 8, and 16 ohm taps. How do you hook them up?

For most power out, put them in series and tie them to the 16 ohm tap, or parallel them and tie the pair to the 4 ohm load.

For tone? Try it several different ways and see which you like best. "Tone" is not a single valued quantity, either, and in fact depends hugely on the person listening. That variation in impedance versus frequency and the variation in output power versus impedance and the variation in impedance with loading conspire to make the audio response curves a broad hump with ragged, humped ends, and those humps and dips are what makes for the "tone" you hear and interpret. Will you hurt the transformer if you parallel them to four ohms and hook them to the 8 ohm tap? Almost certainly not. If you parallel them and hook them to the 16 ohm tap? Extremely unlikely. In fact, you probably won't hurt the transformer if you short the outputs. If you series them and hook them to the 8 ohm or 4 ohm tap? Unlikely - however... the thing you CAN do to hurt a tube output transformer is to put too high an ohmage load on it. If you open the outputs, the energy that gets stored in the magnetic core has nowhere to go if there is a sudden discontinuity in the drive, and acts like a discharging inductor. This can generate voltage spikes that can punch through the insulation inside the transformer and short the windings. I would not go above double the rated load on any tap. And NEVER open circuit the output of a tube amp - it can fry the transformer in a couple of ways.

Extended A: It's almost never low impedance that kills an OT, it's too high an impedance.

The power tubes simply refuse to put out all that much more current with a lower-impedance load, so death by overheating with a too-low load is all but impossible - not totally out of the question but extremely unlikely. The power tubes simply get into a loading range where their output power goes down from the mismatched load. At 2:1 lower-than-matched load is not unreasonable at all.

If you do too high a load, the power tubes still limit what they put out, but a second order effect becomes important.

There is magnetic leakage from primary to secondary and between both half-primaries to each other. When the current in the primary is driven to be discontinuous, you get inductive kickback from the leakage inductances in the form of a voltage spike.

This voltage spike can punch through insulation or flash over sockets, and the spike is sitting on top of B+, so it's got a head start for a flashover to ground. If the punchthrough was one time, it wouldn't be a problem, but the burning residues inside the transformer make punchthrough easier at the same point on the next cycle, and eventually erode the insulation to make a conductive path between layers. The sound goes south, and with an intermittent short you can get a permanent short, or the wire can burn though to give you an open there, and now you have a dead transformer.

So how much loading is too high? For a well designed (equals interleaved, tightly coupled, low leakage inductances, like a fine, high quality hifi) OT, you can easily withstand a 2:1 mismatch high.

For a poorly designed (high leakage, poor coupling, not well insulated or potted) transformer, 2:1 may well be marginal. Worse, if you have an intermittent contact in the path to the speaker, you will introduce transients that are sharper and hence cause higher voltages. In that light, the speaker impedance selector switch could kill OT's if two ways - if it's a break befor make, the transients cause punch through; if it's a make before break, the OT is intermittently shorted and the higher currents cause burns on the switch that eventually make it into a break before make. Turning the speaker impedance selector with an amp running is something I would not chance, not once.

For why Marshalls are extra sensitive, could be the transformer design, could be that selector switch. I personally would not worry too much about a 2:1 mismatch too low, but I might not do a mismatch high on Marshalls with the observed data that they are not all that sturdy under that load. In that light, pulling two tubes and leaving the impedance switch alone might not be too bad, as the remaining tubes are running into a too-low rather than too-high load.

Q: Can I use two single ended output transformers in a push-pull circuit and then parallel the outputs?

A: What you're making really IS two class A output stages run in parallel. With no magnetic coupling between the two half-primaries, there is no interaction on the secondaries, either. You have to run them Class A to keep from having distortion because they really are separate amplifiers. It's not clear what happens if/when you try to use feedback from the secondary into the (presumably)common driver stage.

On the secondaries, you have two 8 ohm outputs that you can connect in series to drive either two 8 ohm loads separately or one 16 ohm by placing the secondaries in series; the resulting power capability, given that you get the rest of the circuit right, is the sum from each transformer, or about 2X the power of each Class A amp by itself. Note that this is far less than you'd get by using a proper push-pull OT and driving it in Class AB, probably ¼ the power.

If you try to parallel the two, you can get some interesting and possibly disturbing results. If the transformers really are IDENTICAL, then for equal primary drive, you get equal secondary voltages, and you could parallel them OK to drive a single load. If there is a difference between primaries, secondaries or drive voltages, then the secondaries try to make different voltages, and fight it out. The differences are reflected into the primaries as a kind of push-back voltage on the output tube plates. Tubes being the forgiving things they are, this will probably not kill anything, but it will at least act like a different loading than you're expecting on a per-tube basis. I'm not certain exactly what effect this will have on linearity or life. If you were driving the primaries from a low impedance source, something would burn.

Q: What are the things about output transformer that cause the differences in tone? How do differences in output transformer construction combine with tubes to give differences in tone? How do I design/modify an OT for a tone I like? How do I duplicate the tone of a OT I already like?

A: What you have asked, translated into transformer-geek language, is "How do I completely describe the equivalent circuit of a transformer and the circuit it resides in?"

To be truthful, there isn't all that much mystery about transformers, but it's not like the rest of your everyday electronic parts. Transformers are susceptible to electronic modelling, and once you get the model correct, you can twiddle the values until you get the "tone" you want, including nonlinear effects. The later versions of SPICE include nonlinear transformer models for exactly this use.

You won't like the answers, primarily because of size. To understand a transformer's effect on tone, you have to be able to model the whole power amp/tube/OPT/speaker chain and account for the effect of changes in the OPT model, then synthesize back to real hardware once you get the response you like. You've asked for a couple of semesters equivalent worth of information on transformer modelling and design linked to a course on the design of the output stage of a tube audio amp.

I suggest that if you really want to know this stuff, you find a copy of Nathan R. Grossner's "Transformers for Electronic Circuits", which is out of print, but available at many technical libraries. I put this reference in the Tube Amp FAQ to answer this kind of question.

You can model any transformer as a shunt primary capacitance across the primary winding, a series leakage inductance to the primary winding, a series resistor equal to the winding resistance, a nonlinear inductance representing the primary inductance, with a nonlinear resistor in parallel with the primary inductance to represent core losses, primarily from eddy currents. Then an ideal "perfect transformer" to convert the voltages and currents correctly, a series secondary winding resistance, a series secondary leakage inductance, and a shunt capacitance across the secondary. A shunt capacitor from primary to secondary completes the model.

Get those component values correct, and you can accurately model everything about any transformer. There are no mysteries hiding in there. The component values are all measurable, and to a certain extent predictable from the start. Any transformer can be copied, Fischer and his ilk to the contrary.

So - tone effect of a OPT? first - what does the base transformation ratio do to the reflected loading on the tubes as a function of frequency, including speaker loading. This is fairly independent of the transformer model, depending only on that "ideal transformer" in the middle, but has a big effect on how the tubes put out power.

Next - What are the values of the model components? That is, how much leakage inductance, shunt capacitance, and core loss is there? At what points in the excitation does the core start going into saturation, and from the composition of the iron, what is the irreducable energy loss per cycle to magnetizing losses, which shows up as pure third harmonic distortion. Core saturation sounds like any soft limit on a signal; its effect on tone also depends on the symmetry of the limiting. You get primarily third, but smaller amounts of fifth and seventh harmonics on pure tones. Combine with the tone of the tubes? I have a problem with that, and I'm not just being difficult. First, define "tone" unambiguously...

The power response of the tubes will be affected a lot by the degree to which the reflected loading on the plates matches the "power transfer sweet spot" for the tube, and this is a function of frequency, depending obviously on the speaker impedance curve and the other parasitics in the model.

The size of the core and the number of turns have a direct effect on the low frequency response, but they affect it by changing how much the primary inductance loads the tubes at the lowest frequency of interest. Good designs make this NOT be a consideration in most cases. Poor designs make it a critical factor, and you hear the poor design as either core distortion or low frequency restriction. The winding inductances are entirely subsumed into primary and secondary inductances and have no effect on tone whatsoever - except to the extent that the physical location and sectionalization of the windings contribute to the leakage inductance and shunt capacitances. The effect of the loading on the plates IS a major contributor. Each tube type has a power response curve, power out at a given impedance. There is also a curve of distortion versus loading. In general, the sweet spot of max power is not the sweet spot for lowest distortion, so changes in loading cause the amount of power out to change as the amount of distortion changes, too. Changes in plate loading will cause big changes in tone - and speakers all by themselves have impedance versus frequency curves that vary by four or more to one. To get a good grip, first get some good background. There is not enough room in this FAQ to type in what you've asked. Get a book, preferably Grossner, but any other that describes the basics of transformer modelling; then I can point you to some books on transformer making that will give you an idea on how to change the things you do in making one that can change those parasitics. A final thought. If the totality of what a transformer does to tone can be modelled by the ideal transformer and some non-ideal components, could you take a transformer with very small parasitics, close to ideal, and add in external "parasitic" components and make it look like any one of a number of less ideal transformers? Yep. You can add inductors and caps to OPTs to make them look more like some transformer you like better, as long as you're not haveing to add negative inductance and/or capacitance. The iron alloy also has an effect, and it's tied up in that business about the BH curve and nonlinearities. If you drive a transformer from a voltage source, 0 ohms impedance, then there is no distortion of the secondary voltage as a result of the BH nonlinearities, as the source can provide any current to keep the voltage correct. If however you use a source with a real impedance, like the plate impedance of a pentode, then the nonlinearities demand current, and the plate impedance then limits the current available, so the voltage waveform is distorted on both primary and secondary. Unfortunately, we need the transfomer BECAUSE the tube has internal impedance, so we can't just wish that away. As a sidelight, this is one of the classical arguments for triode output tubes over pentodes or beam power tubes during the golden age hifi years - triodes have a much lower internal impedance and hence lower the distortion of the transformer.

What you CAN do is to do some fairly simple tests to map the BH curves of the iron you have,

[sidelight: if you find a "magic" transformer, much more "tone" (whatever that means to you) than any other, you can do the work to measure the BH curve nondistructively on the core properties that it has, and then go duplicate them.] and then either get different iron or introduce air gaps to change the effective BH curve of the iron to make a core nonlinearity that matches whatever sounded good. You may not be able to match the iron perfectly, but it's the core properites, not just the iron, that you're looking for, and there are things you can do there.

There are a number of grades of transformer iron, but I doubt that there are larger laminations made especially for audio these days, as there is effectively no money to be made; the money is all in laminations for power transformers. There are several grades of good, linear, high permeability silicon iron made for power transformers, and I suspect that these are what ALL new manufacture OPT's come from.

Note that this may (and probably will) result in a core that is bigger than the one you're copying, you may have to rework the windings to get the necessary primary inductance, shunt capacitancs, leakage, etc, etc. to duplicate the response of an iron core you can't get.

Also **-** there are other ways to introduce the specific nonlinearities that make for a good sound if you can ever define what "good" is well enough.

Q: How can I tell if my output transformer is live or dead?

A:There are some simple tests you can run to quickly determine if a transformer is grossly bad. This is much simpler than determining if it will work well and sound "good" for you. The tests of relative "goodness" are also possible, but require a lot of equipment and experience to do correctly. For the quick and dirty tests described here, you'll need a means of measuring AC voltage and current simultaneously, such as a pair of VOMs or DMMs, and a 110/120 to 6.3VCT filament transformer, and either a variac (variable transformer) or a light bulb socket in series with the primary of the filament transformer to limit the power you put into the transformer under test.

CAUTION CAUTION CAUTION

Both the filament transformer and the transformer under test will have at least AC line voltage on them, an may well have much higher voltage, several hundred volts on one or more windings. You are therefore in danger of being **KILLED** if you are not both knowledgeable and careful about how you do these tests.

DO NOT TRY THIS IF YOU DO NOT HAVE THE KNOW-HOW AND EXPERIENCE TO WORK SAFELY WITH THESE VOLTAGES. IF YOU HAVE ANY QUESTION IN YOUR MIND WHETHER YOU CAN DO THIS WORK SAFELY, YOU CAN'T.

Seek experienced help if you have any question in your own mind.

The tests run like this. Identify which wires are which by color code, circuit connection, or by using an ohmmeter to find which connects to which. Label the wires. From the same ohmmeter test, write down the resistances you measured on the windings. Generally, windings with resistances over a few ohms are high voltage windings, either a power transformer primary or high voltage output, or an output transformer primary. Note that it is common for primary windings on power transformers to have from two to six wires, with the wires over two being taps to adjust for various line voltages from 110-117-120-125-208-220-240. Secondary windings on power transformers and primaries on output transformers will have either two or three leads, and secondaries on output transformers will have to to four leads.

Also note if any winding is shorted to the transformer core. Sometimes an internal shield will be deliberately connected to the core, but if a multi-lead winding is connected to the core, this is usually an internal short, and a dead transformer.

Once you have identified the windings, hook up one and only one winding to either 1/2 of the 6.3VCT or to the variac. Try to select a low voltage winding, one that has low resistance from the ohmmeter test. Make sure that no other leads are connected (or shorted together, or touching your screwdriver on your bench or... well, you get the idea). A turn of plastic tape on each wire end you're not using at the moment is a good idea. Set your voltmeter on this winding, and the current meter to measure the current through it, and bring the circuit up. The voltmeter should measure 3 volts AC, the light bulb (if used) should NOT be lit brightly, and nothing should be humming or smoking ;-). There should be little current going through the winding. If the voltage is lower than 3 volts, or you are pulling amps of current, then there is a load on the transformer, internally since you have disconnected all the leads, meaning that there is an internal short. You should try to select a winding for this test that is normally a low voltage winding, either a filament winding in a power transformer, or a secondary in an output transformer.

If all is well, measure the voltage that now appears on the other windings. The voltages will be equal to the ratios of the voltages that will appear on these windings in normal operations.

B. Where can I get a good replacement output transformer for my vintage DoppelBanger amp?

Dixie Sound Works, Gunthersville, Alabama has a great reputation for (re) winding quality vintage re-makes. The company that made the amp may have service parts. The quality is variable from company to company and time to time, though.

There are a number of companies that have entered the transformer market in the last year, so expect that there will be new places to get quality rewinds and replacement transformers

C. I want to make my own power and output transformers. How do I do this?/ Where can I find information about this?

Designing and hand winding transformers is not terribly difficult, but it does require information and skills that are relatively hard to find. You are unlikely to save a whole lot of money unless used or broken parts are cheaply available to you. You may want to do this if you feel that you were selected by some deity to take this on as a life work. First, take a transformer apart. A burned out tube-type power transformer will do. Do this carefully and slowly, imagining how you would have put it together in the first place to get it the way it was. This is an excellent introduction to the manual skills and materials needed to successfully produce one on your own. Learn about how transformers are designed from one or more of the following, in this order:

1. "Transformers for Electronic Circuits", Grossner (check your library)
2. "Radiotron Designer's Handbook, fourth edition
3. "Audio Transformer Design Manual", Wolpert, $36, privately published, available from: Robert G.Wolpert 5200 Irvine Blvd. #107 Irvine CA 92720
4. "The Williamson Amplifier" D.T.N Williamson, reprint available from Old Colony Sound Labs
5. Handbook of Transformer Design and Applications by William Flanagan (second ed.)
6. "rewinding transformers with CAD" by Hugh Wells W6WTU Ham Radio Dec '86 p.83
7. "Fast Optimization of Transformer Design" EDN Nov '62 by Davis, J. H.

These sources will help. They are NOT a complete cookbook. Note that it is very possible to make a transformer that will operate relatively well, but may break down unexpectedly and KILL you if it is not constructed with safety in mind.

D. Should I replace my stock transformer with a new/old/vintage/ purple one for better clean/grunge/grit/etc. sound?

Unless you REALLY know what you're doing and have heard the transformer you'll be swapping in and like it, no.

There are a huge number of variables in the "sound" of a transformer, and you should exhaust other means first. You might not get that magic sound after all that work unless your ears - and amp tech - are really good.

Are potted / impregnated transformers better? Is potting / impregnation necessary?

Necessary for function? No.
Necessary for long term reliability? Yes.

If transformers are not potted or impregnated in some way, they will eventually have problems with slight repeated movements of the wire wearing the insulation and interleaving material, and with moisture infiltration. In some climates, moisture infiltration will let molds and mildew get started inside the transformer if it's not used almost daily. "Potting" is not the same as "impregnating"."Impregnation" means getting some kind of insulating gook soaked all through out the windings and spaces inside, while potting means putting the whole assembly in a can and filling the can (and transformer, as in impregnation) with goop. To be reliable for years of use, a transformer must at least be impregnated with varnish or epoxy. Almost all commercial transformers of any size are treated this way.

A do-it-yourself way to do this is to dunk the whole transformer in a bucket of varnish and pull a vacuum on it to expand the air out of the windings. A few vacuum cycles will get varnish well infiltrated into the windings. Then bake it at low temperatures (under 140 to 200F) for a long time, until the varnish is truly hardened.

Back to the GEO Home Page

What is the easiest way to get tube sound at a good price?

- Obtain an old piece of tube gear, perhaps intended for another purpose, like mono hifi, at no or low cost. Modify this to duplicate to a certain extent the circuit of an existing amplifier. Tinker to your heart's content.

There is a document on exactly this at http://www.wwu.edu/~n9343176/docs/old2new.html The document goes into excellent detail on the in's and out's of building from old tube gear and the possible and useful variations of which stages with how much gain go where in the amp.

- Build a tube preamp from scratch, and use this to drive another larger amplifier which does not necessarily have to be tube based. I have designed things like this, so have others. Good tube sound, and inexpensive. Really convincing tube distortion, especially if you add some lowpass filtering to simulate the high frequency cutoff of guitar speakers.

This is what the Hughes and Kettner Blues Master and Cream Machine tube preamps did (they've been discontinued). These were entire tube amplifiers with maybe 2 or 3 watts output, a simulated load, and a line level output in addition to the speaker output. They did a VERY respectable job.

Back to the GEO Home Page

How can I modify my tube amp to ... ?

(also see recommended mods, below)

Get lower hum?

- Replace the defective humming tube
- Replace or improve the power supply filter capacitors
- Fix the defective internal ground wiring, as on a reverb tank, or previous "improvements" and modifications
- Run the preamp filaments on regulated DC, not AC, starting with the input tubes
- Rewire the grounding so the amp is star grounded, and does not use the chassis as a ground bus
- Move the signal wires around, nearer/farther from the chassis or 60 Hz AC carrying wires
- Use coax cable in the signal path, at least in the early sections where noise counts the most. Tie one end of the shield to

ground and terminate the other end with some shrink tube so it cannot touch anything. This way the coax shield acts as an antenna and conducts the RF to ground (as well as Faraday shielding hum out). If you tie both ends to ground you set up some capacitance (and the possibility of ground loops) you're better off without. The shield should be tied to the star ground point individually, and bypassed to the chassis locally with a good RF cap of about 0.001 to 0.01.

George notes "You may already use this in your own amps but I thought we might share it with the rest of the tinkerers - it's especially useful for people that are trying to add extra gain stages. I even use it between the input jacks and the first stage since in most Fender amps it has to traverse the width of the board. (Kaschner)

Have higher gain/more distortion?

- Install an extra gain stage by
  - Using an unused tube section if one exists
  - Adding another tube to the chassis
  - Using the reverb tubes as additional gain stages
  - Using a power MOSFET as a cathode follower to drive tone control and volume controls for lower loss
  - Using a power MOSFET to replace an existing cathode follower, freeing up that tube section for more gain
  - Remove the feedback on the power amp stage; newer Fenders and other amps use feedback on the power amp to reduce distortion. Removing this increases gain and and distortion, and makes the distortion start at lower volumes. On Fenders, it's generally a white wire from the 'ext speaker' jack to a 2.2k resistor. Cut this wire, or lift it at one end. To be really slick, put in a toggle switch. (Edelman)
- Use the alternate channel for more gain, perhaps jumpering two channels together

have a smoother, less buzzy distortion?

- Use a lowpass filter somewhere inside the amp in the signal path to cut higher harmonics; perhaps a capacitor to ground from the final preamp tube grid or plate -or-
- Use series grid resistors to cut the high frequencies in and

after distortion stages
- Use a lowpass filter after the amplifier and before the speakers to cut out some of the higher overtones.

Back to the GEO Home Page

When should I bias my amp and how do I do this?

A. What is "bias"?

"Bias" in this context refers to the amount of voltage held on the grids of the output power tubes. This controls the amount of current the output tube(s) conduct exclusive of the signal current, or, looking at it another way, the amount of overlap where both tubes are conducting simultaneously.

I will talk about the output tube current since the terms "underbiased" and "overbiased" are confusing with tube amps. A technician who works with only tube amps will usually refer to the voltage which sets the operating current in the tubes. In these amps, the bias is a negative voltage, so "overbiased" to such a technician would mean that the tubes are held in a condition of too little current, just backwards from the solid state terms most of us are familiar with. "Underbiased" would mean that the tubes have too little negative voltage on their grids and are conducting too much current simultaneously.

The idle current in the output tube and the degree to which the output tubes overlap in conduction is what you're trying to adjust, not how many volts go on the grids; you just have to use the grid volts to change the current and conduction angle.

The whole topic of bias is tied up with the "Operating Class" the power amp is designed for. There are only three classes useful to us in tube amps, Classes A, AB1, and AB2. Class A means that the output tubes are biased so that both tubes are always conducting. Even on maximum signal peaks, the tube driven most "off" will still be conducting some current. In both class AB's, the bias is set so that on a signal peak, one of the tubes can be driven completely off for some part of a signal cycle. In class AB1, no grid current flows into the grid of the tube, and in class AB2 some grid current is driven into the grid of the tubes. There is a class B, where both tubes never conduct current at the same time, only alternately.

The point of all this is this: The Class of the amplifier is determined by how much bias current is present. If there is a lot of bias voltage, the grids are held 'way negative, then only the tube which is driven by the positive going half wave of the signal at any moment is conducting. This is class B. It sounds ugly because the point where the signal crosses over from positive to negative and begins to drive the other tube is not reproduced cleanly, and creates [surprise!] crossover distortion. You can look at the output signal with an oscilloscope and see crossover clearly as you make the bias voltage too negative for both tubes to conduct at the same time. As the bias voltage is made less negative and allows both tubes to conduct a little, the crossover notch diminishes swiftly, and you are in class AB2; a little less negative, and they both conduct more, and you have class AB1. If you go further, you get to the point where both tubes always conduct, making the amp work in class A, which has the least crossover distortion of any of these operating conditions.

Too little simultaneous conduction in the output devices puts them in the most nonlinear region of their transfer characteristic, so crossover distortion is high; but as you increase the amount of simultaneous conduction, the power used and dissipated by the outputs goes up, perhaps to a disastrous degree. You are trading standby current and power dissipation in the output devices off against distortion. If both outputs are biased almost totally off at idle, crossover distortion is very bad. As the simultaneous conduction is increased, crossover goes down rapidly, until it gets smaller than the residual THD of the amp itself, and becomes much less audible. There is a fairly broad sweet spot where the crossover distortion is comparable to the THD and the idle current and idle power dissipation are reasonably low. This is the region you're looking for.

Lots of bias, both tubes conduct all the time - and eat a lot of power, get hot, other Class A kinds of things. Little bias, both tubes overlap less, get less hot, put out more total power - and produce crossover distortion, which sounds especially unpleasant.

Power tubes individually have slightly different DC gains, so the same bias voltage on two different tubes produces two different current levels. "Matched pairs" are two tubes selected to be close together. Groove Tubes grades tubes from 1 to 10 so that any two "3"'s for instance are close enough to sub for any other "3", so you don't need to rebias if you keep buying the same number from them.

Note that you may not want matched pairs, depending you your taste. See section D. below.

B. When should I bias my amp?

You should re-bias the amp whenever you change power tubes or modify the power amp circuits.

Each power tube needs a certain bias current to keep it operating at the point where the amount and type of distortion under normal conditions is well controlled. Individual tubes vary widely in the grid bias that sets the correct idle bias current. If you change tubes or tinker with the circuit, you need to make sure the tubes are set back into operation in a way that sounds good and does not cook the tubes.

Amps typically provide only one adjustment point for bias, assuming that you will have bought matched sets of power tubes.

It is possible to modify your amp to "match" unmatched tubes by setting the bias voltage and AC drive level of each tube individually. This may require some serious soldering, though. See section D. below for a discussion on matching, and the mods section for what you have to change.

C. How do I bias my amp?

CAUTION CAUTION CAUTION

Keep in mind that tube amps use high voltages, and they can *kill* you if you don't know what you're doing. So, if in doubt, leave the job to a qualified technician.

How do you correctly bias an amp? There a few different approaches but first hook up a speaker or a passive load to the output and remove any input signals; tube amps need to have a load or they can sometimes become unstable. Check and make sure the proper size fuse is installed.

Output Transformer Shunt Method

The most common and simplest procedure is to hook a current meter from the plate (anode) across half of the primary of the output transformer; this is called the "output transformer shunt method." The idea here is that milliammeters commonly have a very low series impedance so that when placed in parallel to half of the primary, almost all of the current flows through the ammeter. When you hook things up this way, your meter is floating at the voltage level of the plate, which is typically hundreds of volts -- be very careful! You could open the wire from each plate to the output transformer and hook in a meter in series with the plate temporarily, but that is a terrible amount of work for the small gain in accuracy.

Adjust the bias pot so that the current reading is the appropriate value for the type of tube (see the table below). Let the amp warm up and note if the bias changes significantly. If so, select a compromise bias point.

Keep in mind that if your circuit uses more than one tube per side, the bias current you're reading is multiplied by the number of tubes (e.g., if you're reading 60 milliamps and there are two power tubes per side, if the tubes are matched each of the two are getting nominally 30 milliamps). Check the other side of the circuit to confirm that the two sides are close (within 5 milliamps) to each other.

If your ammeter has too high a series impedance, the shunt method won't work because the bias current gets significantly split between the meter and the transformer; the meter has no idea how much current is going through the transformer. You'll know it's not working because the current values you'll be reading will be much too low no matter how far you adjust the bias pot, the tubes will be glowing hot, and when you note that you'll reach quickly for the power switch! If you don't reach it quickly enough, you might blow a fuse. Don't despair: you can use another method called the "cathode resistor method."

Cathode Resistor Method

If the circuit already has a resistor in-line between the cathode and ground, use it. If the circuit has the cathode hooked up directly to ground, insert a low value resistor (say 1 Ohm/1 Watt) [even 10 ohms will work well, as the currents in a tube circuit will cause only a volt or so max across a 10 ohm resistor, not enough to change the circuit operation a lot.] in between the cathode and ground. This doesn't have to be a permanent change to the circuit; you can make a little adapter that fits between the tube and its socket that runs all the signals straight through except for the cathode lead -- that path gets the low value resistor in-line. If you make the adapter, you don't even have to drop the chassis from the amp to set the bias. Just pull a tube, install the adapter, and adjust.

Hook up a voltmeter across the resistor and measure the voltage. For a 1 Ohm resistor, if you read 30 millivolts Ohm's Law says that you have 30 milliamps running through it. If you have some other value resistor, make the appropriate calculation. Easy! But since the current at the cathode is the sum of the bias current and some other leakage currents, you need to compensate the reading a bit, typically 5 to 10 milliamps.

What's nice about the cathode resistor method is that you're not dealing with high voltages. The cathode sits very close to ground so the chance of a dangerous mistake is lessened. You're also reading each tube's bias current individually.

Other Methods

Some of the manufacturers say to set the bias voltage to some specified voltage, without any other measurements. Presumably some designer somewhere decided how much was good for you and wrote down "Set the bias to xx volts" as a good compromise for all the tubes s/he expected. This method ignores the variability of transconductance in output tubes, and only gives good results for matched sets that happen to be exactly like the "typical" ones the designer thought they'd get. Note that Gr@@ve Tubes tries to help by providing matched tubes with a bias number from 1 to 10. If you have GT's with a "4" bias number, and you replace with a GT "4" set, they will have selected only tubes that are properly biased at that level, and no rebiasing will be necessary. Of course, GT expects to be repaid a fair profit for this service to you...

Another way to set bias is to use a test signal, typically a sine wave. Monitor the output waveform on an oscilloscope and adjust the bias for minimum crossover distortion. The obvious problem is when has it "just disappeared"? Most folks do just a bit more than "just disappeared" and get their outputs too hot causing shortened tube life and overheating. Not very accurate or repeatable.

You can also use a special purpose instrument that nulls the input signal out of the output signal so that you can monitor just the distortion products. You then adjust the bias to get the distortion to a realistic minimum without making it dramatically less than the residual THD. This is the premium method, but requires a distortion analyzer - big bucks.

These methods can be more accurate than the first two methods but they require expertise and tools that most folks don't have.

If you are a circuit hacker, and live on solder fumes and cold coffee, you can modify the amp with solid state servo bias adjusters that twiddle the bias to each output tube on the fly on a continuous, real time basis to keep each tube -* exactly *- where it ought to be. Only recommended for real wiring fanatics...

GENERAL BIAS GUIDELINES (from Tremolux@aol.com)

Currents Per Tube - Class AB1 Operation (most musical instrument amps are designed to run in class AB1)

- 6L6 - 30 to 35 ma
- 6V6 - 22 to 27 ma
- EL-34/6CA7 - 35 to 40 ma., sometimes even higher!
- 6550 - 40 to 50 ma
- EL-84/6BQ5 - 22 to 27 ma

Class A currents will be higher. Example is 50 ma for a 6L6. Don't try to run an amp designed for AB1 in pure class A, it will overheat and probably blow. To handle the higher idle currents, Class A amps usually run at lower plate voltages.

D. Matched output tubes - do you need them?

Do I always have to buy matched pairs of output tubes? The issue of "matching" output tubes, either by buying carefully matched pairs or by tweaking the bias levels and drive signals per output tube is not a settled one. It used to be common wisdom to simply buy matched tubes. A few people noticed, however, that they had a favorite pair of output tubes, which made their amp sound much better than others. The common assumption was that these tubes were better matched somehow. When these tubes get measured, though, it usually turns out that they are NOT matched, at least not matched for AC gain characteristics.

The concept of matched output tubes comes to us musical amp types from the hifi community, where they are trying to get the lowest possible distortion. This was true from the start, when Fender was trying to build low distortion amps and copied hifi circuits. The concept has simply clung to us, largely through inertia. It is relatively well accepted even in the hifi circles now that even-order distortion is euphonic, sounds good to our ears. It is very likely that the even-order distortion produced when mismatched output tubes are used sounds better than perfectly matched tubes.

If you have modified your amp so you can independently set the DC bias and the AC drive signal, you can tune almost any pair of tubes into AC and DC matching. You can also tune in a selective amount of AC drive mismatch to experiment with the selective mismatching sound.

There *are* technical reasons for matching. Getting enough turns of wire on the primary of an output transformer to get the right primary inductance and still using as little iron and copper as possible to do the job properly is an engineering problem that almost always results in Class AB output transformers being smaller for proportional power outptu than a Class A output transformer would be. The (relatively) smaller transformer and wire size makes a class AB (most guitar amps) output transformer susceptible to burning out if one of the half-primaries carries too much current.

If one side of the transformer carries significantly more current (like double) than it would otherwise in "normal" operation, it is possible it will overheat or open, effectively killing the transformer. Tubes that are so mismatched that to get the right total current for a pair means that one is carrying more than 50% over the nominal DC current for a matched pair is getting into the region where you ought to worry about output transformer damage.

If you mismatch, try to get the DC current the same in both sides of the output transformer, and an imbalance in the AC gain of the tubes. The logical limit of this AC mismatching is to remove all the AC drive from one output tube, which is a technique used by at least one commercial amp maker. This effectively keeps the output transformer happy with respect to DC, and gives you a single ended output stage; this also costs you a large amount of your available output power, but, hey, we're after tone, right?

Note that the commercial tube suppliers have good reason for wanting to sell us matched sets at a premium. I would expect their opinion to be that matched sets are absolutely crucial. As in all musical matters, let your own personal ears be your guide.

If you have a set of tubes you know are not matched, or if you have modified your amp to be able to set the bias and drive levels on each output tube separately so you can either match or not match the tubes at will, you might want to try un-matching them and see how it sounds to you.

Q: I have found that if the bias for push-pull with cathode bias design, is set with the bias at 50 mA for EL-34 tubes when idling(i.e. no sound input), over time the cathode bias resistor will blow. Why is this?

A: This is true if the amp is cathode biased into Class AB; in this class, the average current in the outputs rises with signal. On Class A biased amps the current is already at max for that bias point, and should not drift up except if the tubes drift from thermal effects. Note that cathode bias of an amp into class AB IS possible. Cathode bias is not equal to Class A.

Setting the bias point for a little less standing current (which is an unambiguous description for bias) is an OK solution if your cathode resistors are undersized as long as you can live with the increase in crossover distortion at lower sound levels. The "sweet spot" is wide, so that may be fine. If you were previously in Class A and dropped the current a little, this can move you slightly into AB for large signals.

Q: Does amplifier stability have anything to do with the temperature of the output tubes? Can tubes go into thermal runaway?

A: Yes. Emission in tubes increases with temperature, but not a whole lot, as the tube gets hotter. The predominant effect is that as the tube gets hotter, you cause outgassing from the metal, glass, and other materials in the tube. The gasses are attracted to the grid as the most negative point in the tube and stick to the negatively charged grid, causing a decrease in grid bias. If the tube is too gassy (which it can get to by being too hot) you can get into a condition where the grid leak current changes the bias in the direction of more current, which makes the tube hotter, which causes more current. The solution here is to lower the value of the grid leak resistors. This increases the available current to the grids and keeps the tube out of runaway.

Back to the GEO Home Page

Amplifier Modifications

A. OK/Recommended amp modifications

Read the **SAFETY WARNING** first, before you put your hands - or other personal parts - into a tube amp.

- Put a fuse in the B+ line after the rectifier(s) and before the first capacitor filter. This can save burning out your power transformer and maybe your output transformer if you get a shorted filter cap, shorted output tube, or lose bias on an output tube. It -* might *- save an output tube that has lost bias even though it also might not. The fuse current rating should be slightly larger than the max current rating for your output tubes, generally much less than 1A.
- Put a 130 or 150 Volt MOV surge protector across the AC line at the power transformer primary to absorb spikes from air conditioners and motors turning on and punching through the primary insulation. Recent articles say that 130V MOV's will eventually short, recommending only 150V MOV's.
- Get rid of all two wire line cords and line switching arrangements. Refit with three wire cords, tieing the safety ground to the chassis. You'll love this the next time you touch a mike or stand while holding a guitar. No shocks. Oh, yeah. Do it to ALL your equipment to be safe.
- Consider putting a small fan in your amp to cool it. Try a 240vac fan running from the 120 vac line supply, which will run much slower and quieter than a 120vac one.
- Install small cathode resistors and independent bias adjustment for each output tube to make biasing easy.
- Open the feedback from the power amp output to it's input for more power amp gain, more and earlier distortion. Or better yet, put in a spst switch and you can pick the characteristics on the fly...
- For the adventurous, add a separate filament transformer/ rectifier/ filter capacitor to make 9-12VDC at several amps and then use a three terminal rectifier to regulate this down to 6.3VDC, and feed this to your preamp tube filaments. Hum from filaments will drop right through the floor. Lotsa work,

though.

- Put 1500Volt, 1A silicon diodes in series with the two sections of your rectifier tube (if you have a rectifier tube) so that if the rectifier tube shorts, the silicon will save the output tubes, and power and output transformer.
- Gerald Weber advocates using a 270K/27K resistor divider from B+ to raise the filament windings in a DC sense above ground. This keeps electrons from the filament from hitting the plate, another source of hum.
- Put 1500Volt, 1A silicon diodes in series with the two sections of your rectifier tube (if you have a rectifier tube) so that if the rectifier tube shorts, the silicon will save the output tubes, and power and output transformer. The B+ will go up about 50V when (if!) the rectifier tube shorts, so the amp will have a little more power and run hotter. This can still hurt modern manufactured power tubes if it goes on too long, so check the rectifier tube frequently.
- Bill Webb's favorite tone mods for Fender amps
    - at the Vibrato channel's second gain stage, change the ceramic 0.02uF coupling cap to polypropylene or polystyrene
    - replace the coupling cap at the input of the phase inverter with a better cap (polypropylene - polystyrene - mylar in order of preference); change its value to 0.001 to make the amp "sparklier" and to 0.01 to make the amp sound bigger and more midrangy
    - The 3.3M resistor which mixes the dry and reverb at the output of the 3rd gain stage, vibrato preamp, is paralleled by a 10pF ceramic cap. Change this to silver-mica to make the amp sparklier
    - The power amp feedback loop resistor is usually 820 ohms; insert another 820 ohm resistor. This reduces the feedback, increases the power amp's gain, and softens the onset of distortion.
- Remove the single bias adjust pot in your amp and put in two, connecting one to each output tube. You can now set the bias voltage on each tube to be different, which can match the DC currents for un-matched tubes, or un-match matched ones for more even harmonic distortion.
- Tinker the driver circuit to let you adjust the relative amount of AC drive to each output tube. This lets you match/unmatch output tubes in an AC sense just like the bias mod lets you change the relative DC points.

C. NOT Recommended amp modifications

These are likely to be just plain bad, either grossly (it dies soon) or subtly (it dies slowly, eats tubes, or other sicknesses). Don't do these or let a tech do them to... er... for you.

- Using a variac to run it at a higher or lower line voltage. This might be OK except that running it higher can overdissipate parts and burn them up or overvoltage things like filter caps, which can short and burn out your -* expensive *- output transformers, as well as burning out your tube filaments by putting too much current through them; and running it lower starves the filaments for current, so they can't put out enough electrons, and any remaining gas in the tube bombards the cathodes, poisoning the electron emitting materials on the cathode surface, and wearing the tubes out early.
- Adding massive amounts of capacitance to the power supply filters to reduce hum. Probably OK with solid state rectifiers, but in amps with tube rectifiers this can cause current spikes in the rectifiers that exceed the instantaneous current rating of the rectifier and wear it out quickly.

Nathan points out "I seem to recall one of my Tube Amp Mentors telling me that this is pretty much only the case with the first filter cap after the rectifier, and that the impedance of the power supply was high enough that you could dump hundreds of uf worth of filtering on latter stages (though the only place it's of much benefit is at the power tube plate supply point.)

- replacing your rectifier tube with a solid-state plug in module replacement. This effectively just puts in a pair of silicon diodes which take the place of the tube. But it also lets the B+ come up about 50V. This won't kill the amp immediately, but it runs the outputs hotter. Fender often put more than the rated maximum voltage on the output tubes to get moe power out of them; old US and Euro manufactured tubes would usually handle it just fine. Some lower cost modern manufacture tubes CAN'T stand the extra volts as a steady diet, and can succumb to the Dark Side of the Force - soon.

Back to the GEO Home Page

Tube Characteristics and substitutions

Some quick and dirty subs and some tube data such as recommended bias current and appx voltages. These subs are all taken from the Tube Substitution Handbook sold by Antique Electronics Supply. or provided from the net.

A (short) catalog of tubes you are likely to see in a guitar amp:

- 12AX7[A, WA] and substitutes - preamp and driver tubes
- 12AT7, 12AU7 and subs, preamp and driver tubes
- 12AY7 - driver tubes
- 6EU7 - dual triode used in some older amps for preamp tube
- 6L6 types - power output tubes, up to 50 watts/pair, a mainstay of Fender
- EL34 - Euro power pentodes, up to 50 watts/pair, many Marshalls
- 6V6 - smaller, lower power cousin of the 6L6, 10-14 watts per pair; used in smaller Fenders
- EL84 - fits a 9 pin socket like a 12AX7 but twice as tall; miniature power pentode, good for 12-18 watts per pair; used in smaller Vox amps, and a quad of these drives the Vox AC-30 for 30 watts.

Substitutions:

* means appropriate for parallel filament circuits
\# means may not work in all circuits

Preamp and driver tube substitutions:

- 12AX7 (high gain dual triodes with pinout 9A)

```
12AD7*        12DT7           7729
12AU7#        5751*           B339
12AU7A#       5751WA*         B759
12AX7         6057            CV4004
12AX7A        6681            E83CC
12AX7WA       6L13            ECC803
12BZ7*        7025            ECC83
12DF7         7025A           M8137
12DM7*        7494
```

- 12AU7 (moderately high gain dual triodes with pinout 9A)

```
12AU7[A,AW,]    6189          7730
12AX7* and subs 6670          ECC186
5814[A,AW]*     6680          ECC802
5963            7316          ECC82
6067            7489          M8136
```

- 12AT7 (medium gain dual triodes with pinout 9A)

12AT7[many suffixes]	7492	E81CC
6201	7728	ECC801
6679	A2900	M8162
ECC81	B152	QA2406
12AZ7[A]*	B309	QB309
6060	B739	
6671	CV4024	

- 12AY7 (low gain dual triodes with pinout 9A)

12AY7(and suffixes)	6072
2082	

Power tube substitutions:

- 6BQ5/EL84 (miniature pentode with pinout 9CV)

6267	7189	EF86
6BQ5	7189A	EL84
6BQ5WA	7320	N709
6P15	E84L	Z729

- 6L6 (beam power tube with pinout 7AC)

6L6(many suffixes)	7581(A)
5881	WT6
5932	EL37

- EL34/6CA7 (power pentode with pinout 8ET)

EL34	12E13
6CA7	KT77
7D11	KT88

- 6550 (power pentode with pinout 7S)

6550[A]	7027A#
7D11	KT88
12E13	

Cautionary Tubes - these are very hard to find

- 7591/7591A - legend has it that these otherwise excellent tubes were all bought up by an oriental buyer who toured the USA paying cash for all of them he could find, then disappearing. You are likely to only find used ones or the odd pair in some out of the way place. Dealers will in general not have them. I *have* personally seen trays full of NOS 7591A's for sale in the Akihabra electronics district in Tokyo, lending some credence to the rumor.

These were used a lot in old Ampegs. They are very small and high gain for their physical size, so there may not be a lot of room in a chassis for a larger replacement. The 5881 will work in some circuits, but has significantly lower transconductance.

Rumor Update: The rumor mill on the net says that the Russians will soon be making 7591's soon. Cross your fingers...

- 7199 - combination pentode/triode used as a one-tube voltage amp/phase inverter/driver for a pair of output tubes in some Ampeg amplifiers Note: These were once popular, but are now getting rarer and more expensive. There are a number of other pentode/triodes that can be substituted, but the pinouts are different and this will require require rewiring the socket for the tube. Examples are the 6AN8 and the 6U8. There is a Russian tube that is labeled 7199 which may work, although this is new.
- 7027/7027A - this is a high power tube similar to a 6550. The supply of these is very poor.
- 7189/7189A - a higher power/voltage version of the 6BQ5/EL84. Hard to find. A stock 6BQ5/EL84 may work if the power and voltage conditions in the amp are not right out at the limits of the tube design.

Back to the GEO Home Page

Maintenance Issues

Cap Jobs - Do I need one? How often? Why?

What's a cap job? A technician may recommend you have a "cap job". This means that he will replace every single electrolytic capactor in the amp, from the power supply right down to the cathode bypass caps.

This is because electrolytic (polarized) capacitors have an inherent wear-out mechanism and will eventually die even if you don't play death/metal/country/barbershop through them every day - in fact they may wear out sooner if you leave it sitting in the attic. Here's why.

A capacitor is essentially two conductive plates separated by an insulator. The bigger the plate area and the thinner the insulator, the higher the "capacitance" is. Electrolytic capacitors get a very thin insulator by "growing" an insulating layer of aluminum oxide on the outside of a rolled up piece of aluminum foil.

The oxide layer is "formed" at manufacture by feeding the aluminum foil a very small and carefully controlled amount of current. The current causes a chemical reaction between the foil and the water solution (electrolyte! ... hey... is that where they got the name?? yep.) which makes an oxide layer grow. As the layer grows, they use higher and higher voltages to force the same small current through the layer, which gets thicker and more resistive with time. When they have to use the full rated voltage to get the forming current through, the cap is fully "formed" and ready to ship.

If the capacitor is used regularly, has voltage applied to it, and does not get too hot, the oxide film lasts up to a few decades. If the capacitor is not used much, or gets too hot, the oxide film slowly un-forms, the leakage current goes up, and it will eventually short.

Electrolytic caps are designed to last ten years. It is a tribute to the quality of manufacture that they often last three, sometimes four times that.

Old amps, particularly if they have not been used regularly need to have every electrolytic cap replaced. This cap job may be needed every ten or so years.

Non-electrolytic caps do not have this wear out mechanism, and do not need replaced for this reason. Modern capacitors can in some circumstances be much better than old ones, and you can sometimes get a clearer, more sparkly tone by changing the non-electrolytic caps - assuming that is something you want to do.

Do new caps need to be formed?

> There's a lot of controvery on "reforming" replacement caps. Here are a few answers.
> Manufacturers of caps design their caps for a ten year working life, and a five year shelf life. That means that the stresses and heat of working in equipment will leave the vast majority of caps functioning OK after ten years of normal operation. After that, it's gravy to the buyer.
> They also design them to work OK after sitting on a shelf unused for five years, meaning that the cap should not fail if it's put into operation at rated voltage after sitting unused for five years. As noted above, the caps do slowly un-form without regular use.
> If the electrolytic caps you use to fix your amp are over five years old as determined by the date code on them, you ought to at least

worry about forming them, and if they're over ten years old (like NOS multisection cans), definitely re-form them. Other than that, put them in and turn it on.

How do I "re-form" electrolytic caps?

You'll hear folks talk about "bringing an amp up slowly on a variac"; this can work but is not particularly good for your tubes. A better way is this:

1. Pull out all the tubes.
2. if your amp has a tube rectifier, solder in temporarily some high voltage silicon diodes across the tube lugs to be a rectifier that does not depend on the filament voltages. If your amp has silicon diodes, you can skip this.
3. open up the wire that goes from the rectifier tube (or solid state diodes) to the first power supply filter stage and solder in series with the wire a temporary 100K 2-5W resistor. This resistor will limit the current that can flow into the caps and the amount of voltage that is applied to them to safe values that will cause the insulating layer to re-form.
4. clip your voltmeter across the resistor
5. button it up. Turn it on (no tubes in it, remember). Watch the voltmeter.
6. when the voltmeter reading drops to less than 20-30VDC, your caps are formed.
7. open it back up and pull out those diodes and resistor, putting it back in original shape.

The forming could take hours to days.

Sockets

Sockets get dirty, corroded, broken, and "arced" To recondition them, get a can of spray contact cleaner, the kind that says "no residue". Squirt some in each socket hole, then insert that tube in the socket, wiggle it around, and remove it several times to get the crud off. Take a thin tool like a jeweler's screwdriver or ice pick and gently bend the contacts inside each hole so they hold the pins better. If the socket is cracked, or has blackened lines from pin to pin (where an electrical arc has actually burned the socket into a carbon material that conducts electricity), replace the socket.

Q: Are plastic or ceramic sockets better, or is there any difference?

A: The material is significant.

Thermoset plastics are what are usually used for sockets. The black-brown stuff most are made from is "bakelite" a trade name for a kind of clay-reinforced phenolic. Maybe there's a variety that is purer or more sturdy phenolic that is more resistant - I'm fuzzy on that one.

All plastic sockets are vulnerable to arcing. When you get enough voltage from pin to pin on an output tube to cause a spark to jump from pin to pin (like when you run the output transformer unloaded) the spark runs along the surface of the socket material and burns a trail on the surface. Since the plastics contain carbon, there is often a carbon residue left on the surface. This residue is partially conductive, and makes that path susceptible to arcing over at lower voltages next time; this can be so bad that it interferes with normal operation.

Ceramics are not carbon based, do not burn in the normal sense, and don't soften or melt at temperatures achieved in an arc over, so they are essentially immune to arcing unless covered with dirt and gook that can burn and leave stuff on the surface.

I would class them as poorest - thermoplastic sockets; medium (and most common) - thermoset, which included phenolic; best - ceramic. Ceramics are the premium solution, IMHO.

Dirt and Dust

: The dusty, hairy, oily layer that collects on the chassis can conduct electricity as it absorbs humidity from the air. Vacuum it away periodically.

Blue Glow in tubes

: The blue glow in power tubes is a flourescence from the few ionized molecules of gas that still exist in the non-perfect vacuum achievable in tubes, driven to fluorescence by the high voltages in the tubes. Unless it is excessive, it is not harmful. Tubes with softer vacuums glow more.

Other Issues

: Lots of good info is contained in Jack Darr's "Electric Guitar Repair Book", if you can find a copy (it's now out of print) and in Pittman's "The Tube Amp Book" and Webers "Desktop Reference...". Look for: - checking for capacitor leakage

: From watching a tech work on Fenders, I picked up a nice tidbit. The eyelet boards in Fenders have most components mounted across the eyelet board. A very few parts run along the length of the eyelet board. Because the eyelet board flexes, there is a lot of stress on the solder joints at the end of these lengthwise components and the joints often crack. Every time you open up a Fender, take a look and maybe a soldering iron to these joints. If it's your personal amp, you might want to get a new part for these positions with long leads and bend a loop in the leads so that the leads can flex and not put stress on the solder joints.

Back to the GEO Home Page

Appendix B. Tube Makers Producing Today (Eric Barbour news posting)

(The following is the text of a note posted to the alt.guitar news group by Eric Barbour <svetengr@earthlink.netit is also badly out of date, and will be upgraded by Eric soon.)

Different makers of tubes use different designs. There are six makers of common audio tubes right now:

- Shuguang, China--good 12AX7s, so-so power tubes
- Tesla, Czech--ok EL34s, preamp tubes variable
- Reflector, Russia (sold under Sovtek brand)--good 5881, EL84, so-so 12AX7 (they came out with EL34s recently---I am testing them)
- Kaluga, Russia (only a few types--sold under Sovtek, Audio Glassic) good 5881s, not sure what else they make today
- Svetlana, Russia--has a 6550 now, good---will introduce an EL34 soon
- EI, Yugoslavia (in Serbia)--fair 12AX7s, fair EL34s, future supplies are questionable because Serbian products are under economic sanction; thanks to that Bosnia business!

That's ALL there are right now. That's it. Any NEW tube you buy is from one of the above.

For your guitar amp, I would recommend the "Sovtek" 5881, it's a really nice, rugged and smooth-sounding tube. It was a military type used in servo amps in jet aircraft, so it has to be good. If you have a Marshall or other EL34 amp, the Sovtek 6CA7 imitation (recently released) is probably most rugged. If you want more distortion and a more bluesy sound, you want the skinny EL34s. The Svetlana EL34 will be a skinny type, it should be very good.

Back to the GEO Home Page

Musical Instrument Tube Amp Building, Maintaining and Modifying FAQ

Much of this material applies to building or re-building hi-fi equipment, as well but it was originally intended for musical instrument crazies.

Authored, assembled and edited by R.G. Keen, keen@geofex.com
Most recent revision level is Version 2.10, 3/25/02

The first edition of this FAQ was first released in 1992.

Contributors

Thanks to the contributors who helped and taught me:

Hundreds of folks who taught ME stuff when I didn't know a triode from a Tri-Axis; I can't remember all of your names, and it all comes out as general knowledge now, but I appreciate it. A few names in that category stand out:

- Tom Balon David Mourning Mark Hammer

And people who have contributed things that I have included as part of the actual text:

- Dennis O'Neill
- Nathan Stewart
- George Kaschner
- David Kohn
- Michael Edelman
- Len Moskowitz
- John Stokes
- Brian Carling
- Eric Barbour

Special thanks to Nathan Stewart who did the bulk of the work converting the original version of this FAQ into HTML.

Back to the GEO Home Page

Index

Contributors

Back to the GEO Home Page

Basics of Tube Amps for First Timers

- Why use a tube amp?

  Tube amps have always been the amplifier of choice for the working musician. Musical myth has ascribed almost magical tone to them. While the results may not be entirely magic, tubes do have a sound that is different from solid state amplifiers, and one that happens to make amplified music sound better to the human ears and brain. There are lots of technical and psuedo-technical explanations for why this should be true, but there is enough solid evidence that it is a real effect to trust it. The real reason to use tube amps is simply that they sound better. For that advantage, we put up with the poor supply of parts, high prices, fragility and excess heat that they produce.

- Are Tube Amps louder than solid state amps of the same power?
  No. However they do SOUND louder. Let me explain.

  Some excellent scientific work on tube preamplifiers and their distortion products has turned up the mechanism for this. When tubes are driven outside their linear region, for the first 12db or so of overdrive the harmonics that they produce trick the human ear into thinking that the sounds are getting louder, when in fact the sound is getting progressively more distorted.

It is this acoustic trick that can make tube amps sound up to 12db louder than they actually are compared to a perfect, undistorted amplifier. A solid state amplifier of the same power as a tube amp may distort at the same signal level as the tube amp, but the distortions are not subtle, and we hear them as distortion, not as a slightly louder sound. A solid state amplifier of much greater power would remain undistorted at higher levels, and the tube amp would sound comparably loud to the larger solid state amp.

They sound larger than they are.

What is "Standby" for?
Standby is used to make sure the amplifier is quiet and lower the power dissipation inside the amplifier during times when you will not need it for some period of time. Breaks in song sets are the ideal illustration. If you'll be coming back to the amp within a short period of time (under an hour, say), flip it to standby.

Standby also serves as a softer power up switch. To get the most possible life from a set of tubes, the tube heaters should really be hot before the main power supply is applied to the tubes. When tube rectifiers are used, the rectifiers do this almost automatically. However, when solid state rectifiers are used in an amp, the main power supply comes up almost instantly, and this can shorten tube life by the somewhat-esoteric means of cathode stripping. The standby switch can be used to prevent this.

- How should I turn it on and off?
  If it has a standby switch, flip this to standby, and then turn the power switch on if it is separate, or if the power switch is simply ON-OFF-Standby, turn it to standby. Leave it this way for 15-30 seconds, then turn it to normal operation. This gets the heaters hot before the main power supply comes up.

  To turn it off, simply flip the power switch to "off", don't use standby. This lets the still-conducting tubes bring down the high voltages in the power supply.

- How long do tubes last? When should I replace my tubes?
  It depends heavily on use. In a closet, the tubes will last forever, of course. For practice in a bedroom a couple of times a week at modest volumes, you'll probably get five to ten years out of them. If you practice twice a week for a couple of hours at full volume and play two gigs a weekend, count on one to two years out of a set of output tubes. Note that this assumes that you got good ones to begin with and that you had them properly biased when they were put in.

  Tubes wear out by sheer hours of being turned on, by how hard they're worked, how hot they get from just the heat in the box, by the number of times they're turned on and off (thermal shock). Notice that being played at maximum warp into a dummy load (or power brake, or attenuator, etc.) counts as being played hard, and that because you can't hear all the sound, you may not think that you're working them hard.

Your ears tell you when to replace them. When they no longer sound quite as punch and sweet as they used to, start thinking about changing them.

I have a somewhat more extreme approach, myself. The best time to get new tubes is when you DON'T need them. You get the chance to find the best tubes at the best price without time pressure. I prefer to keep a whole spare set ready. That way, a sudden burn out will not cripple the amp, and I can readily tell when one of them is just not sounding right by subbing in a replacement that I already have. Be prepared!

- Can I replace my own tubes?

  Preamp tubes - sure! They're in sockets, any replacement tube of the same type will at least not damage the amp.

  Even preamp tubes that are not exactly the same type can often be substituted as long as they have the same pin connections. For the commonest type, 12AX7, there are many types that have the same pinout and can be put in the same socket for different gains and tone. For instance, you might be able to use 12AU7, 12AT7, 12AY7, ECC82, ECC83, 7025, 5751, 6201, 6072A, 5814A, 12BH7 and others. See the section on tube substitutions for more info.

  Output tubes are more problematical. You really should have a tech check and if necessary adjust the bias on your output tubes whenever they are replaced. This keeps them from getting too hot. Power tubes are much more finicky than preamp tubes in this way, as preamp tubes do not in general need bias adjustment.

  You will undoubtedly have heard that you can substitute in other types of output tubes for better tone as well. This is getting into really tricky areas if you don't have the capability to open up the amp and rebias. You can imagine that if you have to rebias when replacing output tubes of the same type, you certainly have to with different tube types. That being said, there are a number of output tubes that have the same pinout. You should consult a competent tech befor doing this, as some of the "compatible" tubes may need minor rewiring or may use more heater current than your amp can supply. It's not a good idea to just swap in different types of output tubes unless you understand the different requirements they have.
- What things will damage my tube amp, what's safe and what's not?
  We'll assume that you don't need guidance about the obvious: don't drop it in a lake, or from a helicopter, don't pour it full of soda or beer, and so on.

  A few more pointed do not's:

  - Never, never, never run the amp with no speaker plugged in. This can cause major damage.

- Do not flip the power switch off, then back on rapidly. This can cause power supply damage.
- Never replace a burned out fuse with a bigger-amperage one. Remember - there was a reason the first one burned out, usually protecting something more expensive. Putting a bigger fuse in will just rachet up the power level until something really vital burns out. If the second equal-rating fuse pops, turn it off and get a tech to look at it.
- Never ignore signs of high heat inside - a wisp of smoke or a burning smell is NOT normal.
- Your amp produces lots of heat, and will continue to do so even if you block the fresh air vents. Blocking the vents will just allow the amp to heat to the point that you get to buy some very expensive repairs.
- Never ignore a red glow other than the small orange ends of the filaments. A red glow over a large part of the internal plates of the output tubes means they're about to melt (yes, really melt - heat is our enemy). If you notice this, shut it down and get a tech to help you find out what it wrong.

Correspondingly, you can do the following without too much worry:

- Add another speaker into the "external speaker" jack; a mismatched speaker load won't kill it, while an open circuit (disconnected speakers) may do so.
- Overdrive the stuffings out of it. Tubes are very forgiving of massive overdrives, unlike solid state stuff. As long as they tubes don't overheat or stay overdriven for long periods, it's not fatal.

Back to the GEO Home Page

*** SAFETY WARNING *** READ THIS FIRST!!!!!

Working inside a tube amplifier can be dangerous if you don't know the basic safety practices for this kind of work. If you aren't prepared to take the time to learn and apply the right precautions to keep yourself safe, don't work on your own amp. You can seriously injure yourself or get yourself killed. This section is not intended to be a complete guide to safety in tube equipment, just to hit the high points as refresher for those of you who have some experience. The best way to learn the requirements and practices for safety in tube equipment is to find someone who will teach you one on one.

BASIC REQUIREMENTS

- **UNPLUG IT FIRST** Pretty self explanatory. Do not, ever, ever, leave the equipment plugged in and start work on it unless you specifically intend to make some live-voltage measurement. Leaving it plugged in guarantees that you will have hazardous voltages inside the chassis where you are about to work. This is like setting a trap for yourself.

- **LET IT DRAIN** If the amp has been turned on recently, the caps will still have some high voltage left in them after the switch is turned off. Let it sit for five minutes after you turn it off.
- **SUCK IT DRY** When you open up an amp, you need to find a way to drain off any residual high voltage. A handy way to do this is to connect a shorting jumper between the plate of a preamp tube and ground. This jumper will drain any high voltage to ground through the 50k to 100K plate resistor on the tube. To do this successfully, you will need to know which pins are the plate pins. Look it up for the amp you're going to be working on. You'll need to know this for the work anyway. Leave the jumper in place while you do your work (high voltage electrolytics caps can "regrow" voltage like a battery sometimes. Really.) Remember to remove it when you finish your work.
- **TEST IT** Take your multimeter and ground the (-) lead. Probe the high voltage caps and be sure the voltage across them is down, preferably to less than 10V.
- **BUTTON IT BACK UP FIRST** Take the shorting jumper out. Put the chassis back in the cabinet, making sure all of your tools, stray bits of solder, wire, etc. are out of it. You don't have to actually put all the screws and so forth back in if you believe more work might be needed, but make sure that the chassis is sitting stably in the cabinet and won't fall out. At the end of a listening test, either continue buttoning up if you're done, or go back to UNPLUG IT FIRST.

Basics of Tube Amps for Beginning Users

Back to the GEO Home Page

Where can I learn about building tube amps?

Get one or more of the following references (note that these books are mostly old, and highly sought after, and so may be expensive and hard to find):

- "The Ultimate Tone" by Kevin O'Connor. This the best book on guitar amps I've found. It assumes you know some electronics to start with, so is not a beginner's book. Published by Power Press, which now has a web page at http://www.wwdc.com/~power/ .

- "The Tube Amp Book" by Aspen Pittman, now in its fourth edition. This contains the majority of guitar amp schematics ever made. Don't believe all the "technical information" as gospel, though.

- "Electric Guitar Amplifier Repair Handbook" (?) By Jack Darr. Good intro to actually making repairs as well as many schematics.

- "ARRL Handbook", preferably a late 60's or early 70's edition. Read the sections on construction practice, safety, and tube info.

- Guitar Player Magazine's article on tube types and operation from a year or so ago

- Glass Audio magazine, Old Colony Sound in Peterboro NH
- Mesa/Boogie will send schematics of their amps, call 1-707-778-6565; note however, that these schematics are known to be inaccurate.

- "Vacuum Tube Amplifiers" by G.E. Valley, Jr. Part of the MIT radiation lab series, originally published by Boston Technical 1964. Reprints are currently available from Antique Radio Classified (P.O. Box @, Carlisle, MA 01741, 508-371-0512)

- Amplifiers, H. Lewis York. (Evidently part of the Encyclopedia of High Fidelity). Good basic technical ref. Simple math, good explanations. Includes a couple of designs (several use hard to find tubes) and tips on physical construction as well.

- Radiotron Designer's Handbook, Langford-Smith. Heavy theory, heavy technical. Not coffee table reading, but if you want to know, it's probably in there. This book is perhaps the most highly sought after tube related book, and commonly goes for $75-$100 in good shape. You want the 4th edition.

Old Colony Sound just announced a CD ROM version of this book, apparently indexed, illustrations and all, for $69.95.

- RCA Receiving Tube Manual. Reprints available from several sources, including Antique Electronic Supply & others (Old Colony?) Mostly tube spec sheets & some characteristics charts. The intro is a pretty good technical primer.

- Electron Tubes, R.G. Kloeffler. little application, but a good easy to digest explanation of characteristics of diodes, triodes, beam power & true pentodes, with the math to go along. Worth reading if you're trying to do modeling.

- The Audio Designer's Tube Register. Tom Mitchel. 1993, Media Concepts. Volume 1 - Common Low Power Triodes. 144 pages of freshly compiled tube data, some of which was not previously published. Kinda pricey ($18 from Antique Electronic Supply) unless you need the data. Included are plate characteristics, transfer characteristics, constant current curves, mu as a function of grid potential and plate potential, transconductance as a function of plate current and grid potential, and dynamic and static plate resistance as a function of plate potential and plate current.

(Tom mentions a 2nd and 3rd volume in the distant future - covering low power pentodes & oddball tubes, and Power & Beam Power pentodes respectively.)

- Learn about the manual and safety aspects of working on tube amplifier circuits. Read the ARRL handbook, or better yet, get to know a ham radio operator who will give you some guidance and teaching. Do not skimp on the safety aspects. Tube circuits contain deadly voltages. You can - * DIE * - if you mess up or are careless. It is your personal responsibility to learn how to do this safely.
- Get to know a guitar repair technician, perhaps do some free apprentice grunt work for them in return for some teaching.

Back to the GEO Home Page

Where can I find parts to build/repair amplifiers?

When I first wrote the Tube Amp FAQ almost ten years ago, tubes were a dying breed. In that decade, the tube world has turned around. Today, there are major sources for tubes and parts. The list is long enough that I'm severely cutting back this section.

New tube parts and supplies were steadily getting harder to find in the 80's, but in the last decade this has turned around radically. There are now many companies offering new parts, especially power and output transformers. It is still true that used parts are often nominal cost or free. The hard parts to find in high quality are the transformers.

If you're building, I recommend getting your transformers first. If you are getting vintage parts, they are likely to be one-of-a-kind. If you've just ordered new ones, the transformers will have a massive effect on your chassis's mechanical layout.

The easiest but most expensive source for parts is at your retail musical instrument store as "repair" parts. Other sources:

- Musical instrument repair shops will sometimes order parts or sell you parts out of their stock.
- Amp makers' repair parts departments. Many manufacturers will sell their parts to "repair shops" to fix their amps. Some of them are better than others about this, so be polite and businesslike.
- old, broken, or unloved equipment. This may be free, or units-of-dollars. You get transformers, sockets, tubes, and chassis in the deal. May require cruising garage sales or diving in dumpsters. Trash every part except the tubes, transformers, sockets and chassis. I got a 15 Watt mono amp/preamp intended for mono hi-fi music for $20 at a local garage sale. Needs only some tweaking to be a Studio .22 or an AC-15.

Are Carbon Comps really magic tone mojo?

Maybe. Like everything else, there's the hype, and then there's the real world. A good maxim to remember about electronics is that if you can't express it in numbers (that are also measurable by someone else, not just made-up numbers) then you really don't know the thing at all, you're only believing the myth.

The vintage amps we all love had CC's in them, and they certainly have their share of mojo, but the makers of those amps in the 50's and 60's used them because that's what was available. Today we have lots of resistor options. What's different about carbon comp, and can we express it in numbers so we don't keep being superstitious?

So I went to the internet and searched for manufacturer's info on CC's. The makers themselves admit that carbon comps have excess noise, high drift, high pulse power, and high variability. They also have a high voltage coefficient of resistance. Voltage coefficient of resistance?? What's that?

That means that the resistance actually varies with the voltage across the resistor. The resistance is actually different if you put 100V across the resistance than if it's got 0V across it. What that means to us is that if you put a 50V DC level across a CC resistor and a 100V sine wave superimposed on that, the sine wave will be measurably distorted by the resistor itself. We have ***resistor*** distortion.

The distortion is pretty much pure second harmonic. In small amounts, you can't hear second harmonic as distortion, only a certain amount of "sweetening" or liquidity to the tone. That's what carbon comp resistor mojo really is - the resistors are distorting, but in a way our ears like.

The manufacturers also document that CC's have excess noise and bad drift with temperature and aging. That makes them a two-edged sword. Put everywhere in an amp, and they'll both sweeten the tone, and at the same time induce hiss. A little thought leads us to the following guidelines for using carbon comps for tone mojo:

1. high voltage across the resistor is necessary, in the range of 100V on up
2. large signal swings across the resistor are needed - ideally, a large fraction of the static DC voltage so you have signal swings of 50 to 100V too.
3. only positions in the amp that have both high DC voltage and wide signal swings as in 1 and 2 will give you enough resistor distortion to benefit from; other places should be chosen for low noise and/or economy.
4. resistor power rating should be the minimum needed to work for a reasonable life in the circuit to maximize resistor distortion. Maybe a good guideline is that the dissipation should be selected to be as close to two times the average dissipation as possible.
5. as a corollary to the power guideline, we should be prepared to replace CC's every few years as the life at high temp makes them drift and get noisy(-er).

Guidelines 1 and 2 are simply the recognition that the voltage coefficient of resistance is not very big. In fact, although the coefficient is small, it was specified to be small by the makers and controlled tightly, indicating that it was a recognized problem. In the Radiotron Designer's Handbook (4th edition, pg. 1345) they list the JAN-R-11 specification for CC resistors as less than 0.035% per volt for 1/4 and 1/2W resistors, and 0.02% per volt for higher power ratings. Given that the max voltages for these parts was 1/4W- 200V; 1/2W - 350V; 1W and 2W - 500V, that works out to a 7% change in resistance for a 1/4 W part used at its max voltage, a 12.3 % change for a 1/2W, and a 10% change for bigger resistors. That's one of the thrusts of guideline 4 - pick the smallest dissipation resistor you can, to maximize the coefficient.

Of course, that's as big as the effect can get, and you would have to carefully set up the situation to get that much resistor distortion. In an amp, you probably won't be able to get that close to max voltages or signal levels. Realistic levels might be 200V across a 1/2W resistor, and a 75V signal swing. That would give you a 2.6% distortion - enough to be audible as sweetening. That's the point of guideline 3 - you have to have a big enough signal swing across the resistor to have the signal distorted significantly by the voltage coefficient.

But with a 10V signal, you only get 0.35% distortion, and it starts down the slippery slope to inaudibility. More importantly, these percentages represent the maximum beyond which a resistor would have been rejected in the 1950's. Today's CC resistors are much lower distortion. From IRC's web site, we find some numbers. A typical resistor voltage coefficient can be seen at http://www.irctt.com/pdf_files/IBT.pdf - which shows carbon comp at 0.005%/volt for that company's products. Another was 0.008%/V. These are smaller than the max allowed under the JAN military spec.

So where do they work best? Where can we use CC's for their soft distortion, and where can we sidestep them to lower noise?

First, they do no good and lots of noisy bad where the signal level is small and the following amplification is high - a classical description of an input stage. The input to an amp should probably have a metal film plate resistor to minimize noise. Grid resistors in all but output stages also do no good, because the signal level is typically too low. A 12AX7 can be driven from cutoff to positive grid voltage with a couple of volts of signal, so the grid resistor never has a big enough signal to be distorted appreciably.

Cathode resistors are another poor use of CC. They typically only have a few volts across them, and they're often decoupled with a capacitor, both of which would minimize the resistor distortion. In cathode followers, there can be substantial DC and signal voltage across a cathode resistor, but in this case, the resistor is driven by the low impedance of the cathode, and the voltage across the resistor is controlled by the grid voltage very tightly, so the exact resistor value doesn't matter much - there won't be significant distortion.

The place to use CC's is where there's big signal - plate resistors, and ideally the stage just before the phase inverter. The phase inverter would otherwise be ideal, with plate resistors carrying the highest signal voltage in the amp, but phase inverters are often enclosed in a feedback loop. The feedback minimizes the distortion the resistor generates.

Use CC's sparingly - only where your personal ears tell you that they make a difference.

I'm always amused at people who advertise putting carbon comp resistors in their 9V powered effects to give them some kind of magical vintage sound. Urban legend is tough to kill, though - and magic mojo always makes for dynamite advertising copy.

So now you know what's happening, and something of the numbers involved. The effect is real, though slight.

Back to GEO!

How can I modify my Blender Tweety Bird amp to be as loud as a Marshall Major/AC30/Tweed Bassman/SVT/etc.?

(Alternatively, how can I make my amp twice as loud/more power/ etc.?)

You can't do this in a low power amp, at least not electronically. To put out the power the big amps put out, you need the entire power train to be as beefy as the big amps. This means bigger power transformer, rectifiers, filter capacitors, output transformer, more power tubes, bigger chassis, more ventilation to carry off the heat, lots of things. You can't just add a couple of tubes.

An amplifier is properly thought of as primarily a big power supply that has some extra junk tacked onto it to carefully let a little of the power out to the speakers under special, controlled circumstances.

You might be able to just pull a couple of tubes OUT of a high power amp to make it quieter, under some conditions. O'Connor discusses this in "The Ultimate Tone".

Back to the GEO Home Page

How can I extend my tube life?

- Modify the power on switching to heat the filaments first, let them warm up for 30 seconds, then switch on the high voltage plate supply.
- Add more ventilation to the amp chassis, perhaps with a small fan.
- Modify the tube operating conditions so the maximum cathode current is not exceeded under even maximum warp drive conditions. Exceeding max cathode current causes cumulative emission losses and early tube death. This requires a somewhat deep understanding of the design of tube amps to do, unfortunately.

Back to the GEO Home Page

How do I get...

- Blues distortion? Made by overdriving preamp and power tubes a little, enough to just start compressing the peaks of the waveforms, and not very much high frequency content, by electronically cutting highs or running the signal into a speaker cab that acoustically cuts highs.

Guitar Player magazine ran a construction article on this very topic, modifying a Fender Bassman to be the "Ultimate Blues Machine". The article ran in 1995, authored by John McIntyre.

A recently voiced although intuitively applied idea in distortion is that tube distortion sounds best when each successive distortion stage is overdriven by less than about 12db. This has the effect of keeping the tubes inside the area where the signal is more compression-distorted than clipped. That is what those resistive divider chains between distortion stages are for inside those distortion preamp schematics. Mesa's distortion preamps are another good example.

Overdriving a tube stage too much gives you harsher clipping, not the singing, sweet distortion we want. To really get sweet, crunchy distortion, keep each stage that goes into distortion no more than 6-9db into distortion.

- Marshall/metal/Boogie/etc. distortion? Made by massively overdriving preamp tubes until the original waveform is massively compressed and clipped. Usually followed with a moderate amount of high frequency cut to remove some of the "insect attracting" overtones generated in the clipping process. There is commonly some output tube overdrive in this process, too.
- Good distortion at low(er) volumes? overdrive preamp tubes until you get the clipping you want, then feed a limited amount of this to a power amp stage to get the loudness you want. This is how master volume controls work.

Back to the GEO Home Page

Where can I find plans for a Belchfire/Maximo/etc. speaker cabinet?

- ElectroVoice sells (?) makes available (?) plans for cabinets for their speakers.
- Copy an existing cab.
- Some cabinet fitting suppliers have example plans.
- -- (addresses in a future posting) ---

Back to the GEO Home Page

Output transformer questions:

Q: Do output transformers sound different from one another? If so, why do they sound different? Can you for instance wind a transformer to get an intentional frequency response? Like, you think your Marshall has too much midrange, so you put a new OT in that has like a 6-9dB cut around 800hz to get a natural "scooped" sound?

A: These things cause transformers to sound different:

- High and low frequency roll-offs caused by the details of the iron, copper, winding and manufacturing processing.
- Inherent distortion caused by the magnetic properties of the iron and the driving impedance
- Excess distortion caused by lack of coupling between sections of the windings - literally where all the windings are in relationship to one another - in a Class AB or B biased amplifier.

High and Low Frequency Roll-offs: Transformers all by themselves have a high end rolloff point and a low end rolloff point, and a broad flat region between the two. The exact frequencies where the highs and lows roll off are a characteristic of the iron, copper, and how they're wound and stacked together and treated or mis-treated.

It is possible to get a resonance or two between the two ends, but most often there is only a self-resonance point above the high frequency end. Usually any reasonably well-made output transformer has no oddities within the high and low frequency roll-off points.

Given enough info about the transformer and the use (power through it, temperature, DC bias current, etc,) you can use the parasitic parts of the transformer's response, the unavoidable self capacitances and leakage inductances, with other components outside the transformer to shape the frequency response inside the relatively flat pass band; this is more like shaping it externally than designing the response into the transformer, though. The parasitics are largely what cause the high and low frequency cutoffs, so it's not easy to move their effects out into the passband with simple circuits.

You can design in a high and/or low frequency response point, and you may be able to tinker inside the passband a little, but even an experienced designer can't easily just design in a scoop of arbitrary depth at a given frequency with only the transformer windings to work with.

Inherent (or Iron) Distortion: It's not widely understood, but transformers have their own distortion generating mechanism. The iron in a transformer has to be driven to a certain magnetic flux level to couple signals to the secondaries. The output tubes must supply this magnetizing power as well as the power to the secondaries. A well designed transformer can make this power very small. However, the nature of the iron itself is that the magnetizing power is non-linear. It takes proportionately more or less magnetizing power at different magnetization levels, so the iron siphons off more or less of the signal.

This depends on the core material linearity and magnetic softness, and how close the transformer is driven to saturation. The amount of distortion depends, among other things, on the source impedance driving it, as the distortion comes from the nonlinear shunting effect of the transformer's primary inductance. A voltage source driving a transformer will be able to be distortion free on the secondary. A high impedance drive source (like a pentode plate, unfortunately) will not be able to provide all the current the core needs to keep the voltage linear, and so some distortion will show up on the secondary as a result. This distoriton is relatively small, probably 2-5% below the beginning of saturation, and is primarily third harmonic.

Excess Distortion: Only in push-pull Class AB or B amplifiers (that is, most guitar amps) when the crossover point where one tube turns off and the other tube carries all of the power load, EVEN IF THE BIAS FOR THE TUBES PROPERLY ELIMINATED TUBE CROSSOVER DISTORTION the sudden change from two half-primary windings conducting all of the power to the the secondaries to only one tube supplying the secondaries, if the magnetic coupling from both half-primaries to the entire secondary is not excellent, there will be a glitch in the output waveform caused by the change in current in the leakage inductance in both the half-primary that is turning off and the one turning on. This crossover distortion can not be biased away. Cheap, non-interleaved output transformers often have this kind of distortion and sound "harsh".

Q: Obviously, output transformers have tolerances. Are the impedance tolerances the reason one OT may sound better than another?

A: The impedance ratio(s) of a transformer are fixed by the number of turns on each winding, and it's unusual for modern winding machines to forget or miss a turn. Can happen, but it's rare; so the impedance ratios are not what are the biggest contributors to tone differences.

Q: Are paper bobbins really superior to plastic bobbins in output transformers? How about power transformers?

A: No. Both paper and plastic are non-magnetic and non-conductive. The only way they can affect a magnetic field is by taking up space and therefore excluding either a conductor or a magnetic material from that space. As long as the winding window is reasonably filled with turns of copper wire, the effect of one bobbin material versus another is essentially impossible to find even with sensitive lab instruments designed for work on such things. The business about paper bobbins being thinner and letting the copper wires be nearer the core is nonsense. The entire iron core "conducts" the magnetic flux. Moving a turn of copper a tiny fraction of an inch closer to the center leg moves it that same fraction further from the outer leg. As long as the dimensions for paper and plastic bobbins are not grossly different (and the differences between old paper - actually glued-up cardboard- bobbins and plastic bobbins are tiny) then there is no reason that the magnetics should be affected at all.

There is some reason for this myth being started, though. The output transformers from the "golden age" were pretty much all hi-fi output trannys. This meant they were, among other things, carefully interleaved and wound. The earliest plastic bobbins were wound not to get good sound, but because the MBA's that had infiltrated the guitar companies were trying to save a buck. A quick and dirty, lowest-bidder transformer wound without interleaving on a plastic bobbin and laminated with cheap, thick iron costs less than a good on from an old-line hifi maker, so that's what they started making. The plastic was not the problem, but it was all that the uneducated user could see, so plastic got an undeserved bad rep.

Let me be clear - IT'S NOT THE BOBBIN, IT'S THE DESIGN AND ASSEMBLY.

Q:Are differences in transformer sound in the pattern of the windings? Or something else?

A:Having pooh-poohed the idea of paper bobbins being better with the "a turn's a turn" argument, I hesitate to get into this, but I guess I should. The thing that makes for an OT tone is the sum total of the contributions of all those parasitic elements in the transformer - the series wire resistance, the leakage inductance in the magnetic path, the turn-to-turn capacitance, the layering and distribution of layers in the window, the depth of the core stack, the thickness of the iron in the laminations the -*magnetic softness*- of the iron in the laminations and how carefully they have been interleaved and butted together, and how free the laminations are from electrical contacts.

Paper bobbins are one of the few things that DON'T affect a transformer's tone, all other things being equal.

It is really a no-brainer to copy a transformer, but you have to know about and be able to copy all of the details about how it's made. Once you do that, you get fairly repeatable results, with the exception of the handling of the iron. Transformer iron is annealed to be physically and magnetically soft (which go together), and an oxide layer is grown on it to prevent the layers from electrical contact, which affects how much core loss happens. If the iron is roughly handled, it gets hardened and has more core losses and higher distortion, as well as having the oxide scraped and or punctured, which increases eddy current losses. These will have an effect. You can detect the changes in magnetic characteristics of transformer iron by testing the iron into a test coil, then striking it sharply EVEN ONCE. I've performed this test myself on occasion.

Care in stacking the iron and jogging it together also has an audible effect. If the laminations are carefully jogged together so the joints are as tightly fitted as possible, it runs the primary inductance up and the low frequency rolloff down, making for a better bass response.

All this sounds obscure, but is really much easier than learning to play guitar on an intellectual scale. It's just another special language to learn. Most people just don't go there, so it gets shrouded in myth.

Q: I remember reading Matchless's (or others...) ad stating they copied the OT of an incredible sounding amp and that was the key ingredient of their sound. What was it they copied, impedance or winding pattern?

A: They had to do both to get a good copy - as well as having to duplicate or approximate iron composition, thickness, and stacking.

Q: Is hand winding superior to machine winding for output transformers? When a known "good sounding" vintage or modern transformer is duplicated, will modern equipment should be able to consistently reproduce them without varying results? Is hand winding being superior to machine winding is a myth?

A: The devil is in the details. Machines can produce goods with a consistency that a human hand/eye/brain simply can't, so where pure replication is required, bet on the machine. Whenever the materials/situation/adjustments, etc. require judgement and on-the-spot compensation, bet on the human - IF the human is an expert at whatever the situation is.

I would say that historically, the real situation is that cheaply produced and poorly designed (for instance, non-interleaved) machine wound transformers were accurately reproduced, and sure enough, the sound was reliably bad. A good hand winder repro-ing a carefully stacked interleaved OT could, in spite of the inevitable slight variations and flaws produce a much better sounding transformers - at a much higher price - in low quantities. A myth gets started - "I used so-and-so's hand wound OT, and it ran rings around the machine-wound replacements," which is demonstrably true, but then the leap to myth is made "therefore only hand wound transformers are good." This train of reasoning is so seductive in the "vintage-is-god" environment that it almost instantly becomes common wisdom, putting the merit on hand winding when in fact the differences were in different designs.

For duplicating windings, a well made, well adjusted and well maintained machine will produce more consistently identical windings than a human. Note that I put a number of caveats on that statement.

An expert human with little or no equipment will produce better, more consistent goods than a bored, ill-trained, poorly paid operator coping with the wrong wire size on a poorly adjusted forty year old machine, which is how some (especially the cheaper) transformers get made.

So - is the notion that handwound transformers are ALWAYS superior BECAUSE they're hand-wound a myth? Yes.

Are hand-wound transformers SOMETIMES superior to machine wound? Yes, especially where the hand-winder is producing a different design from the machine.

I'd call the quality pretty much the same for hand-wound and machine wound transformers where the hand-wound ones are produced in low quantity by experts (a caveat that excludes fatigue and skills flaws) and the machine wound ones are made on modern equipment with skilled operators in large quantity (which allows adjusting the machines for consistency).

Q: I've read references to modifying PP OTs, adding a mysterious "gap" (mysterious to me at least) for SE use. What does that mean?

A:Probably this: process of adding a gap means carefully unstacking an interleaved PP transformer, restacking the E's and I's into non-interleaved chunks and reinserting the bobbin with a spacer. This gets you a transformer that has a lower primary inductance, but that won't saturate as easily. It's probably not what you would originally have designed for any given SE circuit, as the primary inductance is now lower, but it might work. And it REALLY appeals to the home-handyman tube hacker crafstman instinct.

Q: What are "gaps" in output transformers, and why are they good?

A: The "gap" in single ended transformers is just that - a space where there is no iron. The way this is done with E-I cores is to stack all the e's together and insert them into the bobbin in one chunk, then put a paper or fiber spacer across the end of the "E"'s, and then the I's are laid on in a chunk. The point of this is that there is now a gap where there is no iron bridging it that makes the magnetic field jump across. This linearizes the magnetic properties of the structure as a whole, as the properties of the gap are so different from iron that they dominate, and the gap cannot saturate like the iron can.

The overall primary inductance is much lower now than if you had interleaved the laminations, alternating the direction of the E's in the center of the transformer, though, so you must use much more iron and copper to get as much primary inductance and low frequency response as you would have had if you'd interleaved the laminations, so the transformer gets big expensive, and can support much less output power for its size than it might otherwise. Ten watt gapped single ended OT's for instance may be four to six times as heavy as Class AB transformers designed for fifty watts out.

Q: Can I use a push-pull OT in my single ended amp? How about if I re-stackit to have a gap?

A: The use of PP OPTs for SE is cautionary. The problem is that you must run the bias current through the primary as DC, and this offsets the core magnetically. A transformer which uses interleaved laminations (almost all PP OPT's) has a much higher primary inductance, but is easy to offset and make the iron saturate. Introducing a gap makes the primary inductance lower, but makes the transformer much more resistant to saturation, good for SE OPT's. Using an interleaved PP OPT in SE use necessarily limits the amount of DC bias that can be used without saturation and the corresponding distortion. It works if you keep the DC bias current low enough to not saturate the core, but that limits the amount of power you can use. So in general it probably works if you use a BIG PP OPT for a much smaller SE amp. As a tube hacker, I can understand the urge to just hook up whatever you have that might be a good output, but as a former transformer designer, there are going to be cases where it will not work or won't work well. Experiment if you like, but be prepared to toss the transformer and/or output tubes if they fry, or tear it all down if it just doesn't sound good.

Q: What is an "ultralinear" output transformer?
A: It's a transformer with a tap at about halfway between the B+ connection and the plate connection to which you can attach the output tube's screen grid. This connection provides some feedback to the screen grid as well as a bias voltage and has been found to act like a connection halfway between pure pentode modes and pure triode mode, with lower distortion than either. It's almost a requirement for tube hifi ampliers. Bass amplifiers use it to get large amounts of clean power. It usually sounds too "sterile" or clean for guitar players' tastes.

Q: Can I convert an amplifier with an ultralinear connected OT to normal use?

A: Yes. Just disconnect the ultralinear taps and make sure they don't short to something, then connect the screen grids to a screen voltage supply. This is a common mod to UL connected amplifiers for guitar use.

Q: Can I substitute two single ended transformers for a single plate-to-plate transformer?

A: If you have two single ended transformers, these are running effectively in parallel. It makes no difference whether you are driving them from a phase inverter or not, because the phase on the two (independent) output windings can be changed either way by reversing the leads. This is not going to give you the same operation of either the transformers or the tubes as a true plate to plate transformer. The real plate to plate transformer actually combines the tube power in the flux in the iron, which can never happen in two separate transformers.

Hooking two transformers together to combine the output power is always tricky, series or parallel, because if you combine them wrong, there can be large circulating currents, which can kill the transformers. How did you determine the proper phasing on the outputs when you connected them up? It is coneptually possible to series two outputs and have everything work, but in practice, it's hard to do this well.

For a series connection, you MUST get the secondary voltages to add. If you get the secondary voltages offsetting each other, the series connection is effectively open circuited, no matter what load is on the series combination no current flows because the secondary voltages cancel out. In this connectio, you probably kill the primaries by arcing over the internal insulation, possibly followed by burning the winding open when a turn or two shorted from the puncture in the insulation and the B+ caps dumped through that short.

The safe way to find out the phasing is to use two resistor-loads, one per secondary, and then to connect one end of each secondary together; drive the amp with a signal generator and measure the AC voltage across the free ends. If the voltage is 2X the voltage on either secondary, you're phased correctly, and you can leave the center connection where it is, remove the resistor loads, and put one speaker across the free ends.

If the voltage across the free ends is smaller than the voltage across either secondary, they're phased wrong, and you need to swap the ends of one secondary. Combining the powers of two SE transformers is best done acoustically. Drive a second speaker.

Q: I've seen circuits that use reverse biased diodes connected from ground to the plates of output tubes as "transient spike preventers". How does this work?

A:The 1N4007's serve mainly as an amulets against the voltage gods in this case. An inductive flyback pulse will go to literally ANY voltage until it finds a discharge path. Ideally, transients that would cause very high positive voltages on one push-pull plate would cause high negative voltages on the other plate, and the diodes on the negative going plate would clamp the voltages on the positive going plate through the output transformer. This does indeed happen for small, extremely-tightly coupled transformers. However, any leakage inductance between the two primaries prevents the tight coupling that would let the negative going diodes protect, and worse yet, it's the leakage inductances that cause the spikes on transients anyways.

What really happens is that the first few flyback pulses that occur will break over the 1N4007's rather than than arcing the plates on the positive side, so there really is some protection, it's not just where it looks like it is. If you're lucky, the 1N4007's break over before the transformer insulation punches through, and all is well until the 1N4007's go leaky or short. Probably better than nothing, but not a whole lot of additional protection, either. Heck, amulets are not harmful, I guess.

Q: Can I use an ordinary pushpull output transformer as a single ended ultralinear output transformer?

A: Maybe. It's cheaper than getting one originally designed for that use, but you do have to consider it as experimental - it may or may not return good results, and you may have irretrievably damaged a working OPT, which may or may not be a tragedy, depending which transformer it was and whether you paid real dollars for it and how many. You can try it, but consider the transformer expendable.

Q: What does the "impedance" of my output transformer mean?

A: Transformers don't have impedances, they have impedance RATIOs. This is an important distinction.

Transformers transform impedances as a pure ratio. That is, a 4400 PP to 8 ohm transformer makes any load on its secondary look like it's 550 times bigger to a tube at the primary. An 8 ohm secondary load then looks like a 4400 ohm load at the primary. It also makes a 16 ohm load look like an 8800 ohm load if you hook 16 to it, 2200 if you hook a 4 ohm load to it, and similarly for all values in between. Power tubes have a power output that depends on matching - that is, they have sweet spot load that they do best on, most power out, and other loads will get less power because the tube itself limits how much power it will transfer out. [Actually there are two sweet spots, one for highest power, one for lowest distortion; the two spots are not the same for any known tube. From zero ohms loading up to some ill-defined number of ohms higher than the optimum power load, power tubes do not destroy themselves, they merely change how much they transfer to the load. So - if you have a tube amp with a tap for 8 ohms, you will get the nominal power of the amp only with a "matched" 8 ohm load. If you hook 16 ohms there, the power tubes "see" a proportionately higher ohmage on their plates, and can only put out about half the nominal power. If you hook up a 4 ohm load to the 8 ohm tap, the power tubes "see" a load about half of the matched one, and again will put out only about half of the nominal power. This "half the nominal" power is not fixed because of the 2:1 change in load, but varies from amp to amp and tube to tube, and may not be exactly 2:1. In addition, speakers are NOT single impedance loads. It is convenient to think of "8-ohm" speakers, but the plain fact is that the speaker's impedance varies with frequency and also with the acoustic loading (cabinet and other things) that the speaker sees. That impedance meter is not going to be a huge help, because you have to specify the frequency being tested as well as the impedance to have something meaningful.

Q: Why do I have to match speakers to the output impedance of the amp?
A: You'll get the most power out of the amp if the load is matched.

Q:Will it hurt my amp/output transformer/tubes to use a mismatched speaker load?
Simple A: Within reason, no.
Say for example you have two eight ohm speakers, and you want to hook them up to an amp with 4, 8, and 16 ohm taps. How do you hook them up?

For most power out, put them in series and tie them to the 16 ohm tap, or parallel them and tie the pair to the 4 ohm load.

For tone? Try it several different ways and see which you like best. "Tone" is not a single valued quantity, either, and in fact depends hugely on the person listening. That variation in impedance versus frequency and the variation in output power versus impedance and the variation in impedance with loading conspire to make the audio response curves a broad hump with ragged, humped ends, and those humps and dips are what makes for the "tone" you hear and interpret. Will you hurt the transformer if you parallel them to four ohms and hook them to the 8 ohm tap? Almost certainly not. If you parallel them and hook them to the 16 ohm tap? Extremely unlikely. In fact, you probably won't hurt the transformer if you short the outputs. If you series them and hook them to the 8 ohm or 4 ohm tap? Unlikely - however... the thing you CAN do to hurt a tube output transformer is to put too high an ohmage load on it. If you open the outputs, the energy that gets stored in the magnetic core has nowhere to go if there is a sudden discontinuity in the drive, and acts like a discharging inductor. This can generate voltage spikes that can punch through the insulation inside the transformer and short the windings. I would not go above double the rated load on any tap. And NEVER open circuit the output of a tube amp - it can fry the transformer in a couple of ways.

Extended A: It's almost never low impedance that kills an OT, it's too high an impedance.

The power tubes simply refuse to put out all that much more current with a lower-impedance load, so death by overheating with a too-low load is all but impossible - not totally out of the question but extremely unlikely. The power tubes simply get into a loading range where their output power goes down from the mismatched load. At 2:1 lower-than-matched load is not unreasonable at all.

If you do too high a load, the power tubes still limit what they put out, but a second order effect becomes important.

There is magnetic leakage from primary to secondary and between both half-primaries to each other. When the current in the primary is driven to be discontinuous, you get inductive kickback from the leakage inductances in the form of a voltage spike.

This voltage spike can punch through insulation or flash over sockets, and the spike is sitting on top of B+, so it's got a head start for a flashover to ground. If the punchthrough was one time, it wouldn't be a problem, but the burning residues inside the transformer make punchthrough easier at the same point on the next cycle, and eventually erode the insulation to make a conductive path between layers. The sound goes south, and with an intermittent short you can get a permanent short, or the wire can burn though to give you an open there, and now you have a dead transformer.

So how much loading is too high? For a well designed (equals interleaved, tightly coupled, low leakage inductances, like a fine, high quality hifi) OT, you can easily withstand a 2:1 mismatch high.

For a poorly designed (high leakage, poor coupling, not well insulated or potted) transformer, 2:1 may well be marginal. Worse, if you have an intermittent contact in the path to the speaker, you will introduce transients that are sharper and hence cause higher voltages. In that light, the speaker impedance selector switch could kill OT's if two ways - if it's a break befor make, the transients cause punch through; if it's a make before break, the OT is intermittently shorted and the higher currents cause burns on the switch that eventually make it into a break before make. Turning the speaker impedance selector with an amp running is something I would not chance, not once.

For why Marshalls are extra sensitive, could be the transformer design, could be that selector switch. I personally would not worry too much about a 2:1 mismatch too low, but I might not do a mismatch high on Marshalls with the observed data that they are not all that sturdy under that load. In that light, pulling two tubes and leaving the impedance switch alone might not be too bad, as the remaining tubes are running into a too-low rather than too-high load.

Q: Can I use two single ended output transformers in a push-pull circuit and then parallel the outputs?

A: What you're making really IS two class A output stages run in parallel. With no magnetic coupling between the two half-primaries, there is no interaction on the secondaries, either. You have to run them Class A to keep from having distortion because they really are separate amplifiers. It's not clear what happens if/when you try to use feedback from the secondary into the (presumably)common driver stage.

On the secondaries, you have two 8 ohm outputs that you can connect in series to drive either two 8 ohm loads separately or one 16 ohm by placing the secondaries in series; the resulting power capability, given that you get the rest of the circuit right, is the sum from each transformer, or about 2X the power of each Class A amp by itself. Note that this is far less than you'd get by using a proper push-pull OT and driving it in Class AB, probably ¼ the power.

If you try to parallel the two, you can get some interesting and possibly disturbing results. If the transformers really are IDENTICAL, then for equal primary drive, you get equal secondary voltages, and you could parallel them OK to drive a single load. If there is a difference between primaries, secondaries or drive voltages, then the secondaries try to make different voltages, and fight it out. The differences are reflected into the primaries as a kind of push-back voltage on the output tube plates. Tubes being the forgiving things they are, this will probably not kill anything, but it will at least act like a different loading than you're expecting on a per-tube basis. I'm not certain exactly what effect this will have on linearity or life. If you were driving the primaries from a low impedance source, something would burn.

Q: What are the things about output transformer that cause the differences in tone? How do differences in output transformer construction combine with tubes to give differences in tone? How do I design/modify an OT for a tone I like? How do I duplicate the tone of a OT I already like?

A: What you have asked, translated into transformer-geek language, is "How do I completely describe the equivalent circuit of a transformer and the circuit it resides in?"

To be truthful, there isn't all that much mystery about transformers, but it's not like the rest of your everyday electronic parts. Transformers are susceptible to electronic modelling, and once you get the model correct, you can twiddle the values until you get the "tone" you want, including nonlinear effects. The later versions of SPICE include nonlinear transformer models for exactly this use.

You won't like the answers, primarily because of size. To understand a transformer's effect on tone, you have to be able to model the whole power amp/tube/OPT/speaker chain and account for the effect of changes in the OPT model, then synthesize back to real hardware once you get the response you like. You've asked for a couple of semesters equivalent worth of information on transformer modelling and design linked to a course on the design of the output stage of a tube audio amp.

I suggest that if you really want to know this stuff, you find a copy of Nathan R. Grossner's "Transformers for Electronic Circuits", which is out of print, but available at many technical libraries. I put this reference in the Tube Amp FAQ to answer this kind of question.

You can model any transformer as a shunt primary capacitance across the primary winding, a series leakage inductance to the primary winding, a series resistor equal to the winding resistance, a nonlinear inductance representing the primary inductance, with a nonlinear resistor in parallel with the primary inductance to represent core losses, primarily from eddy currents. Then an ideal "perfect transformer" to convert the voltages and currents correctly, a series secondary winding resistance, a series secondary leakage inductance, and a shunt capacitance across the secondary. A shunt capacitor from primary to secondary completes the model.

Get those component values correct, and you can accurately model everything about any transformer. There are no mysteries hiding in there. The component values are all measurable, and to a certain extent predictable from the start. Any transformer can be copied, Fischer and his ilk to the contrary.

So - tone effect of a OPT? first - what does the base transformation ratio do to the reflected loading on the tubes as a function of frequency, including speaker loading. This is fairly independent of the transformer model, depending only on that "ideal transformer" in the middle, but has a big effect on how the tubes put out power.

Next - What are the values of the model components? That is, how much leakage inductance, shunt capacitance, and core loss is there? At what points in the excitation does the core start going into saturation, and from the composition of the iron, what is the irreducable energy loss per cycle to magnetizing losses, which shows up as pure third harmonic distortion. Core saturation sounds like any soft limit on a signal; its effect on tone also depends on the symmetry of the limiting. You get primarily third, but smaller amounts of fifth and seventh harmonics on pure tones. Combine with the tone of the tubes? I have a problem with that, and I'm not just being difficult. First, define "tone" unambiguously...

The power response of the tubes will be affected a lot by the degree to which the reflected loading on the plates matches the "power transfer sweet spot" for the tube, and this is a function of frequency, depending obviously on the speaker impedance curve and the other parasitics in the model.

The size of the core and the number of turns have a direct effect on the low frequency response, but they affect it by changing how much the primary inductance loads the tubes at the lowest frequency of interest. Good designs make this NOT be a consideration in most cases. Poor designs make it a critical factor, and you hear the poor design as either core distortion or low frequency restriction. The winding inductances are entirely subsumed into primary and secondary inductances and have no effect on tone whatsoever - except to the extent that the physical location and sectionalization of the windings contribute to the leakage inductance and shunt capacitances. The effect of the loading on the plates IS a major contributor. Each tube type has a power response curve, power out at a given impedance. There is also a curve of distortion versus loading. In general, the sweet spot of max power is not the sweet spot for lowest distortion, so changes in loading cause the amount of power out to change as the amount of distortion changes, too. Changes in plate loading will cause big changes in tone - and speakers all by themselves have impedance versus frequency curves that vary by four or more to one. To get a good grip, first get some good background. There is not enough room in this FAQ to type in what you've asked. Get a book, preferably Grossner, but any other that describes the basics of transformer modelling; then I can point you to some books on transformer making that will give you an idea on how to change the things you do in making one that can change those parasitics. A final thought. If the totality of what a transformer does to tone can be modelled by the ideal transformer and some non-ideal components, could you take a transformer with very small parasitics, close to ideal, and add in external "parasitic" components and make it look like any one of a number of less ideal transformers? Yep. You can add inductors and caps to OPTs to make them look more like some transformer you like better, as long as you're not haveing to add negative inductance and/or capacitance. The iron alloy also has an effect, and it's tied up in that business about the BH curve and nonlinearities. If you drive a transformer from a voltage source, 0 ohms impedance, then there is no distortion of the secondary voltage as a result of the BH nonlinearities, as the source can provide any current to keep the voltage correct. If however you use a source with a real impedance, like the plate impedance of a pentode, then the nonlinearities demand current, and the plate impedance then limits the current available, so the voltage waveform is distorted on both primary and secondary. Unfortunately, we need the transfomer BECAUSE the tube has internal impedance, so we can't just wish that away. As a sidelight, this is one of the classical arguments for triode output tubes over pentodes or beam power tubes during the golden age hifi years - triodes have a much lower internal impedance and hence lower the distortion of the transformer.

What you CAN do is to do some fairly simple tests to map the BH curves of the iron you have,

[sidelight: if you find a "magic" transformer, much more "tone" (whatever that means to you) than any other, you can do the work to measure the BH curve nondistructively on the core properties that it has, and then go duplicate them.] and then either get different iron or introduce air gaps to change the effective BH curve of the iron to make a core nonlinearity that matches whatever sounded good. You may not be able to match the iron perfectly, but it's the core properites, not just the iron, that you're looking for, and there are things you can do there.

There are a number of grades of transformer iron, but I doubt that there are larger laminations made especially for audio these days, as there is effectively no money to be made; the money is all in laminations for power transformers. There are several grades of good, linear, high permeability silicon iron made for power transformers, and I suspect that these are what ALL new manufacture OPT's come from.

Note that this may (and probably will) result in a core that is bigger than the one you're copying, you may have to rework the windings to get the necessary primary inductance, shunt capacitancs, leakage, etc, etc. to duplicate the response of an iron core you can't get.

Also - there are other ways to introduce the specific nonlinearities that make for a good sound if you can ever define what "good" is well enough.

Q: How can I tell if my output transformer is live or dead?

A:There are some simple tests you can run to quickly determine if a transformer is grossly bad. This is much simpler than determining if it will work well and sound "good" for you. The tests of relative "goodness" are also possible, but require a lot of equipment and experience to do correctly. For the quick and dirty tests described here, you'll need a means of measuring AC voltage and current simultaneously, such as a pair of VOMs or DMMs, and a 110/120 to 6.3VCT filament transformer, and either a variac (variable transformer) or a light bulb socket in series with the primary of the filament transformer to limit the power you put into the transformer under test.

CAUTION CAUTION CAUTION

Both the filament transformer and the transformer under test will have at least AC line voltage on them, an may well have much higher voltage, several hundred volts on one or more windings. You are therefore in danger of being **KILLED** if you are not both knowledgeable and careful about how you do these tests.

DO NOT TRY THIS IF YOU DO NOT HAVE THE KNOW-HOW AND EXPERIENCE TO WORK SAFELY WITH THESE VOLTAGES. IF YOU HAVE ANY QUESTION IN YOUR MIND WHETHER YOU CAN DO THIS WORK SAFELY, YOU CAN'T.

Seek experienced help if you have any question in your own mind.

The tests run like this. Identify which wires are which by color code, circuit connection, or by using an ohmmeter to find which connects to which. Label the wires. From the same ohmmeter test, write down the resistances you measured on the windings. Generally, windings with resistances over a few ohms are high voltage windings, either a power transformer primary or high voltage output, or an output transformer primary. Note that it is common for primary windings on power transformers to have from two to six wires, with the wires over two being taps to adjust for various line voltages from 110-117-120-125-208-220-240. Secondary windings on power transformers and primaries on output transformers will have either two or three leads, and secondaries on output transformers will have to to four leads.

Also note if any winding is shorted to the transformer core. Sometimes an internal shield will be deliberately connected to the core, but if a multi-lead winding is connected to the core, this is usually an internal short, and a dead transformer.

Once you have identified the windings, hook up one and only one winding to either 1/2 of the 6.3VCT or to the variac. Try to select a low voltage winding, one that has low resistance from the ohmmeter test. Make sure that no other leads are connected (or shorted together, or touching your screwdriver on your bench or... well, you get the idea). A turn of plastic tape on each wire end you're not using at the moment is a good idea. Set your voltmeter on this winding, and the current meter to measure the current through it, and bring the circuit up. The voltmeter should measure 3 volts AC, the light bulb (if used) should NOT be lit brightly, and nothing should be humming or smoking ;-). There should be little current going through the winding. If the voltage is lower than 3 volts, or you are pulling amps of current, then there is a load on the transformer, internally since you have disconnected all the leads, meaning that there is an internal short. You should try to select a winding for this test that is normally a low voltage winding, either a filament winding in a power transformer, or a secondary in an output transformer.

If all is well, measure the voltage that now appears on the other windings. The voltages will be equal to the ratios of the voltages that will appear on these windings in normal operations.

B. Where can I get a good replacement output transformer for my vintage DoppelBanger amp?

Dixie Sound Works, Gunthersville, Alabama has a great reputation for (re)winding quality vintage re-makes. The company that made the amp may have service parts. The quality is variable from company to company and time to time, though.

There are a number of companies that have entered the transformer market in the last year, so expect that there will be new places to get quality rewinds and replacement transformers

C. I want to make my own power and output transformers. How do I do this?/ Where can I find information about this?

Designing and hand winding transformers is not terribly difficult, but it does require information and skills that are relatively hard to find. You are unlikely to save a whole lot of money unless used or broken parts are cheaply available to you. You may want to do this if you feel that you were selected by some deity to take this on as a life work. First, take a transformer apart. A burned out tube-type power transformer will do. Do this carefully and slowly, imagining how you would have put it together in the first place to get it the way it was. This is an excellent introduction to the manual skills and materials needed to successfully produce one on your own. Learn about how transformers are designed from one or more of the following, in this order:

1. "Transformers for Electronic Circuits", Grossner (check your library)
2. "Radiotron Designer's Handbook, fourth edition
3. "Audio Transformer Design Manual", Wolpert, $36, privately published, available from: Robert G.Wolpert 5200 Irvine Blvd. #107 Irvine CA 92720
4. "The Williamson Amplifier" D.T.N Williamson, reprint available from Old Colony Sound Labs
5. Handbook of Transformer Design and Applications by William Flanagan (second ed.)
6. "rewinding transformers with CAD" by Hugh Wells W6WTU Ham Radio Dec '86 p.83
7. "Fast Optimization of Transformer Design" EDN Nov '62 by Davis, J. H.

These sources will help. They are NOT a complete cookbook. Note that it is very possible to make a transformer that will operate relatively well, but may break down unexpectedly and KILL you if it is not constructed with safety in mind.

D. Should I replace my stock transformer with a new/old/vintage/purple one for better clean/grunge/grit/etc. sound?

Unless you REALLY know what you're doing and have heard the transformer you'll be swapping in and like it, no.

There are a huge number of variables in the "sound" of a transformer, and you should exhaust other means first. You might not get that magic sound after all that work unless your ears - and amp tech - are really good.

Are potted / impregnated transformers better? Is potting / impregnation necessary?

Necessary for function? No.
Necessary for long term reliability? Yes.

If transformers are not potted or impregnated in some way, they will eventually have problems with slight repeated movements of the wire wearing the insulation and interleaving material, and with moisture infiltration. In some climates, moisture infiltration will let molds and mildew get started inside the transformer if it's not used almost daily. "Potting" is not the same as "impregnating"."Impregnation" means getting some kind of insulating gook soaked all through out the windings and spaces inside, while potting means putting the whole assembly in a can and filling the can (and transformer, as in impregnation) with goop. To be reliable for years of use, a transformer must at least be impregnated with varnish or epoxy. Almost all commercial transformers of any size are treated this way.

A do-it-yourself way to do this is to dunk the whole transformer in a bucket of varnish and pull a vacuum on it to expand the air out of the windings. A few vacuum cycles will get varnish well infiltrated into the windings. Then bake it at low temperatures (under 140 to 200F) for a long time, until the varnish is truly hardened.

[Back to the GEO Home Page](http://www.geofex.com)

What is the easiest way to get tube sound at a good price?

- Obtain an old piece of tube gear, perhaps intended for another purpose, like mono hifi, at no or low cost. Modify this to duplicate to a certain extent the circuit of an existing amplifier. Tinker to your heart's content.

There is a document on exactly this at http://www.wwu.edu/~n9343176/docs/old2new.html The document goes into excellent detail on the in's and out's of building from old tube gear and the possible and useful variations of which stages with how much gain go where in the amp.

- Build a tube preamp from scratch, and use this to drive another larger amplifier which does not necessarily have to be tube based. I have designed things like this, so have others. Good tube sound, and inexpensive. Really convincing tube distortion, especially if you add some lowpass filtering to simulate the high frequency cutoff of guitar speakers.

This is what the Hughes and Kettner Blues Master and Cream Machine tube preamps did (they've been discontinued). These were entire tube amplifiers with maybe 2 or 3 watts output, a simulated load, and a line level output in addition to the speaker output. They did a VERY respectable job.

[Back to the GEO Home Page](http://www.geofex.com)

How can I modify my tube amp to ... ?

(also see recommended mods, below)

Get lower hum?

- Replace the defective humming tube
- Replace or improve the power supply filter capacitors
- Fix the defective internal ground wiring, as on a reverb tank, or previous "improvements" and modifications
- Run the preamp filaments on regulated DC, not AC, starting with the input tubes
- Rewire the grounding so the amp is star grounded, and does not use the chassis as a ground bus
- Move the signal wires around, nearer/farther from the chassis or 60 Hz AC carrying wires
- Use coax cable in the signal path, at least in the early sections where noise counts the most. Tie one end of the shield to ground and terminate the other end with some shrink tube so it cannot touch anything. This way the coax shield acts as an antenna and conducts the RF to ground (as well as Faraday shielding hum out). If you tie both ends to ground you set up some capacitance (and the possibility of ground loops) you're better off without. The shield should be tied to the star ground point individually, and bypassed to the chassis locally with a good RF cap of about 0.001 to 0.01.

George notes "You may already use this in your own amps but I thought we might share it with the rest of the tinkerers - it's especially useful for people that are trying to add extra gain stages. I even use it between the input jacks and the first stage since in most Fender amps it has to traverse the width of the board. (Kaschner)

Have higher gain/more distortion?

- Install an extra gain stage by
  - Using an unused tube section if one exists
  - Adding another tube to the chassis
  - Using the reverb tubes as additional gain stages
  - Using a power MOSFET as a cathode follower to drive tone control and volume controls for lower loss
  - Using a power MOSFET to replace an existing cathode follower, freeing up that tube section for more gain
  - Remove the feedback on the power amp stage; newer Fenders and other amps use feedback on the power amp to reduce distortion. Removing this increases gain and and distortion, and makes the distortion start at lower volumes. On Fenders, it's generally a white wire from the 'ext speaker' jack to a 2.2k resistor. Cut this wire, or lift it at one end. To be really slick, put in a toggle switch. (Edelman)
- Use the alternate channel for more gain, perhaps jumpering two channels together

have a smoother, less buzzy distortion?

- Use a lowpass filter somewhere inside the amp in the signal path to cut higher harmonics; perhaps a capacitor to ground from the final preamp tube grid or plate -or-
- Use series grid resistors to cut the high frequencies in and after distortion stages
- Use a lowpass filter after the amplifier and before the speakers to cut out some of the higher overtones.

Back to the GEO Home Page

When should I bias my amp and how do I do this?

A. What is "bias"?

"Bias" in this context refers to the amount of voltage held on the grids of the output power tubes. This controls the amount of current the output tube(s) conduct exclusive of the signal current, or, looking at it another way, the amount of overlap where both tubes are conducting simultaneously.

I will talk about the output tube current since the terms "underbiased" and "overbiased" are confusing with tube amps. A technician who works with only tube amps will usually refer to the voltage which sets the operating current in the tubes. In these amps, the bias is a negative voltage, so "overbiased" to such a technician would mean that the tubes are held in a condition of too little current, just backwards from the solid state terms most of us are familiar with. "Underbiased" would mean that the tubes have too little negative voltage on their grids and are conducting too much current simultaneously.

The idle current in the output tube and the degree to which the output tubes overlap in conduction is what you're trying to adjust, not how many volts go on the grids; you just have to use the grid volts to change the current and conduction angle.

The whole topic of bias is tied up with the "Operating Class" the power amp is designed for. There are only three classes useful to us in tube amps, Classes A, AB1, and AB2. Class A means that the output tubes are biased so that both tubes are always conducting. Even on maximum signal peaks, the tube driven most "off" will still be conducting some current. In both class AB's, the bias is set so that on a signal peak, one of the tubes can be driven completely off for some part of a signal cycle. In class AB1, no grid current flows into the grid of the tube, and in class AB2 some grid current is driven into the grid of the tubes. There is a class B, where both tubes never conduct current at the same time, only alternately.

The point of all this is this: The Class of the amplifier is determined by how much bias current is present. If there is a lot of bias voltage, the grids are held 'way negative, then only the tube which is driven by the positive going half wave of the signal at any moment is conducting. This is class B. It sounds ugly because the point where the signal crosses over from positive to negative and begins to drive the other tube is not reproduced cleanly, and creates [surprise!] crossover distortion. You can look at the output signal with an oscilloscope and see crossover clearly as you make the bias voltage too negative for both tubes to conduct at the same time. As the bias voltage is made less negative and allows both tubes to conduct a little, the crossover notch diminishes swiftly, and you are in class AB2; a little less negative, and they both conduct more, and you have class AB1. If you go further, you get to the point where both tubes always conduct, making the amp work in class A, which has the least crossover distortion of any of these operating conditions.

Too little simultaneous conduction in the output devices puts them in the most nonlinear region of their transfer characteristic, so crossover distortion is high; but as you increase the amount of simultaneous conduction, the power used and dissipated by the outputs goes up, perhaps to a disastrous degree. You are trading standby current and power dissipation in the output devices off against distortion. If both outputs are biased almost totally off at idle, crossover distortion is very bad. As the simultaneous conduction is increased, crossover goes down rapidly, until it gets smaller than the residual THD of the amp itself, and becomes much less audible. There is a fairly broad sweet spot where the crossover distortion is comparable to the THD and the idle current and idle power dissipation are reasonably low. This is the region you're looking for.

Lots of bias, both tubes conduct all the time - and eat a lot of power, get hot, other Class A kinds of things. Little bias, both tubes overlap less, get less hot, put out more total power - and produce crossover distortion, which sounds especially unpleasant.

Power tubes individually have slightly different DC gains, so the same bias voltage on two different tubes produces two different current levels. "Matched pairs" are two tubes selected to be close together. Groove Tubes grades tubes from 1 to 10 so that any two "3"'s for instance are close enough to sub for any other "3", so you don't need to rebias if you keep buying the same number from them.

Note that you may not want matched pairs, depending you your taste. See section D. below.

B. When should I bias my amp?

You should re-bias the amp whenever you change power tubes or modify the power amp circuits.

Each power tube needs a certain bias current to keep it operating at the point where the amount and type of distortion under normal conditions is well controlled. Individual tubes vary widely in the grid bias that sets the correct idle bias current. If you change tubes or tinker with the circuit, you need to make sure the tubes are set back into operation in a way that sounds good and does not cook the tubes.

Amps typically provide only one adjustment point for bias, assuming that you will have bought matched sets of power tubes.

It is possible to modify your amp to "match" unmatched tubes by setting the bias voltage and AC drive level of each tube individually. This may require some serious soldering, though. See section D. below for a discussion on matching, and the mods section for what you have to change.

C. How do I bias my amp?

CAUTION CAUTION CAUTION

Keep in mind that tube amps use high voltages, and they can *kill* you if you don't know what you're doing. So, if in doubt, leave the job to a qualified technician.

How do you correctly bias an amp? There a few different approaches but first hook up a speaker or a passive load to the output and remove any input signals; tube amps need to have a load or they can sometimes become unstable. Check and make sure the proper size fuse is installed.

Output Transformer Shunt Method

The most common and simplest procedure is to hook a current meter from the plate (anode) across half of the primary of the output transformer; this is called the "output transformer shunt method." The idea here is that milliammeters commonly have a very low series impedance so that when placed in parallel to half of the primary, almost all of the current flows through the ammeter. When you hook things up this way, your meter is floating at the voltage level of the plate, which is typically hundreds of volts -- be very careful! You could open the wire from each plate to the output transformer and hook in a meter in series with the plate temporarily, but that is a terrible amount of work for the small gain in accuracy.

Adjust the bias pot so that the current reading is the appropriate value for the type of tube (see the table below). Let the amp warm up and note if the bias changes significantly. If so, select a compromise bias point.

Keep in mind that if your circuit uses more than one tube per side, the bias current you're reading is multiplied by the number of tubes (e.g., if you're reading 60 milliamps and there are two power tubes per side, if the tubes are matched each of the two are getting nominally 30 milliamps). Check the other side of the circuit to confirm that the two sides are close (within 5 milliamps) to each other.

If your ammeter has too high a series impedance, the shunt method won't work because the bias current gets significantly split between the meter and the transformer; the meter has no idea how much current is going through the transformer. You'll know it's not working because the current values you'll be reading will be much too low no matter how far you adjust the bias pot, the tubes will be glowing hot, and when you note that you'll reach quickly for the power switch! If you don't reach it quickly enough, you might blow a fuse. Don't despair: you can use another method called the "cathode resistor method."

Cathode Resistor Method

If the circuit already has a resistor in-line between the cathode and ground, use it. If the circuit has the cathode hooked up directly to ground, insert a low value resistor (say 1 Ohm/1 Watt) [even 10 ohms will work well, as the currents in a tube circuit will cause only a volt or so max across a 10 ohm resistor, not enough to change the circuit operation a lot.] in between the cathode and ground. This doesn't have to be a permanent change to the circuit; you can make a little adapter that fits between the tube and its socket that runs all the signals straight through except for the cathode lead -- that path gets the low value resistor in-line. If you make the adapter, you don't even have to drop the chassis from the amp to set the bias. Just pull a tube, install the adapter, and adjust.

Hook up a voltmeter across the resistor and measure the voltage. For a 1 Ohm resistor, if you read 30 millivolts Ohm's Law says that you have 30 milliamps running through it. If you have some other value resistor, make the appropriate calculation. Easy! But since the current at the cathode is the sum of the bias current and some other leakage currents, you need to compensate the reading a bit, typically 5 to 10 milliamps.

What's nice about the cathode resistor method is that you're not dealing with high voltages. The cathode sits very close to ground so the chance of a dangerous mistake is lessened. You're also reading each tube's bias current individually.

Other Methods

Some of the manufacturers say to set the bias voltage to some specified voltage, without any other measurements. Presumably some designer somewhere decided how much was good for you and wrote down "Set the bias to xx volts" as a good compromise for all the tubes s/he expected. This method ignores the variability of transconductance in output tubes, and only gives good results for matched sets that happen to be exactly like the "typical" ones the designer thought they'd get. Note that Gr@@ve Tubes tries to help by providing matched tubes with a bias number from 1 to 10. If you have GT's with a "4" bias number, and you replace with a GT "4" set, they will have selected only tubes that are properly biased at that level, and no rebiasing will be necessary. Of course, GT expects to be repaid a fair profit for this service to you...

Another way to set bias is to use a test signal, typically a sine wave. Monitor the output waveform on an oscilloscope and adjust the bias for minimum crossover distortion. The obvious problem is when has it "just disappeared"? Most folks do just a bit more than "just disappeared" and get their outputs too hot causing shortened tube life and overheating. Not very accurate or repeatable.

You can also use a special purpose instrument that nulls the input signal out of the output signal so that you can monitor just the distortion products. You then adjust the bias to get the distortion to a realistic minimum without making it dramatically less than the residual THD. This is the premium method, but requires a distortion analyzer - big bucks.

These methods can be more accurate than the first two methods but they require expertise and tools that most folks don't have.

If you are a circuit hacker, and live on solder fumes and cold coffee, you can modify the amp with solid state servo bias adjusters that twiddle the bias to each output tube on the fly on a continuous, real time basis to keep each tube -* exactly *- where it ought to be. Only recommended for real wiring fanatics...

GENERAL BIAS GUIDELINES (from Tremolux@aol.com)

Currents Per Tube - Class AB1 Operation (most musical instrument amps are designed to run in class AB1)

- 6L6 - 30 to 35 ma
- 6V6 - 22 to 27 ma
- EL-34/6CA7 - 35 to 40 ma., sometimes even higher!
- 6550 - 40 to 50 ma
- EL-84/6BQ5 - 22 to 27 ma

Class A currents will be higher. Example is 50 ma for a 6L6. Don't try to run an amp designed for AB1 in pure class A, it will overheat and probably blow. To handle the higher idle currents, Class A amps usually run at lower plate voltages.

D. Matched output tubes - do you need them?

Do I always have to buy matched pairs of output tubes? The issue of "matching" output tubes, either by buying carefully matched pairs or by tweaking the bias levels and drive signals per output tube is not a settled one. It used to be common wisdom to simply buy matched tubes. A few people noticed, however, that they had a favorite pair of output tubes, which made their amp sound much better than others. The common assumption was that these tubes were better matched somehow. When these tubes get measured, though, it usually turns out that they are NOT matched, at least not matched for AC gain characteristics.

The concept of matched output tubes comes to us musical amp types from the hifi community, where they are trying to get the lowest possible distortion. This was true from the start, when Fender was trying to build low distortion amps and copied hifi circuits. The concept has simply clung to us, largely through inertia. It is relatively well accepted even in the hifi circles now that even-order distortion is euphonic, sounds good to our ears. It is very likely that the even-order distortion produced when mismatched output tubes are used sounds better than perfectly matched tubes.

If you have modified your amp so you can independently set the DC bias and the AC drive signal, you can tune almost any pair of tubes into AC and DC matching. You can also tune in a selective amount of AC drive mismatch to experiment with the selective mismatching sound.

There *are* technical reasons for matching. Getting enough turns of wire on the primary of an output transformer to get the right primary inductance and still using as little iron and copper as possible to do the job properly is an engineering problem that almost always results in Class AB output transformers being smaller for proportional power outptu than a Class A output transformer would be. The (relatively) smaller transformer and wire size makes a class AB (most guitar amps) output transformer susceptible to burning out if one of the half-primaries carries too much current.

If one side of the transformer carries significantly more current (like double) than it would otherwise in "normal" operation, it is possible it will overheat or open, effectively killing the transformer. Tubes that are so mismatched that to get the right total current for a pair means that one is carrying more than 50% over the nominal DC current for a matched pair is getting into the region where you ought to worry about output transformer damage.

If you mismatch, try to get the DC current the same in both sides of the output transformer, and an imbalance in the AC gain of the tubes. The logical limit of this AC mismatching is to remove all the AC drive from one output tube, which is a technique used by at least one commercial amp maker. This effectively keeps the output transformer happy with respect to DC, and gives you a single ended output stage; this also costs you a large amount of your available output power, but, hey, we're after tone, right?

Note that the commercial tube suppliers have good reason for wanting to sell us matched sets at a premium. I would expect their opinion to be that matched sets are absolutely crucial. As in all musical matters, let your own personal ears be your guide.

If you have a set of tubes you know are not matched, or if you have modified your amp to be able to set the bias and drive levels on each output tube separately so you can either match or not match the tubes at will, you might want to try un-matching them and see how it sounds to you.

Q: I have found that if the bias for push-pull with cathode bias design, is set with the bias at 50 mA for EL-34 tubes when idling(i.e. no sound input), over time the cathode bias resistor will blow. Why is this?

A: This is true if the amp is cathode biased into Class AB; in this class, the average current in the outputs rises with signal. On Class A biased amps the current is already at max for that bias point, and should not drift up except if the tubes drift from thermal effects. Note that cathode bias of an amp into class AB IS possible. Cathode bias is not equal to Class A.

Setting the bias point for a little less standing current (which is an unambiguous description for bias) is an OK solution if your cathode resistors are undersized as long as you can live with the increase in crossover distortion at lower sound levels. The "sweet spot" is wide, so that may be fine. If you were previously in Class A and dropped the current a little, this can move you slightly into AB for large signals.

Q: Does amplifier stability have anything to do with the temperature of the output tubes? Can tubes go into thermal runaway?

A: Yes. Emission in tubes increases with temperature, but not a whole lot, as the tube gets hotter. The predominant effect is that as the tube gets hotter, you cause outgassing from the metal, glass, and other materials in the tube. The gasses are attracted to the grid as the most negative point in the tube and stick to the negatively charged grid, causing a decrease in grid bias. If the tube is too gassy (which it can get to by being too hot) you can get into a condition where the grid leak current changes the bias in the direction of more current, which makes the tube hotter, which causes more current. The solution here is to lower the value of the grid leak resistors. This increases the available current to the grids and keeps the tube out of runaway.

Back to the GEO Home Page

Amplifier Modifications

A. OK/Recommended amp modifications

Read the **SAFETY WARNING** first, before you put your hands - or other personal parts - into a tube amp.

- Put a fuse in the B+ line after the rectifier(s) and before the first capacitor filter. This can save burning out your power transformer and maybe your output transformer if you get a shorted filter cap, shorted output tube, or lose bias on an output tube. It -* might *- save an output tube that has lost bias even though it also might not. The fuse current rating should be slightly larger than the max current rating for your output tubes, generally much less than 1A.
- Put a 130 or 150 Volt MOV surge protector across the AC line at the power transformer primary to absorb spikes from air conditioners and motors turning on and punching through the primary insulation. Recent articles say that 130V MOV's will eventually short, recommending only 150V MOV's.
- Get rid of all two wire line cords and line switching arrangements. Refit with three wire cords, tieing the safety ground to the chassis. You'll love this the next time you touch a mike or stand while holding a guitar. No shocks. Oh, yeah. Do it to ALL your equipment to be safe.

- Consider putting a small fan in your amp to cool it. Try a 240vac fan running from the 120 vac line supply, which will run much slower and quieter than a 120vac one.
- Install small cathode resistors and independent bias adjustment for each output tube to make biasing easy.
- Open the feedback from the power amp output to it's input for more power amp gain, more and earlier distortion. Or better yet, put in a spst switch and you can pick the characteristics on the fly...
- For the adventurous, add a separate filament transformer/rectifier/ filter capacitor to make 9-12VDC at several amps and then use a three terminal rectifier to regulate this down to 6.3VDC, and feed this to your preamp tube filaments. Hum from filaments will drop right through the floor. Lotsa work, though.
- Put 1500Volt, 1A silicon diodes in series with the two sections of your rectifier tube (if you have a rectifier tube) so that if the rectifier tube shorts, the silicon will save the output tubes, and power and output transformer.
- Gerald Weber advocates using a 270K/27K resistor divider from B+ to raise the filament windings in a DC sense above ground. This keeps electrons from the filament from hitting the plate, another source of hum.
- Put 1500Volt, 1A silicon diodes in series with the two sections of your rectifier tube (if you have a rectifier tube) so that if the rectifier tube shorts, the silicon will save the output tubes, and power and output transformer. The B+ will go up about 50V when (if!) the rectifier tube shorts, so the amp will have a little more power and run hotter. This can still hurt modern manufactured power tubes if it goes on too long, so check the rectifier tube frequently.
- Bill Webb's favorite tone mods for Fender amps
    - at the Vibrato channel's second gain stage, change the ceramic 0.02uF coupling cap to polypropylene or polystyrene
    - replace the coupling cap at the input of the phase inverter with a better cap (polypropylene - polystyrene - mylar in order of preference); change its value to 0.001 to make the amp "sparklier" and to 0.01 to make the amp sound bigger and more midrangy
    - The 3.3M resistor which mixes the dry and reverb at the output of the 3rd gain stage, vibrato preamp, is paralleled by a 10pF ceramic cap. Change this to silver-mica to make the amp sparklier
    - The power amp feedback loop resistor is usually 820 ohms; insert another 820 ohm resistor. This reduces the feedback, increases the power amp's gain, and softens the onset of distortion.
- Remove the single bias adjust pot in your amp and put in two, connecting one to each output tube. You can now set the bias voltage on each tube to be different, which can match the DC currents for un-matched tubes, or un-match matched ones for more even harmonic distortion.
- Tinker the driver circuit to let you adjust the relative amount of AC drive to each output tube. This lets you match/unmatch output tubes in an AC sense just like the

bias mod lets you change the relative DC points.

C. NOT Recommended amp modifications

These are likely to be just plain bad, either grossly (it dies soon) or subtly (it dies slowly, eats tubes, or other sicknesses). Don't do these or let a tech do them to... er... for you.

- Using a variac to run it at a higher or lower line voltage. This might be OK except that running it higher can overdissipate parts and burn them up or overvoltage things like filter caps, which can short and burn out your -* expensive *- output transformers, as well as burning out your tube filaments by putting too much current through them; and running it lower starves the filaments for current, so they can't put out enough electrons, and any remaining gas in the tube bombards the cathodes, poisoning the electron emitting materials on the cathode surface, and wearing the tubes out early.
- Adding massive amounts of capacitance to the power supply filters to reduce hum. Probably OK with solid state rectifiers, but in amps with tube rectifiers this can cause current spikes in the rectifiers that exceed the instantaneous current rating of the rectifier and wear it out quickly.

Nathan points out "I seem to recall one of my Tube Amp Mentors telling me that this is pretty much only the case with the first filter cap after the rectifier, and that the impedance of the power supply was high enough that you could dump hundreds of uf worth of filtering on latter stages (though the only place it's of much benefit is at the power tube plate supply point.)

- replacing your rectifier tube with a solid-state plug in module replacement. This effectively just puts in a pair of silicon diodes which take the place of the tube. But it also lets the B+ come up about 50V. This won't kill the amp immediately, but it runs the outputs hotter. Fender often put more than the rated maximum voltage on the output tubes to get moe power out of them; old US and Euro manufactured tubes would usually handle it just fine. Some lower cost modern manufacture tubes CAN'T stand the extra volts as a steady diet, and can succumb to the Dark Side of the Force - soon.

Back to the GEO Home Page

Tube Characteristics and substitutions

Some quick and dirty subs and some tube data such as recommended bias current and appx voltages. These subs are all taken from the Tube Substitution Handbook sold by Antique

Electronics Supply. or provided from the net.

A (short) catalog of tubes you are likely to see in a guitar amp:

- 12AX7[A, WA] and substitutes - preamp and driver tubes
- 12AT7, 12AU7 and subs, preamp and driver tubes
- 12AY7 - driver tubes
- 6EU7 - dual triode used in some older amps for preamp tube
- 6L6 types - power output tubes, up to 50 watts/pair, a mainstay of Fender
- EL34 - Euro power pentodes, up to 50 watts/pair, many Marshalls
- 6V6 - smaller, lower power cousin of the 6L6, 10-14 watts per pair; used in smaller Fenders
- EL84 - fits a 9 pin socket like a 12AX7 but twice as tall; miniature power pentode, good for 12-18 watts per pair; used in smaller Vox amps, and a quad of these drives the Vox AC-30 for 30 watts.

Substitutions:

* means appropriate for parallel filament circuits
\# means may not work in all circuits

Preamp and driver tube substitutions:

- 12AX7 (high gain dual triodes with pinout 9A)

```
12AD7*        12DT7          7729
12AU7#        5751*          B339
12AU7A#       5751WA*        B759
12AX7         6057           CV4004
12AX7A        6681           E83CC
12AX7WA       6L13           ECC803
12BZ7*        7025           ECC83
12DF7         7025A          M8137
12DM7*        7494
```

  - 12AU7 (moderately high gain dual triodes with pinout 9A)

```
12AU7[A,AW,]    6189          7730
12AX7* and subs 6670          ECC186
5814[A,AW]*     6680          ECC802
5963            7316          ECC82
6067            7489          M8136
```

- 12AT7 (medium gain dual triodes with pinout 9A)

12AT7[many suffixes]	7492	E81CC
6201	7728	ECC801
6679	A2900	M8162
ECC81	B152	QA2406
12AZ7[A]*	B309	QB309
6060	B739	
6671	CV4024	

- 12AY7 (low gain dual triodes with pinout 9A)

12AY7(and suffixes)	6072
2082	

Power tube substitutions:

- 6BQ5/EL84 (miniature pentode with pinout 9CV)

6267	7189	EF86
6BQ5	7189A	EL84
6BQ5WA	7320	N709
6P15	E84L	Z729

- 6L6 (beam power tube with pinout 7AC)

6L6(many suffixes)	7581(A)
5881	WT6
5932	EL37

- EL34/6CA7 (power pentode with pinout 8ET)

EL34	12E13
6CA7	KT77
7D11	KT88

- 6550 (power pentode with pinout 7S)

6550[A]	7027A#
7D11	KT88
12E13	

Cautionary Tubes - these are very hard to find

- 7591/7591A - legend has it that these otherwise excellent tubes were all bought up by an oriental buyer who toured the USA paying cash for all of them he could find, then disappearing. You are likely to only find used ones or the odd pair in some out of the way place. Dealers will in general not have them. I *have* personally seen trays full of NOS 7591A's for sale in the Akihabra electronics district in Tokyo, lending some credence to the rumor.

These were used a lot in old Ampegs. They are very small and high gain for their physical size, so there may not be a lot of room in a chassis for a larger replacement. The 5881 will work in some circuits, but has significantly lower transconductance.

Rumor Update: The rumor mill on the net says that the Russians will soon be making 7591's soon. Cross your fingers...

- 7199 - combination pentode/triode used as a one-tube voltage amp/phase inverter/driver for a pair of output tubes in some Ampeg amplifiers Note: These were once popular, but are now getting rarer and more expensive. There are a number of other pentode/triodes that can be substituted, but the pinouts are different and this will require require rewiring the socket for the tube. Examples are the 6AN8 and the 6U8. There is a Russian tube that is labeled 7199 which may work, although this is new.
- 7027/7027A - this is a high power tube similar to a 6550. The supply of these is very poor.
- 7189/7189A - a higher power/voltage version of the 6BQ5/EL84. Hard to find. A stock 6BQ5/EL84 may work if the power and voltage conditions in the amp are not right out at the limits of the tube design.

Back to the GEO Home Page

Maintenance Issues

Cap Jobs - Do I need one? How often? Why?

What's a cap job? A technician may recommend you have a "cap job". This means that he will replace every single electrolytic capactor in the amp, from the power supply right down to the cathode bypass caps.

This is because electrolytic (polarized) capacitors have an inherent wear-out mechanism and will eventually die even if you don't play death/metal/country/barbershop through them every day - in fact they may wear out sooner if you leave it sitting in the attic. Here's why.

A capacitor is essentially two conductive plates separated by an insulator. The bigger the plate area and the thinner the insulator, the higher the "capacitance" is. Electrolytic capacitors get a very thin insulator by "growing" an insulating layer of aluminum oxide on the outside of a rolled up piece of aluminum foil.

The oxide layer is "formed" at manufacture by feeding the aluminum foil a very small and carefully controlled amount of current. The current causes a chemical reaction between the foil and the water solution (electrolyte! ... hey... is that where they got the name?? yep.) which makes an oxide layer grow. As the layer grows, they use higher and higher voltages to force the same small current through the layer, which gets thicker and more resistive with time. When they have to use the full rated voltage to get the forming current through, the cap is fully "formed" and ready to ship.

If the capacitor is used regularly, has voltage applied to it, and does not get too hot, the oxide film lasts up to a few decades. If the capacitor is not used much, or gets too hot, the oxide film slowly un-forms, the leakage current goes up, and it will eventually short.

Electrolytic caps are designed to last ten years. It is a tribute to the quality of manufacture that they often last three, sometimes four times that.

Old amps, particularly if they have not been used regularly need to have every electrolytic cap replaced. This cap job may be needed every ten or so years.

Non-electrolytic caps do not have this wear out mechanism, and do not need replaced for this reason. Modern capacitors can in some circumstances be much better than old ones, and you can sometimes get a clearer, more sparkly tone by changing the non-electrolytic caps - assuming that is something you want to do.

Do new caps need to be formed?

There's a lot of controvery on "reforming" replacement caps. Here are a few answers.
Manufacturers of caps design their caps for a ten year working life, and a five year shelf life. That means that the stresses and heat of working in equipment will leave the vast majority of caps functioning OK after ten years of normal operation. After that, it's gravy to the buyer.
They also design them to work OK after sitting on a shelf unused for five years, meaning that the cap should not fail if it's put into operation at rated voltage after sitting unused for five years. As noted above, the caps do slowly un-form without regular use.
If the electrolytic caps you use to fix your amp are over five years old as determined by the date code on them, you ought to at least worry about forming them, and if they're over

ten years old (like NOS multisection cans), definitely re-form them. Other than that, put them in and turn it on.

How do I "re-form" electrolytic caps?

You'll hear folks talk about "bringing an amp up slowly on a variac"; this can work but is not particularly good for your tubes. A better way is this:

1. Pull out all the tubes.
2. if your amp has a tube rectifier, solder in temporarily some high voltage silicon diodes across the tube lugs to be a rectifier that does not depend on the filament voltages. If your amp has silicon diodes, you can skip this.
3. open up the wire that goes from the rectifier tube (or solid state diodes) to the first power supply filter stage and solder in series with the wire a temporary 100K 2- 5W resistor. This resistor will limit the current that can flow into the caps and the amount of voltage that is applied to them to safe values that will cause the insulating layer to re-form.
4. clip your voltmeter across the resistor
5. button it up. Turn it on (no tubes in it, remember). Watch the voltmeter.
6. when the voltmeter reading drops to less than 20-30VDC, your caps are formed.
7. open it back up and pull out those diodes and resistor, putting it back in original shape.

The forming could take hours to days.

Sockets

Sockets get dirty, corroded, broken, and "arced" To recondition them, get a can of spray contact cleaner, the kind that says "no residue". Squirt some in each socket hole, then insert that tube in the socket, wiggle it around, and remove it several times to get the crud off. Take a thin tool like a jeweler's screwdriver or ice pick and gently bend the contacts inside each hole so they hold the pins better. If the socket is cracked, or has blackened lines from pin to pin (where an electrical arc has actually burned the socket into a carbon material that conducts electricity), replace the socket.

Q: Are plastic or ceramic sockets better, or is there any difference?

A: The material is significant.

Thermoset plastics are what are usually used for sockets. The black-brown stuff most are made from is "bakelite" a trade name for a kind of clay-reinforced phenolic. Maybe there's a variety that is purer or more sturdy phenolic that is more resistant - I'm fuzzy on that one.

All plastic sockets are vulnerable to arcing. When you get enough voltage from pin to pin on an output tube to cause a spark to jump from pin to pin (like when you run the output transformer unloaded) the spark runs along the surface of the socket material and burns a trail on the surface. Since the plastics contain carbon, there is often a carbon residue left on the surface. This residue is partially conductive, and makes that path susceptible to arcing over at lower voltages next time; this can be so bad that it interferes with normal operation.

Ceramics are not carbon based, do not burn in the normal sense, and don't soften or melt at temperatures achieved in an arc over, so they are essentially immune to arcing unless covered with dirt and gook that can burn and leave stuff on the surface.

I would class them as poorest - thermoplastic sockets; medium (and most common) - thermoset, which included phenolic; best - ceramic. Ceramics are the premium solution, IMHO.

Dirt and Dust

The dusty, hairy, oily layer that collects on the chassis can conduct electricity as it absorbs humidity from the air. Vacuum it away periodically.

Blue Glow in tubes

The blue glow in power tubes is a flourescence from the few ionized molecules of gas that still exist in the non-perfect vacuum achievable in tubes, driven to fluorescence by the high voltages in the tubes. Unless it is excessive, it is not harmful. Tubes with softer vacuums glow more.

Other Issues

Lots of good info is contained in Jack Darr's "Electric Guitar Repair Book", if you can find a copy (it's now out of print) and in Pittman's "The Tube Amp Book" and Webers "Desktop Reference...". Look for: - checking for capacitor leakage

From watching a tech work on Fenders, I picked up a nice tidbit. The eyelet boards in Fenders have most components mounted across the eyelet board. A very few parts run along the length of the eyelet board. Because the eyelet board flexes, there is a lot of stress on the solder joints at the end of these lengthwise components and the joints often crack. Every time you open up a Fender, take a look and maybe a soldering iron to these joints. If it's your personal amp, you might want to get a new part for these positions with long leads and bend a loop in the leads so that the leads can flex and not put stress on the solder joints.

[Back to the GEO Home Page]

Appendix B. Tube Makers Producing Today (Eric Barbour news posting)

(The following is the text of a note posted to the alt.guitar news group by Eric Barbour <svetengr@earthlink.netit is also badly out of date, and will be upgraded by Eric soon.)

Different makers of tubes use different designs. There are six makers of common audio tubes right now:

- Shuguang, China--good 12AX7s, so-so power tubes
- Tesla, Czech--ok EL34s, preamp tubes variable
- Reflector, Russia (sold under Sovtek brand)--good 5881, EL84, so-so 12AX7 (they came out with EL34s recently---I am testing them)
- Kaluga, Russia (only a few types--sold under Sovtek, Audio Glassic) good 5881s, not sure what else they make today
- Svetlana, Russia--has a 6550 now, good---will introduce an EL34 soon
- EI, Yugoslavia (in Serbia)--fair 12AX7s, fair EL34s, future supplies are questionable because Serbian products are under economic sanction; thanks to that Bosnia business!

That's ALL there are right now. That's it. Any NEW tube you buy is from one of the above.

For your guitar amp, I would recommend the "Sovtek" 5881, it's a really nice, rugged and smooth-sounding tube. It was a military type used in servo amps in jet aircraft, so it has to be good. If you have a Marshall or other EL34 amp, the Sovtek 6CA7 imitation (recently released) is probably most rugged. If you want more distortion and a more bluesy sound, you want the skinny EL34s. The Svetlana EL34 will be a skinny type, it should be very good.
