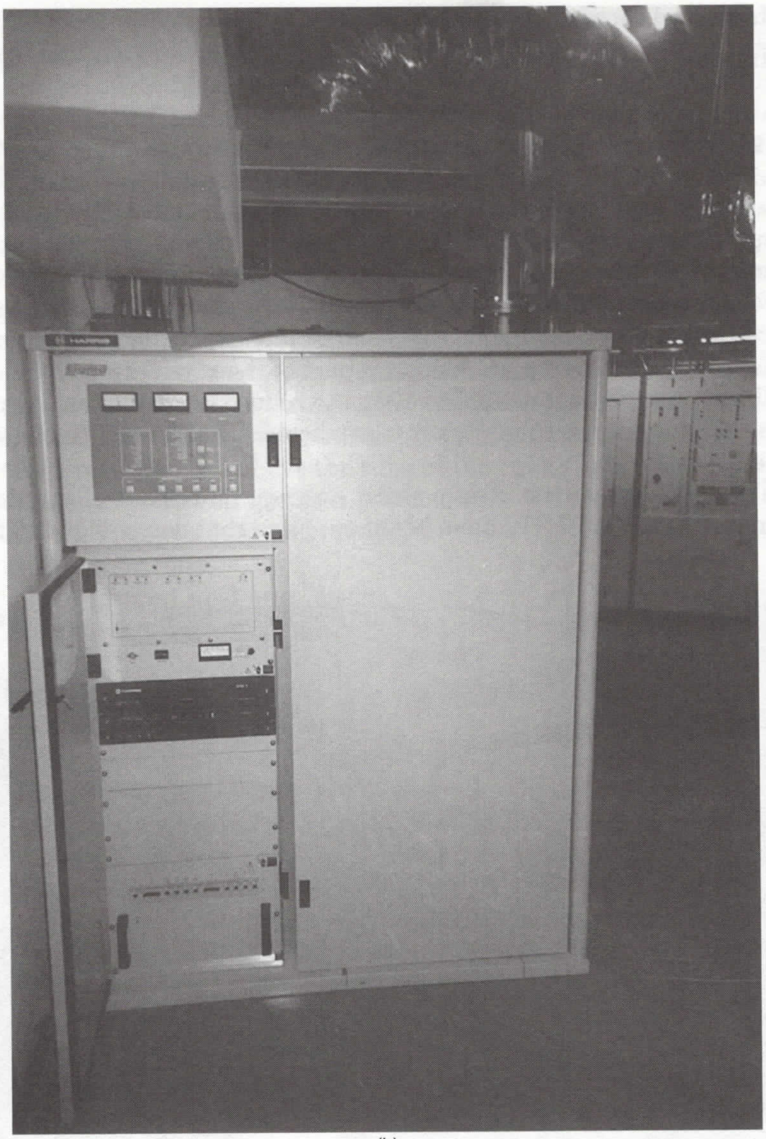


(b)

Figure 13.15 (*Continued*)

larger IOTs need approximately 35 kV of high voltage. This requires a separate oil-filled power supply. Most purchasers of transmitters that use IOTs are opting for power levels at the high end. IOT has gain of around 22 to 24 dB. Although absolutely not recommended, the output of the IOT can be pushed past its rated limit, but the S/N ratio will suffer.

A common IOT transmitter can be configured for 10- to 90-kW average power. The transmitter would achieve this power range using one to four amplifier

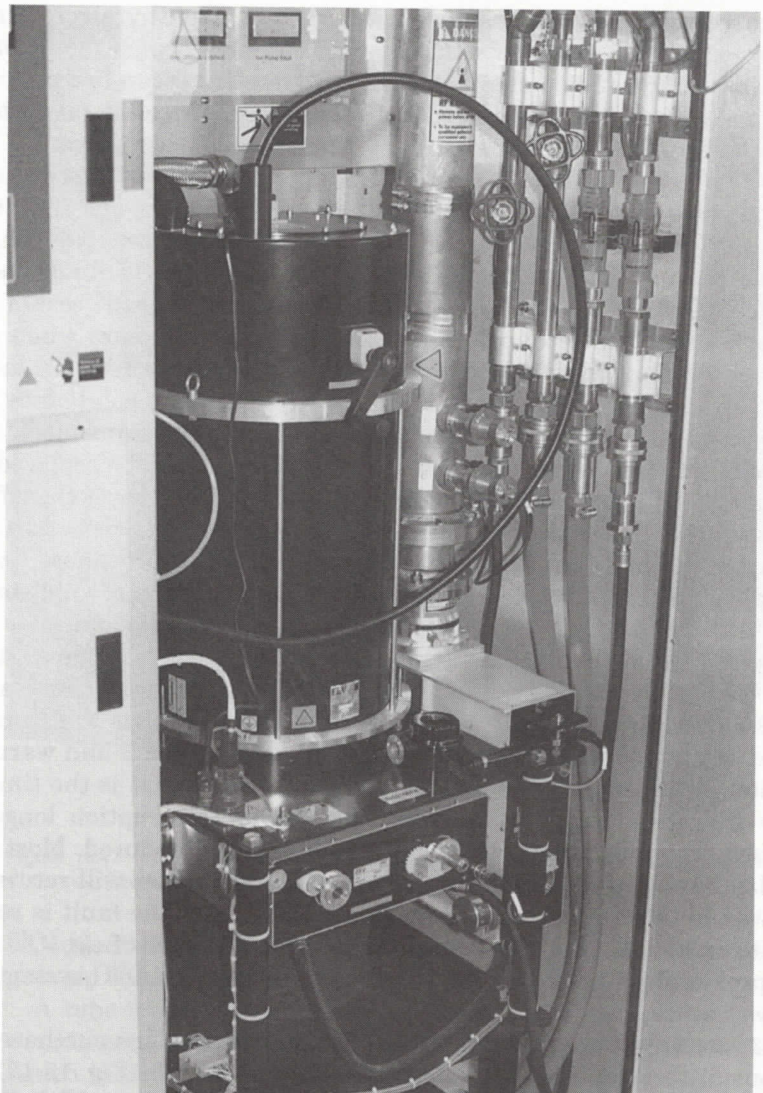


Figure 13.16 IOT installed in transmitter.

cabinets. The outputs of the cabinets are combined with a magic tee, so that they can be switched in and out hot. Most designs have no high voltage in the front of the PA cabinets; it is all at the back.

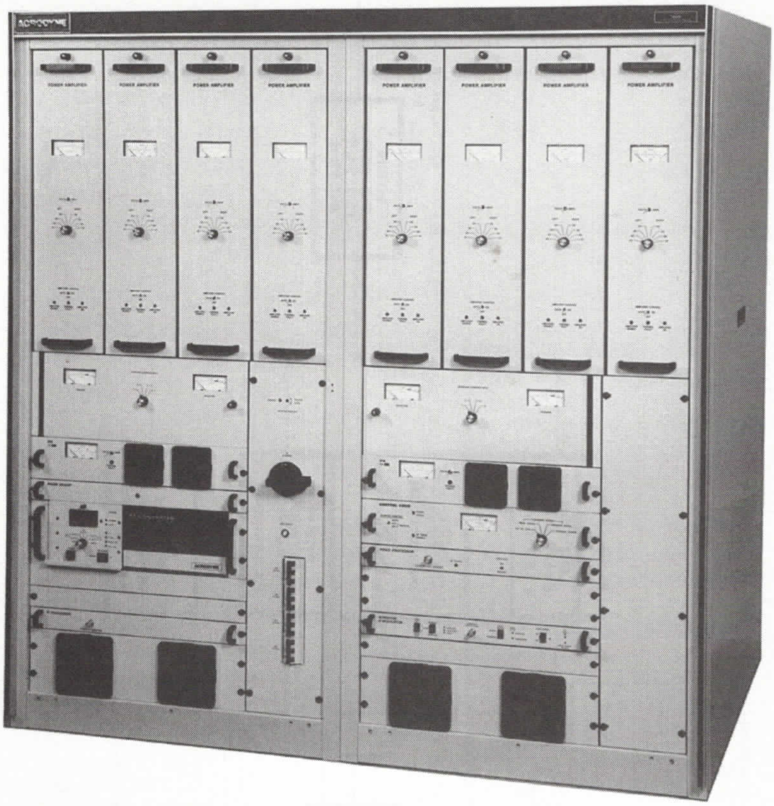
IOTs need high-speed thyratrons, which act as a "crowbar" to protect the IOT grid when high voltage is removed. In addition, young IOT tubes tend to cause thyratron arcing more than older IOTs. The thyratron must crowbar approximately 4 J of energy in about 1 ms. This is done by sensing a rapid raise in beam current. If the thyratron filament is set incorrectly or if the tube is gaseous, it will fire or crowbar on its own. The thyratron is not normally needed on start-up because the control circuitry brings the beam current up slowly using a simple step-start circuit. Thyratrons can fire tens of thousands of times. They are used in radar systems. A thyratron is faster to fire than a spark gap. They should be replaced when the IOT is replaced.

IOTs have mean time between failures (MTBFs) of more than 10,000 h. Solid state has MTBFs of 300,000 h. Some claim average IOT life is greater than 25,000 h. Although most tubes are prorated for 10,000 h, tubes have remained in NTSC service for over 50,000 h. Some IOT finals operate class A for NTSC and class AB for DTV. A general rule is that the cost of ownership is less for solid state than IOT transmitters over 10 years when dealing with power levels under 10 kW. The opposite is generally true when the power level exceeds 15 kW. Redundancy is inherently built into solid-state transmitters because one or more power modules can fail and the transmitter will continue to operate but at a reduced power level. Modules can be replaced hot. Redundancy in IOTs requires additional cabinets, which decreases the efficiency of the entire system because the standby IOT consumes some power. In addition, full filament heat counts against warranty hours, while black heat operation (reduced filament voltage) does not. The rms efficiency of solid state is 18 to 20 percent and 25 to 30 percent for IOTs. Ongoing maintenance for solid state is one-tenth that required for IOTs. However, system cost per watt at 10 kW of average power is approximately 40 percent higher for solid state.

Another big advantage to a solid-state transmitter is that it can go from a cold start to transmit in less than 3 s. The IOT has a 5-min warm-up, but the system warm-up time is actually 10 min because that is the time it takes for the thyratron to warm up. Also, if a power interruption longer than 20 s occurs, the full 10-min warm-up period must be endured. Most transmitters today have power-fail memory, where the transmitter will return to the state it was in (after any required warm-up time) after the fault is removed. Solid state is usually the choice for VHF. Since the gain of an IOT decreases by approximately 1 dB as it warms up over 20 min, an AGC system is required.

13.2.2.6 Solid state. When new VHF transmitters are purchased, solid-state transmitters have been steadily replacing the tetrode (Fig. 13.17). The same is true for low-power UHF. Bipolar and metal oxide silicon FET (MOSFET) are the two basic technologies used, but the use of silicon carbide transistors is currently under development. The actual power line ac to rf efficiency of a solid-state transmitter may not be any greater than a tube transmitter. A considerable amount of rf efficiency is lost in the output combining process from the individual solid-state modules (Fig. 13.18).

A power loss of 0.25 dB is typical of each level of power combining. It is not uncommon to find nine such levels in a solid-state transmitter. This would amount to 2.25 dB or 40 percent wasted power. A typical solid-state rf module is capable of 250 to 300 W of average power. A single cabinet may contain from four to eight such modules. If more power is needed, additional cabinets must



(a)

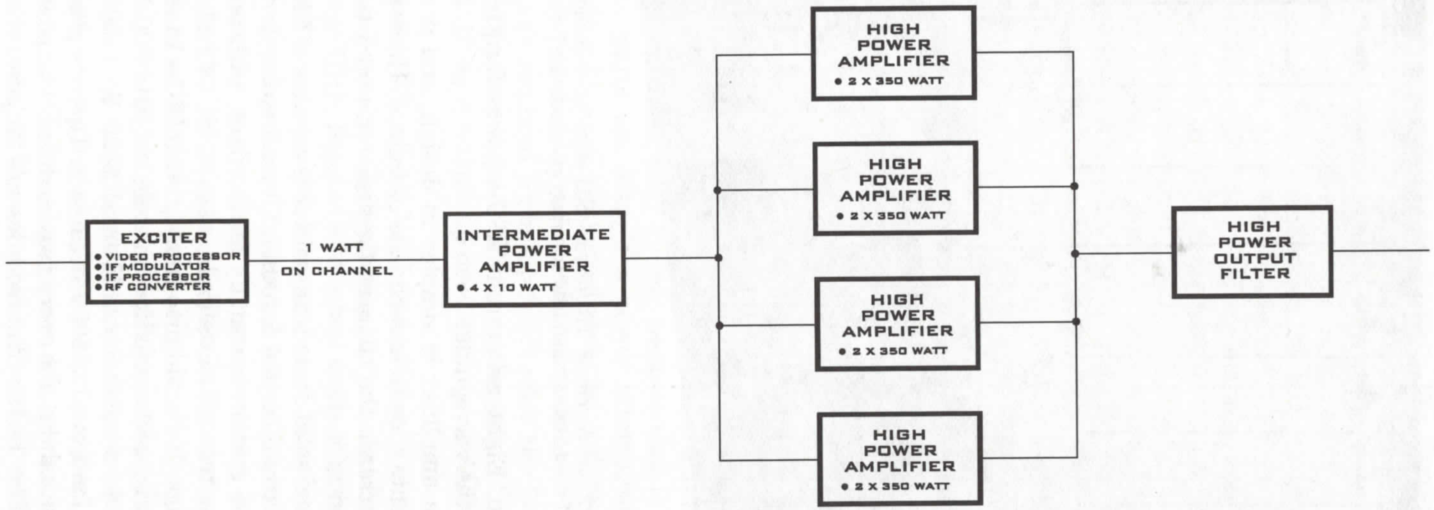
Figure 13.17 (*a*) Acrodyne TRU/5-km solid-state transmitter. (*b*) Basic block diagram of solid-state transmitter (*courtesy of Acrodyne*).

be added. Eighteen percent of the power feed into a solid-state transmitter goes up the waveguide.

A tube amplifier is simpler in design, and it requires fewer parts. Fewer components means less chance of failure. However, tubes use high voltages, which increase the chances for disaster, and a tube slowly consumes its filament and cathode.

A typical solid-state transmitter is capable of 5 kW per PA cabinet. Up to five cabinets could be tied together. Overall power levels of 1.25 to 30 kW are possible. The system is usually fairly silent, with an acoustic noise level of −65 dBA. The transmitter should meet ANSI C62.41 transient voltage tests with no damage. It should also comply with IEC-215 safety standards.

Typically, each amplifier module outputs 400 W. Although that means 16 modules in a cabinet would total 6400 W, 1400 W is lost in the combining process, for a total of 5000 W/cabinet. There is generally a separate power supply in the cabinet for every two modules. The power factor for the transmitter is 0.99 (Fig. 13.19). The modules are 25 percent efficient, although the whole



(b)

Figure 13.17 *(Continued)*

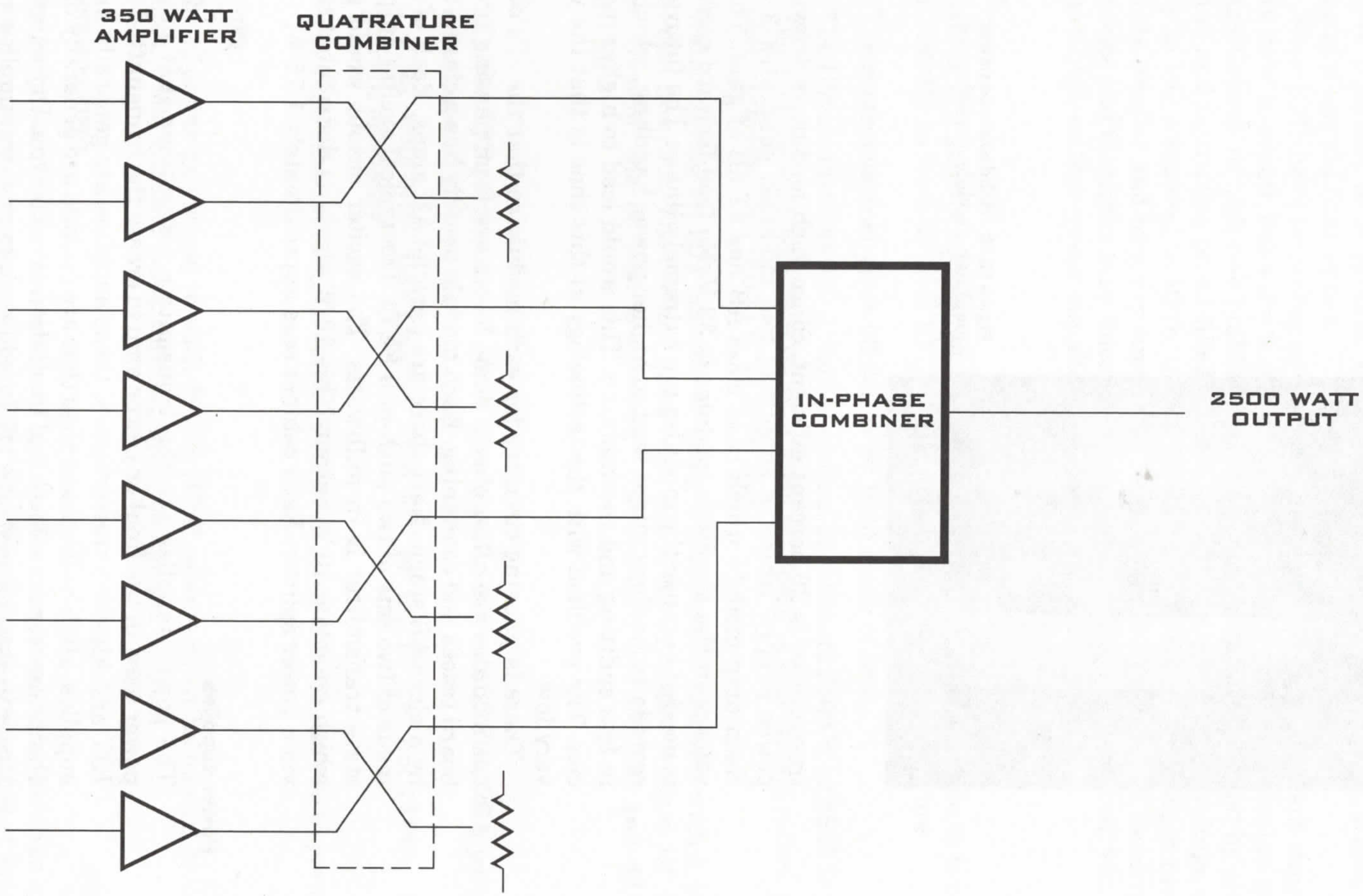


Figure 13.18 rf combining process, solid-state transmitter (*courtesy of Acrodyne*).

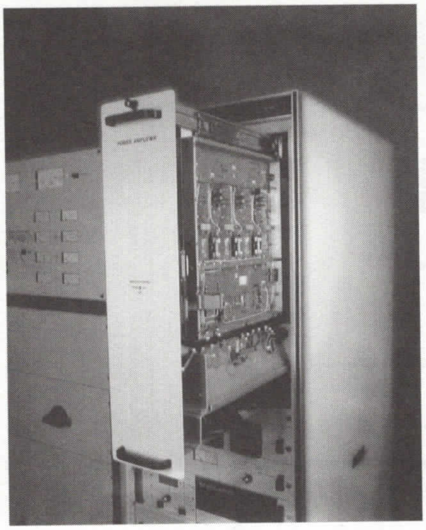


Figure 13.19 Solid-state or power amplifier module (*courtesy of Acrodyne*).

transmitter is 20 percent efficient. Since each module is drawing 50 A, each power supply, which is supplying two modules, generates 3 kW of power. Each amp module which runs class AB has 41 dB of gain. The highest rail voltage in the amplifier modules is 32 V. No feed-forward correction system is needed because the modules are extremely linear. The future use of silicon carbide technology might lead to higher power handling, which would result in less splitting and recombining. This would lead to higher module efficiencies. The problem with the technology at this time is that the yields are still very low.

There is phasing circuitry for each module so that the rf's out of the various modules are all in phase. Some losses are from phasing problems due to board traces and combining. Each module usually has a class A stage followed by a class AB stage. Next there are parallel AB amps. Each of these amps is made of two sets of two push-pull FETs. The typical exciter output for a solid-state transmitter is in milliwatts. The exciter output would go to a driver which creates a 10-W output. This 10-W signal is distributed to each cabinet via a power splitter. Each cabinet sees approximately 1.75 W.

13.2.3 Power supplies

The power supplies are the transmitter subsystems that provide the high power used in the final or power amp to create the transmitted rf power. With IOT and klystron transmitters, these supplies are generally known as beam supplies. High-voltage supplies that are outside are generally oil filled, which eliminates corona effects and insulation breakdowns. Dry supplies need to be larger to stand everything off. In addition, to cool dry supplies air has to move through them. Beam supplies have to float since they have to supply negative beam current. Plate supplies can be tied to the ground because the negative potential is at ground. Usually, for safety all control and status are brought out via fiber optics.

Some IOTs have switching power supplies. These active component supplies are hard to repair, but a dry supply is fairly light. They are used because some installations in high-rise buildings have weight limitations (limited by elevators) and restriction on oil-filled devices. Since the diacrode high-voltage supply is low compared to IOTs, the diacrode high-voltage power supply can be made smaller and be a dry supply. As long as you don't run out of headroom, triodes and diacrodes stay linear as plate voltage changes. Therefore, you can have high-voltage power supplies that do not regulate.

13.2.4 Cooling

Cooling is a greater concern at higher altitudes. High voltage tends to behave differently as well. Typical IOT transmitter cooling requirements are

The control cabinet gives off 300 W or 1020 Btu/h of heat.

The IPA cabinet has 320 ft^3/min of airflow. It exhausts 2500 W or 8530 Btu/h.

The IOT cabinet has 72 ft^3/min of airflow. There is ≈15° temperature rise over ambient. This is 650 W or 2220 Btu/h.

Water cooling an IOT consists of using a 50/50 glycol mixture with a 13.8-gal/min flowrate. The coolant flows back out of the amplifier cabinet 12° hotter. Overall, the ac load is between 13.6 and 14.3 kW (36,640 and 48,840 Btu/h).

13.2.5 Efficiency

Typical IOT performance. 66 kW ac in, 17.5 kW out (TPO), 26.5 percent efficiency

Typical solid-state performance. 76.6 kW ac in, 15 kW out (TPO), 19.6 percent efficiency

It is more efficient to run a single HPA at full speed than to run two in parallel.

13.3 rf Plumbing

The rf power generated in each PA (or HPA) cabinet must be totaled or combined. Final channel mask filtering must be applied as well.

13.3.1 Combiners and filters

The path that rf takes through the rf system after the transmitter involves some losses that are a function of frequency. The loss through the output rf system for channel 14 = 3 kW, for channel 36 = 3.3 kW, and for channel 52 = 4.3 kW.

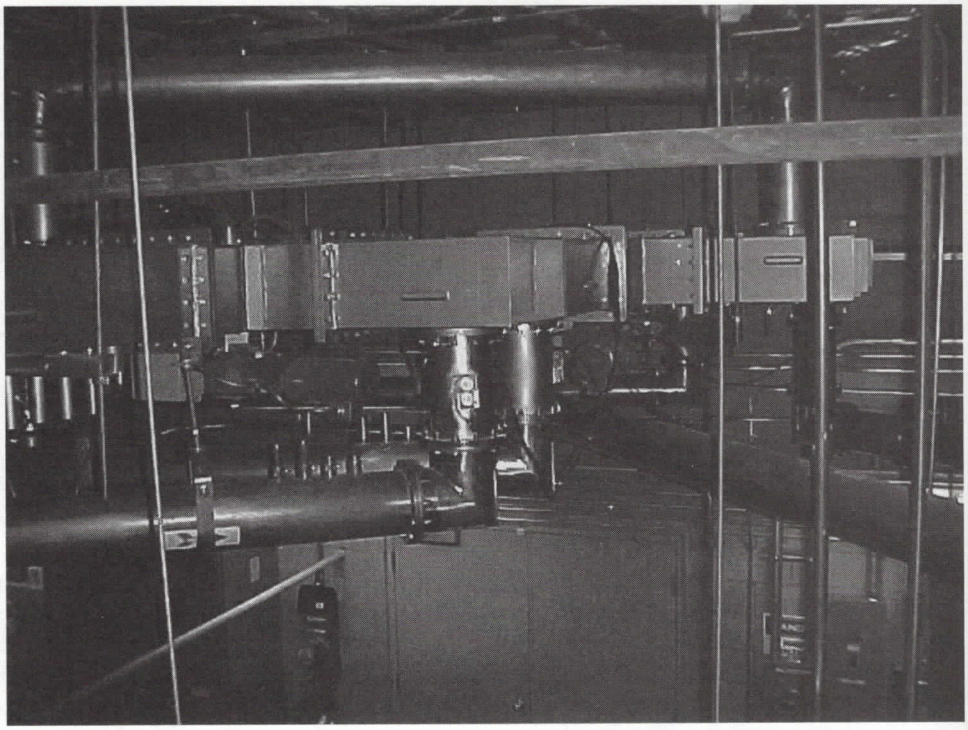


Figure 13.20 RF plumbing combining two visual, one aural, and one standby cabinets in a high-power UHF transmitter.

The first thing the rf system must do is combine the rf power from the various HPAs. This can be done with either a coax switch, which selects an HPA for use, or with a combiner known as a magic tee. With a magic tee you can switch HPAs hot; you can't do that with a coax switch. However, coax switches have less loss than a magic tee does (Fig. 13.20).

In the case of DTV the rf power must also go through an extremely sharp channel mask. Any energy just outside your channel must be −47 dB down from in-band power. At the far side of adjacent channels, though, the power must be −110 dB down. Filters will drift as the temperature changes (Figs. 13.21, 13.22, and 13.23). In addition to the channel mask filter, the rf system consists of reject and dummy loads. Some systems use the same coolant that flows through the tube to also flow through any system loads. Some systems use resistorless loads in the rf plumbing. Water is used to actually absorb the rf. Early examples of this approach had varying impedance values. Modern cooling systems use a glycol mixture which has a rust inhibitor in it so that brass or bronze pumps can be used instead of only stainless steel pumps. There is a separate pump cabinet in most transmitter systems. The pump cabinet produces a large percentage of overall transmitter system noise.

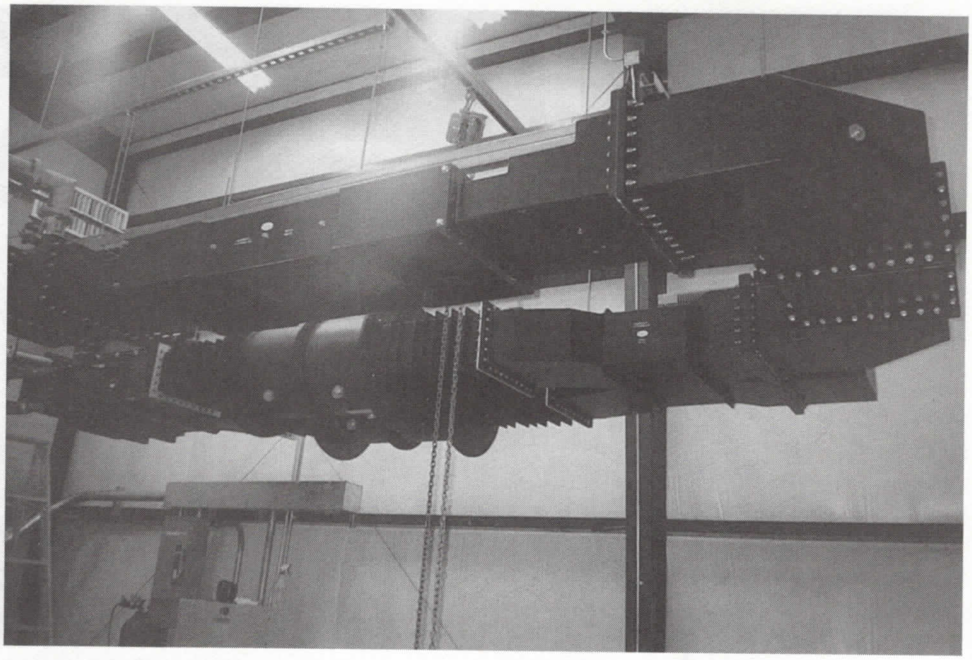


Figure 13.21 DTV channel mask.

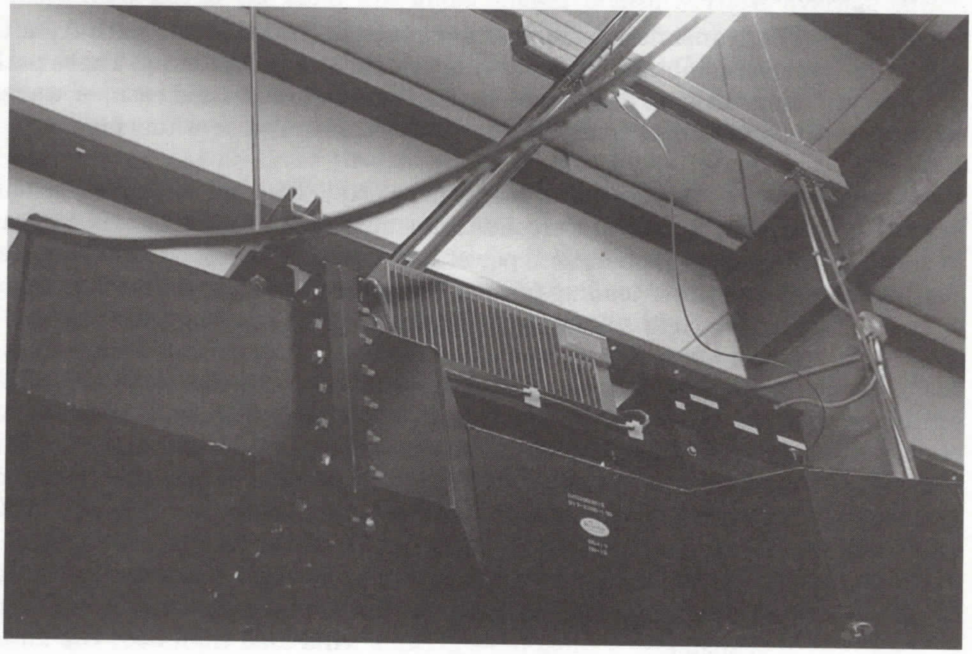


Figure 13.22 Air-cooled reject load (on top of waveguide).

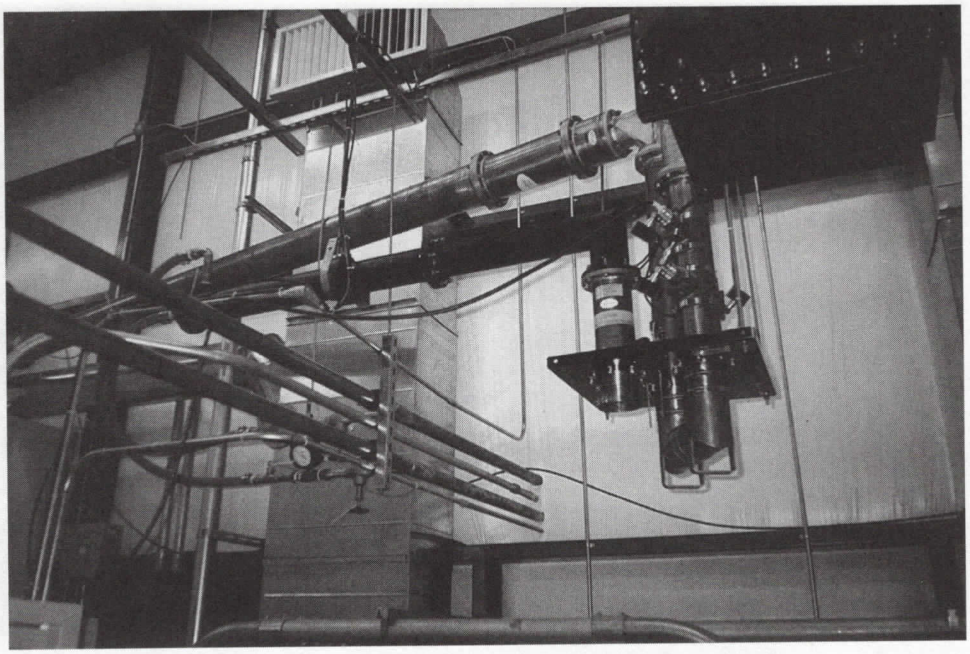


Figure 13.23 Water-cooled dummy load (at center, to left of coax patch).

13.3.2 Transmission lines and waveguides

The transmission lines and waveguides provide the path from the output of the rf combining and filtering system and the antenna. These paths use either transmission line, which is often referred to as rigid coax, or waveguide, which has no center conductor and often appears to be water pipe.

13.3.2.1 Transmission lines (rigid coax). Transmission line efficiency is usually around 70 to 80 percent. Transmission line selection is typically based on frequency of operation, power handling, attenuation or efficiency, characteristic *Z,* and tower loading (size and weight) (Fig. 13.24). Common transmission line size for rigid coax is $3^1/_8$, $6^1/_8$, and $8^3/_{16}$ in. Larger rigid coax can handle more power but it has a lower cutoff frequency. Coax cutoff frequency is based on the dielectric constant or relative permittivity of dielectric to air and the diameters of the inner and outer conductors. For rigid coax lines the dielectric losses are considered negligible. Dielectric spacers or pegs are placed at intervals along the length of the coax. With age, oxidation will increase the conductor losses. Conductivity varies with temperature, with tests done at 20°C. The inner conductor runs hotter than the outer conductor, often by as much as 100°C.

Group delay is now a concern in some lines. However, group delay is not an important factor in coaxial lines that are homogenous throughout their length.

Transmission lines have greater wind load than does the antenna. A given transmission line's power-handling capability can be increased by using a

Figure 13.24 Disassembled rigid coax. Smaller-diameter copper is center conductor with dielectric spacers installed.

more inert gas or the same gas under higher pressure. Here, average power, and not peak power, is the major concern. A flexible transmission line has a lower wind load than does rigid line. There is no bullet VSWR (see Fig. 13.26), installation is faster, and its cost is less than rigid line. Flexible line also has long life but only handles low to medium power, and therefore, is only used for VHF and low UHF. Solid transmission line has higher windloads, its bullets cause VSWR, and it is costly to purchase and install. But it has less loss, a very long life, and a wide frequency and power range. Transmission lines of 50 Ω are good up to about 45 kW, and 75-Ω lines are good up to about 50 kW. Transmission lines cost less than one-half of what waveguide does. Also, coax is nowhere near as frequency dependent as waveguide.

13.3.2.2 Waveguide. Waveguide attenuation is inversely proportional to the frequency (Fig. 13.25). Both waveguide and coaxial lines exhibit very little change in attenuation values across a 6- or 8-MHz channel. The variation is typically less than 0.05 dB. However, unlike coax, waveguide has both lower and upper cutoff frequencies. The upper frequency limit is where undesirable propagation modes occur. The lower cutoff frequency is where true wave propagation begins. The velocity of propagation is different for waveguide due to the lower cutoff frequency. There is also a slight amount of group delay in waveguide because the lower edge of a channel has a slightly slower velocity of propagation than the upper end of the channel. For channel 30 that difference