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Author: Tom O'Hara, W6ORG

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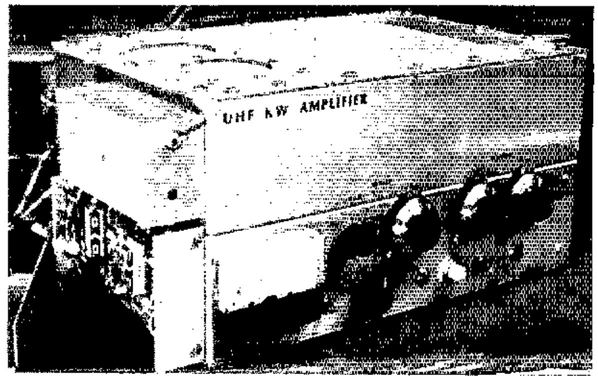
The Care and Feeding of Linear Amplifiers for ATV



Your amplifier doesn't like to be fed ATV signals? Careful grooming will give it a healthy appetite for this delectable mode!

By Tom O'Hara,* W6ORG

The increased availability and affordability of video equipment has helped account for the growing number of fast-scan ATVers. Microcomputers, video cassette recorders, color cameras, and video Teletype and cw converters have encouraged hams to want broadcast-quality, real-time pictures. Just receiving a snowy, black-and-white call-letter plate from 40 or more miles away is "old hat." Emphasis today is on getting good-color, snow-free pictures with which to play computer games, coordinate public-service events, or show the latest home movies or videotapes.

Once your 10-watt ATV station is working well, and all the antenna and tower height the wife and neighbors will allow have been put up, thoughts turn to more power. This article covers trade-offs between transistor- and tube-type amplifiers, gives test results of three popular transistor amplifiers, and discusses system considerations to enable you to decide which suits your needs best.

Tubes vs. Transistors

What is the difference between a tube amplifier and a transistor amplifier? Watts are watts, aren't they? Well, if you are using fm or cw, it may not matter. With ATV you need to reproduce the video without degrading the linearity, video-to-sync ratio, or bandwidth (to the point of poor contrast), tearing or jittering, or lack of sound and color. With a-m, the choice of amplifying device must be made with these characteristics in mind, or results can be disappointing.

Let's consider bandwidth first. Uhf power transistors are low-impedance devices (input and output impedances are often around 1 ohm), while tubes have much higher impedances, in the thousands of ohms. This high impedance dictates input and output loaded Qs that limit bandwidth. It also determines the level of sound and color subcarriers, and resolution. Transistor loaded Qs are often below 10 because of the relatively high resistive- to reactive-component ratios. These values determine the matching-circuit strip-line dimensions. Tubes, on the other hand, usually have high grid capacitance and lead inductance — the limiting factor in the values used to make a resonant circuit at 400 MHz. Grid Qs can end up being more than 75 in tubes, such as the 4X150, with all the matching tricks normally employed. In tube amplifiers of this kind, the grid is the major killer of resolution, color and sound. For this reason, many hams end up using their 10-W ATV rig as an rf driver and adding a high-power video modulator.

Linearity is a factor that enables tubes to fare better than transistors, so a trade-off is often considered between bandwidth, (favoring transistors) and linearity (favoring tubes). Tubes are linear up to the abrupt point of limiting in Class C operation, so you can expect good gray scale and little reduction of sync. With transistors, input-to-output gain varies greatly, depending on the power-output level. Generally, the last 3 dB of output increase takes more than 6 dB of input increase. Many hams like this characteristic for ssb because the soft limiting effect gives a higher average power, termed "talk power." Voice recognition suffers little from the peak distortion, and it does improve the signal-to-noise ratio. With video, you must have the sync to enable the TV set to sweep correctly and give a stable picture. Since the sync tip is transmitted at peak envelope power, a transistor power amplifier can compress the sync amplitude to half or less, giving a jittery, torn or rolling picture in the TV. A rule of thumb for using power transistors in the linear mode is to set the peak envelope power at half the manufacturer's rating. For instance, a Motorola MRF648 is rated at 60 W and should be run at 30-W PEP for ATV.

I ran tests using a video-processor amplifier, which enables setting the sync-to-video ratio at any level. Among six TV sets tested, all would lock up with the sync level cut in half. So, as a minimum, set 50% sync compression as the worst case, or 20 IEEE units out of 40. This varies with each TV model and assumes the camera is properly set with 40 IEEE units of sync and 100 units of video. More than 50% of rated PEP can be obtained by use of sync expansion, but more on that later.

Kilowatt ATV

Before we turn to the three tested transistor amplifiers, a discussion of one of the popular tube amplifiers is in order. The K2RIW KW amplifier[1] is available in

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[1]Notes appear on page 28.

kit or complete form from ARCOS.[2] On cw, 10 W of input power from my P. C. Electronics TC-1 transmitter/converter (with no video applied) gave 325 W of output power. The only change I could see in this amplifier over the original K2RIW design was that, rather than the original 4CX250s, the tubes are now Eimac 8930s (100 watts more dissipation each). I stopped testing at 450 watts out (14 watts of drive) because the coaxial cable to my dummy load got very warm to the touch after a few minutes.

The grid loaded Q caused the 4.5-MHz sound subcarrier to roll off 11 dB in the linear mode. Color was almost nonexistent, and the resolution of the 10-W ATV transmitted signal was gone. There is a simple way to overcome this deficiency. With a P. C. Electronics VM-2 grid modulator, the grid loaded Q does not restrict the transmitted-video bandwidth. This leaves only the plate circuit loaded Q to roll off the response.

The modulator was put into a chassis and mounted to the side of the amplifier, as shown in the lead photo. A P.C. Electronics FMA5 sound subcarrier board is mounted in the covered box. A short piece of RG-174/U cable connects the modulator with the amplifier grid circuit. Best results were obtained with −65 V grid bias and no video applied. The modulator is clamped to the video sync so that, regardless of what is in the picture or the average picture level, the power level at the sync tips remains constant. With the 10-W drive, I got 325 W of output power, and then added video. I measured about 250 W of output after adjusting the video gain for best contrast, just above white limiting. The average power on the wattmeter will change, decreasing for a predominantly white picture and increasing for a principally black picture, but the peak envelope power will remain constant at 325 watts.

Amplifiers are best compared by stating PEP, because this eliminates modulation type as a factor. With clamped or dc-restored video modulators, this is as easy as removing the video and reading the power directly from a wattmeter. I will state power as PEP, or power as read on a wattmeter with no video modulation applied. The wattmeter will read PEP in the cw case (no modulation) with a clamped video modulator.

Fig. 1 shows how the P. C. Electronics VM-2 modulator is connected to the K2RIW/ARCOS amplifier. Q3 was added for improved clamping and linearity, and to set the bias point. The plate Q is still high enough to warrant fine adjustment of the plate and output tuning to the high-sideband side of the response. The roll off is just about 1 to 2 dB at the sound subcarrier, and can easily be compensated for by a little extra 4.5-MHz injection. Color is down about 1 dB and is not degraded noticeably except in weak reception cases. Resolution is great, with the TV set i-f bandwidth being the limiting factor (most are only 3 to 3.5 MHz). A resolution rule of thumb is 75 to 80 lines per MHz. I let this amplifier run for 1/2 hour continuously at 325-W PEP, and it seemed to be loafing. So, for a really strong signal, I can recommend this unit, but suggest high-level modulation for quality video work.

50-Watt Triode Amplifier

The old faithful 2C39 (and newer variations) also makes a good linear amplifier. These tubes can give full bandwidth in grounded-grid operation if the plate line is modified to a half-wave section. All cavities have a loaded Q that is much too high for good bandwidth, if they are 1/4-wave lines. They are physically very short because the internal capacitance of the tube is high. Again, this limits the resulting Q that can be achieved without loading the tube down so far as to make the stage gain too low.

The flat plate line (1/2-wave circuits) allows a much lower loaded Q, seems to work better, and is quite simple to build. You can tell a 1/2-wave line from a 1/4-wave line by the tuning capacitor placement. The 1/4-wave line capacitor is placed next to the tube plate and resonates with the tube plate capacitance. The 1/2-wave line has the tuning capacitor at the end opposite the tube, and usually the B+ rf-choke connection is near the middle of the line.

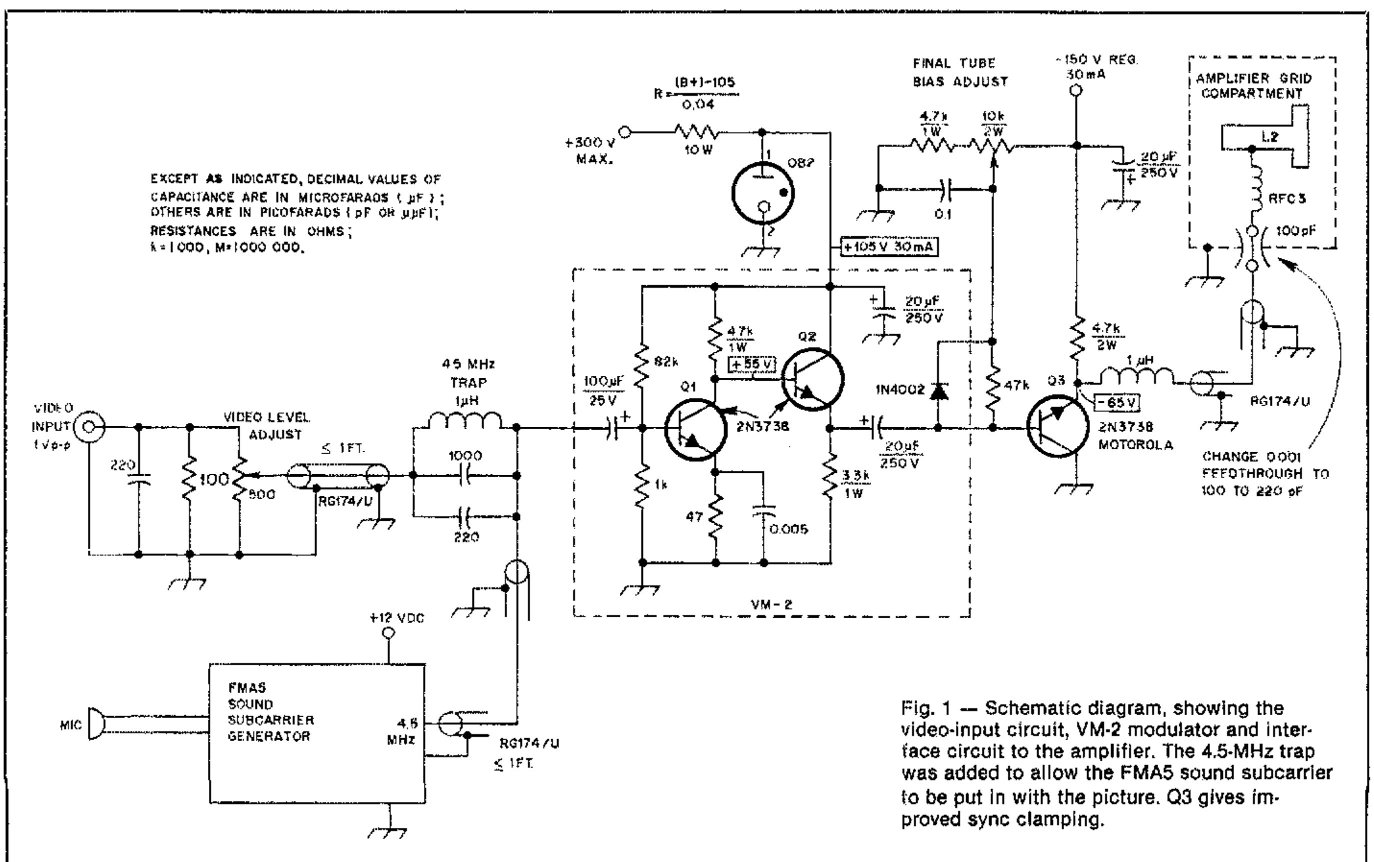


Fig. 1 — Schematic diagram, showing the video-input circuit, VM-2 modulator and interface circuit to the amplifier. The 4.5-MHz trap was added to allow the FMA5 sound subcarrier to be put in with the picture. Q3 gives improved sync clamping.

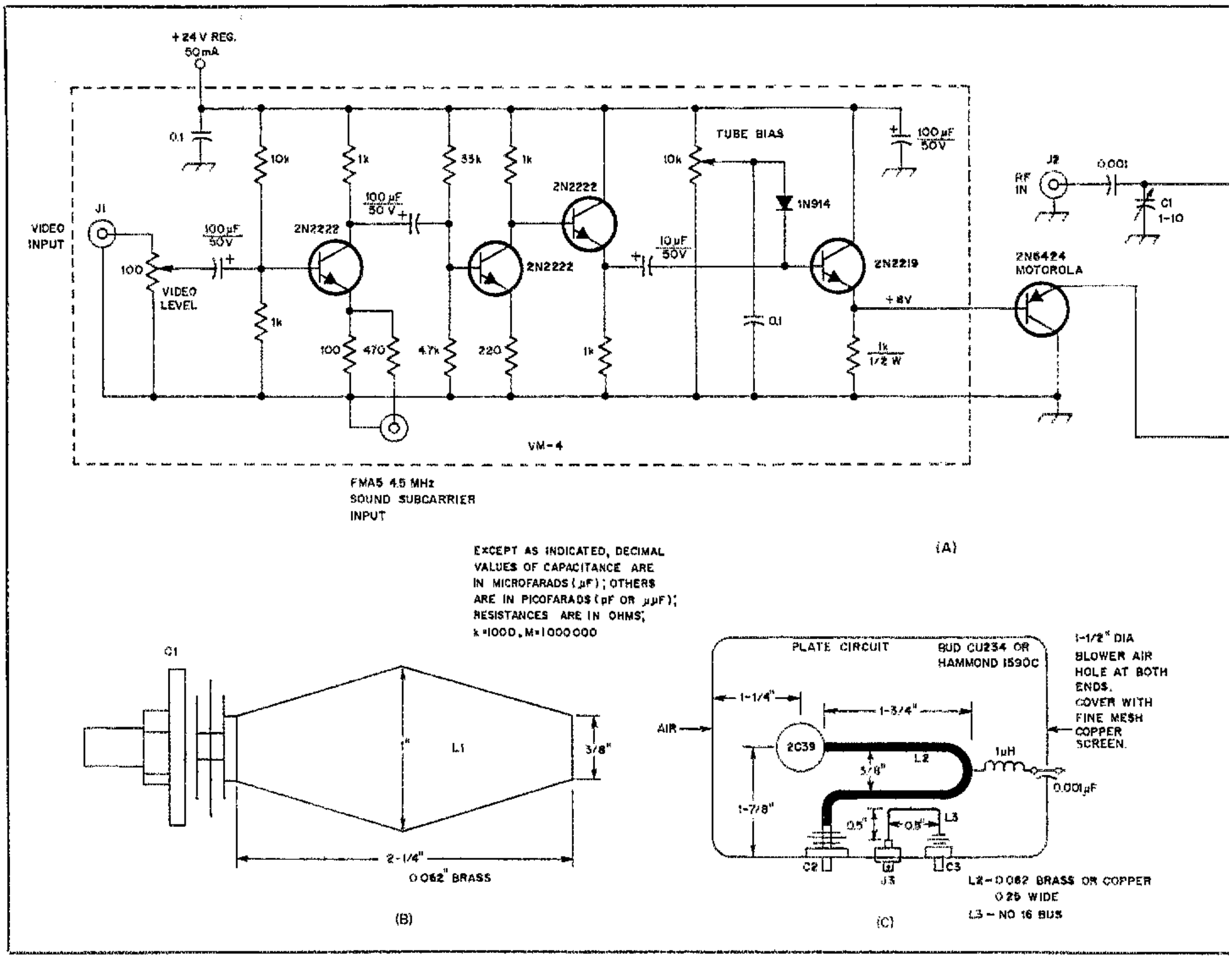


Fig. 2 — Schematic diagram showing a VM-4 modulator with an added 2N6424 transistor as a cathode modulator for a 2C39 amplifier tube. The grid is grounded for dc and rf to provide stability and efficiency. Operating bias is set by means of a 10-kΩ potentiometer on the VM-4 modulator. The 6-V filament transformer must be isolated from ground so that it doesn't attenuate the video. mm = inches × 25.4

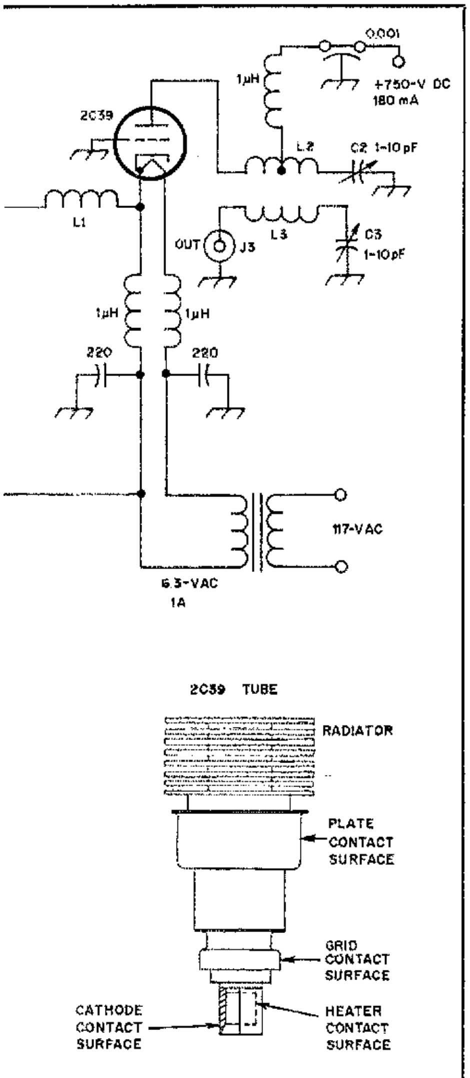
Tests on a Sota EDL432P amplifier, which has a 1/2-wave line, gave good linear sound and color with 50- to 60-W PEP out and 4- to 5-W PEP drive. These units are no longer being built, but the test proved the principle. Many long-time ATVers are familiar with the Motorola T44s, which use a 1/4-wave line and only give about 200 lines of resolution, with poor color and sound. The 2C39 tubes from these rigs can be used to provide nice 50-W linear amplifiers or cathode-modulated final amplifiers (Fig. 2).

The conversion description basically involves removing the housing, discarding the plate line, and removing the grid capacitor. The grid must be dc-grounded for video stability and rf efficiency. The cathode tuned circuit is also changed to lift it above ground. A 100-Ω, 5-W potentiometer can be used to set the tube operating bias at 10 mA under no-drive conditions, or, if high-level cathode modulation is desired, a P. C. Electronics VM-4 modulator can be inserted and the on-board, tube-bias potentiometer used. A blower is necessary at these power levels to keep the tube cool. The cathode is close to 50-Ω impedance as is, so a simple low-loaded-Q tuned circuit is put in for fine adjustment and does not affect the linear-mode video bandwidth significantly. The existing T44 plate line can be used if top-quality color and sound are not important to you. Or, you can build a video equalizing amplifier ahead of your modulator to compensate for the higher plate loaded Q. I think the change to a 1/2-wave line is much easier, and you can build it for best efficiency at the ATV frequency, rather than taking the lower efficiency of the existing 1/4-wave line designed for the 450-to 470-MHz commercial band. To make a nice neat assembly, the top cage can be replaced with a Hammond 1590C or Bud CU234 diecast aluminum box. Actually, it might be cleaner to use the T44 2C39 socket assembly and discard the rest. After all, the hard-to-get part is the concentric-ring socket assembly and mount. It can all be put on a chassis with blower, 750-V, 180-mA power supply, and may be self-contained with a 5-W exciter.

Solid State Amplifiers

Transistor amplifiers have the advantage of wide bandwidth. All three amplifiers I tested showed very little change in output power when switched between 439, 434 and 426 MHz. For an area that has many ATVers, all wanting to get on the air at the same time, it is as easy as flipping the frequency switch to QSY if the favorite calling frequency is busy. There is no need to retune. The color and sound are not degraded because of the low-Q matching circuits typical of these high-power uhf devices.

The other side of the coin is poor linearity. If you look at the input-power versus output-power curves of some of the popular uhf power transistors (Motorola RF Data Manual, for example) you will notice that the curve bends quite a bit, especially as the maximum-power point is reached. This nonlinearity will cause gain compression at the high-power end of the



signal (sync pulse and black levels). The average picture level will shift in favor of the darker shades of gray. Some people may actually prefer this picture, but, unless the system is adjusted to compensate for the compression, there may not be a stable picture if the sync is not at a sufficient level.

Different biasing methods can make small improvements in linearity, but only at the low-power end of the curve. A common-emitter rf-power amplifier with the base dc biased to ground through an rf choke may be considered Class C, but as drive is applied it may quickly approach Class B with a near 180 degree conduction of the rf sine wave. For ATV this would show up as turning the lighter shades of gray into white. A bias that allows a trickle of collector current ensures conduction at the low power modulation swing, providing a full range of grays and white.

Broadcast TV transmitters often have linearity-adjustment circuits in their modulators to compensate for any nonlinearities in the transmitter. For ATV, the most important part of getting a good picture to another ATVer is to have the TV receiver lock up to the transmitted sync. Included on the P. C. Electronics TXA5 exciter/modulator pc board is a sync-stretcher circuit that detects the incoming camera video sync, separates it from the video, and pulls up the modulator output only during sync time. This results in an output waveform that has much more sync than the camera is putting in. Rf-amplifier sync compression is thereby equalized (Fig. 3). The PEP output can be brought up from around 50% of the saturated power capability of the uhf power transistor to roughly 80%. The video portion does not have to be stretched because the maximum power point, or black level, is approximately the 50% point on the power curve, and goes downward, staying in the linear portion.

Tested Amplifiers

The three amplifiers sent by manufacturers to be tested for ATV were: a Microwave Modules MML432-50-W amplifier with a built-in receive "preamp" from Spectrum International, a KLM PA15-110CL 100-W amplifier and the Mirage D1010 100-W amplifier. All are basically the same type, consisting of a pair of power transistors in push-pull on a strip-line board. They all require an external regulated 13.8-V dc supply. The internal T-R relay or the PIN diodes switch automatically from receive to transmit, using rf sensing. All ATV PEP levels are given with full sync stretching; if you use an amplifier without sync stretching on ATV, try running it at 50% of full rated power.

Microwave Modules MML432-50

This unit took 5-W PEP drive to give 40-W PEP out on ATV. It has a single CTC CM50-12, which drew 8 A at 13.8-V dc. For fm or cw, the full 50-W output will require 10 watts of drive. The receive preamp is listed as a BFR34A on the schematic, but turned out to be an NE021. It provided 14.5 dB of gain and a noise figure equal to that of the popular MRF901. T-R switching is done by detecting some of the rf and activating a small relay, which turns on some UM9401 PIN diodes. The documentation that came with this unit was poor. While the basic schematic is given, the parts may be a little different. The diagram shows an 8-A fuse in the B+ line, but there is no fuse in the circuit! The "klutz" who always reverses the red and black power leads will have a "crispy critter" for an amplifier. I suggest you add a fuse in this line. Also, nowhere on the schematic or in the literature does it say which of the 5 pins on the DIN plug is the B+, or which one is ground. You have to open the case and trace the circuit to be sure. Pin 3 is ground, pin 5 is +13.8-V dc, and pin 1 can be grounded for push-to-talk with an ssb rig. The rf sensing does not have a switchable time constant for ssb. The amplifier does perform well and will give superior station performance if mounted at the antenna rather than in the shack.

100-Watt Transistor Amplifiers

The KLM and Mirage 100-W transistor amplifiers are similar and will be discussed together. Both use Motorola MRF648 60-W transistors in push-pull, driven by a single transistor. The Mirage unit uses a Motorola 25-W device (MRF644) as the driver transistor, and the KLM uses a TRW J03037 37-W driver transistor. The Motorola transistor curves show it to be loafing and linear at the required 20-W output level. It is well underrated at 25 W. The TRW device, on the other hand, is internally matched for zero reactance from 450 to 512 MHz, and is rated at 37 W full output with lots of compression. It's hard to say what the linearity is at 20 W, since the curves are not given in the TRW catalog. The Mirage amplifier also has a resistive input pad.

The KLM unit ran best at 65- to 70-W PEP with only 2.5 W of drive and full sync expansion, to give at least 50% sync output. The Mirage gave better than 75% sync at up to 90-W PEP output with 4 W of drive. Efforts to push it to the full 100-W output with 5 or more watts of drive just flattened the sync pulse. For fm or cw, 10 watts is more than enough to fully saturate either amplifier. The KLM unit had a maximum output of 100 W, but the Mirage amplifier delivered over 110 W.

Current draw at 70-W PEP was 15 A with the KLM, and 17 A at 90-W PEP with the Mirage. My Astron RS-20M 20-A power supply served well on ATV, but the 35-A version was needed for fm.

Antenna Mounting

If you consider that a 100-W signal in the shack will lose half the power going through 75 feet (23 m) of Belden 8214 foam dielectric RG-8/U cable to the antenna, the Microwave Modules amplifier will deliver the same power to the antenna when mounted next to it. Not only that, you will not have to adjust the bias potentiometer on your 10-W transmitter for 5-W output, since the 3-dB loss in the coaxial cable will take care of it. But the big plus is the extra 3 dB gained by the preamplifier on receive. Why give the guys watching your pictures all the benefits of your new system when you can double your station sensitivity on receive, too?

There is the effort and special considerations for mounting the box on the tower, but there are always practical trade-offs for improved performance. The amplifier will have to be mounted in a weatherproof aluminum box with a 13.8-V regulated supply. Even though the heat given off is lower with ATV, the amplifier will have to be silicone-greased

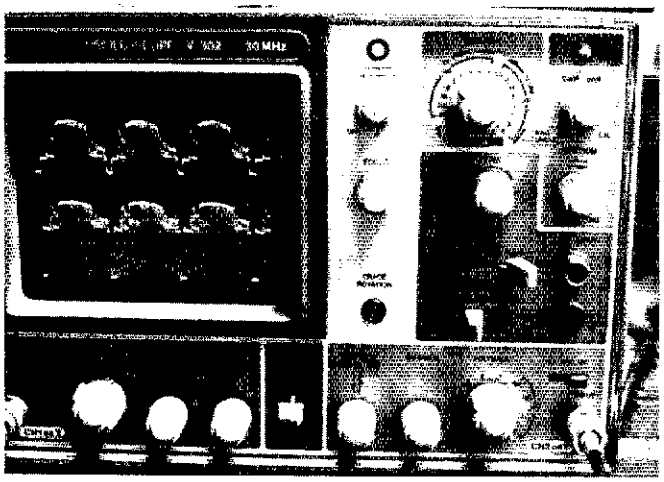


Fig. 3 — Oscilloscope used to observe the video waveform. The lower trace is the video signal as it comes out of the sync stretcher. The upper trace is the signal from the Mirage D1010-N amplifier.

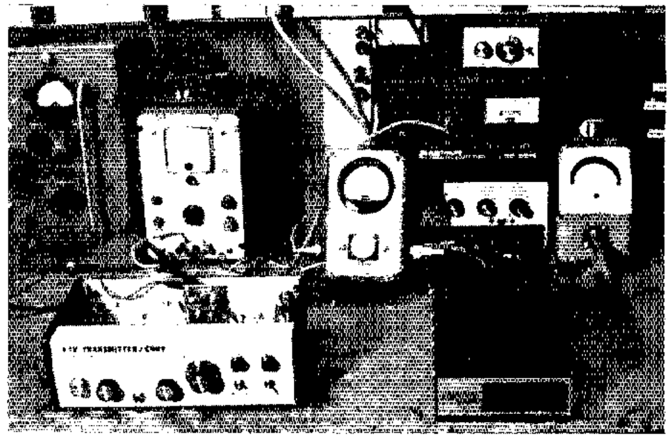


Fig. 4 — Setup used to test the three transistor amplifiers. Shown left to right is a TC-1 transmitter/converter with a DM-1 detector/monitor to sample the sync-stretched waveform, a Bird 43 Thruline wattmeter, the amplifier under test, another DM-1 inline to monitor the output waveform, and a Bird Termaline wattmeter/dummy load.

and mounted against the aluminum box. Use the rule-of-thumb temperature test! After the amplifier has been on a few minutes put your thumb on the heat sink. If, after gritting your teeth, and with tears forming in your eyes, you can hold your thumb on it, it will probably be okay. The power supply should also be tested for temperature rise, but aluminum angle brackets and direct mounting should do it. If running 117-V ac up the tower bothers you, try running the 20-V ac at 8 A between the power transformer in the shack and the bridge rectifier and regulator at the amplifier.

Why does the power supply have to be right next to the amplifier for ATV? Most regulated power supplies are designed for presenting a low impedance at the terminals, with good line and load regulation for 120-Hz ripple. With a-m, the load varies at the modulation rate. This amplifier draws 8 A at 13.8-V dc during sync pulses and at maximum signal levels, but draws only a few hundred milliamperes for the white level. It would not be so bad if we only transmitted vertical blanking pulses 60 times per second, because the big filter capacitors, regulator devices and time constants do a good job at these frequencies. But the current changes at video rates up to 5 MHz. The larger the filter capacitance, the higher the impedance at any given frequency above the audio range. This is caused mainly by the internal inductance and by what is called "equivalent series resistance." Add to that the small but significant resistance and inductance in the leads between the amplifier and the power supply, and a scope on the B+ supply at the amplifier will show a few volts of ripple that look like horizontal sync and video.

This ripple is another cause of sync compression, besides the normal gain curve of the uhf power transistors. Consider that the gain of the transistor is going to be much lower if the ripple component on the 13.8-V line swings down as much as 2 V to 11.8 V during the horizontal sync pulse. There are two ways around this problem; both things should be done, if possible. The only capacitors in the amplifier are for low-frequency stability in the uhf power transistors. They usually consist of a good quality bypass for 450 MHz, a 0.1- or 0.01-μF unit for the vhf frequencies and a 22-μF unit for hf and lower frequencies. But these won't do a thing for frequencies between 3 kHz and 500 kHz. Before I added 100-μF and 470-μF capacitors (25 V), the circulating current in the Mirage amplifier was too much for the 22-μF unit after 10 minutes of continuous video at 90-W PEP. Next, the power leads should be as short in length and as large in wire size as possible to ensure a good regulated supply. Anything over 3 feet (1 m) may be too long, so building a supply next to the amplifier is ideal.

Test Setup

The test setup consisted of a P. C. Electronics TC-1 Transmitter Converter with the sync stretcher built into the TXA5 exciter modulator, a DM-1 rf demodulator to sample the driving video waveform, a Bird Model 43 Thruline wattmeter with a 25-W, 400- to 1000-MHz slug and the amplifier under test. Also included were another DM-1 to sample the high-power video waveform and a Bird Termaline wattmeter with a 100-W, 400- to 1000-MHz slug and dummy load (Fig. 4). The sound subcarrier was shut off to display a clear video-only waveform on the dual-trace 30-MHz scope.

To set up any amplifier without a scope or a DM-1 demodulator, try this procedure:

1) Add the sync-stretcher parts to the TXA5 exciter, or the P. C. Electronics SS-1 sync-stretcher board to your transistor modulator.

2) Remove all video from the modulator input. The sync stretcher will put out sync if the video is still connected but turned down. Also, turn the 4.5-MHz subcarrier injection-level potentiometer to minimum.

3) Rotate the bias potentiometer, which controls the clamped PEP power output, to minimum (fully ccw).

4) Turn on the amplifier and the transmitter. Slowly rotate the bias control until just reaching the suggested PEP output for best ATV operation.

5) Now, the video can be reconnected and the video gain can be increased slowly for the best picture. Turn the sync-stretcher control cw for a good, stable picture. For most amplifiers this is fully cw or within 10 degrees of full rotation, and there is some interaction with the video-gain control. Turn the 4.5-MHz subcarrier-injection potentiometer back to the original position.

Linear, full-bandwidth, a-m video requires a little extra care and consideration. Whether you select a tube or a transistor amplifier to throw your pictures farther and clearer, I hope the results of these tests will help you achieve good, stable video.

My personal thanks to Mel Farrer, K6KBE, at KLM; Ken Holladay and Everett Gracey, WA6CBA, at Mirage; John Beanland, G3BVU/W1, at Spectrum International; and Fred Merry, W2GN, at ARCOS. The loan of their off-the-shelf amplifiers made this study possible.

Notes

[1]R. Knadle, Jr., "A Strip-Line Kilowatt Amplifier for 432 MHz," *QST*, April 1972, pp. 49-55 and May 1972, pp. 59-62.

[2]ARCOS, P.O. Box 546, 35 Highland Dr., East Greenbush, NY 12061.

References

Rusgrove, J. and G. Woodward, eds. *The Radio Amateur's Handbook* (59th edition). Newington: The American Radio Relay League, Inc., 1981.

A good continuing source of ATV information is *A5*, P.O. Box H, Lowden, IA 52255.