

AM and FM TRANSMITTER MAINTENANCE

GENERAL

Safety First. Wear your safety equipment when appropriate. Take off your rings and watch. Tuck in your shirt; loose clothing can cause problems. Keep one hand in your pocket. It really works; it saved my life more than once. You really can troubleshoot a transmitter without power being on the transmitter--working on a "hot" transmitter is dangerous. Radio is important; it pays your salary. But, it's not important enough to get hurt over. That means you drive to the site in a safe, sane manner. Haste makes waste isn't just a motto, it's a fact. Use the buddy system when you can. Fewer engineers are maintaining more transmitters. Work out a cooperative arrangement if you can. Sleepy makes danger nearer. Night is a bad time to repair a transmitter. When night work is inevitable, use extra caution. Let someone know where you are working. And, please, make sure any operators at the studio know you're at the transmitter site so they don't turn on something accidentally.

SAFETY FIRST

Nobody ever died
from a lack of
Rock 'n Roll...



CONTROL CIRCUIT

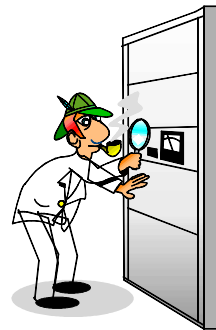


Transmitter RF sections are ever more reliable; most problem that will keep you off the air are control-circuit problems. The time to learn the control circuit is before you have a problem. Don't bypass overloads or other protection devices. Post a control-ladder for you station with all external interlocks shown. In my experience, the problems that keep you off the air are control circuit problems. If that ratio has any relation to reality, it makes much more sense to concentrate your familiarization of the transmitter to its control circuits. Memorize the control circuit if you can. Remember, there are really two stages to get a transmitter on the air. Close the interlocks. That turns on the bias in a tube-type transmitter and puts a solid-state transmitter in the ready mode. The second stage is actually getting the high-power circuits to operate. Once the first step has been completed, the second step is almost trivial.

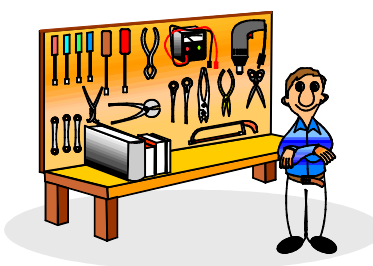


Visual inspections can resolve or localize over half of all control circuit and RF circuit problems. The first step in trouble shooting is a careful visual inspection. An inspection mirror is invaluable, keep one handy. Keep trouble lights and flashlights handy and ready. Most RF problems have some physical manifestations. If it failed, i.e., there are probably broken pieces lying around. Control circuits also should be inspected first since most problems start there. Don't forget built-in diagnostic help. For example, the 802D Digital Exciter has a full help section built in with answer to questions slightly more important than whether the power cord is plugged in.

VISUAL INSPECTION



PREPARE



Prepare for problems. Are your critical schematics enlarged and covered in plastic? When you're working on a transmitter, you don't want to tear a critical schematic. Learn the control circuit! Use control ladder diagrams. Put a copy of the control ladder diagram on the wall. Be sure to add any external connections to the control ladder drawing. Learn how the computer monitors the control line and the limitations of the computer's diagnostic ability. Understand the RF-flow path. Know the normal currents and signal levels throughout the transmitter. Keep tools specific to the transmitter on site. Keep a separate VOM at each site.

What not to do, i.e. what you don't do, is almost as important as what you do. Don't change the tube. One of my Rules of Radio is: "The problem is never the tube, and if you change the tube, you'll break something." It is also clear

that if you change the tube and don't solve the problem, you've introduced a new variable into the situation. Don't retune the transmitter. If the tuning has changed, you need to determine why. More than likely it's a load problem.

Don't replace components that aren't bad. Frustrated engineers sometimes replace items that are perfectly good and you may wonder why. They just want to try *something--anything*. One time in a thousand it works. Which means that nine hundred and ninety-nine times out a thousand, it doesn't. Not very good odds are they? Don't re-design the transmitter to avoid the problem. One engineer added a slave relay to his interlock system because the low current in the transmitter control circuit wasn't sufficient to keep his interlock contacts clean. The easy way would simply have been to increase the current in the interlock circuit, a change that would use one resistor. Instead, he wound up with another relay and a new control circuit.

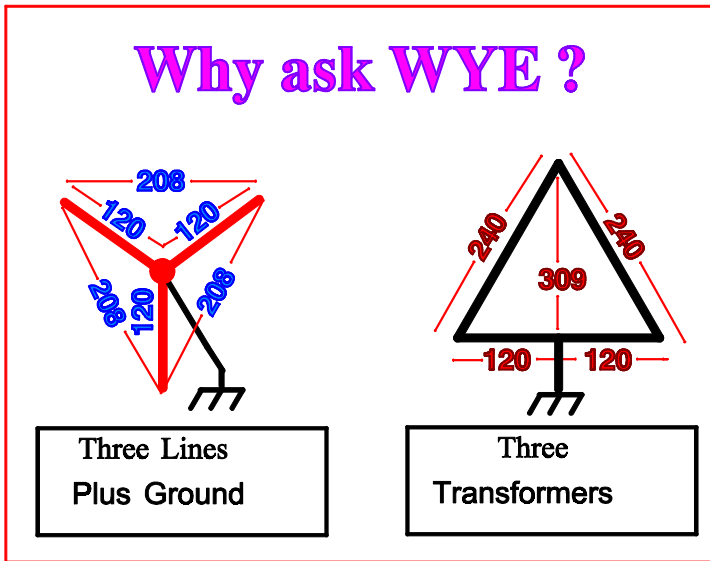
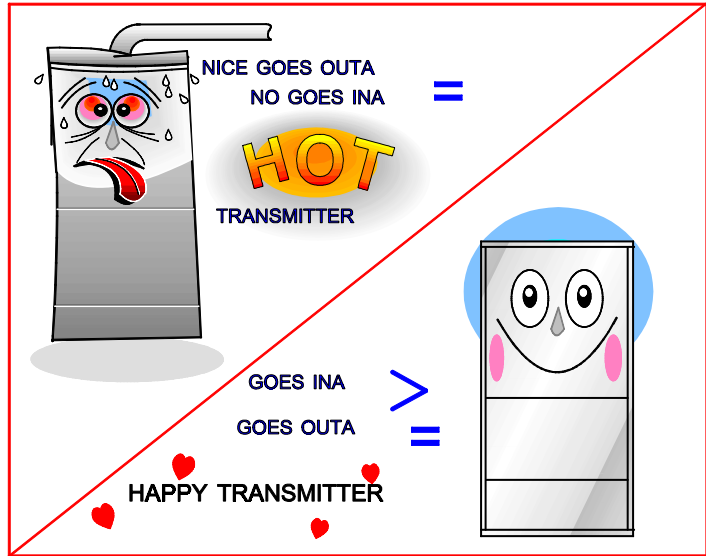
What to do when trouble strikes is straightforward: Make sure you have good primary power in advance. Make full inspections of the transmitter and load. Perform basic circuit checks. Formulate a clear description of the problem in with all the details. Compare your meter reading to the factory test data--you do have copies on the wall handy don't you. Call the Manufacturers field service Department for help if you get in over your head. When you talk to a service engineer, identify the transmitter model clearly: 18 kW FM isn't a type number that the engineer will immediately identify with. I spent a good fifteen minutes one night trying to communicate with an engineer who accidentally gave me the model number of an AM transmitter. He really had an FM transmitter and he thought I had lost my mind when my questions didn't make sense. Brace yourself for the possibility that the engineer on call may already be on a telephone call with another customer. No one wants to wait when he has a problem. But sometimes it's inevitable. Don't get mad. Just get better prepared.

WHAT NOT TO DO.

The high voltage wouldn't come on, so I changed the PA tube.



A clean, cool transmitter will work better and last longer than a hot, dirty transmitter. Inlet air volume must meet the exhaust volume requirements. Positive pressure is a positive idea. Avoid directly attaching the transmitter to an exhaust system. If something happens to obstruct the exhaust line or the building air inlet, the transmitter can be starved for airflow even though the air pressure is normal. A good alternative is to put a duct for the air exhaust one-foot above the transmitter. If the transmitter room is adequately supplied with air, the hot exhaust air will be ducted out of the room. If something blocks airflow, the transmitter can still maintain airflow over the tube anode or the transistor heat sinks. Watch for obvious indications of air starvation. The notion of positive pressure is simply that you try to push more air into a transmitter room than the transmitter can exhaust. This tends to push dirt and dust out of the transmitter building as it settles on the floor.



There are two acceptable types of primary power available for three-phase equipment: Closed-Delta and Wye connections. Both types offer good balance. But our anecdotal evidence is that customers who have a Wye service suffer less power-line-related outages than those with a Delta connection. Why? Probably because the Wye connection is more symmetrical with respect to ground. You won't always have a choice. But if you do, ask for a Wye. A Wye will cost more money because its line-to-line voltage is lower and line currents will be higher. The return on investment seems to be high enough to justify the expense.

Closed-Delta and Wye connections require that the power company run three HT lines and use three transformers. Sometimes, a power company will install an Open-Delta service. This requires only two HT lines and two transformers. But the reduction in cost for the power company means much more trouble for your transmitter. The open-delta connection has leg-to-leg voltages and phase relationships that can vary as the load on the line changes. And the open-delta means there's no return for harmonic currents on the line. (That's why you always see a power transformer connected to a commutating supply--like a DC power supply--have its primary or secondary configured in a delta: a return path for harmonic currents.)



Lightening is just a fact. It hits towers. It hits power lines. It hits everything eventually. But most of the damage a station--AM or FM--will suffer is because of power-line transients. One thing that must be done is to have some way to conduct the current of the return strike to ground. A lightening strike is, in reality, a multiple-event occurrence. One the arc is established, there are, on average, four or five return strokes over a period of a quarter-second. The current in the return strokes can vary over several orders of magnitude. Whatever the current, you do not want it flowing through your electronic equipment. That means the tower, whether AM or FM, must be well grounded. The power line almost certainly is not well grounded and you need transient suppressors on the incoming power line. The transient suppressors must be connected to a solid earth connection if they are to work. Since we must try to control voltage spikes--and we know the voltage spike is in the 100 kHz-1 MHz frequency range, a low impedance ground means much more than a piece of copper wire. The frame of the transmitter, The frame of the equipment rack, the frame of the transient suppressor

enclosure, the frame of the incoming power box--all these points must be connected to earth with a low-impedance (read low inductance) ground.

Check those interlocks: air, safety, and protection. Set up a schedule. Almost every engineer who works with transmitters has experienced some type of problems with air interlocks. They protect the transmitter from serious damage so they're very important. Vane-type air interlocks are the most desirable in the sense that they measure airflow. Pressure interlocks are the most desirable because they don't flutter and bounce the way vane air switches can. In fact, it's very difficult to get a vane-type air switch to have enough sensitivity to stay closed during normal airflow and yet open when the airflow is at its lower limit. If the exhaust and inlet of a transmitter are unrestricted, the diaphragm-type pressure switch is preferable. But dust and dirt can accumulate around the edge of the diaphragm and cause changes in the pressure sensitivity. Follow your manufacturer's recommendations concerning adjustment. Check all air switches regularly. Some transmitters rely on thermal sensors to determine if sufficient cooling is present.

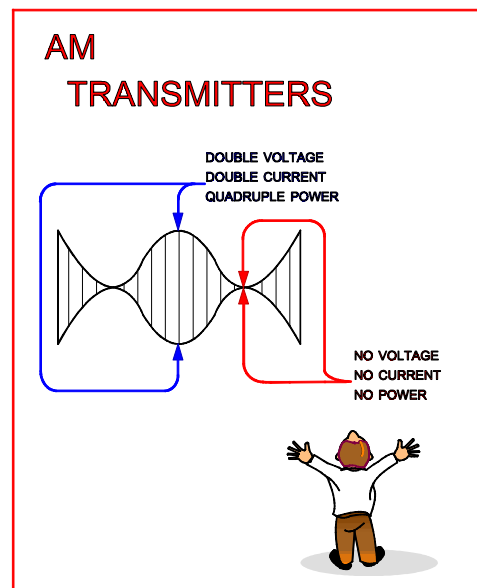
RF stages are usually quite simple. Transistors fail shorted. Tubes don't fail catastrophically. Under-drive kills transistors and tubes. The first question I ask, when dealing with an RF problem in a tube-type transmitter, is: "What is the PA Grid Current?" Working with solid-state transmitters, the first question will be: "What is the gate-drive voltage?" All transmitters require adequate grid current or gate drive voltage to function correctly. Otherwise RF components may fail and efficiency will be poor. It cannot be said enough: unless the drive is right, all bets are off. You can over-current a transistor many times but you over-voltage it but once. When an over-voltage situation occurs, the transistor or diode will fail and that will normally result in the loss of a protection fuse. Replacing a blown fuse on a solid-state module, by itself, won't fix the problem in a solid-state transmitter. Until you fix the underlying problem, you'll continue to blow fuses. I shouldn't have to say this but I will: If it says not to remove the module under power, don't! One engineer blew up the combiner stage of his new transmitter by pulling an RF Module under power. When I asked him why he pulled the module he said that he wanted to see what would happen. He did, in a most dramatic way!

Tube transmitters are still important. Not all tube-type transmitters have been replaced--nor will they be in our life times. Many stations who have bought solid-state-type transmitters still use tube-type transmitters for backup. Tubes can survive over-current AND over-voltage whereas you can over-voltage a transistor but once. For those stations with tube-type transmitters, filament voltage maintenance is a money saver. The smaller the tube the more important the requirement for filament-voltage maintenance since a smaller portion of the tube's filament structure has been carburized. Filament-voltage maintenance isn't time consuming considering the rewards. Rebuilding is also a good idea. Recarburizing the filament gives you new-tube performance with the same elemental structure intact. Rebuilding is also economical. Very high-power transmitting tubes have used circuits that reduce the filament voltage during standby periods. This is often called black heat. Reducing the filament voltage on a thoriated-tungsten tube to 80% of operating voltage during standby periods can significant increase tube life. If you are running a transmitter in hot standby mode, incorporating a simple black-heat circuit might prove cost effective. If you lower the filament voltage below 75% of operating voltage, you might as well turn it off completely. Phase transitions in the filament structure that reduce tube life occur as you drop below 75% of the operating voltage.

A tetrode tube without a screen power supply is a very low-gain triode. Screen voltage sets the gain of the tube and is a critical element. One of the first checks on transmitters using tetrode tubes is the value of screen voltage. Screen Voltage controls plate current much more than plate voltage does. Screen Current is the most sensitive indicator of tuning and loading when the drive and Screen Voltage are held constant. Some transmitter use "soft" power supplies for the screen. Screen voltage varies as the screen current tries to change. On those transmitters, tuning and loading is best accomplished by tuning with the output meter.

AM TRANSMITTERS

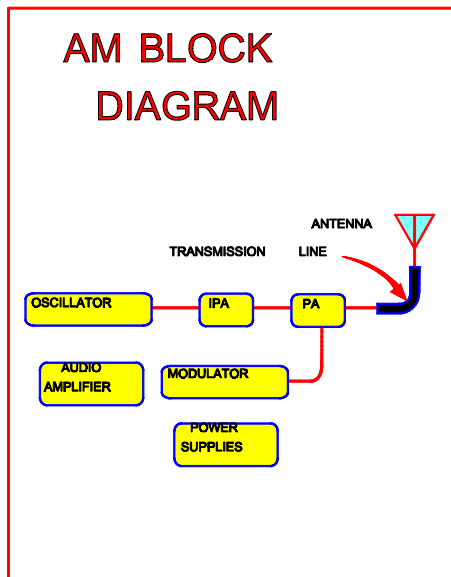
Modulation means that elemental voltages can double and that power output can quintuple. 125% positive modulation means peak voltages are 2.25 times carrier level. 100% negative modulation means the carrier is cut off, completely. 95% negative modulation means the carrier voltage is 1/20th carrier value (only 5% remains) and that the output power is 1/400th the carrier value. The meaning of 100% negative modulation seems to escape some engineers. There's no such thing as 110% negative modulation; there is nothing less than nothing! The relationship between voltage and power also has profound impacts on transmitters operating at reduced power. All transmitters--all transmitters--have changes in their performance as the operating power is reduced. When a 5 kW transmitter is operating at 1 kW, you are asking a modulator capable of delivering 30 kW of peak power to modulate linearly down to 2.5 Watts at 95% negative modulation.



Reduced antenna bandwidth (most often seen in older directional systems) makes VSWR protection more difficult. Reflectometer sensitivity must be reduced to prevent false trips in normal operation. One of our engineers found a simple, elegant way to overcome this problem. His solution is, of course, proprietary and most transmitters don't have it. But there are still some things you can do to help protect your transmitter. AM Transmitters are tied to a lightning rod--or system of lightning rods. They are guaranteed to get hit eventually. Take steps to keep lightning damage out of the transmitter output network. One easy way is to make sure there's a series capacitor in the ATU. Much of the lightning

energy (not voltage, energy) is at about 5 kHz. A simple series capacitor makes sure that this damaging energy stays out of the transmitter. Ask your consultant to install a capacitor if it's not already in your ATU. And be sure to include a static drain coil (or other DC path) on both sides of the capacitor. Low power towers and low-power transmitters require special treatment.

Most damage does not come from tower strikes. If the transmitter output network and ATU networks are given basic protection, most of the damage experienced will come from proximity strikes. As noted in the General Section of this paper, protection from proximity strikes requires the use of transient suppression coupled with solid grounding of the equipment to be protected.



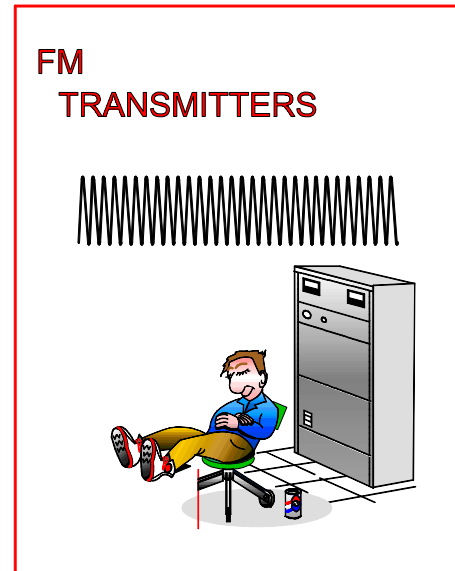
Most modern AM transmitters use modulators that are just switching regulators. These switching modulators use filters that behave quite differently when incorrectly loaded. Lack of drive results in low plate current that changes the termination impedance. An antenna impedance change is reflected as a termination impedance change. Anything that changes the termination impedance causes the performance of the filter to change. That means that the transmitter, whether tube-type or solid-state should be tuned for the right relationship between voltage and current to the final stage. Once tuned, a MW transmitter should not require any retuning. Many solid-state transmitters have no front-panel accessible tuning controls. They work on the set-it and forget-it principle. If more tube-type transmitter were operated on this principle, there would be an increase in reliability.

Few antenna systems operate at their nominal impedance. I have seldom--if ever--seen a 50-Ohm system measure 50 Ohms at the transmitter end of the connecting coax. Because the real world involves impedances different than the dummy load at the factory, there are facilities in every transmitter to tune and load the transmitter to the desired voltage and current ratio. These should be adjusted only when the system load impedance is changed on a permanent basis. If you retune a transmitter to a bad load, you've only put a patch on a problem; you haven't fixed the problem.

C. FM TRANSMITTERS

FM Transmitters are simple devices. And they give very little notice of impending failure because they can produce an acceptable signal even when seriously mistuned. Limiters in the receiver minimize the effects of amplitude variations. Receivers generally switch to mono when the signal-to-noise ratio drops. Fringe area listeners usually don't complain.

They are frequently quite different when cold than when up to operating temperature because of the physical changes in the grid circuit or input matching circuits of the PA. Quarter-inch changes may shift the frequency of the grid circuit 1.5 MHz so even small changes in dimensions cause input match shifts. Grid swamping is used to limit the input impedance shift and to broaden the response of the grid circuit. Less than half the drive applied to the PA actually gets to the grid circuit. In a heavily swamped amplifier, half the drive power may end up in the swamping resistor. The benefit of heavy swamping is wider grid bandwidth; that means better stereo performance.



**FM TRANSMITTER
OUTPUT NETWORKS
ARE MORE
MECHANICAL
THAN AM
TRANSMITTERS.**



PA components are more mechanical than discrete; physical inspections must be done with care; if you move it, you retuned it. Components often are transmission-line equivalents of lumped constants. Circulating currents are often high and require tight fittings. RF seals must be tight to prevent RF leakage. Typically, tube-type FM transmitters use $1/4\lambda$ output networks with blocking capacitors or $1/2\lambda$ output networks without blocking capacitors at the expense of higher RF voltages. Most solid-state transmitters use some form of the Wilkinson combiner which employs $1/4\lambda$ sections of transmission line in the combining circuit. This is not a lossless device and can account for several percent in overall efficiency reduction. Solid-state FM transmitters (and solid-state AM transmitters) require a large number of discrete devices and combiners because of the problems associated with lower efficiency (because of frequency) and the difficulty in removing power from the transistor junction.

All FM transmitters require adequate drive to the RF amplifiers to operate properly. Without proper drive, the amplifier is no longer saturated and may behave in peculiar ways. Efficiency and performance drops. On tube-type transmitter other meters (Screen, Plate, Output) show the impact of reduced grid current more than the grid-current meter itself. Solid-state transmitters show the impact of reduced drive as dramatically lowered efficiency and increased rated of device failure. New transmitters often monitor the temperature of the heat sinks of the individual RF Amplifier modules.

A block diagram reinforces the notion that the FM transmitter is simply an AC-AC converter. It converts 50 or 60 Hz AC to DC and then converts that DC to 100 MHz AC. It is a very simple system. But FM transmitters are usually located in much more difficult-to-access sites and operate over widely varying conditions. Proper protection means that power line conditioning becomes much more important. When coverage is important and the remote site is far away, consider a backup transmitter and antenna near town. Some remote sites are not always accessible, especially in winter.

FM transmitters are often blamed for harmonic or intermodulation problems without basis. The next problem comes when spectrum analyzers are used to solve harmonic problems. FM transmitters have harmonic outputs that are attenuated at least 80 dB; that one ten-thousandth the voltage and one one-hundred-millionth the power of the fundamental.

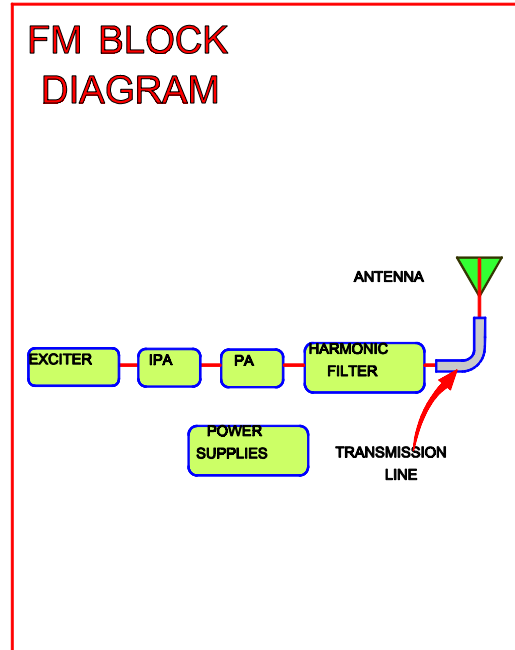
They are coupled to transmission lines that attenuate the harmonic components quite severely. These RF feed lines are connected to antennas that do not radiate harmonics very effectively. Special circumstances may require that harmonics be attenuated more than normal. One of the worst combinations is an engineer armed with spectrum analyzer and a harmonic complaint but lacks knowledge of the severe and significant limitations of the instruments he will use. Most harmonic problems don't involve the transmitter; overload in receivers is the most common cause of complaints.

First, spectrum analyzers have a limited dynamic range, typically much less than the 100 dB--or so--of dynamic range that most people want to check. Harmonic measurements should not be made without a fundamental reject filter or the numbers will almost surely be in error. The pick-up characteristics of the sample are often overlooked. Most uncompensated probes have a 6 dB/Octave rising response characteristic. When harmonic measurements are made on a transmitter feeding an antenna system, the measurements are almost surely inaccurate because the antenna is not properly terminating the harmonic. If measurements are made in the far field, the characteristics of the receiving antenna must be known or the measurements cannot withstand scrutiny. Again, as a rule, a harmonic problem isn't a transmitter problem.

There are, of course, some situations where individual attention is necessary for resolution. In some cases, the station engineer will have to install additional harmonic suppression devices to satisfy the regulatory agencies. Even then, the engineer may be forced to install fundamental traps at the site claiming interference just to deal with the complaint. The best rule about these situations is simply to go beyond what is reasonable and to keep your sense of humor.

VHF frequencies make exact power determination difficult and this can often cause concerns about efficiency. A look at power-measurement devices show that calibrated calorimeters only have an accuracy of $\sqrt{3}$ %. Power meters usually are accurate to 5% of full scale, not 5% of reading. The accurate determination of how much power is actually getting to the coax is a difficult challenge. Efficiency curves are beneficial when there's a question of metering accuracy.

The importance of record keeping cannot be overstated when dealing with FM transmitters. Performance questions can often be resolved by simply referring to the record of past performance. Take, for instance, the question of Reflected Power drift. I, like most engineers, test the VSWR sensor's operation



periodically by simply rotating the directional coupler slug in its holder. If the circuit doesn't work and the slug is not immediately returned to the Reflected Power direction, the coupler slug will almost surely be damaged. This damage will manifest itself as a drift in Reflected Power over time. This is identified by the lack of a corresponding change in the Screen Current or Anode Current of the PA stage.

The key to successful maintenance of the FM transmitter requires that it be provided with protected power, that it be thoroughly grounded (earthed), that accurate records be kept, and that the transmitter be properly cooled. Tube-type transmitters can benefit from filament-voltage management. The best suggestion might also be the oldest: Never fix a working transmitter. The problem is never the tube. Knowing the control circuit is the secret to quick repairs.

And remember: Safety First. Nobody every died from a lack of rock and roll.