Technical Correspondence

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REVISITING "THE NEARLY PERFECT AMPLIFIER"

Publication of "The Nearly Perfect Amplifier" by Richard Measures, AG6K, in January 1994 *QST* sparked correspondence from a number of readers questioning the technical accuracy of several points made in the article. We asked ARRL Technical Advisor Fred Telewski, WA7TZY, to review the article and the correspondence received. Fred's comments are presented here, along with excerpts from some of the letters received from readers (see the Contributors sidebar).—*N1FB*

Fred Telewski: Many of the things Rich Measures describes (but not all of them) exist. The issue is to what degree they're relevant in the design of a practical amplifier. Measures tends to stress some aspects of amplifier design which do not significantly contribute to the performance of the final product.

Filament Voltage

Fred Telewski: I substantially agree with Measures' observations concerning filament life as a function of voltage. Where Measures and I depart regards his idea of using a regulated dc supply for filaments. Five volts dc at 5 to 30 A, although conceptually easy to generate, could prove uneconomical for most amateurs and manufacturers of amateur equipment. I suggest using a separate filament transformer with taps set at 5% intervals for easy setting of the filament voltage.

Filament Inrush Current

Fred Telewski: Although the "ideal" ratio for inrush to operating current is 1 to 1, the question is how significant is it to achieve this ratio in an amateur amplifier. I have perused both Eimac and RCA literature and find that for extremely high-power tubes (approximately 500 kW anode dissipation) that the inrush to operating current ratio is approximately 1.2 to 1. For tubes in the 250 kW dissipation class, this ratio is in the 2.5 to 1 range. I found one RCA 5 kW dissipation triode where the inrush to operating current ratio is specified as approximately 5 to 1. That Eimac does not discuss inrush current for tubes with less than 100 kW dissipation, leads me to conclude that this is not a major factor in the design of amateur transmitters.

While it is theoretically possible, as Measures points out, that a 15-A tube can draw 125 A, I must also agree with Tom Rauch's observations that this is extremely unlikely due to the impedance of filament chokes, transformers and wiring. I think the message to amateurs building their own amplifiers is to avoid oversizing the filament transformer. The right size filament transformer works best, and if available, use one designed to have high leakage reactance.

Measures also asserts that indirectly heated cathodes are not affected by inrush current. Here again, I must agree with Rauch's observations that truly excessive inrush current can be detrimental to indirectly and directly heated cathodes.

Tom Rauch: Inrush current to a tube's filament does have a deleterious effect on the filament. Inrush current can affect all types of tubes, although problems are very rare in the types of tubes used in amateur service. Contrary to the statements presented in the article the principal damage has been found to be thermal in nature and not magnetic.

Grid Protection

Fred Telewski: Here I have to agree with Eimac and Tom Rauch. The loss of load or plate voltage while drive is applied can be very detrimental to grids. Therefore, I favor electronic protection. I agree with Rauch that fuses and resistors afford poor protection for a grid under these fault conditions.

Reid Brandon: The suggestion that grid-protection circuits are unnecessary is ludicrous. Agreed, tubes such as the 3-500Z with rugged grids are not easily damaged, provided the operator keeps an eye on the grid-current indicator. Oxide cathode tubes using focus-cathode design are more easily damaged in a short time (such as milliseconds) under fault conditions. Newly developed circuits are quite effective in protecting tubes from excessive grid dissipation, which can result from loss of load due to failure in the feed line, balun, or antenna. To suggest that a grid can be protected by fuses is incorrect. Fuses are too slow to react to fault conditions; they may not operate at all in the case of brief overloads, and when they do operate, there is no feedback to shut off drive power or plate voltage or any other parameter. What Measures has proposed is to discard good engineering practice and adopt a dangerous situation for some tube applications.

We do not understand the reference to "sudden bursts of VHF or UHF grid current." If Measures meant to imply that this is something which is occurring in even one commercial HF linear amplifier manufactured for the amateur market today, it is an amplifier we have not yet seen. With no proof of this phenomenon, we have to assume this is a clever method of promoting "low-Q parasitic suppressors."

Tom Rauch: Measures states that VHF and UHF parasitics result in super-heated grid surfaces, magnetically bent grids and filaments, destruction of tank capacitors, damaged band switches and cathode to anode arcing. Although VHF and UHF parasitics are undesirable characteristics and must be avoided, there is no basis in amplifier tube theory or actual experience to support such conclusions. They are not supported by design theory or the experience of recognized experts in the RF amplifier community that include Eimac, Siemens, ETO, Henry, and Ameritron. In fact, it is impossible to perform a failure analysis of a tube and determine if the failure resulted from excessive VHF or UHF grid current. The article further states that its author has, "never found a tube damaged by excessive HF grid current." This statement is contrary to common sense and to the experience of manufacturers of power grid tubes. It is also contrary to the sad expe-

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riences of those hams who have inadvertently driven the fuse- or resistor-protected grid of a 3CX1500 or 3CX800 with as little as 100 W for only a moment.

In contrast, those who have attempted to overdrive carefully designed home-brew or commercial electronically protected amplifiers, have found that their tubes survive. To replace these fast-responding circuits with fuses or resistors would be foolish. Fuses are notorious for their slow response to overloads, and resistors are worse. Overloads to grid circuits must be controlled in milliseconds. Fuses and resistors cannot provide this speed.

Glitch Protection

Fred Telewski: Beyond the obvious approach of protecting meters by using diodes in parallel, protection becomes a matter of design choice. One needs to look at the entire amplifier design and the protection philosophy employed before making judgments here. Rich obviously has some amplifier designs in mind, but has not shared their schematics or the protection rationale of their designs with us. For example, judicious use of clearance around the dc high-voltage paths will successfully mitigate high voltage arcs caused by hairs, insects, etc.

Tom Rauch: Glitch protection must consider the equivalent series resistance (ESR) of the components in the high voltage circuit. Typical high-voltage electrolytic capacitors can exhibit more than 1 Ω of ESR per capacitor. When the RF choke and other component resistances are added to the capacitor's ESR, the total supply resistance generally exceeds 10 Ω. The addition of a 10-Ω resistor may only offer a negligible improvement in most circuits. It is alarming to note that the article recommends the use of a resistor rated at 500 V. Any device rated at 500 V is subject to catastrophic failure if subjected to the stress of several thousand volts. The manufacturer of such resistors absolutely do not endorse the use of this type of resistor in this application. The correct component would be an energy absorbing type of resistor such as the Carborundum SP type, or RCD Corporation's PCN type. The PCN series resistor for this application should be rated at 80 watts or more dissipation to safely handle the stored energy of a 25-µF capacitor charged to 3 kV.

Power Supplies

Transformers

Fred Telewski: Potting transformers seals the windings against moisture. It does not fill up the air spaces unless it is done under vacuum. Vacuum-potted transformers are more costly. The leakage reactance of the transformer determines what type of filter (choke or capacitor input) is most practical.

Filters

Fred Telewski: I agree that capacitor-filtered power supplies are the norm in Amateur Radio amplifiers. In order the achieve good regulation, these supplies should employ transformers with very low leakage reactances. I have seen capacitor-input supplies with regulations from quiescent current to peak current of approximately 4% using such transformers. It is also imperative that a step-start circuit be used with a low leakage reactance transformer to limit surge currents, which can run as high as 40 times the normal operating current.

I do not understand Measures' comments about choke filters, swinging chokes and transient loads. I have seen many fine commercial-grade transmitters produced with 10 to 12-H chokes and 12 to 20-µF capacitors for operation on single-phase 60-Hz mains. I might add that these commercial grade amplifiers have intermodulation distortion (IMD) specs which are far better than most amateur amplifiers (home-brew or manufactured) achieve. If one has a plate transformer of high leakage reactance design, the only practical choice for good regulation is to use a choke-input filter. Use of capacitive-input filters with high leakage reactance transformers will result in poor regulation (approximately 35%), even with very large capacitors (120 µF).

Rectifiers

Fred Telewski: I must agree with Steve Katz's fine letter on the selection and application of rectifier diodes. I also find that while there is some good advice about not mixing rectifiers, this section of Measures' article is somewhat confusing.

Steve Katz: Measures implies that rectifiers "of the same type" will be successfully used in series without the need for any type of equalization. This is misleading. "Of the same type" hardly qualifies P-N junction rectifiers as being equal, or even similar. The ubiquitous 1N4007, for example, has a PIV rating of 1 kV and an I_0 (forward current) rating of 1 A. Does this make it a 1-kW rectifier? Are they all the same?

In reality, most 1N4007s and similar commercial devices cannot possibly be operated at 1 kV (peak reverse) and 1 A of forward conducted current simultaneously, as they will go into thermal runaway due to the extreme rise in junction temperature created by this application. With a V_f (forward voltage drop) of 1.2 V at 1 A forward current, the device is called on to dissipate 1.2 W. Under these conditions, even if the ambient temperature could be maintained at 55°C (very cool for a large power supply environment), the device's junction temperature would be 94.6°C (derived from its thermal resistance rating). At this junction temperature, the device's reverse leakage current would normally be about 1 mA. At 1 mA leakage current times 1 kV peak reverse potential, the device would dissipate an additional 1 W from reverse losses. Add this 1 W to the original 1.2 W, and now we're up to 2.2 W of power dissipation in a subminiature device that can really only handle perhaps ½ W total. Thermal runaway can set in very quickly under these conditions.

The 1N4007 (and many similar devices) are neither uniform nor consistent from device to device, lot to lot, or manufacturer to manufacturer. More accurately stated, a 1N4007 can withstand either 1 kV reverse bias, or 1 A forward current, but never both (simultaneously). I purchased a reel of 10,000 1N4007s and evaluated 500 diodes at random, measuring breakdown voltage at 1 mA and leakage current at 1 kV dc. Within this single reel of diodes (obviously all from one source), the devices varied in leakage current from less than 1 µA up to more than 10 µA at 1 kV dc (25°C test temperature); and they varied in breakdown voltage from less than 770 V up to more than 1150 V (BV measured at 1 mA reverse current). Where's the lot consistency? (Remember, no consistency is guaranteed on these parts. They are supposed to meet the JEDEC specification for a 1N4007, however, and 76 samples out of 500 didn't even do that.)

As such, these would be extremely poor candidates for series-string operation in a high-voltage power supply. While Measures is correct in the assumption that the reverse current in a string of series-connected rectifiers will be equal in all devices (it will be the equivalent to whichever device has the lowest leakage), he doesn't address the fact that the devices, even if the same part number type, will often break down at varying voltages, placing the most stress (and dissipation) on the highest-voltage breakdown parts. This is the evil of using series-string P-N junction rectifiers without resistive equalization. Equalizing resistors can force all devices to break down at the same voltage.

High-voltage rectifier assemblies or modules manufactured specifically for applications such as Amateur Radio vacuum tube amplifiers are available, however. Rather than using equalizing resistors, which add more components that can potentially fail in the system, the manufacturers of such assemblies use carefully selected junction rectifiers that are well matched for reverse characteristics at high voltage and temperature. Usually the devices used in these assemblies are simple series-strings of junction rectifiers, but they are matched for breakdown within one or two percent prior to overall assembly and encapsulation, so they don't require any additional special equalizing or balancing.

Also, Measures says, "A better solution is to connect a metal-oxide varistor across each half-wave rectifier..." with respect to solving some of the problems detailed in this section. I guess he hadn't heard about all the problems MOVs have caused in the industry. MOVs are specifically credited for causing a number of industrial fires, as has been well documented in, for example, *Electronic Buyers' News*, April 13, 1992.

Metal-oxide varistors are pseudosemiconductors made of doped grains of zinc oxide. To achieve higher breakdown potential, many grains are used in series. Each grain contributes only about 3 V toward the total voltage rating of the device; thus, a "200-V" MOV would have about 67 grains in series. (Compare this with a silicon P-N junction, which can be fabricated to break down at more than 1 kV in a single junction.) Transient events or an isolated single transient event can degrade or destroy individual grains, incrementally and permanently reducing the MOVs nominal voltage. As the nominal voltage is reduced, the leakage current increases accordingly. The increase in leakage current causes a corresponding increase in joule heating effects on the devices. This heating, coupled with the negative temperature coefficient of an MOV (typically –0.01 to –0.05%

per °C) causes even further "self-induced voltage reduction" and eventual thermal runaway.

When the MOV's nominal voltage degrades to an extent that the working voltage can no longer be maintained, the circuit in which it is used ceases to function properly. Since the MOV device tends not to degrade abruptly or electrically short-circuit due to the many oxide grains in series, it effectively becomes a parasitic resistive load. Substantial parasitic heating currents will flow through the MOV in the peak cycles of ac potential applied and progressively worsen with the continuing MOV degradation. In a dc application, the effective heating energy is greater. While in this state, sufficient heat energy can develop to cause a fire either directly or indirectly via combustion of adjacent materials. A circuit with this type of device failure is difficult to fuse and may not adequately protect against a potential fire hazard.

Conclusion: MOVs are a poor choice for circuits which may be exposed to line transients, high temperatures, or a combination of the two. Do you really want MOVs in your amplifier?

Tom Rauch: Equalization of voltage through the power-supply rectifier string is important. However, the article incorrectly places emphasis on equalization of current. Low-cost diode rectifiers must be protected by equalization of the reverse voltage since they are not matched for capacitance or reverse leakage resistance. Manufacturers of these devices simply put them through a go/no-go acceptance test. The reverse voltage characteristics of individual diodes can vary considerably from device to device.

During a discussion with a Motorola power rectifier engineer to verify my understanding of their testing procedures, he made the following statement: "Diodes are not matched, only tested in a go/no-go test. There is no guarantee that like-marked diodes are from the same country, let alone the same manufacturing lot. Even if diodes were matched, they would have to be maintained at relatively close temperatures to one another to ensure they stay matched."

John C. Fakan: Measures seems to not understand that the use of resistor and capacitor arrays in parallel with series-connected diodes is to equalize the reverse voltage (not current, as stated in the article) across the individual diodes. During the nonconducting half of the cycle a bare, series-connected diode string will divide the impressed reverse voltage according to the individual capacitance of each diode junction. The diode with the least capacitance will see a proportionately higher voltage than the others. If that voltage exceeds the diode's reverse breakdown value it is likely to fail.

A properly designed resistor and capacitor array will establish the reverse-voltage distribution across each element regardless of differences in individual diode capacitances and leakage currents and thus prevent this failure mode.

Measures' statement that the currents in the elements of a series circuit are exactly equal is certainly correct. However, the flaw in his logic is to presume that equal currents in the component leads implies that the conduction mechanism within each component is the same. A diode experiencing a reverse bias below its break-down voltage is acting like a capacitor and thus storing energy in the dielectric of its junction. Above the breakdown voltage "actual" current (rather than "displacement" current) will be flowing through the high resistance of the reverse-biased junction, and the resulting ohmic heating may destroy the diode.

Electrolytic Capacitor Equalizing Resistors

Tom Rauch: The article is again in error where it recommends the use of a 'carte blanche' equalizing resistor for electrolytic filters. The leakage current range of an electrolytic capacitor is very important in determining the proper resistor value. Different types of capacitors require different values of resistance. Correct values should be selected from information supplied by the capacitor manufacturer. A good rule of thumb is to use the lowest value of resistance that can be tolerated in the application.

Biasing

Fred Telewski: The bias string with 0.7-V increments is not a bad idea. I have successfully used it myself. Where I disagree with Measures is in the area of electronic bias switching. Here again I must agree with Tom Rauch, but also point out that improperly designed bias switches can cause problems.

Tom Rauch: The commentary regarding electronic bias switches having a deleterious affect on amplifier performance is misleading. It is possible—with poor design and poor construction—to build an electronic bias switch which would result in excessive IMD in an amplifier. However, properly designed and constructed electronic bias switches, such as those used by reputable amplifier manufacturers or skilled amateurs, will not cause any deterioration in the IMD characteristics of an amplifier.

High-Speed Relays

Fred Telewski: Fast relays are essential for QSK operation and I applaud Rich's attempt to get them sequenced. I am not sure, however, that he's got it right from a systems point of view. There's also the obvious erroneous connection in Figure 3,[1] and I agree with Bill Clemow's comments concerning the switching voltage and current. This circuit would certainly not pass muster with the safety folks in my company.

Steve Katz suggests the use of high-power PIN diodes for RF output switching. Measures' counterpoint is that they might not be as robust as vacuum relays when it comes to lightning and other such hazards. I don't have experience in this area, other than to say that I myself use vacuum relays and consider them excellent.

Steve Katz: Measures addresses the "relay problem" relating to high-powered amateur amplifiers but doesn't really offer any solutions. This is ironic, since there is an obvious solution, albeit a recently introduced one: Don't use relays at all!

There is a new family of very high-power, high-voltage, long carrier-lifetime PIN diode RF switches available which can solve a multitude of problems for amateurs. Although early PINs were mostly available only for lower-power or microwave work due to their low breakdown voltages and short carrier lifetimes, a new product family from Microsemi Corporation[2] is ideal for high-powered operation in the HF spectrum, down to below 1.8 MHz. This is the UM2100 product family. The device is characterized by the manufacturer to have ratings that are ideal for amateur applications.

Instead of the 15 to 25-ms switching speed of a conventional relay, or even the 2-ms switching speed of a vacuum relay with a "speed-up circuit" as referenced by Measures, the PIN diode switch, using only two diodes costing one-tenth as much as a vacuum relay, will switch in microseconds—not milliseconds—making it ideal for modern data modes. No moving parts, nothing to wear out, and performance equivalent to even the best coaxial relay.

The Ameritron model QSK-5 2.5 kW QSK TR Switch makes intelligent use of high-powered PIN diodes, and this accessory can be added to any MF/HF amplifier. It uses older-generation UM4001Bs, also made by Microsemi Corporation, but the newer-generation UM2100 family better lends itself to the application. Hopefully, the QSK-5 will be updated to use UM2110s.[3]

To prove that the new-generation PINs are as good as they look on paper, I replaced the vacuum relay in my Henry model 3K Premier amplifier with a set of UM2110 diodes, using two in parallel for the forward (conducting) switch, and a single diode for the shunt (isolating) switch. Using a 600-mA bias to switch the diodes, the amplifier still delivers full power, more than 40 dB isolation (comparable to the original relay) at 29 MHz, and the diodes get just perceptibly warm under full-output conditions, key down for 10 minutes. There is additional circuitry associated with using diode switches (two RF chokes and two dc blocking capacitors, which must be high quality), but my total investment in the circuitry was less than $40.

Do the diodes survive high SWR and local lightning transient conditions? No problems to date, using antennas with SWRs greater than 5:1 on some frequencies, and leaving the antennas connected during local thunderstorms. It's only been 10 months since the modification, so I cannot comment on overall operating life, but I'd anticipate the diodes will last at least as long as any relay possibly could, and they switch 100 times faster.

VHF Stability

Fred Telewski: The whole subject of VHF stability and parasitics is where Measures' material seems to be at its weakest. When he speaks of striking gongs and the magic of how spark-gap transmitters convert dc to RF, I become worried. Nowhere does he quantify the fault energies associated with these phenomena and whether or not they are in fact truly detrimental to tubes. We also find no laboratory substantiation or comparison between a fully functional output network with and without his parasitic suppressors. It would be useful to see an output network swept on a network analyzer and attempt to draw some sound conclusions.

VHF stability and parasitics are a consequence of the gain around some loop (unintentional, perhaps) being equal to one, and the phase angle being equal to 0°. These conditions constitute the definition of oscillation. They come about when the tube in question has gain at frequencies beyond which we have adequately modeled and understood our input and output tank circuits, and are not given to moving in and out of our amplifiers as some of Measures' comments might suggest. I would also like to point out that I've seen a number of commercial-grade transmitters function properly without the aid of plate parasitic suppressors. Suppression in these instances was often achieved on the input side and through judicious layout and component choice in the plate-tank circuit. In this area, I think the comments made by Tom Rauch and Eimac bear serious consideration.

Tom Rauch: Measures' description of the causes, effects, and cures of parasitics is flawed, both in the theory and the practical applications described.

There is no evidence to support the article's claims that intermittent VHF parasitics bend grids and filaments, destroy switches, instigate arcing, or cause the plating to fall off the grids of tubes. There is no support for these claims in extensive tests, the field experience of reputable manufacturers of power grid tubes and RF amplifiers, and even basic science.

For example, the article states that replacing the copper or silver-plated copper wire in a parasitic suppressor will radically lower the VHF Q of the suppressor. This is not true. In a typical parasitic suppressor, the coil is in parallel with a low-value resistor. This combination is in series with the signal path, usually in the anode circuit between the tube and the plate tuning capacitor. The coil's reactance increases with frequency, and at VHF most of the signal path is through the resistor. It is plainly evident that the dominant component at VHF is the resistor, not the coil. Changing the coil has very little effect on VHF Q.

On the other hand, changing the resistance of the suppressor's coil radically affects the HF circuit Q. The tube's output capacitance almost always comprises the major part of the 10 and 15-m tank-circuit input capacitance. The majority of the HF signal travels through the parasitic suppressor's coil. Any additional series resistance in this path, such as resistance introduced with nichrome wire, places additional resistance in the portion of the HF tank circuit carrying very high circulating currents. The reduction of circuit Q, the increased loss, and the reduced harmonic suppression caused by this faulty modification peaks in the 10-m band.

The only practical application for nichrome wire in the anode circuit of an amplifier is if the component or layout creates a stability problem near the upper HF region. This would occur if old tubes with long, thin grid leads (ie, 811As or 572Bs) were used, if the RF layout was inadequate (long, thin leads or poor shielding), or if several tubes were connected in parallel. The best solution would be correcting the specific cause of the stability problem, but if a loss in HF performance is acceptable, nichrome might be a viable option.

The most misleading and erroneous statements in the article are those addressing VHF stability. As stated earlier, parasitic oscillations do not bend grids or filaments. Nor do they cause bandswitches and tuning capacitors to fail. The use of nichrome wire in the parasitic-suppressor coil does not significantly change the Q of the suppressor at VHF or UHF. Nichrome suppressor coils will lower the Q at HF. This is because the coil is the primary path for HF signals and the suppressor's resistor is the primary path for VHF and UHF signals. The experience of the technical community, including both manufacturers and knowledgeable amateurs, absolutely contradicts the conclusions of this section of the article.

Reid Brandon: Measures' inference that modern tubes used in linear amplifiers have inherent "VHF parasitic oscillations" is incorrect. Parasitic oscillations are a result of improper ampli-fier circuit design and/or component layout.

Measures states that "...much has been published about VHF parasitic oscillations," but unfortunately he does not indicate any references to these publications.

The proposed "low-Q VHF parasitic suppressor" appears to hold no proven advantages over conventional suppressors. With no scientific proof or technical references, the appearance of a new device called the "low-Q VHF parasitic suppressor" seems to be more of a commercial venture than a technological breakthrough.

Is More Gain Always Better?

Fred Telewski: Here is an area where Measures and I disagree. Measures takes an amplifier-only view of IMD, and I take a systems view. Most solid-state transceivers, particularly those operating on 12 V, have IM levels in excess of those produced by the tubes in the linear amplifiers in question (3-500Z, 3CX800-A7, 8877). This can clearly be seen by examining some of the fine product reviews done in *QST* for transceivers and amplifiers. One approach to reducing the total IMD of the transceiver/power amplifier system is to use a high-gain amplifier and reduce the drive required from the transceiver. This permits the transceiver to function at a power level where it produces less IMD. The result is lower overall IMD at the PA output than that achieved with Measures' approach.

The insertion of cathode negative feedback will reduce the gain of the PA, as Measures suggests, and improve the PA's IMD by itself. This is of no consequence unless one is using a commercial-grade exciter whose IMD is better than that of the open-loop performance of the triode in question. Cathode feedback will also increase the input impedance of the tube in question. Measures does not deal with the effects that this will have on the input network and matching of the amplifier to the transceiver. Measures' comments about ALC being generically flawed are inappropriate. I would suggest referring to the comprehensive discussion on the plusses and minuses of ALC in *Single Sideband Systems & Circuits.*[4]

The only merit I find in Measures' "gain argument" lies in the fact that some amateurs suffer from the "knobs at 5 o'clock" syndrome, and will overdrive anything they own.

Adjustable Tuned Inputs

Fred Telewski: Although I agree that it would be nice to have some adjustability on the input network (particularly if you've added a cathode feedback resistor) in order to be able to tune the amplifier input for minimum SWR, I agree with Rauch's comments concerning SWR. Measures' notion here is quite in error. Tom Rauch is correct.

Tom Rauch: The comments regarding adjustable tuned inputs are incorrect. The article implies that the reactance of the output network of a transceiver affects the input SWR of an amplifier. This finding is without basis in theory or practice. The output impedance of a source has nothing to do with the input impedance of a load.

Finally

Fred Telewski: A few words about transformer leakage reactance are in order. I haven't quantified leakage reactance as to what is considered high and low. I am not sure that this is a readily designable quantity for most transformers. I do know that certain transformer architectures provide very low leakage reactance, while others will provide comparatively high leakage reactance. Their geometries are as follows. The high leakage reactance type usually consists of a **C**-core pair with the primary wound on one leg and the secondary wound on the other leg (this looks like the typical **UI** lamination configuration). Many plate transformers intended for use with choke-input filters have been wound this way for reasons of economy. The lowest practical leakage reactance transformer I'm aware of for plate application usually consists of 2 **C**-core pairs with the primary and secondary windings split and interleaved on the adjoining legs (this looks like the typical **EI** lamination configuration).

Notes

1. See R. Measures, "The Nearly Perfect Amplifier," *QST,* Jan 1994, p 33, Figure 3. The label "Negative High Voltage" (at the bottom left of the schematic) is erroneously shown on the positive side of the capacitor; it should be on the negative side of the capacitor near the junction of the resistors and diodes (Dgp). Bill Clemow adds: Note the Short to Transmit control line: There is 80 to 120 V at 80 mA on this line. This is a shock hazard.
2. Microsemi Corporation, 580 Pleasant St, Watertown, MA 02172, tel 617-926-0404. For further information, request a free copy of their *RF Application Note MPD-101,* (April 15, 1994), which discusses "A Comparison of PIN Diodes and Rectifier Diodes."
3. Contact Ameritron at 116 Willow Rd, Starkville, MS 39759, tel 601-323-8211.
4. For a comprehensive discussion on the plusses and minuses of ALC, see W. Sabin and E. Schoenike, *Single Sideband Systems & Circuits* (New York: McGraw-Hill, 1987).