audioXpress
The Audio Technology Authority

*Article prepared for www.audioXpress.com*

# Techniques To Maximize Power Tube Life

By David C. Gillespie

Identifying circuit design that reduces life and what you can do about it.

In a recent issue of *audioXpress*, Edwin G. Pettis wrote an article in which he describes how the lack of a sufficient space charge in a power tube can promote the possibility of arcing within it ("Why Power Tubes Arc," p. 28, Nov. '04). His description of the emission process and how peak currents cause it to deteriorate was excellent. Modern design practice can also contribute to this process, and significantly shorten the life of a power tube if it is not properly applied. When older equipment is updated, and new designs are contemplated, paying attention to a few basic rules will help ensure maximum life from your tubes.

## MODERN POWER SUPPLY DESIGN

One area of amplifier design that's undergone some of the biggest change over time has been the B+ supply. Years ago, an economical power supply for a fixed bias class AB1 amplifier might consist of one transformer for all the power requirements, with a center tapped full wave rectifier (tube) and capacitor input filter. With only modest µF and maybe a small choke for filtering, this design produced only fair regulation. A more substantial approach typically used a separate large high voltage transformer with the same rectifier design, but used (possibly) solid-state rectifiers and a choke input filter instead. With (usually) multiple chokes, oil caps, and a large bleeder resistor, this supply had good regulation under load.

With modern design however, the same performance is usually met with a transformer of much lower voltage and higher current, in (typically) a solid-state voltage doubler design. This supply often uses a separate transformer, high µF photo flash caps and usually just a small dropping resistor (if any) for filtering. The regulation of this supply is very good, usually surpassing that of the choke input design above.

This new supply has two major differences from the old designs. (1) The effective output impedance of the supply has been lowered significantly by the large photo flash caps used. They now provide a very large reservoir for the amplifier to operate from. (2) The internal resistance of the supply has been similarly lowered by the reduced winding and filter losses possible. This allows significant current flow to maintain the low output impedance under very heavy loads. It is these two qualities that produce the excellent dynamic regulation at the output of this supply. But the tight regulation can also damage the power tubes if it is not properly accounted for in the overall design. Ironically, what enables it to do the most damage is a common feature that was supposed to help prevent damage in the first place.

**(Figs. 1A-1C)**

## DELAYED B+

Most of the power supplies from yesteryear applied the B+ to the amplifier tubes in one of two ways. It was either there quickly—well before the audio tubes started to conduct—or applied gradually by a cathode rectifier tube after the other tubes were almost fully heated. Either way, this allowed the tubes to start conducting in a smooth and uneventful process.

A few of those supplies used a delay relay and possibly a separate transformer to apply the B+ after the amplifier tubes were fully heated. With this approach, the tubes are usually turned on more abruptly. However, the internal resistance of those supplies limited their peak current capabilities, so any damage to the tubes was limited as well.

When delayed B+ is combined with modern supplies however, there is little internal resistance to protect the tubes. The peak current capabilities of these supplies are such that the potential damage to the tubes can be significant when the B+ is turned on. This damage can either take the form of an arc, which will end a tube's life

FIGURE 1A: Classic economical power supply. Even with a low drop rectifier tube such as a GZ34, the internal resistance of this supply is ≈ 165Ω.

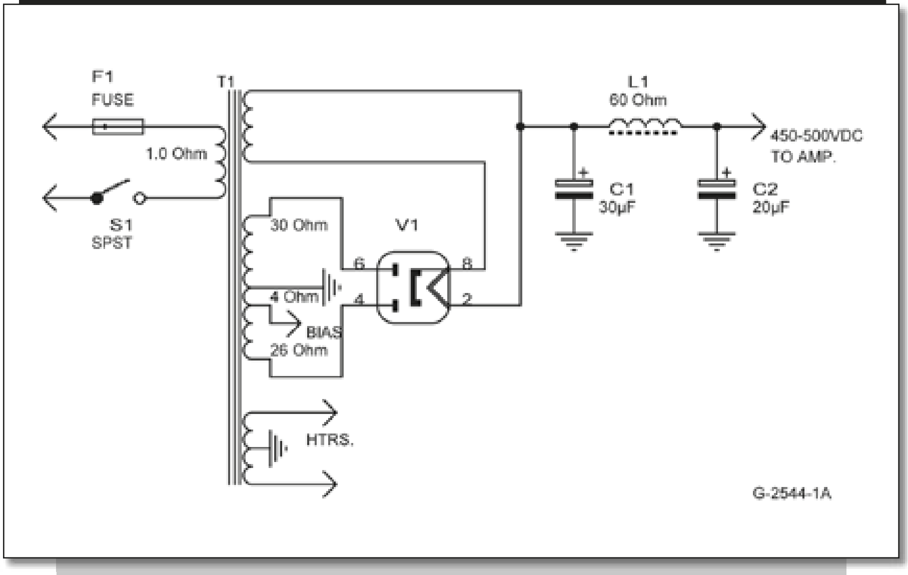



FIGURE 1B: Classic supply with better regulation. The internal resistance is now ≈ 140Ω, but the combined bleeder and choke action effectively reduces this to ≈ 85Ω.

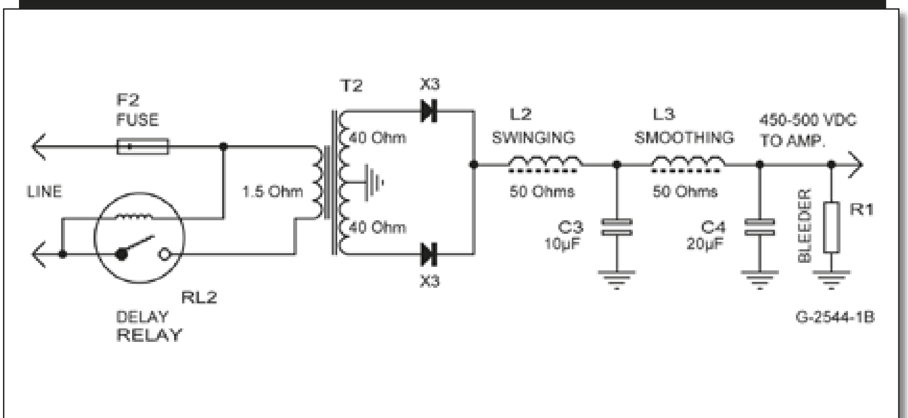
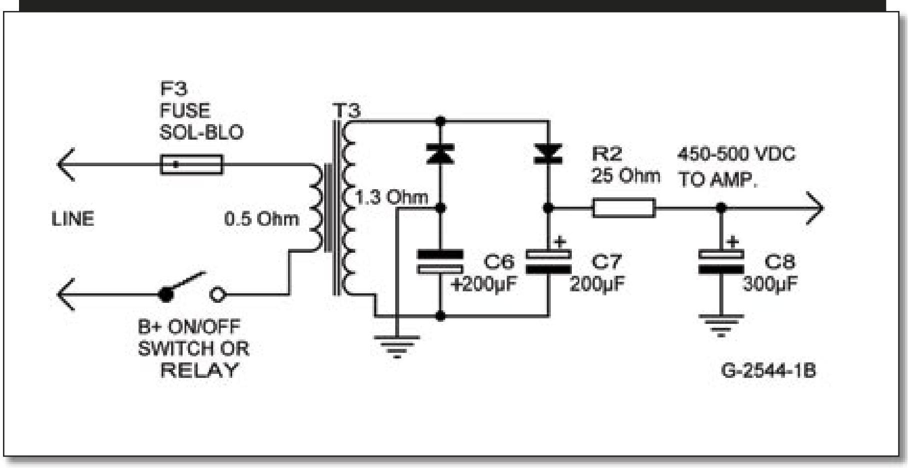



FIGURE 1C: Modern supply design. The internal resistance of this supply is only ≈ 28Ω with significant peak current reserve.




immediately, or be more gradual in effect, damaging a tube over time—or both. These are two separate problems, requiring two separate solutions.

## ARCING

Equipment from hifi's golden age was never particularly prone toward output tube arcing. Most of this equipment used very reliable high transconductance suppressor grid or beam power output pentodes because of the efficiency and/or versatility they afford in operation. But it was also these tubes that became so problematic, although only under certain conditions.

When the arcing first began during the '70s, it was initially blamed on cheap foreign tubes—and some really were. But when NOS examples started exhibiting the same behavior, it couldn't be so easily written off. With little information available on the matter, the sporadic arcing continued unchecked. It was also during this time however, that the power supplies of this equipment were starting to be upgraded.

These supplies were easy to improve. Silicon rectifiers typically replaced a higher drop tube rectifier for lower internal resistance. Filter caps in the basic supply were increased by a factor of five or more to lower the output impedance and add current reserves, and a B+ delay switch was usually added to do what the new silicon units couldn't. Since most of this equipment used a single power transformer with (typically) a tap on the HV winding for bias, the B+ switch was usually placed at the output of the B+ filter so the bias supply (if present) would always operate. All the characteristics of modern design were now coming into play.

The upgrades provided obvious performance improvements, but also changed the relationship between the power supply and the output tubes in two important ways: (1) After preheat, the full B+ (or more) was now applied from a running B+ supply with fully charged high µF filter capacitors. This new arrangement allowed for high peak current capabilities when the B+ is turned on. (2) The output tubes were now operating from a power source of much lower impedance. After these changes, many output tubes—regardless of their age—began to arc.

(**Fig. 2**)

## TUBE/CIRCUIT INTERACTION

While the condition inside a tube that produces an arc under these new conditions can be debated, it is almost certainly a violent oscillation, and therefore represents instability at its worst. Long ago however, I determined these arcs were always to the screen grid, and therefore represent a "screen stability" issue. As it turns out, controlling it is very easy. But understanding what factors combine to produce the instability would be helpful for any contemplated design or modification.

Due to the lack of any definitive reference material for this issue (to my knowledge), the information I've gathered has been derived empirically. However, the factors involved are definable and the results repeatable, which makes the information very reliable. Specifically, there are four elements of design that can combine to produce screen instability:

(1) To obtain maximum power output means running the screen at or near its design maximum voltage rating. Although many designs do this, it does not particularly promote an unstable screen by itself in practice. But it does mean that the screen is operating at the safe limits for the physical design of the tube. *However, if the screen is running at greater than 80% of its design maximum voltage rating* ***in combination*** *with the other three elements, it is a factor in producing screen instability.*

(2) Many designs operate the plate and screen at nearly identical DC voltage levels. This includes triode configurations, and many ultralinear and pentode designs as well. Although this too is a very common design feature, it does not particularly promote screen instability by itself in practice either—even with the screen operating near its design maximum voltage limit. *However, if the screen is operating at 85% or more of the actual plate voltage* ***in combination*** *with the other three elements, it is a factor in producing screen instability.*

(3) Fixed bias is often used to maximize power output, reduce distortion, and provide greater bias stability. As such, it allows for the *possibility* of much greater current flow through the screen circuit (versus self bias), due to the lack of any significant resistance in the cathode circuit.. Again, by itself, fixed bias does not necessarily promote screen instability. But in combination with the previous two elements, its use can be a significant factor. *When fixed bias is used with the previous two elements, a design precaution is highly recommended to prevent tube damage.* This will be discussed further in a moment.

(4) For the lowest distortion in a fixed bias class AB1 pentode or ultralinear design, the screen supply (or main B+ supply for UL) should be tightly regulated. When this is done with modern solid-state components or large amounts of capacitance, the impedance in the screen circuit can become **very** low. *When tight regulation is used in conjunction with the preceding three elements, a design precaution is* ***mandatory*** *to prevent tube damage.*

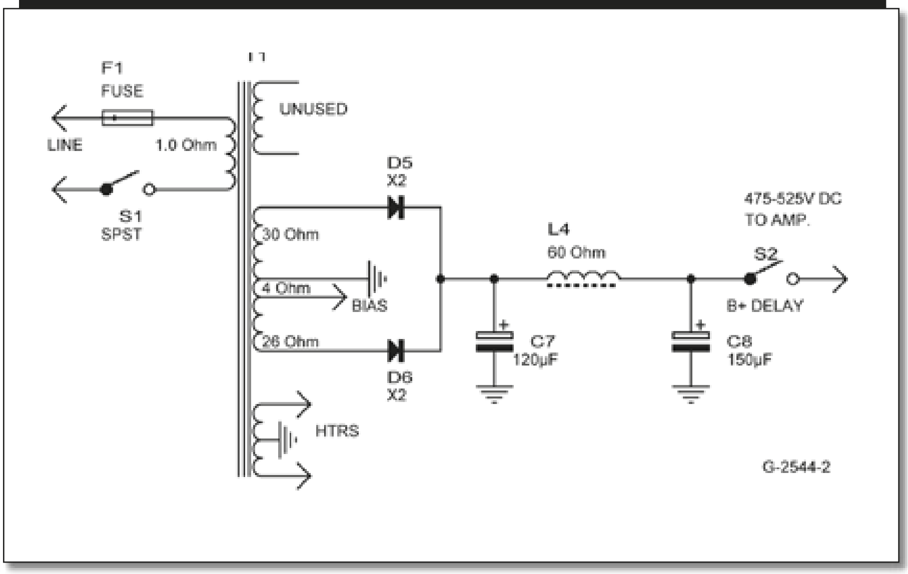
(**Figs. 3A and 3B**)

## SIMPLE SOLUTION

Of course the design precaution necessary is to make sure a little resistance is provided in the screen lead to each output tube if the design or modification meets the criteria above. Sometimes, this has already been provided in a design in the interest of preventing high frequency parasitic oscillations, limiting screen dissipation, stabilizing push-pull parallel output stages, or some combination of all three. In these instances, the resistance provided is usually more than enough to prevent any screen instability problems that could produce an arc. In triode configurations, the limiting resistor between the plate and screen automatically takes care of any screen stability issues.

However, many of the older pieces of hi-fi equipment that operate in ultralinear fashion and use the first three design elements above do not include any additional resistance in the screen circuit, other than that provided by the screen tap in the output transformer. Because they generally operated with-

**FIGURE 2: Improved design of *Fig. 1A*. Internal resistance is now ≈ 90Ω, and the peak current reserve is much greater.**



out any screen stability issues, it is clear that the original power supplies for that equipment were also aiding in maintaining screen stability through the relatively high impedance they presented to the screen grid circuits.

But with the upgrading of the power supplies in that equipment, the impedance to the screens became so low that the output tubes could no longer remain stable without some additional resistance in place. Since that was not part of those original designs, the sudden application of B+ from the new supplies *after* preheat was often all it would take to trigger instability and a resulting arc. Other times, program material would do it, or any likely transient that came along. In any case, expensive tubes were ruined with each arc.

FIGURE 3A: Cathode bias ultralinear output stage. Even though the screens are running at their design maximum voltage rating and at a nearly identical voltage as the plate, screen stability is maintained because of the cathode resistance. The use of a lower transconductance tube also aids in maintaining screen stability in this design.

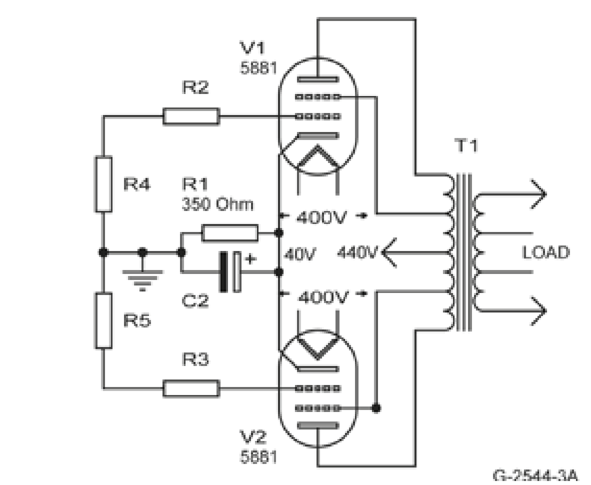
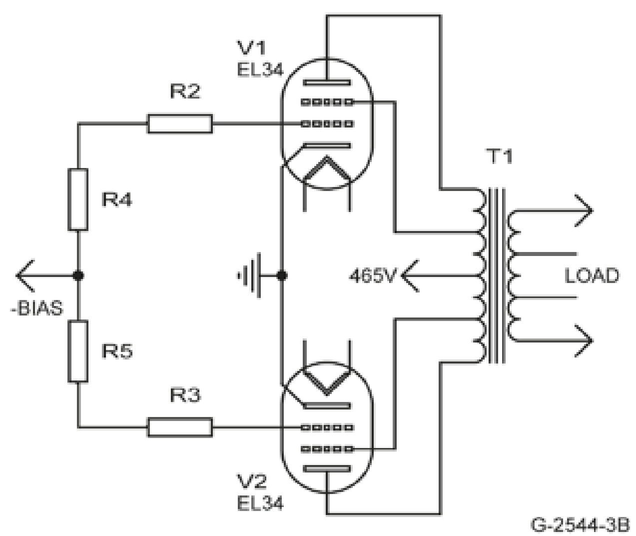



FIGURE 3B: Fixed bias ultralinear output stage. Same conditions as in *Fig. 3A* except for the use of fixed bias and higher transconductance tubes. This design has only conditional screen stability, remaining acceptably stable only when operated from a power supply with characteristics as shown in *Figs. 1A* or *1B*. Operating this design from the supply in *Fig. 1C* will promote output tube arcing.



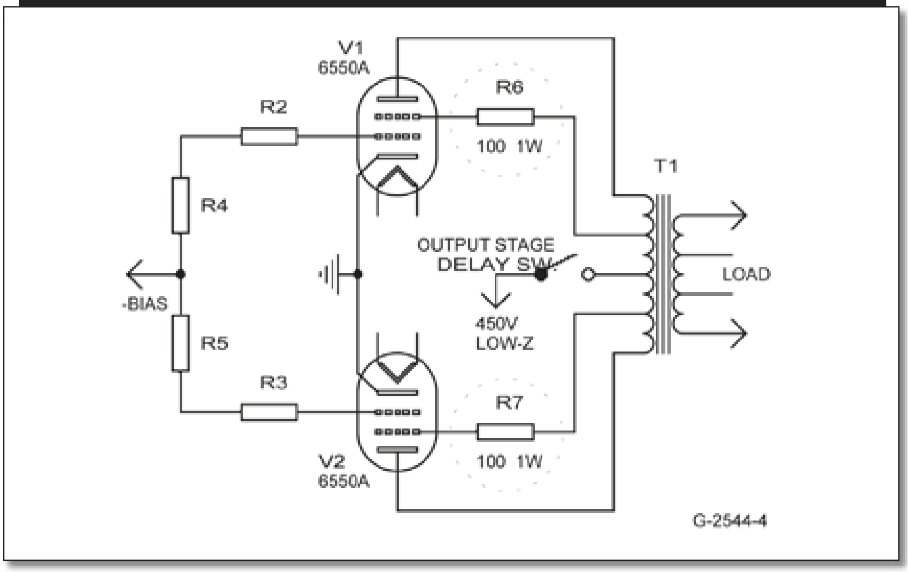

When the four design elements are used together, using as little as 100Ω in each screen lead will eliminate any screen stability issues, and produce a negligible loss of power. UL taps alone are not capable of maintaining stability under these conditions. With the screen resistors in place, the impedance of the screen supply is no longer a factor in achieving screen stability. Even if you operate the older equipment in stock form, I highly recommend that you add these resistors as a strong measure of safety. They are cheap insurance for expensive tubes.

It is worth noting that the transconductance of a tube is a factor in this issue as well. That is, all else being equal, a high transconductance tube such as an EL34, EL84, or 6550 will have a greater tendency towards screen instability than tubes of a lower figure such as a 6L6 or 6V6. However, the four design elements above apply to all of these tube types, or their derivatives.

In guitar amplifiers, screen arcing due to a lack of screen resistance is generally very rare. Most of the popular designs already use screen resistors for a variety of reasons that prevent its occurrence. In this equipment, modern music trends that overdrive the power tubes are the main culprit. This can cause arcing to happen in one of two ways: (1) As outlined in the Pettis article where heavy current draws have depleted the space charge, or (2) where fluctuating load conditions and the back emf of the output transformer during overdrive cause large spikes to be introduced at the plate to cause arcing from that element. Some designs use a diode reverse connected from each output tube plate to ground to help minimize the latter condition and help protect both the tubes and the transformer. But the only real answer is to realize the toll this kind of use has on the tubes and the penalties that will result.

Finally, as Mr. Pettis warned, any tube that has arced should be imme-

**FIGURE 4: Screen stability resistors. In spite of operating the screens at their design maximum voltage rating, at the same voltage as the plate, in a fixed bias design, and from a very low impedance power supply (*Fig. 1C* with a regulator), these high transconductance tubes will now maintain screen stability under all signal conditions.**




diately pulled from service, as the damage is irreversible. But screen arcing isn't the only way a tube's life can be cut short. It can also be damaged every time it's cycled with use. (**Fig. 4**)

## CYCLING PULSES

Cycling pulses are damaging pulse signals that stress the output tubes potentially twice with each use. They can occur when the amplifier is turned on as well as turned off. If they are both present, with just one complete cycling every day, the ultimate life of the tubes can be much more related to the number of cycling pulses generated than the actual hours of use logged. Although turn off pulses are present in some older designs, it is the modern supply's characteristics and features that allow both pulses to be so damaging. But once again, the cures are pretty simple. Since the events that surround the two pulses are different, they will be addressed separately.

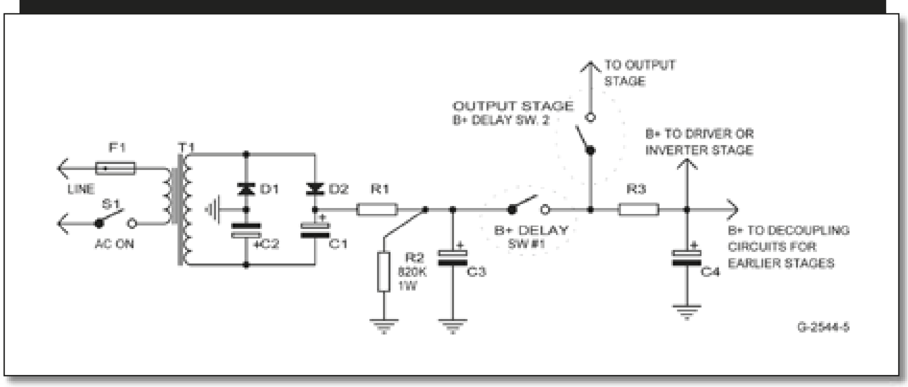
## TURN ON PULSES

The same combination of preheating, abrupt application of B+, and high peak current capability causes this problem as well. When the B+ is applied this way, it surges quickly through the distribution system and throughout the entire amplifier. When that happens, the coupling circuits to the output stage can deliver a very large positive going pulse to the output tubes, driving them momentarily into a very hard saturated condition. And, because the RC factor of the coupling networks to the output stage can drag this event out, the output transformer can end up looking more like its DC resistance than its AC impedance during this time. When this situation occurs and the power supply has significant reserve capability, the results are extremely hard on the output tubes.

For decades, many guitar amplifiers have used a standby switch that controls the B+ in this manner. While the potential for damage is still there, it is usually limited by the rather short coupling circuit time constants, and the limited power supply capabilities that are typical of these designs. In high fidelity designs however, the coupling constants are usually longer and the power supplies of modern practice have such capability that the damage to the power tubes can be significant.

Regardless of the power supply configuration, the answer is to apply the B+ to the output stage *after* it has been applied to the earlier stages. The easiest solution in theory is to use a second B+ switch, turning them on in order (after a slight delay) if preheating of all the tubes is desired. Or, the existing switch could be configured to control only the output tubes, and eliminate preheating of the earlier stages. Either way, the output tube delay switch should be positioned between the output of the power supply and the output stage, with no filter capacitors on the output stage side of the switch. If the stage operates in pentode mode, both the plate and screen sources must be switched together to prevent damage to the tubes. If neither of these approaches are appealing, a more elegant solution will be offered in a moment. (**Fig. 5**)

**FIGURE 5: Using two delay switches. When turning these switches on (1 then 2) and off in order (2 then 1), all cycling pulses in the output stage will be eliminated. If the B+ supply uses a separate power transformer, B+ delay SW #1 could have an alternate location on the pri side of the transformer. New bleeder resistor shown (circled) aids in discharging the filter caps at turn off for safety.**



## TURN OFF PULSES

The power supplies of yesteryear did not allow the B+ to linger significantly when they were turned off. It disappeared rather quickly, so that in most cases, shut down was uneventful. But with the large filter capacitors that are used in modern practice, the B+ falls away much slower now. This enables more potential damage to the tubes.

When the amplifier is initially turned off, all the operating voltages start to collapse. However, with the tubes still near operating temperature and the large current reserves now available, they try to amplify this ever-changing condition as they would any other signal. This too can result in a large low frequency pulse to the output stage, similar to the one previously mentioned. But the tubes are especially prone to damage during this time because a saturated condition can occur while the cathodes are cooling off.

This condition can happen in equipment of all ages, but is most prevalent in contemporary designs without a B+ delay switch, or those where a delay switch controls the AC to a separate B+ transformer. In any case, the answer is simply to de-energize the output stage B+ first, or simultaneously when the amplifier is shut down. If this is done with the output stage delay switch mentioned earlier and it is configured as suggested, there won't be any filter capacitors for the stage to draw from if a pulse should be presented.

Turn on and turn off pulses can be seen in the output tubes, and heard in the speaker—although the audible effects are somewhat canceled with push-pull configurations. However, the importance of eliminating both of them cannot be emphasized enough as it relates to tube life. The damage can be severe with each pulse, and since the pulses are rarely balanced in push-pull designs, they are also the principal reason that power tubes can require more frequent balancing and ultimately wear out at very different rates.

## PRACTICAL SOLUTIONS

The solution offered to prevent cycling damage is the addition of a simple switch. When used as discussed it will eliminate both pulses, but requires manual operation and does not provide protection against fast AC interruptions. If these are not a concern, then the additional switch is a simple, effective solution, although it is not very elegant. Therefore, other methods were also investigated.

One approach is to ramp the B+ up slowly enough to prevent the turn on pulse altogether. This could be done on the DC side of the supply with either a simple cap multiplier circuit, or an LM-317 based regulator circuit. Another possibility is to stage the B+ by applying it through an appropriate resistor, and then shorting it out after a brief delay period. A third possibility is to use the staging system on the AC side of the supply, providing a soft start and control of the B+ at the same time. Actually, all of these systems help provide a soft start for the supply, but they each have limitations that cause all of them to be an incomplete answer.

Compared to simple switching, the multiplier or regulator circuits can eliminate the turn on pulse, but are certainly more complicated to implement. The staging designs can be simpler, but are never completely effective. Even with multiple stages and careful control of the timing and resistance values, the turn on pulse is never totally eliminated. In addition, none of these designs address the turn off pulse, so even more components would be required for that. Finally, they all still have various problems with fast power interruptions, so in the end, none of them represent a practical solution.

The best solution by far consists of two series type 120V AC timers, and two 120V AC DPDT relays. With these, both pulses are eliminated, control is automatic (no switches required), and it provides complete protection in the event of power interruptions.

These timers have been around for decades, and are similar to the type Rick Spencer used in his Mini SE Amp project (*aX* April '04). Besides the source he recommended, these timers are also widely used in commercial cooking equipment, so many restaurant parts suppliers will carry them also. The most flexible units will have four terminals—two for placing the timer in series with the load (in this case, the relay coil), and two for an external resistor to adjust the time. It needs to be of the delay on make type so the relay will close after the delay period. Two excellent qualities of these timers are their reliability, and the fact that they reset almost instantly even with extremely short power interruptions. The relays can be Radio Shack part number 275-217, while typical timers are manufactured by National Controls Corporation (800-323-2593).

Each timer is paired with a relay, and each relay replaces one of the two B+ delay switches discussed. One relay/timer combo is set for 30 seconds to allow for preheating, and activates the B+ supply and/or all stages before the output stage. The second relay/timer is set for ten seconds or so later to allow the turn on pulse to settle down, and then activates the output stage. For maximum protection, the second timer is in fact a ten-second timer, activated by the completion of the first timer. At turn off or during a power interruption, both relays immediately drop out and go through their full timing cycle with the reapplication of power. This eliminates any pulses from either of these events. This solution is simple, complete, and practical, and eliminates all damage to the output tubes from cycling pulses.

(**Fig. 6**)

## RESULTS

The information in this article is the result of a study I undertook many years ago to determine why the power tubes in my equipment seemed to fail much earlier than expected. At the time, my equipment was experiencing both types of cycling pulses, and sporadic arcing as well. The equipment was all of my own design using classic configurations, but incorporating many of the (then) new power supply concepts recommended. In the process of that study, I used hour meters, a power output tube tester (of my own design), and logs of all my efforts to see if I was making any progress.

The tube tester was a side venture

within this study, designed to obtain accurate information as I tracked the numerous tubes throughout the effort. It is designed to test only specific types, but capable of driving a bogey tube to its design maximum rated current flow, under dynamic conditions. All supply potentials are tightly regulated during the test, so the results are repeatable and independent of line voltage variations. In this way, a given tube could be tested against known standards, and its power output accurately tracked from new to the end of its useful life. After numerous tests, I determined 64% of power output to be a more realistic figure for the end of useful life for my purposes, than I considered Mullard's 50% figure to be. Therefore, that is the figure I used during the study, and continue to use today.

As a base line, I was able to track twelve GE 6550 power tubes before any changes were made to my equipment. The tubes operate in a fixed bias ultralinear configuration with 485V of actively regulated B+, and 70mA of standing current. They are loaded such that they will produce 70W RMS power output under these conditions. The design facilitates bias and balancing adjustments to maintain each tube at the proper operating point.

During the tracking period, there were six arc events, so those tubes were immediately discarded. But fortunately, they all happened within the first 50 hours of their operation, so I was able to replace them without too much lost time. There was also a consistent difference in the rate of wear between the sides of a push-pull pair. This meant I ended up with two averages, each consisting of six tubes. But since I was tracking the time and position on each tube individually, this was easy to do.

All twelve tubes were exhausted in an overall average of 386 hours per tube. This was the result of six tubes averaging 276 hours on one side of the push-pull pair, and six averaging 496 on the other. These tubes were typically cycled once daily, over a period of a year and a half. They were properly ventilated, run within their dissipation ratings, and well maintained in their installation. They were never overdriven or abused. It is of interest to note that when all of these tubes were pulled, they still read "good" on two commercial micro-mho tube testers, which illustrates the fallacy of that type of testing for power output tubes.

I then made changes to eliminate the pulses and arcing as outlined. Twelve more GE power tubes were tracked, but this time they were able to be tracked in three sets of four as there were no arc events to remove any of these tubes from service early. These three sets yielded a total life of 7,929 hours for an average of 2,643 hours per set, with all twelve tubes declining uniformly in performance throughout their lives. It took over ten years to exhaust these tubes from service. The conditions of use remained consistent throughout the test as did my listening preferences, so the results were clearly from the addition of the screen resistors and eliminating the damage that the cycling pulses were producing.

The figures for useful life have remained consistent in this equipment, and there have been no further arc events throughout the years since the test was conducted. As a result, I started incorporating these concepts in all of my designs many years ago. With them, it has not been uncommon for some output tubes to approach 3000 hours of life, depending on the operating conditions employed. This compares favorably against Dynaco's recommendation of replacing the matched set of British KT88s in their MK III amplifier after 1500 hours of use. I do not know what criteria that recommendation was based on, but it does serve as a good benchmark for comparison.

All of this work began nearly 26 years ago. Since then, the results have been very conclusive, so my recommendations are offered with confidence. By following the basic rules I've outlined, I've enjoyed all the benefits of modern power supply design in all of my equipment, while also maintaining all the life expectancy my tubes are capable of. I leave the installation details up to the individual reader for his/her own particular equipment if you implement these ideas. However, if your tubes suffer from any of the problems I've noted, your efforts will be well rewarded from the solutions given. I hope they will be of help for all of you. aX

**FIGURE 6: (Using *Fig. 5*, delay switches #1 and #2 could be replaced with relays and timers as described in the text.) Complete control. Simple and reliable. Eliminates all power tube cycling pulses—even during fast AC interruptions.**