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Transmission Lines for Broadcast Use

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Since the early days of broadcasting, transmission lines have been one of the vital elements of the broadcasting plant—the connecting link between transmitter and antenna. The choice of the proper line for adequate planning, construction, and maintenance procedures is an all-important ingredient of a satisfactory system. Transmission-line technology has changed along with changes in broadcasting. Starting with open-wire lines in the early days of AM broadcasting, the art has progressed through a wide variety of coaxial-line types, both air and solid dielectric, rigid and semi-flexible.

It is not the intent here to describe basic transmission-line theory or design methods. A wide variety of transmission lines are available to the broadcaster of today. His chief concern is the selection of the best one for his application and an understanding of the proper methods of installation and maintenance. Factors to be considered in selecting a line for various broadcast services will be presented. A discussion of recommended installation procedures will allow the broadcaster to lay out and construct a system suited to his specific requirements.

A large number of different transmission lines have been used in the past, including lines of various characteristic impedances, sizes, and physical characteristics.

Most of the coaxial lines and waveguides in this presentation and their flanges and connectors are those that have been standardized by the EIA (Electronic Industries Association). Most manufacturers of electronic products adhere to these standards so that interchangeability and interconnection between products of different companies can be accomplished. Current EIA standards include transmission-line conductor diameters as well as line flanges and connectors. The standard lines described herein have a 50-ohm characteristic impedance. Other standard lines having a 75-ohm impedance, are also used, but mostly for special UHF-TV applications. It is, of course, true that there are in existence transmission lines that are not covered by standards; however, the selection and use of these lines are usually considerations of the equipment designer rather than the broadcaster. Such special lines will therefore not be included in this chapter.

DESCRIPTION AND APPLICATION

In general, a transmission line is selected on the basis of efficiency (degree of attenuation), power handling, and mechanical considerations. In AM, FM, and TV, power handling is one of the most important factors to be considered. After a transmission line has been selected which will satisfy the power-handling requirement, the attenuation of the line must then be examined. A long-transmission-line installation requires a lower per-unit attenuation. It is a question of economics, balancing line cost, installation cost, and maintenance, versus the alternatives of antenna gain, tower height, and transmitter power. These economics usually favor a larger diameter transmission line (having less attenuation) and a better antenna rather than a high power transmitter.

Flexible Solid-Dielectric Coaxial Cable

The simplest and cheapest type of RF energy transfer is through the use of solid-dielectric cables such as RG-213/U and RG-218/U, as shown in Fig. 1. Solid-dielectric cables are com-

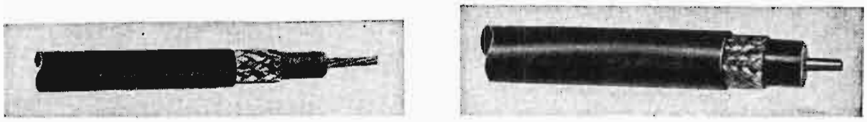


Fig. 1. RG-213/U and RG-218/U solid-dielectric cables.

prised of a solid or stranded inner conductor, plastic insulating material, braided copper sheath outer conductor and a protective plastic jacket. These highly flexible cables are used in applications where the length is short or the frequency is low enough that attenuation is not an important factor. Since attenuation in this type of cable is high, it is not recommended for long runs. Because of its aging characteristics, low isolation, and tendency to absorb moisture, it is not recommended for permanent outdoor use.

In the broadcast field, its use is generally limited to sampling lines, jumper connections, and occasionally as the main feeder line. In FM and TV installations, it is rarely used except for receiver monitor systems. For microwave, it is sometimes used for interconnections between components and in jumper connections at the bottom and top of the semi-flexible coaxial cable run. Solid-dielectric cable is frequently used in translator service because of short-length requirements.

Semiflexible Foam Dielectric Coaxial Cables

Semiflexible foam dielectric cables consist of a copper inner conductor, a foam polyolefin dielectric, and a flexible solid metallic outer conductor of copper or aluminum. Inner conductors are either copper wire or tubing, depending on cable size. These cables are available in continuous lengths either jacketed or unjacketed. Pressurization is not required with this type of cable. Sizes are available from 1/4 in. to 3-1/8 in. in diameter. A typical cable of this type, employing a corrugated copper outer conductor, is shown in Fig. 2.

Foam dielectric cables have become very popular in many services due to their moderate cost. In the broadcast field, they have found application in low-power AM directional arrays, AM sampling lines and FM main feeders. Foam dielectric cables have much better phase versus temperature characteristics than solid dielectric cables, as illustrated in Fig. 3.

The attenuation, size for size, is considerably lower than for solid dielectric cables. The foam dielectric is only about 50% solid, the remaining volume being a homogenous dispersion of fine closed cell bubbles, thus reducing dielectric losses. In addition, the dielectric constant is lower, allowing a larger inner conductor, thus reducing loss further.

The solid sheath also yields lower attenuation than braided sheaths and eliminates the RF leakage inherent in braided constructions.

Generally, this cable type offers of the low-attenuation advantages of semiflexible air dielec-

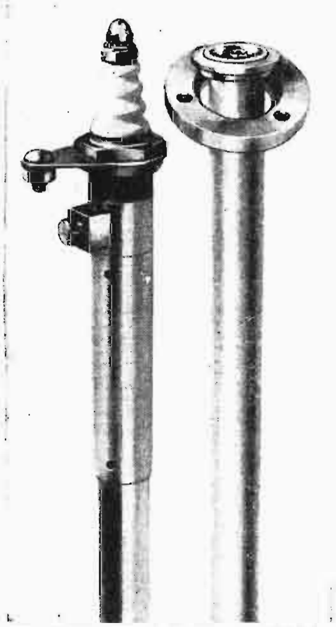


Fig. 2. Semiflexible foam dielectric coaxial cable.

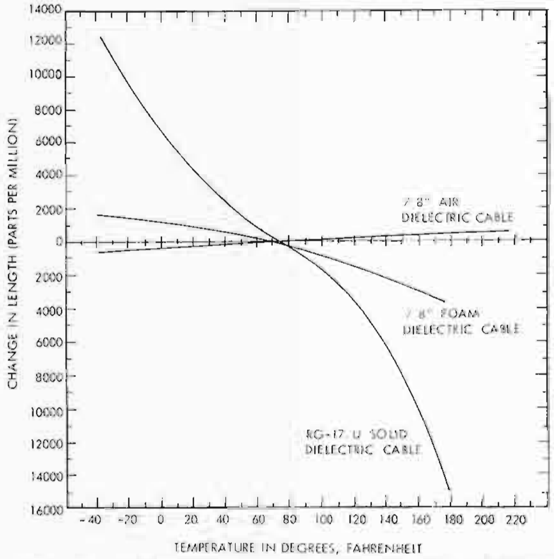


Fig. 3. Phase-temperature characteristics of coaxial cables.

Fig. 4. Semiflexible air dielectric coaxial cable.

tric cables, yet retains the advantage of no pressurization. A variety of end fittings are available and finished assemblies may be obtained from most manufacturers.

Semiflexible Air-Dielectric Coaxial Cable

Continuous semiflexible air-dielectric cable is the most popular cable for many installations, since it combines high efficiency and high power handling with ease of installation and a very low VSWR. It is used for all applications including microwave. There are several types on the market today. Electrical and mechanical data can be obtained from the various manufacturers. A typical continuous air-dielectric cable is shown in Fig. 4. Cable of this type is comprised of a continuous inner and outer conductor. The inner insulation is continuous throughout the entire length of the cable and comprises a very small percentage of the total volume. Since the cable is produced by a continuous manufacturing process, no joints are required even for very long lengths of several thousand feet. The continuous process eliminates many electrical discontinuities, and a low VSWR is achieved.

These cables are now available in sizes from 1/4 in. to 8 in. in diameter. The larger sizes (3 in., 5 in., and 8 in.) are particularly well suited to the high power levels used in broadcasting today; in AM, HF, FM, and TV. Installed cost and performance are better than in rigid line. Another advantage is that the entire performance may be measured on the reel before shipment.

Weatherproofing for most continuous cables is accomplished by a tough jacket covering the outer conductor. This enables the cable to be used in almost any environment such as salt air, direct ground burial, or under water.

Some continuous air-dielectric cables can withstand repeated bending, while others are limited to a few bending cycles. The manufacturer's flexing recommendations should be followed. Most continuous cables are shipped on reels and are uncoiled without difficulty. They can also be attached directly to a tower, thus eliminating the need for spring or sliding hangers. Pressurization is normally necessary for this type of cable to prevent accumulation of moisture.

Rigid Coaxial Transmission Line

Rigid air-dielectric transmission line has low attenuation and VSWR. It is manufactured from hard-temper copper tubing in standard 20-ft. flanged lengths. The rigid inner conductor is generally supported by Teflon pegs or discs. The inner connector used with rigid lines has a Teflon insulator which anchors the inner conductor and supports it in vertical runs. Fig. 5 shows 1-5/8 and 9-in.-diameter rigid lines.

Rigid transmission line is used mainly for high power levels. Its use in AM is generally limited to the main feeder lines on omnidirectional or

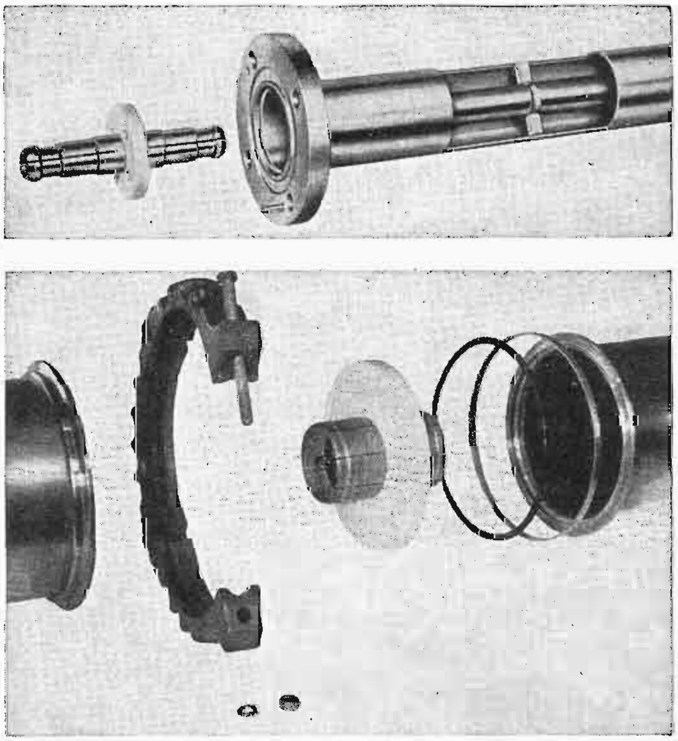


Fig. 5. 1-5/8- and 9-in. rigid coaxial lines.

directional AM arrays using 5 kw or more. In FM and TV, rigid line is often used for the transmitter-room interconnections, and sometimes as the main feeder to the tower. The 7/8- and 1-5/8-in.-diameter rigid lines are ideal for inside runs in low- or medium-power communications or TV broadcasting installations. These rigid transmission lines are especially recommended for connections between transmitters, diplexers, receivers, dummy loads, switching systems, and other components.

For FM and moderate power VHF TV installations, 1-5/8-in. and 3-1/8-in. lines are often chosen. For high-power applications in VHF TV and low-channel UHF TV, 6-1/8-in.-diameter transmission line is recommended. For the higher UHF TV frequencies up to 890 MHz (Channel 83) 75-ohm 6-1/8-in. line is used. Nine-inch-diameter rigid transmission line has been designed for very high-power systems. EIA standards RS-225 and RS-259 cover 50 ohm and 75 ohm rigid coaxial transmission line, respectively.

ELECTRICAL CHARACTERISTICS OF TRANSMISSION LINES

Attenuation

Attenuation in a transmission line is loss created by imperfect conductivity of the conductors and the imperfect insulating medium or dielectric. In open-wire lines, an additional loss is incurred in the form of radiation. In coaxial lines and waveguides, this loss is not incurred, since the RF field is totally enclosed within the cable. Attenuation for RF cables is generally expressed in decibels per 100 ft. In waveguides, the entire loss is conductor loss. In coaxial cable, the losses are conductor losses and the dielectric losses associated with material used as the inner-conductor support. In solid-dielectric cables, the dielectric loss is appreciable and at high frequencies may exceed the conductor losses in spite of high-quality dielectric materials. In air-dielectric coaxial cables, the insulating supports are limited to a very small portion of the total dielectric space, so that the dielectric is principally air; therefore, the total dielectric losses are generally negligible. At very high frequencies, they may become large enough to become a significant portion of the total loss.

Because of skin effect, the RF current penetrates less of the conductor as frequency increases. Attenuation due to conductor losses thus increases with frequency and is proportional to the square root of frequency. Attenuation due to dielectric loss is directly proportional to frequency. Measured attenuation curves for several line sizes are shown in Fig. 6.

Actual attenuation experienced in operation may be further influenced by VSWR occurring on the line owing to an imperfect load. This is generally not significant, since a considerable VSWR is necessary to produce any measurable loss increase. Loss is increased by VSWR by the factor $1 + (\mathrm{VSWR})^2/2\mathrm{VSWR}$. Fig. 7 illustrates this effect.

Efficiency of a transmission-line system can be easily calculated from the total attenuation.

$$\text{Efficiency in percent} = \frac{1}{\text{antilog}\,(a/10)} \times 100$$

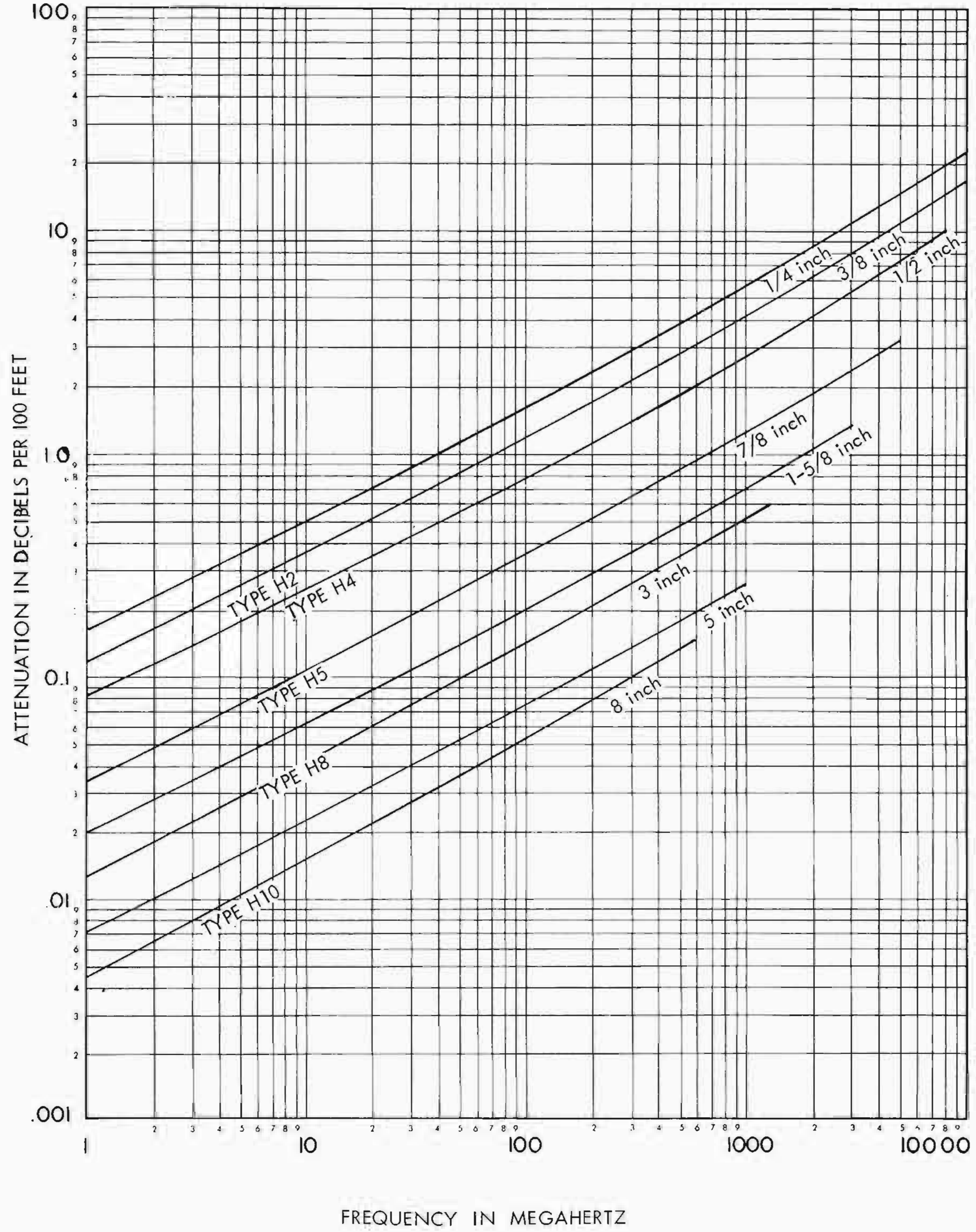
where a is the total attenuation in decibels. Often line sizes larger than necessary from the power-handling standpoint alone are used in order to obtain better line efficiencies.

Voltage Standing-Wave Ratio (VSWR)

When a transmission line is terminated in an impedance different from the characteristic impedance of the line, a portion of the energy traveling down the line is reflected. The amount of reflection depends on the degree of mismatch. The incident and reflected traveling waves combine to produce an uneven voltage distribution, or standing wave, along the line, and voltage and current maxima and minima occur. VSWR has been defined as the ratio of the maximum to minimum voltage; that is, $\mathrm{VSWR} = E_{\max}/E_{\min}$. This effect is measurable with various types of instruments such as slotted lines, bridges, and reflectometers.

The effects of VSWR may or may not be a problem, depending on the type of service, power levels involved, etc. As VSWR increases, the maximum voltage points increase, and breakdown problems might occur if the power level and VSWR were high enough and the cable choice was small. Irregular heating along the cable due to current maxima may cause problems also, especially in solid-dielectric cables, where the plastic dielectric material may soften. These possibilities would require large VSWR values to cause problems. Other effects of VSWR, where the cable is not impaired but the service may be, are distortions in TV and, intermodulation in multiplex FM. As already described, VSWR also causes some increase in the actual attenuation of a transmission line.

In most services, a moderate VSWR is of no consequence as long as the line ratings are not exceeded. In AM broadcast applications, VSWR may be as much as 3 or more with perfectly satisfactory operation. In FM broadcasting, system VSWR is generally less than 1.75. In TV, a system VSWR of less than 1.1 is considered desirable. In general, discontinuities contributing



Attenuation curves based on:
VSWR 1.0
Ambient Temperature 24°C(75°C)
One atmosphere absolute dry air pressure (0 psig)

Conversion Data:
1 dB/100 feet=3.28 dB/100 meters
For 75 ohm cables, multiply values by .95
For ambient temperature 20°C(68°F) multiply value by .99

Fig. 6. Attenuation of semiflexible 50 ohm air dielectric coaxial cable with copper out conductor.

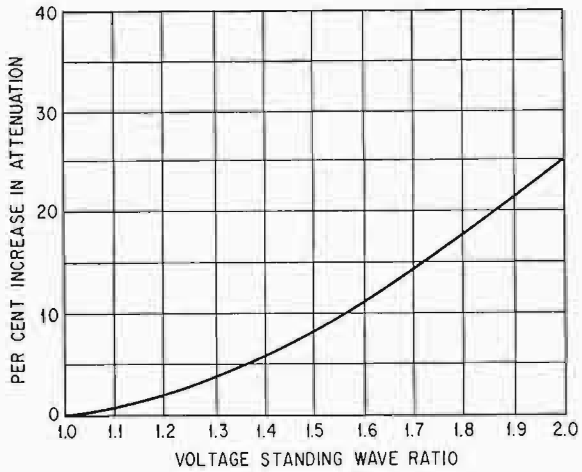


Fig. 7. Increase in attenuation in line due to VSWR on line.

to VSWR that are located close to the transmitter will have little or no effect on picture quality. The transmission line itself, the line fittings, or both may produce some VSWR. This is usually very small and is of little consequence for most services. For TV or certain microwave applications, it is sometimes large enough to influence performance.

In cases where the line has considerable attenuation, VSWR at the input end is lower than that of the antenna or load itself. The curves in Fig. 8 illustrate the extent of this effect.

Power Ratings

There are two power ratings for transmission lines. One is based on the maximum heating the cable construction might safely withstand. It is generally referred to as the "average power rating." The other is based on voltage-breakdown considerations and is generally described as the "peak-power rating." Consideration of both ratings is necessary for most services.

Average power is the power in the signal capable of creating heat. Peak power is that maximum rms power which can be reached in any interval (such as during a modulation cycle) and should not be misinterpreted as any relation between peak and rms voltages such as $\sqrt{2}$ in sine waves. In a continuous CW carrier (including FM), peak power equals average power. In 100 percent AM, the power rises to four times the carrier power, so in this case, the peak power is four times the carrier power. Since average-power rating is limited by heating which is created by line losses, this rating decreases with increasing frequency. Peak-power rating is dependent on voltage breakdown considerations which are not significantly frequency sensitive; thus this rating is constant with frequency. Transmission-line ratings can be arrived at by various experimental and calculated procedures. The overall picture is

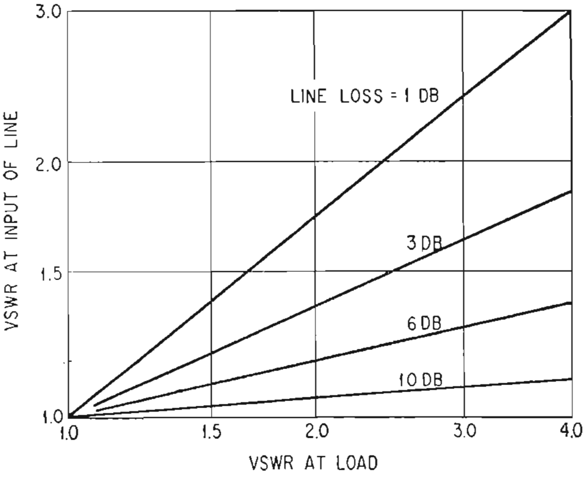


Fig. 8. VSWR improvement due to line attenuation.

complicated by the effects of environment, such as ambient temperature, cable pressure, and others. Whatever basis for rating is used, it must be stated with the rating. Once a rating is determined for the conditions stipulated, the rating can be adjusted for other conditions. As was mentioned, ratings can be arrived at by various means. The following procedure is one way which has been used for many years and has been found to be very satisfactory. Curves illustrating these ratings for several popular line sizes are shown in Fig. 9.

Rigid Air-Dielectric Coaxial Line

Peak-power rating. The procedure here is to establish a peak voltage the line will withstand every time if it is manufactured properly. The maximum voltage gradient occurs at the inner-conductor surface in a coaxial line.

A theoretical breakdown gradient cannot be used, since breakdown is a highly variable phenomenon occurring at widely different values depending on small effects such as scratches, dust particles, and insulator condition. Derating theoretical breakdown to 35 percent of theoretical has been found to be a practical value for a dc test voltage (or 60-cycle peak test voltage). The equation below is derived from the maximum voltage gradient in a coaxial line and includes factors considering pressure, temperature, and inner conductor curvature. It also includes the derating of 35 percent described above and results in a very reliable production test voltage. This test voltage is then further derated and used for power rating purposes.

$$E_p = 3.17(10)^4 a\delta \left(\log_{10}\frac{b}{a}\right)\left(1 + \frac{0.273}{\sqrt{a\delta}}\right)$$

where E_p = production test voltage, volts
a = inner-conductor OD, in.
b = outer-conductor ID, in.
δ = air-density factor = $3.92B/T$
where B = absolute pressure, cm of mercury
T = temperature, °K

($\delta = 1$ for $B = 76$ cm and $T = 23°\text{C} = 296°\text{K}$)

The values are generally rounded off as follows for the common 50-ohm line sizes:

Nominal Line OD, In.	*Production Test Voltage, dc Volts*
3/8	2,200
7/8	6,000
1-5/8	11,000
3-1/8	19,000
6-1/8	35,000
9	50,000

The next step is to derate this production test voltage to a realistic RF rms operating voltage. The voltage is derated to 0.7 of its above value to go to RF conditions, by $1/\sqrt{2}$ to go to rms value, and by a suitable safety factor which is usually 2.

$$E_{rf} = \frac{0.7E_p}{\sqrt{2}(\text{SF})} = 0.247E_p \quad \text{volts}$$

where E_{rf} = maximum RF rms operating voltage with no allowance for VSWR or modulation, but including safety factor
SF = safety factor on voltage of 2

This voltage, E_{rf} determines peak power rating.

$$P_{pk} = \frac{(E_{rf})^2}{z_0} \quad \text{watts}$$

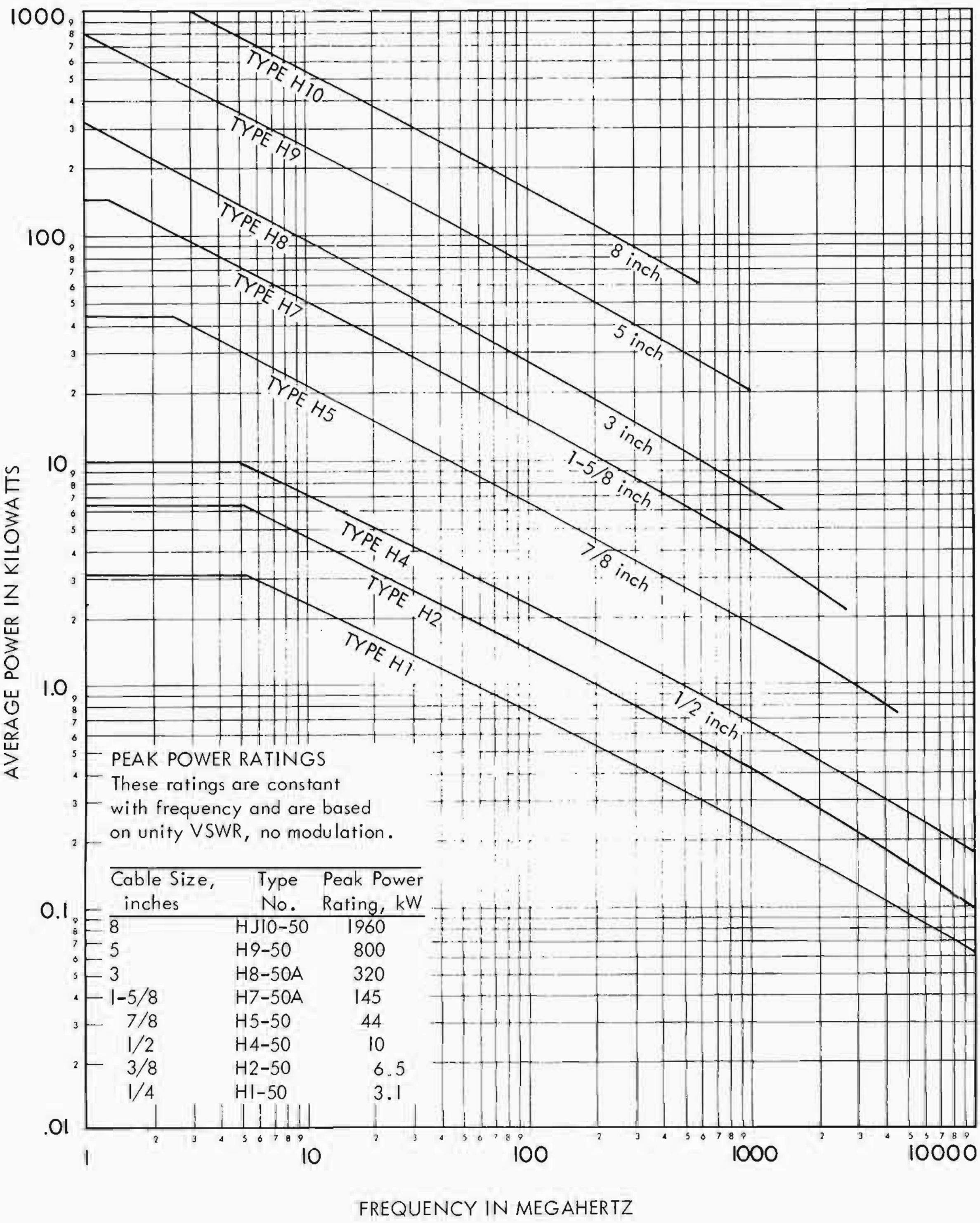
This rating must be derated further for VSWR and amplitude modulation, although these vary with the application and are not a part of the basic rating. This would be done as follows:

$$P_{\max} = \frac{P_{pk}}{(1+M)^2\,\text{VSWR}} \quad \text{watts}$$

where M is the modulation index and 1 is for 100 percent. This would derate P_{pk} by 4 for 100 percent AM due to modulation to obtain the rating in terms of carrier power or transmitter nameplate rating. Notice that peak-power rating must be reduced directly by VSWR.

A very significant point should be noticed in the equation for E_p, in that the breakdown voltage, in the range of pressures normally used, is approximately proportional to absolute pressure; thus, the peak-power rating is roughly proportional to the absolute pressure squared. This is often a valuable tool in achieving high-peak-power operation. Certain high-dielectric-strength gasses other than air, such as sulfur hexafluoride, have also been used to increase peak-power rating. This gas, as compared with air at equivalent pressures, will effect approximately a 2-to-1 voltage- or 4-to-1 peak-power-rating improvement. Combining the effects of using special gaseous dielectrics and pressurizing to several atmospheres pressure are also possible, compounding the improvement.

Average-power rating of coaxial line. Average-power rating is limited by heating due to line losses. Owing to the character of coaxial-line construction, the loss and temperature rise of the inner conductor are greater than those of the outer conductor. The ultimate temperature that the inner conductor might be safely allowed to reach determines the rating. This temperature is determined by such considerations as inner-



PEAK POWER RATINGS
These ratings are constant with frequency and are based on unity VSWR, no modulation.

Cable Size, inches	Type No.	Peak Power Rating, kW
8	HJ10-50	1960
5	H9-50	800
3	H8-50A	320
1-5/8	H7-50A	145
7/8	H5-50	44
1/2	H4-50	10
3/8	H2-50	6.5
1/4	H1-50	3.1

Average Power ratings based on:
VSWR 1.0
Ambient Temperature 40°C(104°F)
Inner conductor temperature 100°C(212°F)
One atmosphere absolute dry air pressure (0 psig)

Conversion Data:
For 75 ohm cables, multiply values by .70
For ambient temperature 35°C(95°F), multiply values by 1.11
For 5 psig dry air pressure, multiply values by 1.07
For 15 psig dry air pressure, multiply values by 1.2

Fig. 9. Average power rating for semiflexible 50 ohm air dielectric coaxial cable with copper outer conductor.

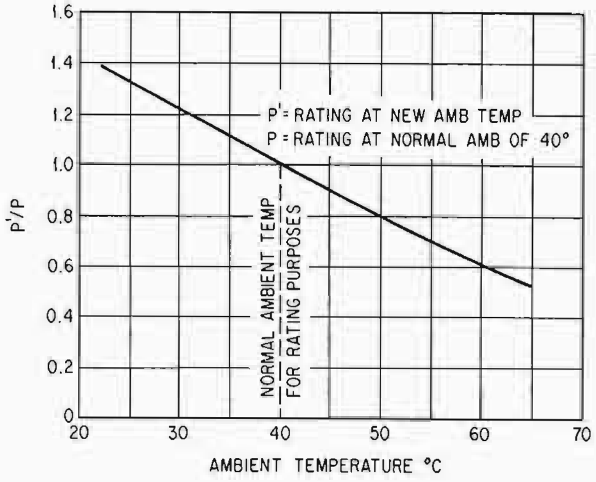


Fig. 10. Average-power-rating variation in transmission line for variation in ambient temperatures for a maximum center conductor temperature of 100°C.

conductor expansion and oxidation and dielectric life at an elevated temperature.

Most manufacturers base their average power ratings on an ambient temperature of 40°C (104°F). The temperature rise of the inner conductor, and therefore the average power rating, will vary with cable type and design details. A study of the ratings will usually reveal the conditions used to determine them. To be meaningful, these conditions should be stated on the ratings. See Fig. 10 for example. The sloping line is the average power ratings.

Average power ratings may be changed if the ambient temperature is changed. This is because the maximum temperature of the center conductor is the determining factor and the ambient temperature influences this. A graph is shown in Fig. 10 for a cable where the maximum inner conductor temperature is to be limited to 100°C.

Average power ratings may also be increased by special techniques such as pressurization with special gasses, coated conductors, etc. It is best to obtain information such as this from the manufacturer, since recommendations will vary with cable types.

Power Ratings for Various Services

Power ratings often published are already derated for various types of service depending on expected VSWR, modulation, and peculiarities in transmitter ratings (such as in TV).

In derating for VSWR, it is common to consider system VSWR as follows: broadcast and HF: AM, 3.0; FM, 1.75; TV, 1.1.

In derating for AM services, the peak-power rating is often derated by 4.5 to allow for modulation with some overmodulation, resulting in a rating for AM in terms of carrier power or transmitter nameplate rating.

For TV, transmitter nameplate ratings are usually the peak video power output value. The actual average power output for a black level picture (assuming the aural power equal to 20 percent of peak video power) is approximately 83 percent of the peak video power level. Thus, the actual average power output is less than the transmitter rating (for the 20 percent level aural example). Thus, for TV, some increase in average power ratings for the transmission line is possible.

Some of these deratings may seem of minor effect but are given to provide consistent ratings for the initial conditions of temperature rise or voltage governing the ratings. If the VSWR is known, it would be better to derate accordingly.

INSTALLATION

Mechanical considerations of a radio or TV station should involve not only the installation of the transmission line but also its maintenance. A carefully planned and executed original installation will assure long and trouble free operation.

The transmission line system (in the case of FM and TV consists of a vertical and horizontal run which connects to the antenna which connects to the transmitter or diplexer. A variety of hangers is required for supporting and anchoring transmission lines. Connections between various units of transmitter equipment inside the building are made by unpressurized line, which may incorporate a switching system for switching between units.

The use of continuous semiflexible coaxial cable simplifies installation planning and reduces the total cost of the installed line. When using semiflexible coaxial cable, expansion and contraction are negligible. The cable is attached to fixed hangers on the tower or directly to tower members.

The rigid transmission line requires the use of spring hangers on the tower and swinging hangers for the horizontal run to accommodate the expansion and contraction of the lines due to internal heating and changes in ambient temperature. The rigid line is anchored at the antenna by a rigid hanger and at the transmitter building by a wall anchor, so that movement of the line is away from the equipment. Over a temperature range of —25 to +125°F, expansion of the copper rigid line is about 1-1/2 in. per 100 ft. Provision must be made to allow for this movement. A steel tower expands or contracts with temperature change a rate of about 1 in. per 100 ft., and copper conductors of a transmission line will change length relative to the tower, approximately 1/2 in. per 100 ft., over the above temperature range. The spring and swinging hangers support the weight of the line but permit free axial movement during changes in temperature. This expansion contraction accumulates at the base of the tower; therefore, 15 or 20 ft. of line on each side of the elbow at the base of the tower must be free to flex and accommodate the change in length.

The importance of the effects of expansion and contraction of the rigid transmission line cannot be overemphasized. The force in the rigid transmission lines due to temperature changes is sufficient (when causing contraction) to tear hangers from the structure and pull the line from the transmitter building bulkhead fitting. When the line expands, severe buckling can occur and cause tower strain which could end in failure of the transmission line or tower.

Semiflexible Coaxial Cable Installation

Coaxial cable is often used in new installations. The following presents a step-by-step approach to the planning and installing of a TV or FM system on a typical 500-foot tower.

Precaution must be taken when planning an installation to consider the correct connectors to make the antenna and transmitter connections.

The antenna and equipment flanges may be of a different size than the transmission line; the antenna may or may not require pressurization and dry air inlet and purge ports may not be provided.

The connector on coaxial cable can usually perform all functions with the same fitting. A gas barrier and gas port will help eliminate unnecessary transmission line connections in the system. See Fig. 11.

BILL OF MATERIALS

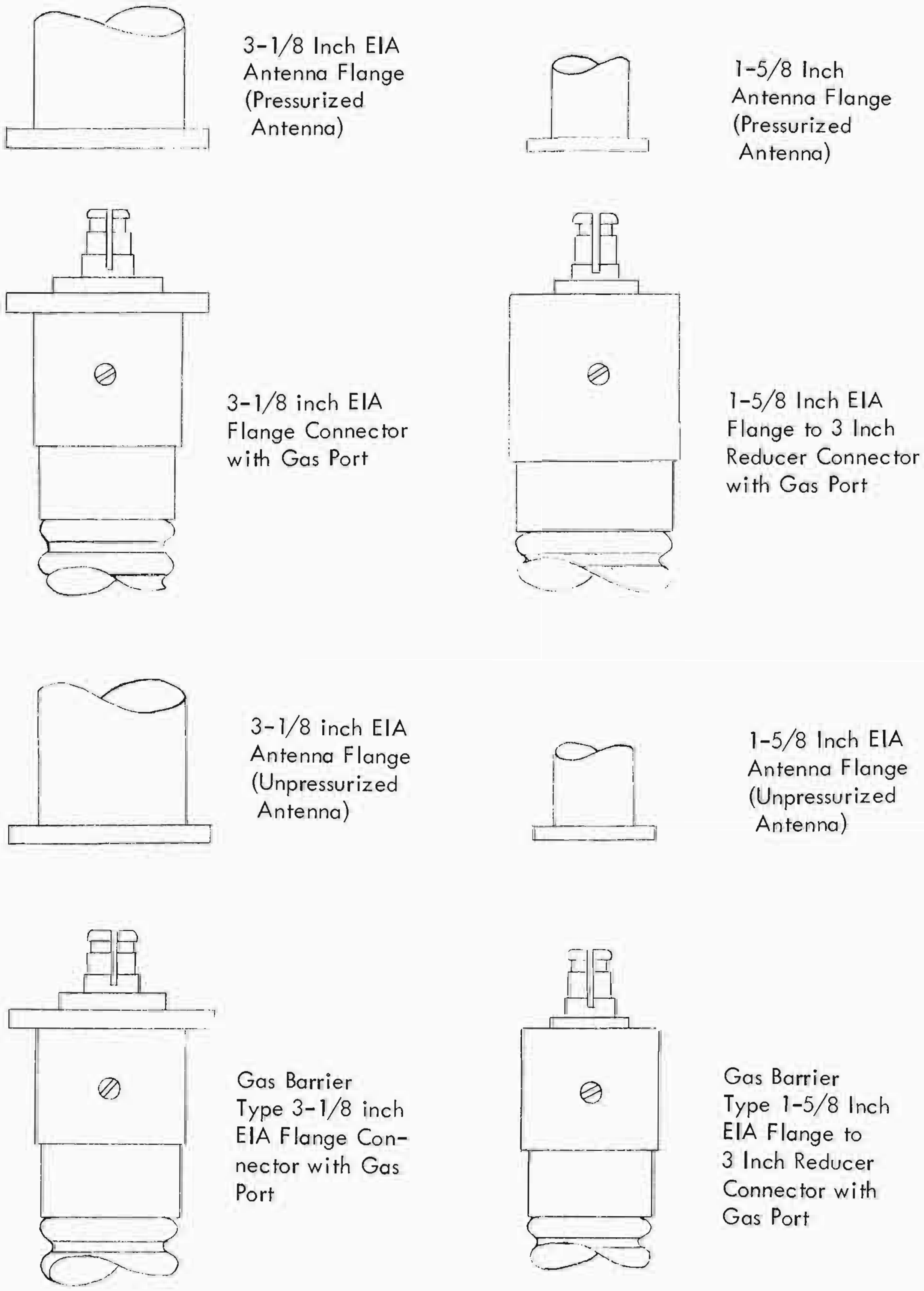
Items	*Quantity*	*Use*
1. End connector	1	For antenna end (as required to mate with antenna)
2. 600 feet continuous length/flexible coaxial cable.	1	For main run
3. End connector	1	For transmitter end (as required)
4. Wraplock, 100 ft./package	3	For attaching transmission line to tower and catwalk
5. Insulated hanger*	As Required	Prevent AM energy from being grounded
6. Grounding kit	3	For lightning protection
7. Wall/Roof feed-through	1	For weatherproof wall joint
8. Automatic dehydrator	1	To maintain line pressure
9. Hoisting kit	3	For hoisting coaxial cable

*If required for use on AM tower.

If an antenna with an air dielectric harness is not to be pressurized, a gas barrier antenna connector on the transmission line must be used. In this case, the unpressurized line above the gas barrier connector may collect moisture, so drain holes should be drilled immediately above the gas barrier.

The flexible coaxial cable is pressurized with dry air prior to shipment, to prevent contamination. The cable is shipped on a wood reel with the antenna end connector factory attached. The line should be kept pressurized during the installation.

Coaxial cable is generally hoisted directly from the reel up the tower. A pulley is placed high enough on the tower to allow the transmission line to be elevated sufficiently to make the connection to the antenna. A means of hoisting, such as a truck or a power winch, is required with a suitable steel hoisting line or rope. An axle is inserted through the hub of the cable reel and supported so that the reel turns easily, as the cable is being hoisted. The hoisting line is passed through the pulley at the top of the tower and sent back down the tower through the openings where the cable



3-1/8 Inch EIA Antenna Flange (Pressurized Antenna)

1-5/8 Inch Antenna Flange (Pressurized Antenna)

3-1/8 inch EIA Flange Connector with Gas Port

1-5/8 Inch EIA Flange to 3 Inch Reducer Connector with Gas Port

3-1/8 inch EIA Antenna Flange (Unpressurized Antenna)

1-5/8 Inch EIA Antenna Flange (Unpressurized Antenna)

Gas Barrier Type 3-1/8 inch EIA Flange Connector with Gas Port

Gas Barrier Type 1-5/8 Inch EIA Flange to 3 Inch Reducer Connector with Gas Port

Fig. 11. Coaxial cable connector options.

will be attached. It may be brought down the outside of the tower if the cable is to be attached to the tower leg or on the outside lattice. Flexible coaxial cable is attached to the hoisting line with a "basket" hoisting grip. To prevent kinking, rotation of the reel must be controlled to regulate payout of the cable. The cable should be tied to the hoisting line with strong tape at 50-ft. intervals. Additional "basket" hoisting grips are applied at 200-ft. intervals. See Fig. 12.

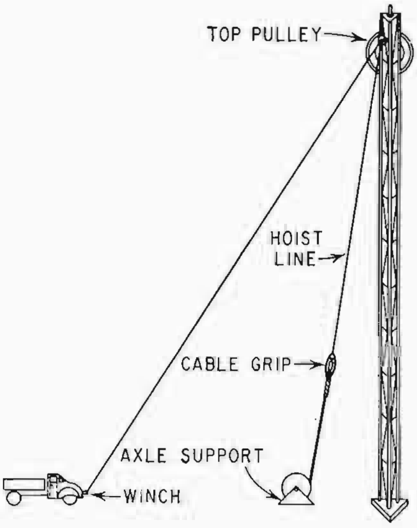


Fig. 12. Installation of cable.

When the cable is in position, antenna connection is made. The cable run is then attached to the tower with wraplock or rigid hangers. The weight of the cable is supported by the hoisting line while the attachment to the tower is made; at 3-ft. intervals for small diameter cables and 5-ft. intervals for cable over 1-5/8 in. in diameter. Fig. 13 shows standard attachment methods.

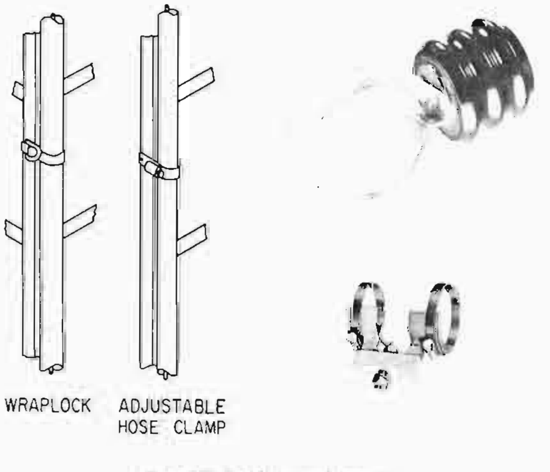


Fig. 13. Cable attachment.

If the supporting tower is also used as an AM broadcast radiator, some method must be used to prevent the AM energy from being grounded by the transmission line that feeds the TV or FM antenna. One method is to isolate the line up the tower for a distance of a quarter wavelength (at the AM broadcast frequency) from the base, using insulated cable hangers. Because of the quarter wave isolation at the base of the tower, a very high impedance between the tower and the line is presented to the AM energy. Common practice is to make the isolated section approximately .22 wavelength long and to use a variable capacitor at the base of the tower to tune to quarter wave resonance. Fig. 14 shows an installation on an AM tower.

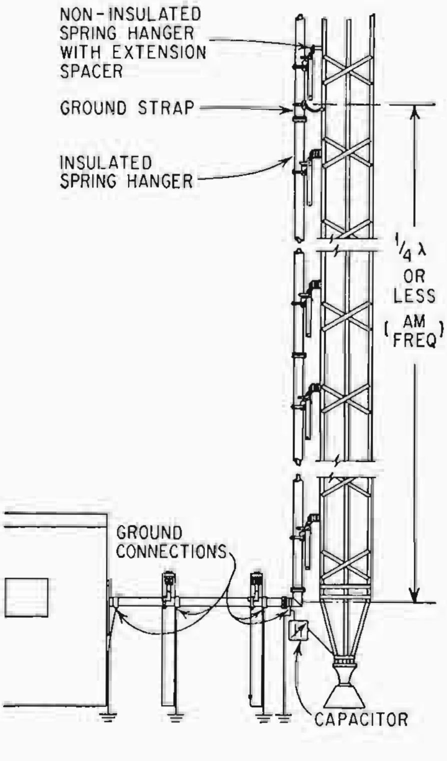


Fig. 14. Installation of AM tower.

Caution. Since a high RF potential exists between the line and the tower, the line should be mounted where it will not be accidentally touched by anyone on the tower ladder.

When coaxial cable is completely attached to the tower, the remaining cable is removed from the reel and laid out on the ground away from the tower. The transmitter end of the cable is either hung along a messenger cable, protected by an ice shield, Fig. 15, or buried in a trench, and routed through the wall of the transmitter building. The end of the cable is then trimmed to the required length, and the end fitting is applied. The cable

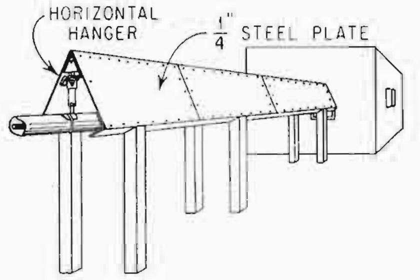


Fig. 15. Protected horizontal run.

fitting is then connected to the transmitter switch or diplexer.

Long horizontal cable runs may require that certain sections be placed underground. Vinyl or polyethylene jacketed lines are suitable for direct burial, or underwater use, with no effect of galvanic or corrosive action. A 6-in. layer of fine sand under and over the flexible coaxial cable should be provided to prevent damage from stones or other sharp objects. Buried cable should be below the area frost line and at least 3-ft. deep under roadways. It is good practice to install marders where cables are buried so that their presence is known.

Protection from lightning is obtained by grounding the cable outer conductor at the antenna end, at the tower base, and at the building entrance. In areas of known high incidence of lightning, grounding is done every 50 ft. along both the vertical and horizontal run. Grounding of the cable is done by removing the "jacket" and attaching copper strap or conductor from the cable to the tower.

After completing the installation, the coaxial cable should be purged. Purging and pressurizing can be done with an automatic dehydrator or with a nitrogen bottle and pressure regulator.

Purging with an automatic dehydrator in the system is done by allowing the dehydrator to operate continuously and loosening or removing the gas port plug or the antenna end of the cable run. The time for purging is dependent upon the length of the cable and the automatic dehydrator output capacity, usually one hour is sufficient. If purging is done with a nitrogen bottle, it can be done the same manner maintaining approximately 5 pounds pressure while purging. It is recommended that the line be pressurized three or four times to 5 pounds gauge pressure, releasing all pressure from the antenna end and between pressure cycles.

After purging, all outlets should be closed and the line should be kept pressurized as changes in temperature can cause moisture to condense and seriously impair performance and efficiency of the line.

Rigid Coaxial Transmission Line Installation

Rigid transmission line systems require care in planning an installation because of the accurate alignment required. Tower cross members, work platforms, ladders, and conduit boxes must be considered to assure that a straight path is available through the entire tower for the transmission line.

The following bill of material lists the typical components required for an FM or TV installation of 3-1/8 in. rigid transmission line on a 500-ft. tower.

BILL OF MATERIAL

Items	*Quantity*	*Use*
1. 90° mitered elbow, flanged	3	For changing line direction
2. Special lengths of line, unflanged	7	For custom applications
3. Soft-soldered flange kit	7	For field flanging lines and elbows
4. Rigid hanger	1	For anchoring top of line to tower
5. Mounting adaptor	50	For use if tower members do not have holes.
6. Combination spring and sliding hanger	49	For hanging transmission line
7. 20 ft. section of line	27	For main run
8. 15 ft. section of line	2	For main run
9. Lateral brace	1	For prevention of lateral line movement
10. Horizontal hanger	4	For free-swing support of horizontal line
11. Horizontal anchor	1	For anchoring line at building wall
12. Gas barrier	1	For pressure termination of line
13. Automatic dehydrator	1	For automatically pressurizing line
14. Straight coupling	7	For joining unflanged line
15. 90° elbow, unflanged one end	3	For changing line direction
16. 90° elbow, unflanged	2	For changing line direction
17. Grounding kit	3	For lightning protection

Transmission line assembly normally starts at the antenna end. A variety of conditions can exist at the antenna connection, so proper fittings must be selected. Where the antenna flange is of a smaller diameter than the transmission line, a reducer must be used. When the antenna harness is of air dielectric, air from the transmission line should be permitted to enter the antenna and an air inlet fitting should be inserted at the point of connection for use in purging the line. The air inlet fitting is not required if the antenna harness has an air inlet. When the antenna is not to be pressurized, a gas barrier must be used. Various antenna connections and fittings are shown in Fig. 16.

Since the connection at the top of the tower depends on the type of tower, type of antenna, and the position of the antenna, a custom fitted transmission line connection must be made at the antenna with two mitered elbows and two special lengths of line. The special lengths are field-cut to the exact dimension required and are flanged with soft-soldered flange kits. A rigid hanger is used at the top of the transmission line run so that thermal expansion and contraction of the line does not affect the antenna. A typical installation at the top of the tower is shown in Fig. 17.

For new installations using towers having angle-type members, the tower manufacturer, in most cases, will punch the members with holes for mounting the hangers. For towers that are already erected and for new towers with round members, mounting adaptors that attach the hangers to the towers without drilling are used. Tower members should not be drilled without approval of the manufacturer because of possible weakening of the structure.

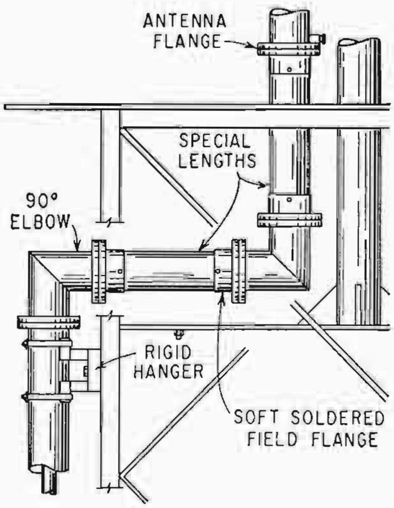


Fig. 17. Installation at top of tower.

The second step of the installation is attachment of the vertical run to the tower where the spring hangers and sliding hangers are used. The sliding hangers are merely guides placed at 10-ft. intervals along the vertical run to prevent any lateral motion of the transmission. Spring hangers are used to support the weight of the line and to accommodate differential expansion between line and tower. Sliding and spring hangers

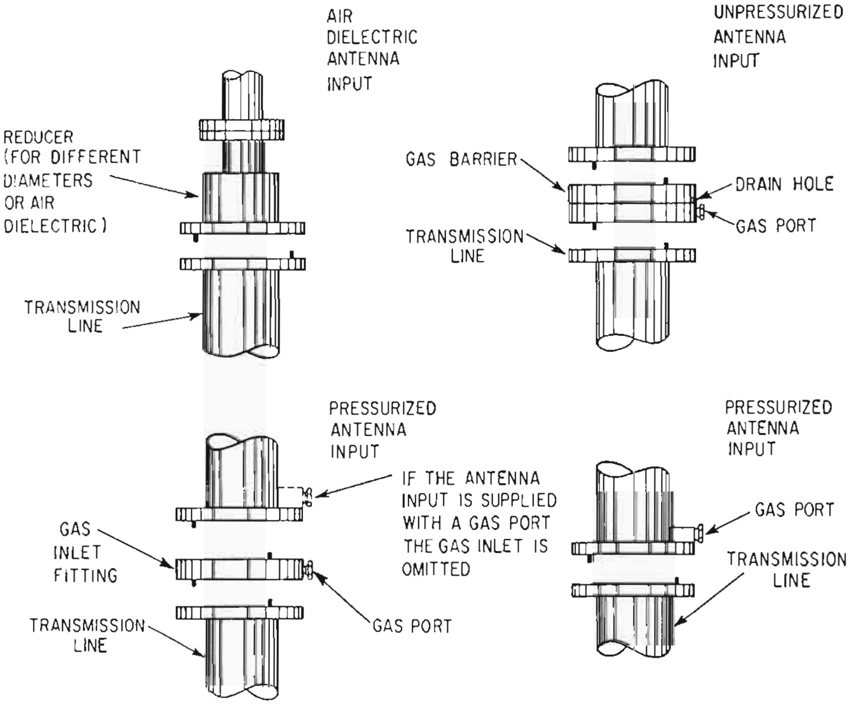


Fig. 16. Various antenna connections and fittings.

are made with and without insulators by some manufacturers as a combination hanger, as shown in Fig. 18. As the assembly proceeds, make certain to use a combination spring and sliding hanger at 10-ft. intervals, placing a hanger 5 ft. from each end of the standard 20-ft. section, Fig. 19. The most convenient location to hang the transmission line is near the tower ladder, where it is easily accessible for periodic inspection.

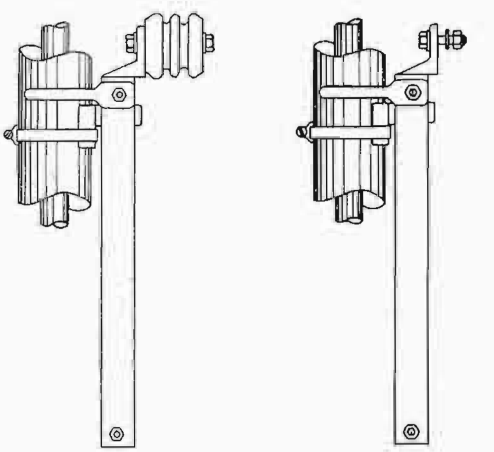


Fig. 18. Spring and sliding hangers (with and without insulators).

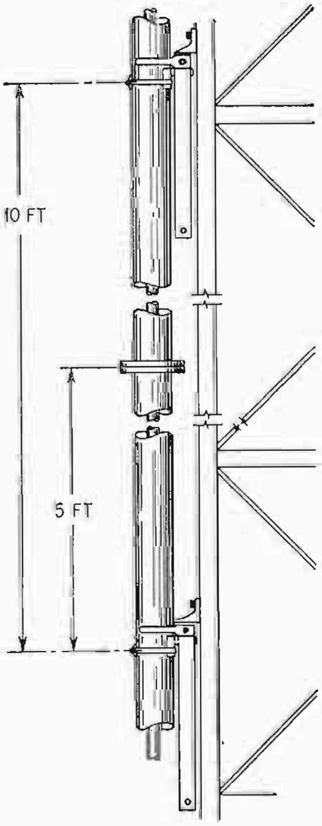


Fig. 19. Installation on tower.

Flexible line sections are used to correct transmission line misalignment for providing a slight change in direction as may be necessary. The flexible section for 3-1/8 in. transmission line is only 18 in. long; yet it can take up to 1/2 in. offset in the transmission line path, and can accommodate up to 30° bend. Flexible sections are used to accommodate vibration in transmission lines between equipment components, but are not intended to compensate for expansion or contraction due to temperature change. A flexible transmission line section is shown in Fig. 20.

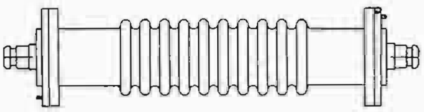


Fig. 20. Flexible section.

It is good practice in long transmission line runs to use breakaway sections (see Fig. 21) so that the line can be opened to measure antenna characteristics or to troubleshoot the line. With the use of a breakaway section, it is a simple matter to service antenna or transmission line. If a means of servicing the line is not provided, it is necessary to disassemble the run. Do not support more than one section of line on a flange joint without using hangers. As a precaution, leave the hoist line tied to the transmission line section until after the hangers are attached. Tapered towers involve changes in the line direction that are different from the 45° and 90° permitted by the standard elbows. In such cases, it is possible to bend a section of transmission line to make a change of up to 5° for 3-1/8 in. line or smaller, and up to 1° for 6-1/8 in. line. For greater changes, special angle elbows are required or two 90° mitered elbows can be connected in tandem as shown in Fig. 22 to produce the desired angle.

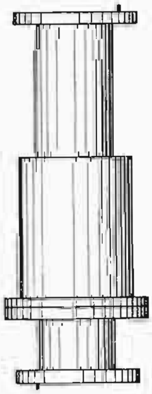


Fig. 21. Breakaway section.

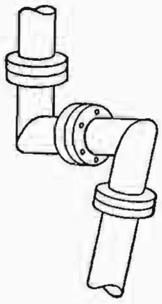


Fig. 22. Two 90° elbows in tandem.

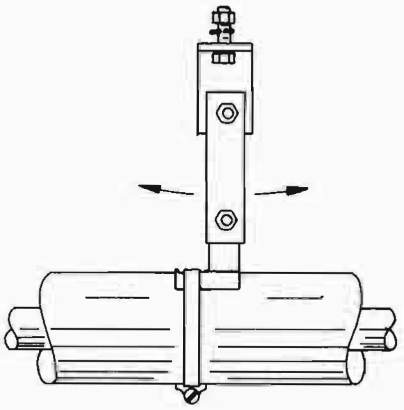


Fig. 24. Horizontal hanger.

The third step of the installation is at the base of the tower. The 15-ft. sections of line are installed here; one length vertically and one starting the horizontal run. These lengths are not supported by hangers but are left free to flex and accommodate the changes in length caused by line expansion and contraction, Fig. 23. If the bend from the vertical run to the horizontal run is 90°, a mitered elbow is used; however, if the bend is of some other angle as in the case of a tapered tower, two 90° elbows can be used in tandem to produce any angle from 0° to 180°. The bottom of the line (near the elbow) is supported with a lateral brace. The brace prevents lateral motion of the line, but permits line expansion and contraction.

The horizontal run, like the vertical run, is also affected by thermal forces, so provisions must be made to provide horizontal support while permitting the line to change length. To accomplish this, the line is supported by horizontal swinging hangers which bolt to support post arms. A horizontal swinging hanger is shown in Fig. 24. On vertical runs, the hangers should be placed at 10-ft. intervals.

The line is anchored at the building wall with a horizontal anchor which is similar to the rigid anchor used at the top of the vertical run. A horizontal anchor is shown in Fig. 25. Its purpose is to keep line movement away from the equipment, permitting expansion and contraction to build up at the tower end of the horizontal run.

Inside the building, the transmission line connects to the gas barrier immediately upon enter-

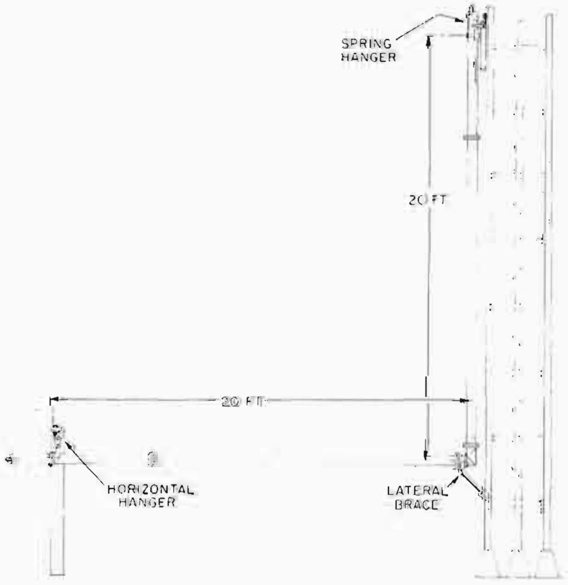


Fig. 23. Installation at base of tower.

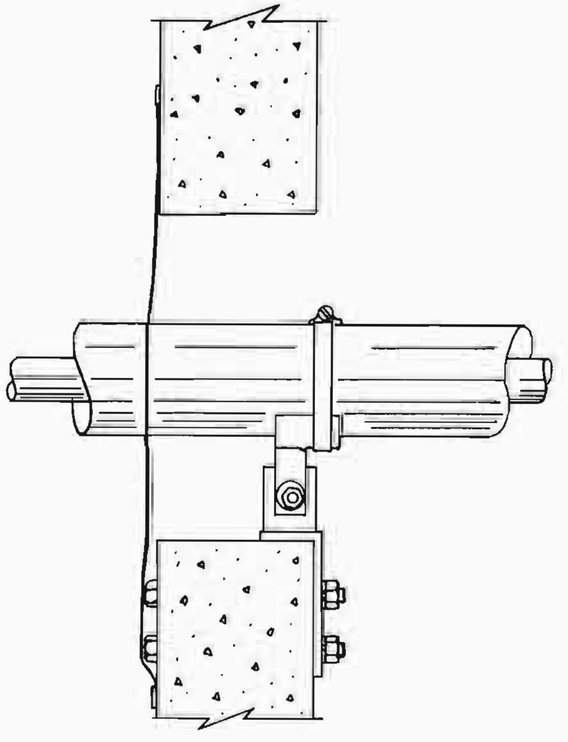


Fig. 25. Horizontal anchor.

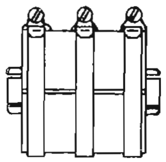


Fig. 26. Straight coupling.

ing the building. The barrier has a gas port to which the automatic dehydrator is attached. The automatic dehydrator keeps the entire length of line from the building to the antenna pressurized.

Connections between transmitters, diplexers, and switches inside the building are made with either flanged pressurized rigid line or with unpressurized coupling type connectors as illustrated in Fig. 26 and unflanged line.

Switching Systems

Coaxial switching systems such as patch panels or switches are recommended for all radio stations. These systems greatly reduce transmitter tune-up and testing time. "Off-the-air" time caused by equipment failure is also reduced, as standby equipment can be rapidly switched into use.

The type and configuration of the switching system required depends upon the needs of the station. The use of patch panels or remotely controlled switches is dependent upon local conditions. The systems described in this section are typical, having been used in many stations.

Patch panels are receptacles which are terminations of transmission line from equipment, strategically located on a panel so that desired connections between the terminations can be made by U links. These allow manual transfer or switching into dummy loads, alternate drivers, amplifiers and antennas. Usually, interlock circuits following the RF path are provided for safety. Figs. 27 and 28 show two typical patching systems, both using standard patch panels. Figs. 29 and 30 are photographs of the front and rear view of a standard five terminal 3-1/8 in. coaxial patch panel.

The power ratings of patch panels are usually the same as that for the equivalent size transmission line.

Coaxial switches are also used in switching systems. These have the advantage over patch panels in that they can be remotely controlled and are faster in operation. Remotely controlled switches make it possible to switch in auxiliary or standby equipment at remote, unmanned AM or FM stations. It is possible to control switches over telephone lines along with the other controls and metering circuits.

Coaxial switches are available for all sizes of transmission line up to and including 6-1/8 in. The power ratings of switches are usually equal to or slightly lower than the power rating of the equivalent size transmission line. They are available in many configurations, the most common being SPST, SPDT, and transfer types.

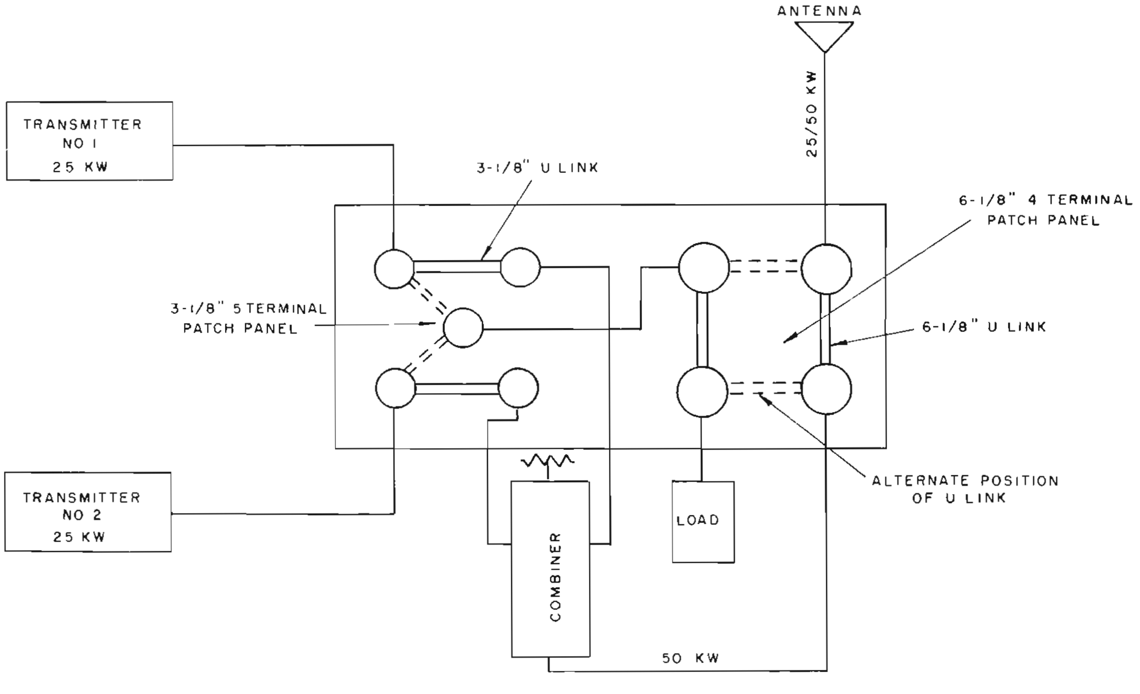


Fig. 27. 3-1/8 in. and 6-1/8 in. patch panels connecting two transmitters for greater power.

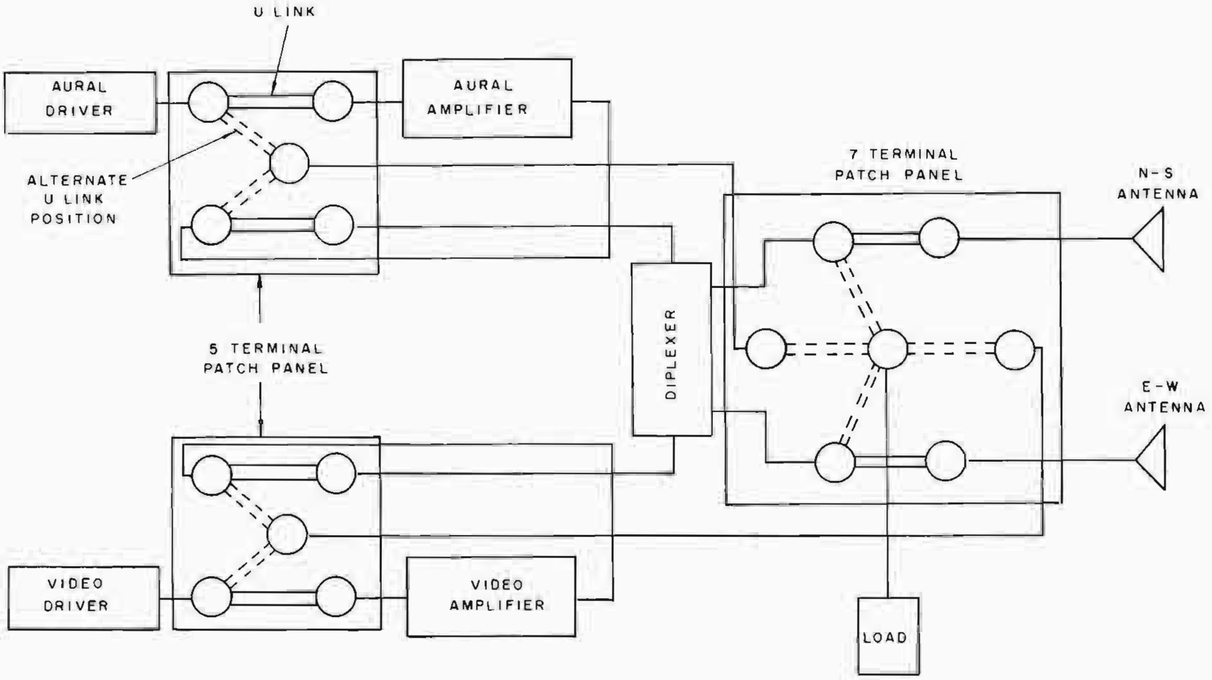


Fig. 28. Five terminal and seven terminal patch panel system.

Fig. 31 shows a commercially available transfer switch for 3-1/8 in. line. Figs. 32 through 35 show four typical switching systems varying from a rather simple system Fig. 32 to a complex system, Fig. 35.

The control circuits are also variable in design and depend upon the requirements of the station. Simple individual control switches or elaborate systems using relay logic, as shown in Fig. 36 can be used. Fig. 36 is a photograph of the control panel for the switching system shown in Fig. 35. This system automatically switches the proper switch to select the path desired. An illuminated RF path indicator is also included.

Fig. 37 is a photograph of the switching panel for the circuit shown in Fig. 35. This shows all the switches mounted on one panel or cabinet. It is not necessary to do this. It may be more desirable to mount the switches along the transmission line run, near the apparatus being switched. This will usually result in savings of transmission line and space. The control wires can be run to a central

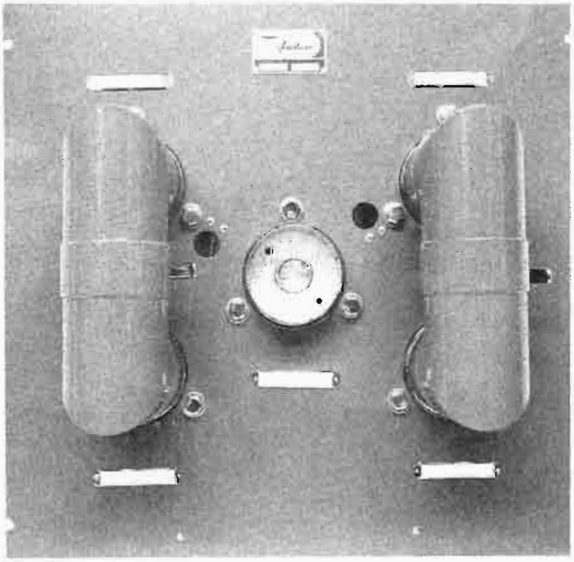


Fig. 29. Front view of standard five-terminal patch panel for 3-1/8 in. line.

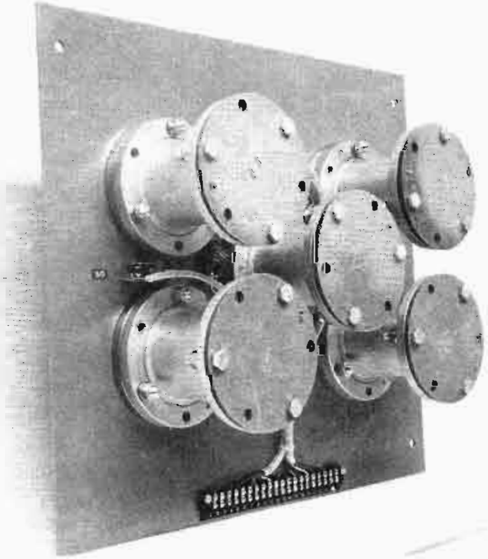


Fig. 30. Rear view of standard five-terminal patch panel for 3-1/8 in. line.

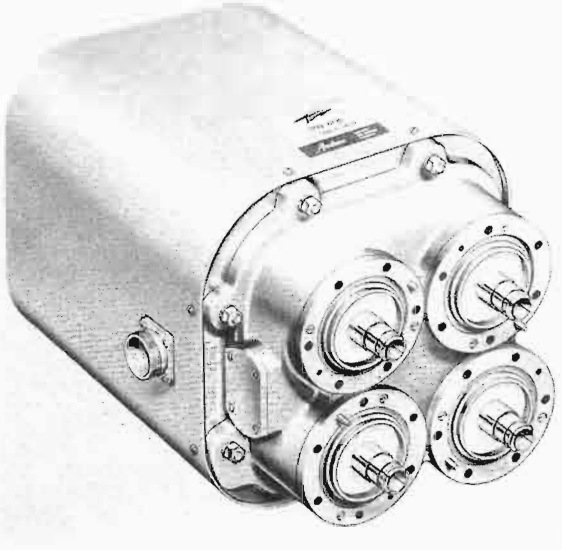


Fig. 31. 3-1/8 in. coaxial switch.

control panel located at the transmitter control panel.

Waveguide Installation

1. Installation of waveguide for broadcast use requires much more advance planning than a comparable installation of coaxial line. Each installation introduces special problems in mounting the waveguide on the supporting structure and in connecting it to the transmitter equipment. A great advantage of installing copper-clad steel waveguide is that there is no differential problem of expansion and contraction between the tower and the waveguide. This is true for two reasons: first, because the waveguide and tower are both made of steel and are identically affected by changes in temperature, and second, because of the very high efficiency and extremely low loss, no heat is created from the RF energy. Aluminum waveguide, because of its expansion and contraction, must be suspended by spring hangers in the same manner as rigid copper lines. The transitions at either end of the waveguide run are equipped with a gas barrier for pressure termination of the 3-1/8-in. coaxial line. Though the waveguide is unpressurized, the antenna and the 3-1/8-in. coaxial-line jumper connections outdoors usually are kept under pressure. A small copper tube is used to bring the gas supply up to the antenna.

The coaxial line between the transmitter building and the waveguide is also pressurized. Inside the building, however, the line is not pressurized.

The following Bill of Materials gives the approximate items and quantities needed for a

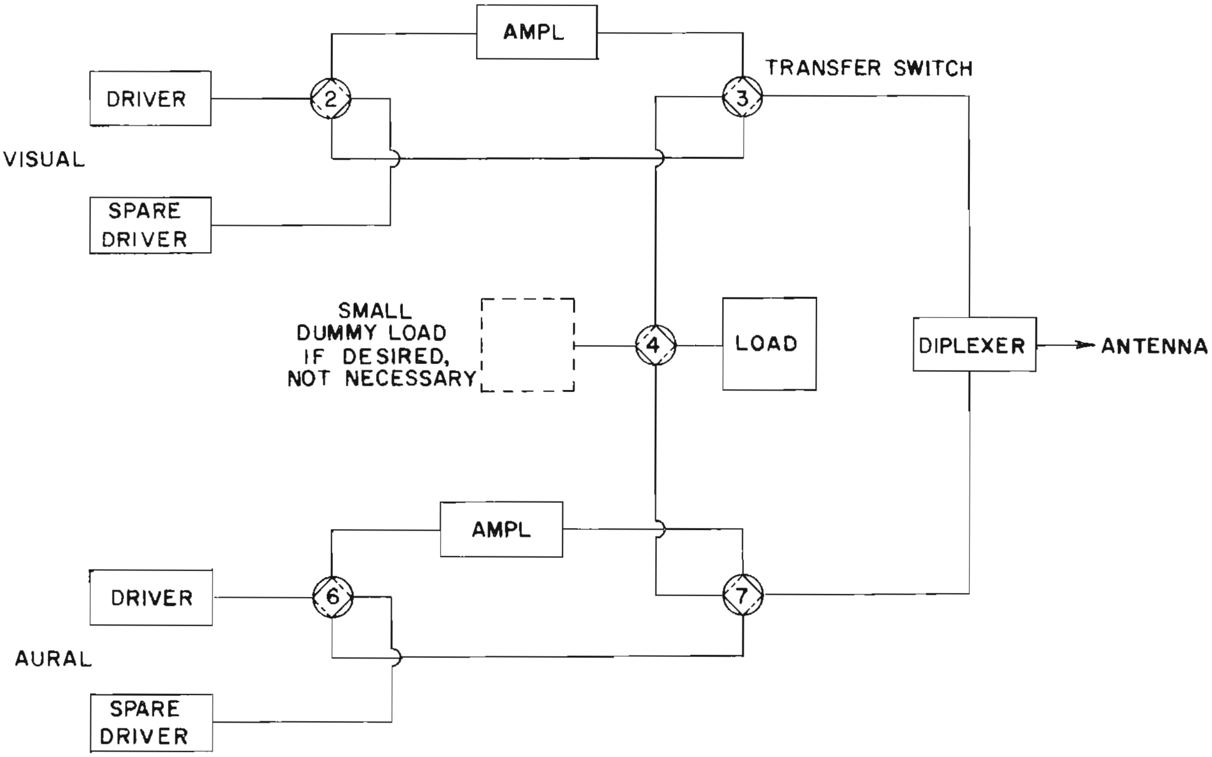


Fig. 32. Typical switching system for television station.

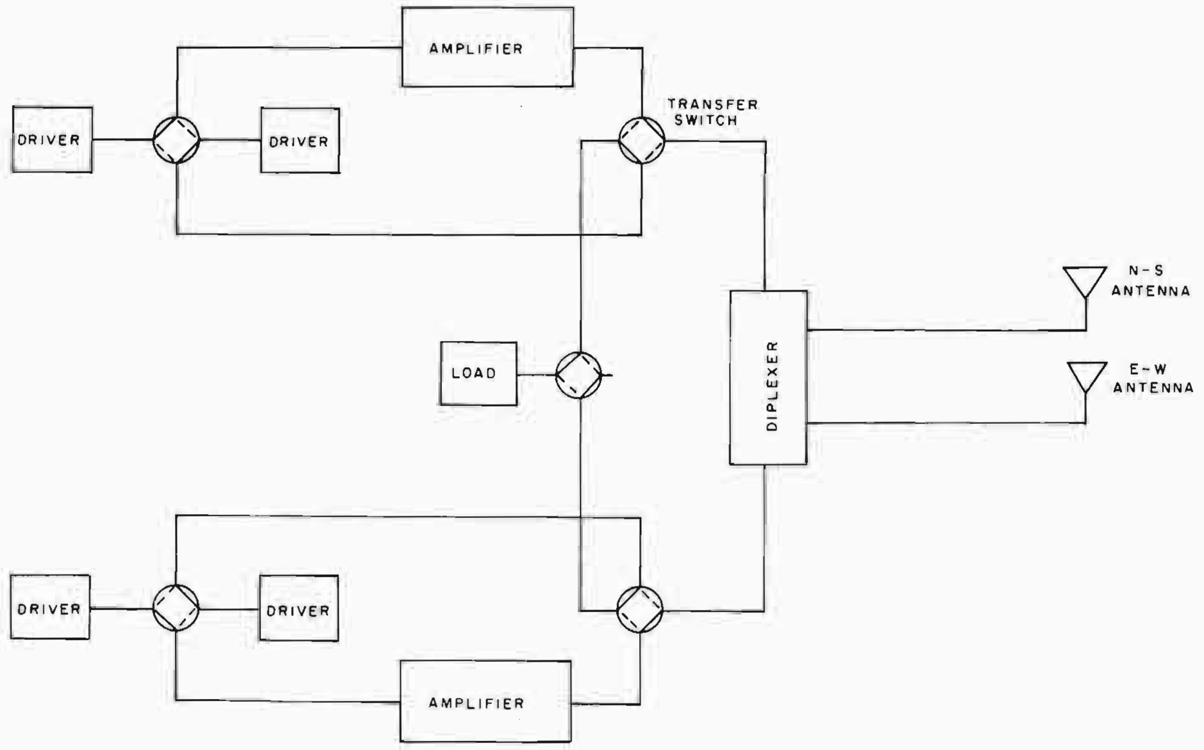


Fig. 33. Switching matrix for a quadrature feed antenna system.

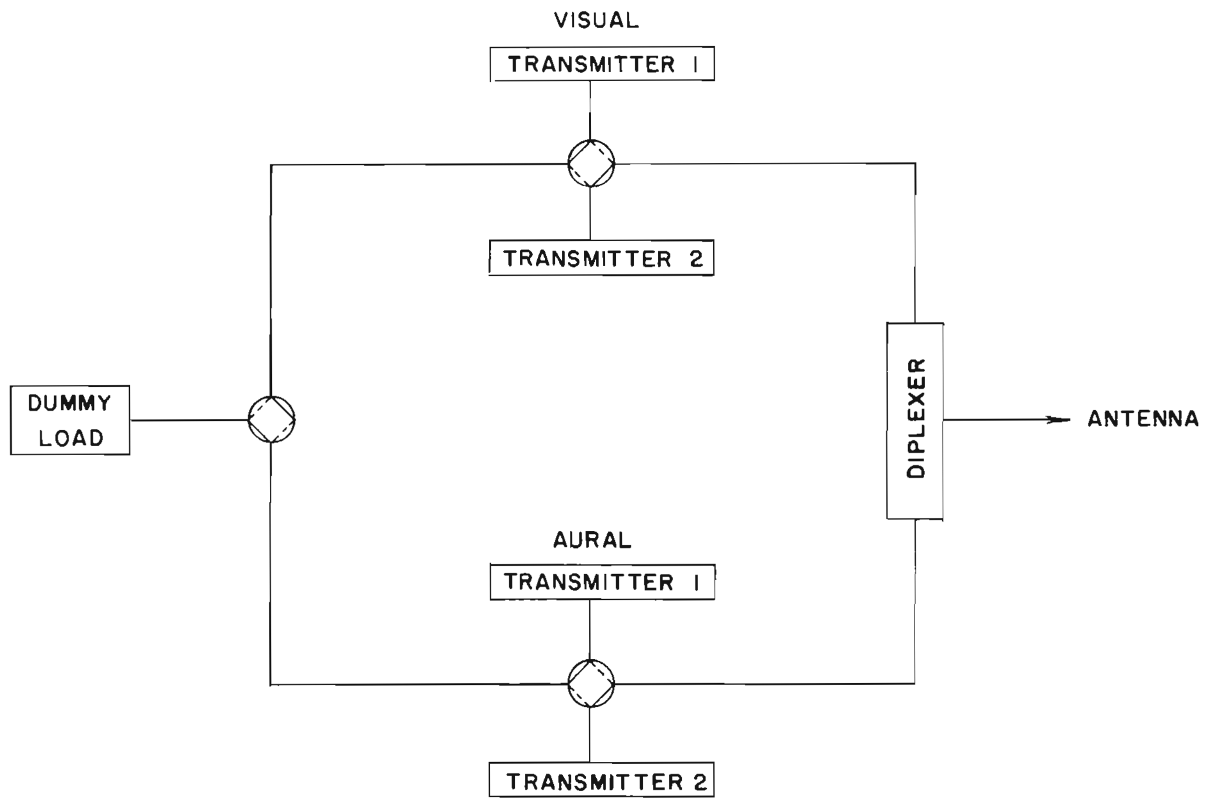


Fig. 34. Diagram of visual/aural system.

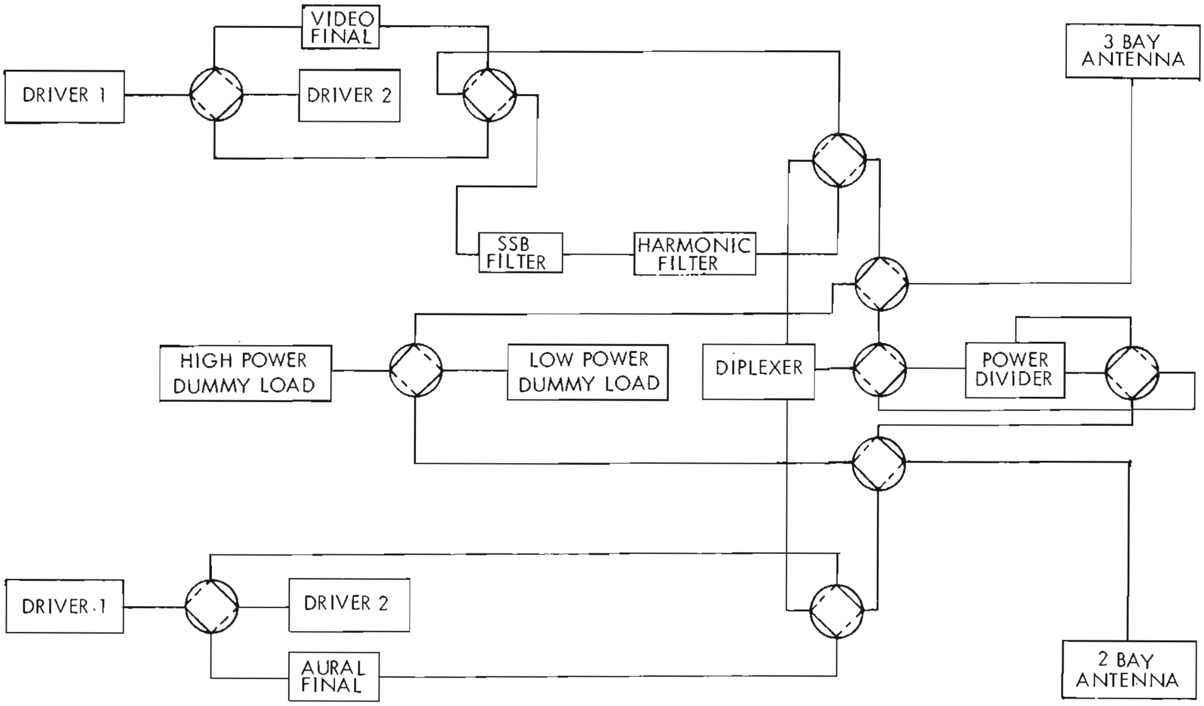


Fig. 35. Complex circuit diagram for switching matrix (see Fig. 37).

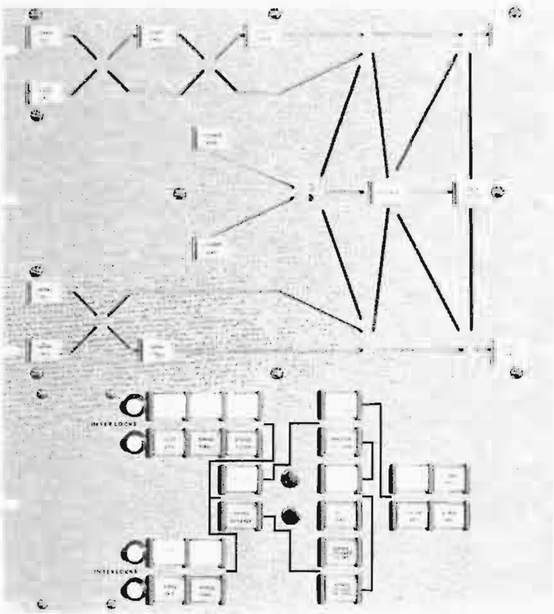


Fig. 36. Remote control panel.

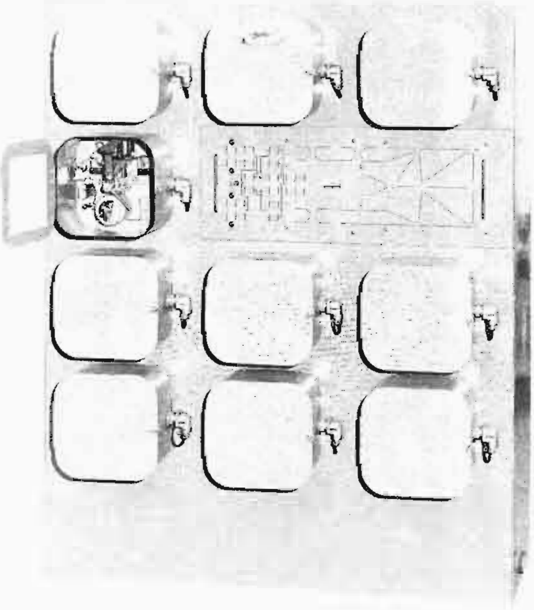


Fig. 37. Switching matrix.

typical copper-clad steel waveguide installation on a 600-ft. tower plus a 30-ft. horizontal run:

BILL OF MATERIALS

Items	*Quantity*	*Use*
1. 90° mitered elbow, flanged	3	For changing line direction
2. Special lengths of line, unflanged	8	For custom applications
3. Soft-soldered flange kit	9	For field flanging lines and elbows
4. Gas barrier	1	For pressure termination of line
5. Straight couplings	7	For joining unflanged line
6. 90° elbow, flanged one end	3	For changing line direction
7. 90° elbow, unflanged	2	For changing line direction
8. Automatic dehydrator	1	For automatically pressurizing line
9. Transition, waveguide to 3-1/8-in. line	2	For RF energy passage from waveguide to coaxial line
10. Tower hanger	59	For attaching waveguide to tower
11. Horizontal hanger	3	For horizontal support of waveguide
12. Waveguide, standard 10-ft. lengths	62	For main run
13. 90° waveguide elbow	1	For changing waveguide direction

2. At the top of the tower (as in the rigid coaxial transmission-line installation) a custom connection to the antenna is necessary. The coaxial connection from the antenna flange to the waveguide transition is made with two 90° mitered elbows, a special length of line cut as required, and two soft-soldered field flanges, as shown in Fig. 38.

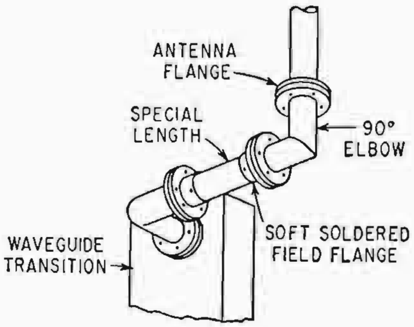


Fig. 38. Installation at top of the tower.

3. Along the tower, the waveguide hangers are used at 10-ft. intervals. They are placed at the middle of each standard 10-ft. waveguide section. Do not support more than one section of waveguide on a flange joint without using a hanger. It is much safer to leave the hoist line tied to the waveguide section until after the hanger attaches the section to the tower. The hangers used are the type that bolt directly to angle-type towers. Lateral-position adjustment is provided. Attachment to the waveguide is not difficult, as the hardware is captive and the clamping plates slide easily into place after the waveguide is positioned. A waveguide installation is shown in Fig. 39.

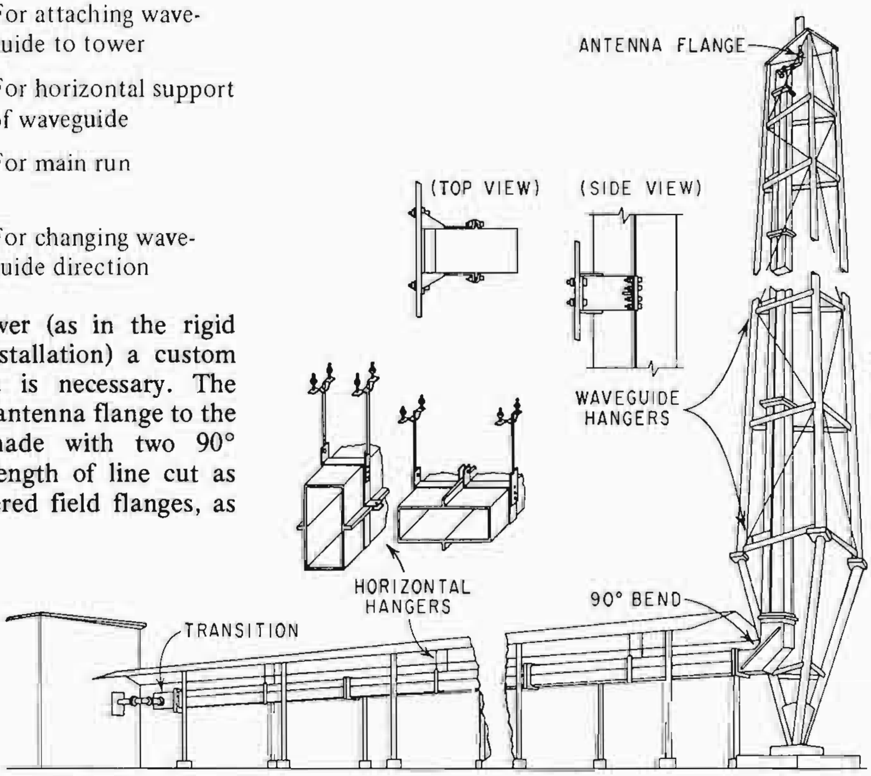


Fig. 39. Installation of Waveguide.

4. At the bottom of the waveguide run, a 90° waveguide bend is used. The one shown in Fig. 39 is an *H*-plane bend. Bends are usually supplied for 45° or 90°, but most suppliers fabricate special bends to customer specifications. A hanger is not required for the bend.

5. The horizontal run is supported with hangers that can be adapted to support the waveguide in either plane, as shown in Fig. 39. These are equipped with threaded adjustments so that perfect alignment of the waveguide sections can be made.

6. A transition is added to the end of the horizontal waveguide run for connection to the 3-1/8-in. coaxial line. (In some installations, the transmitter building is very close to the base of the tower. In such cases the transition can be installed at the bottom of the vertical run of waveguide and coaxial line used for the horizontal run.) From the transition, a 90° mitered elbow and two special lengths of line are used to bring the horizontal run inside the transmitter building. A gas barrier is then attached to the line, and the automatic dehydrator is connected to the gas barrier. For short lengths of line, a dry-air hand pump can be used for pressurization.

7. Once inside the building, all installations, procedures, accessories, etc., are the same for stations using waveguide as they are for those using rigid coaxial transmission line for the main RF feeder.