CHAPTER 4

LF/MF COMMUNICATION EQUIPMENT

4.1 GENERAL

The VLF and LF bands are characterized by the relatively large physical size of the transmitter, helix house, and antenna system, and the power required to transmit these signals. MF transmitting components are somewhat smaller in size.

A Navy MF communication system consists of emergency transmitting and receiving equipment which is maintained in a ready state, the receiver on, and the transmitter in standby. Navy LF transmitting systems presently in operation at various stations, in many cases use portions of previous LF systems that have been modified. The existing helix house and monopole tower is used with updated transmitters and/or other modified equipment. Receiving-systems are primarily located aboard ship; the only shore application is the monitoring of the quality of signals being transmitted by the local LF station.

4.2 TRANSMITTING SYSTEM

A basic LF or MF transmitter is composed of pretransmitting and transmitting equipment.

4.2.1 Pretransmitting Equipment

The LF pretransmitting equipment consists of tape readers or other teletype (TTY) equipments which convert alpha-numeric tape symbology into a series of plain-text DC pulses, cryptographic (crypto) equipments which convert plain-text pulses from the tape-reader into encrypted DC keying-signals, multiplex (mux) equipments which accept the keying signals from several crypto equipments and combined them into a composite signal which modulates the transmitter. The LF pretransmitting equipments are described more fully in the Fleet Multichannel Broadcast System Handbook, NAVSHIPS 0967-376-2010 and the Naval Communication Station Design Handbook, NAVELEX 0101, 102.

Emergency MF communication at 500 kHz uses interrupted continuous wave (ICW) emission only with manual keying (an operator sends the signal, rather than an automatic keyer operating from precut tape). Therefore, the only MF pretransmitting equipment used is a keyer. The standard key is still used, but several devices have been produced which ease the task for the operator and at the same time insure clear, uniform dots and dashes.

One device, an electronic keyer, works with a clapper-type key. The clapper is a single-pole double-throw switch which, when moved in one direction, causes the keyer to produce a series of dots; when moved in the other direction the keyer output is a series of dashes. The dot and dash pulses each are uniform in magnitude, width, and separation. Thus the operator need only synchronize his control of the clapper to produce the proper codes. The vibro-keyer, another convenience-device for the radio operator, is similar to the electronic keyer, except that it is mechanical. When the operator moves the key to one side, it will produce a limited number of dots or dashes (more than enough for any code). Instead of electronic oscillations, a spring-controlled vibrator produces uniform pulses and spacing.

One keyer permits the operator to transmit his message in standard ICW code by depressing the keys of a simulated typewriter keyboard. Most typewriters have 44 keys; this unit has 48 keys, including several frequently-used code combinations. The manufacturer claims an operator should be able to transmit from 12-72 words per minute (without even knowing the code).

4.2.2 Transmitting Equipment

The LF transmitters in present use are the AN/FRT-19 (obsolescent) and AN/FRT-74 which cover the entire LF range of 30 to 300 kHz, the AN/FRT-72 which covers the 30 to 150 kHz range, and the TAB7, TCG (obsolescent).

The sideband frequencies for transmission are produced by the modulator utilizing the frequencies generated by the synthesizer and the information supplied by the tone intelligence unit. Conventional balance modulators and crystal filters are used to generate SSB signal at a fixed frequency of 100 kHz. The 100 kHz is modulated with 2.1 MHz to produce a second intermediate frequency of two megacycles which permits the output frequency range (30-150 kHz) to be covered with the 2.030 to 2.150 MHz variable oscillator of the synthesizer. The unit is capable of operating both sidebands simultaneously with individual gain control for each channel and a voice operated circuit for use on either channel. The capability of carrier reinsertion is provided through a switch on the front panel from -55 dB to 0 dB. The automatic load control level is also controlled from the modulator. Filament and B+ voltage are provided by the modulator power supply.

Aboard ship it would not be cost effective to have separate equipment installed solely for MF emergency transmission. Therefore, ships usually use an MF or HF transmitter which is easily tuneable to the emergency frequency of 500 kHz. Ashore, in communication-center facilities such as sea air rescue or search and rescue activities, a tuned transmitter is always in standby for use on the emergency frequency.

Two transmitters frequently used for MF communications are the AN/FRT-19 and the AN/FRT-74. The former, an LF transmitter which normally operates from 30 to 300 kHz with 15 kW output, is capable of MF operation (to 600 kHz) with a 3 kW output. The AN/FRT-39 is an HF transmitter normally operating from 2 to 28 MHz at 5 kW output, but with the addition of a Low Frequency Adapter, LFA 4, it provides an output of 5 to 500 kHz. When so adapted, the transmitter nomenclature is AN/FRT-74.

a. Radio Transmitting Set AN/FRT-19 (see figure 4-1), a continuous-wave (CW) transmitter used primarily in shore-to-ship communications, operates from a 230-volt 3-phase, 50-or 60-hertz power source and delivers 15-kW RF output in the continuously variable LF range of 30 to 300 kHz to a vertical radiator through an antenna coupler. It may also be operated as an MF 3-kW transmitter over the range of 30 to 600 kHz.

For LF operation this transmitter is capable of providing five types of keying:

- On-off keying (A1 emission) to 600 words per minute (wpm)
- Telegraphy modulated by AF (A2 emission) to 100 wpm
- Frequency-shift telegraphy (F1 emission)
- Frequency-shift telegraphy modulated by an audio frequency (F2 emission with phase modulation)
- Facsimile transmission (F4 emission).

The AN/FRT-19 block diagram (figure 4-1) shows the four transmitter enclosures, cabinets I through IV, and the antenna coupler which make up the major units of the system. Cabinet I contains the frequency generator, crystal oscillator, and keyer. The frequency generator produces a highly stable carrier signal to be keyed by the keying circuits before it is delivered to the amplifier in cabinet II. The output is continuously variable over the 30 to 600 kHz range. The crystal oscillator (which contains 10 crystal units), or an external exciter, may be used instead of the frequency generator as the source of carrier frequency. Only A1 emission is used for MF communication. (See figure 4-2.)

Cabinet II amplifies the RF signal from cabinet I to a maximum power of 3 kW and delivers it to a balanced 300- to 1200-ohm load at any frequency from 30 to 600 kHz. This cabinet contains an overload alarm system which will automatically shut-off plate voltage in cabinets II and III if a pre-determined number of overloads take place within a pre-determined time interval.

Cabinet III amplifies the RF signal from cabinet II to a maximum power of 15 kW and delivered it to a balanced 300- to 1200-ohm load at any frequency from 30 to 300 kHz. The output of cabinet III feeds the transmission line going to the Antenna Coupler Kit, MK-156/FRT-19. This cabinet is by-passed when operating at 500 kHz, and the output of cabinet II is terminated in a balanced 600-ohm resistive load at 3 kW.

Cabinet IV provides 6000 volts DC for the plates of the amplifier tubes in cabinet III. It also contains the remote control panel for the antenna coupler (a duplicate of the control panel in the antenna coupler, to make it possible to tune the antenna from the transmitter).

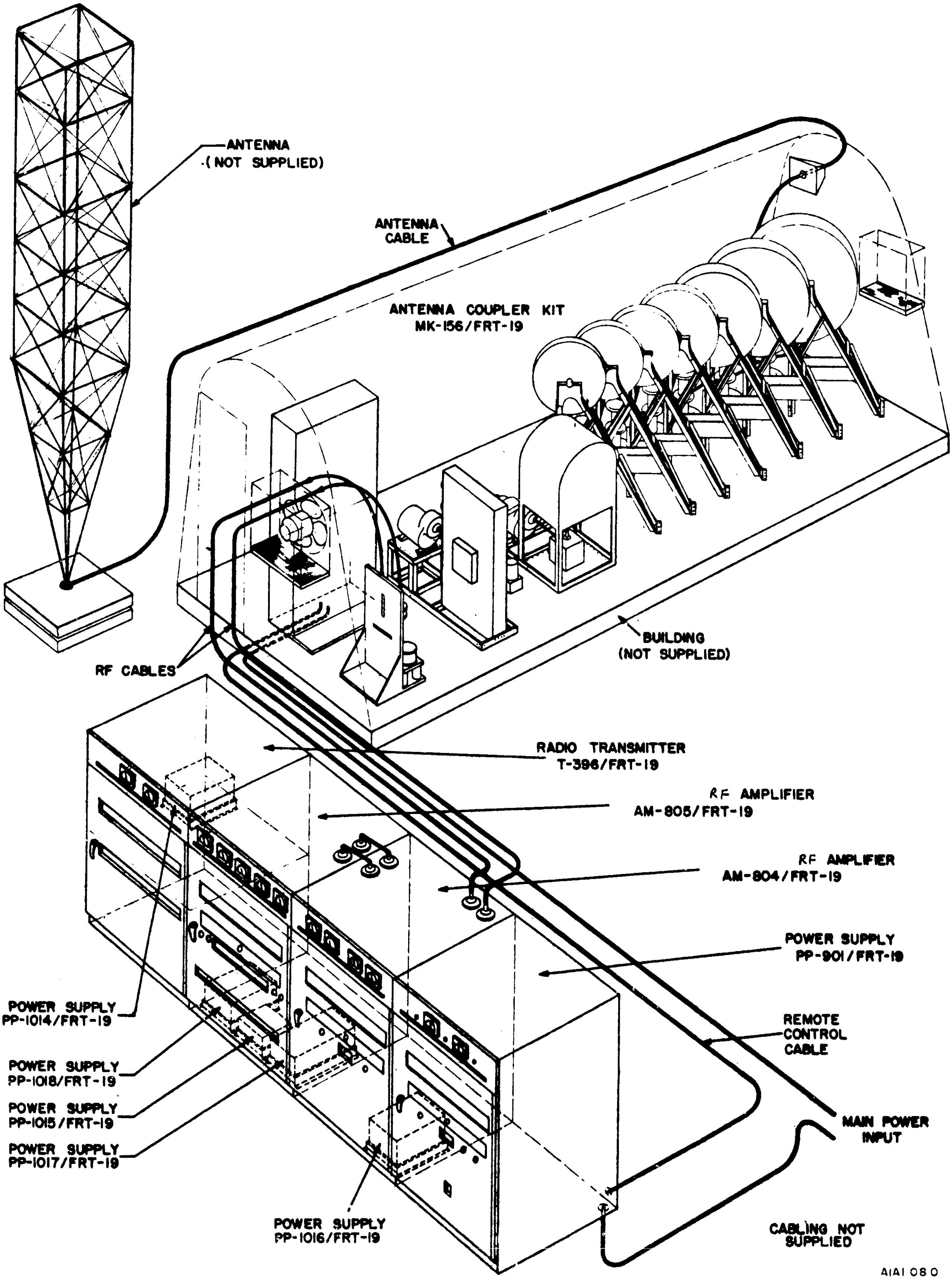


Figure 4-1. Radio Transmitting Set AN/FRT-19 (Obsolescent)

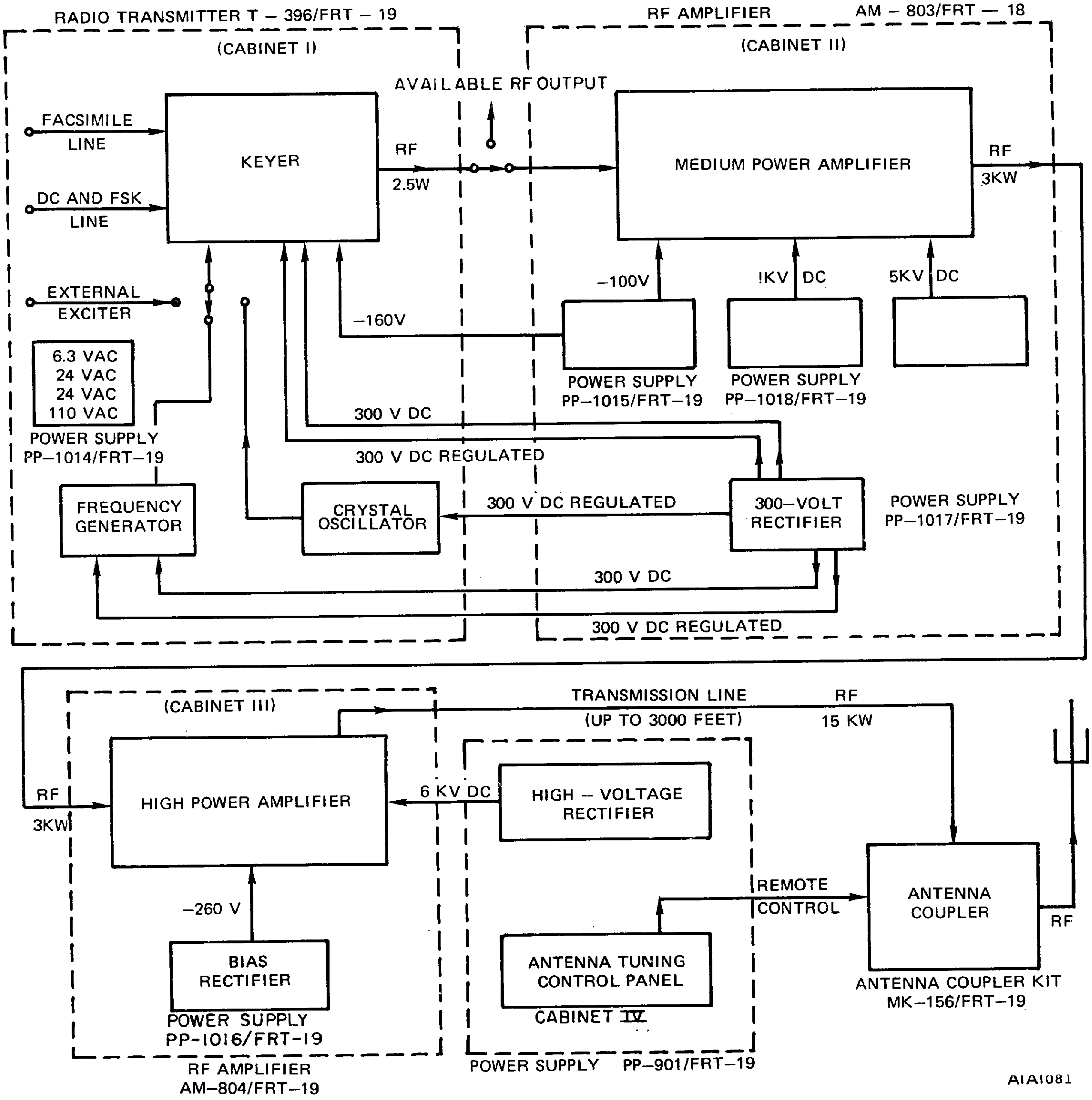


Figure 4-2. Radio Transmitting Set AN/FRT-9, Detailed Block Diagram

The antenna coupler includes a matching network and its control system, a 48 volt DC power supply, and a regulated 105 volt DC power supply. The antenna coupler matches the impedances of the transmission line and the antenna tower, for frequency-antenna height combinations listed in table 4-1. This is done by means of a variometer and a vari-coupler driven by motors, and several capacitors and inductors which may be switched into or out of the circuit electrically. Control is afforded by a local control panel in the house, and remotely by a similar panel in cabinet IV.

Table 4-1. Antenna Characteristics

ANTENNA HEIGHT	FREQUENCY RANGE TUNABLE USING FRT-19 COUPLER
250 feet	100 to 300 kHz
450 feet	60 to 300 kHz
600 feet	45 to 300 kHz
800 feet	30 to 233 kHz
-	500 kHz

b. Radio transmitting set AN/FRT-72 ( ) is a medium-power shore installation transmitter designed for radio telegraph and TTY communications. The relationship of major units and their relative size is shown in figure 4-3. The block diagram of a typical installation is shown in figure 4-4.

A typical helix house floor plan is illustrated in figures 4-5 and 4-6. The transmitters operate from 30 to 150 kHz and consist of two separate power amplifiers, each capable of generating 50 kW peak effective power (PEP) or 25 kW average power. The two power amplifiers are normally independent except for common exciter equipment, but may be inter-connected for 100 kW PEP or 50 kW average power capability. Two separate exciters are supplied, but only one is used as a common excitation-source.

The transmitter provides continuous communications output for varied emission modes. The transmitter is housed in six cabinets. Several cabinet configurations may be utilized as denoted in figure 4-7. Meters, controls, and interlocks denote transmitter operating status, remove high potential during maintenance, and protect components during fault conditions. The transmitter building should provide adequate space to perform necessary maintenance and repairs. Sufficient clearance should also be provided to allow front and rear cabinet doors to be fully opened. Equipment layouts, interface wiring requirements, and power input data is provided by NAVELEX Standard Plans for each transmitter configuration.

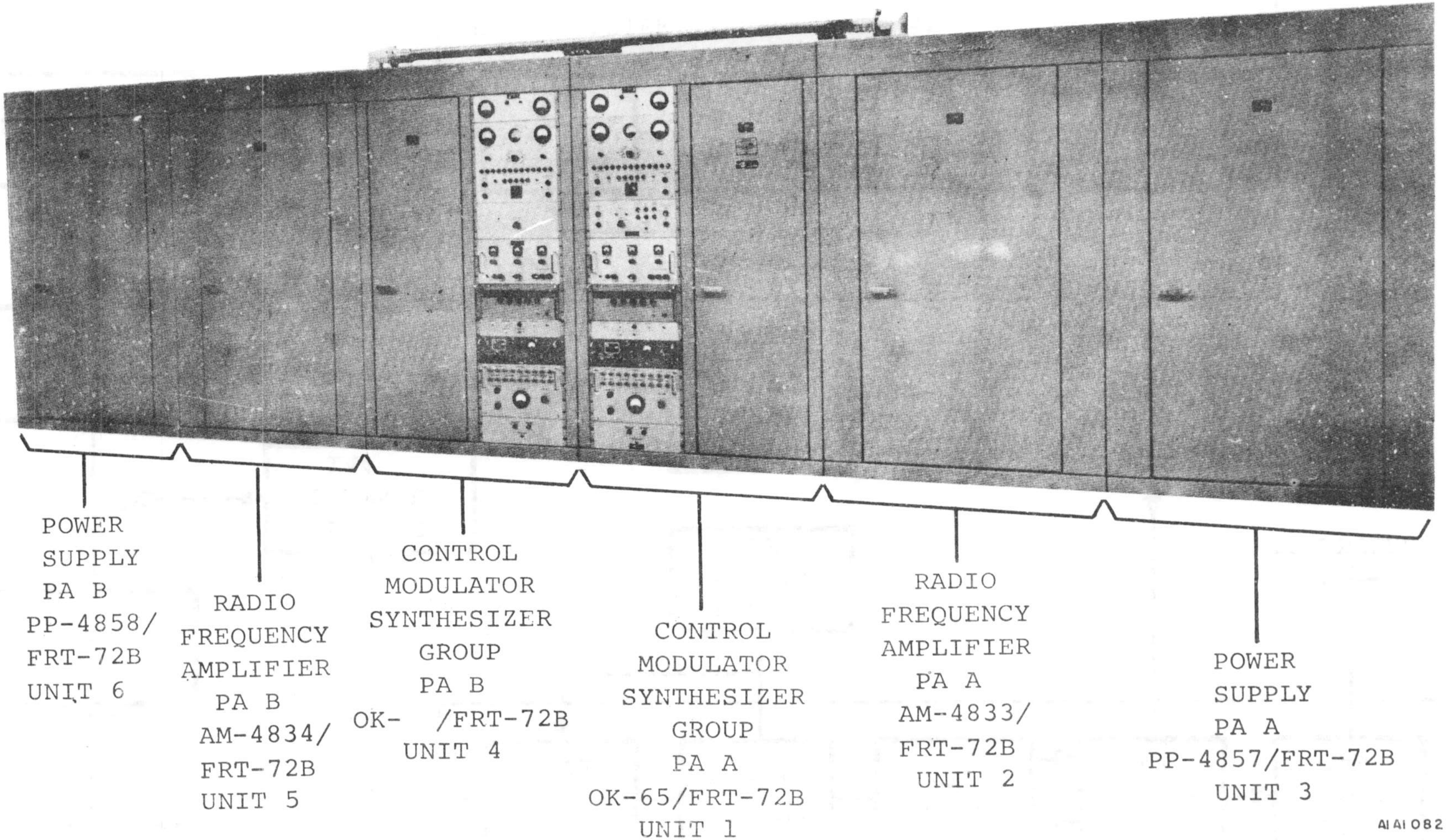


Figure 4-3. Radio Transmitting Set AN/FRT-72B, Pictorial View

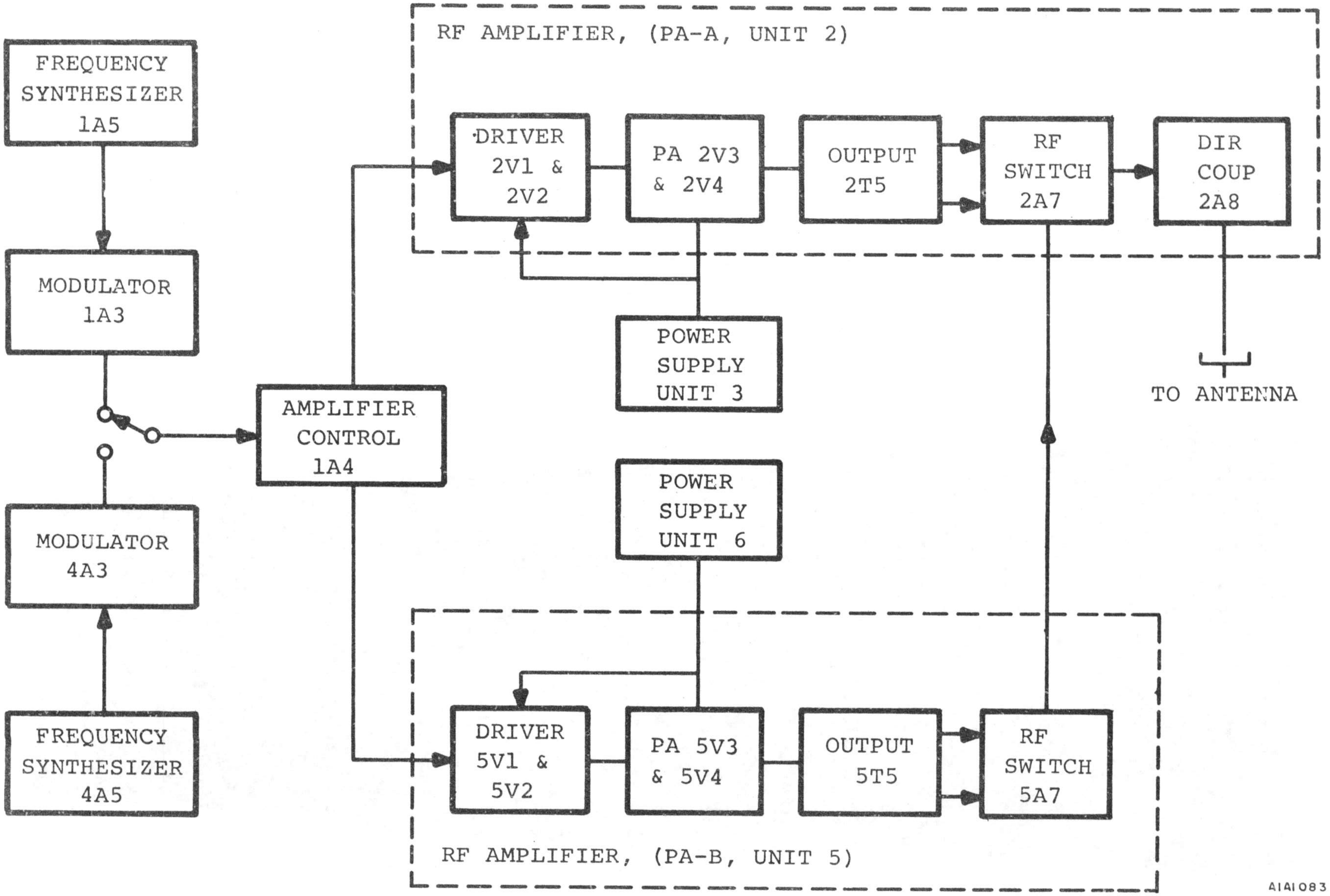


Figure 4-4. Radio Transmitting Set AN/FRT-72B, Block Diagram

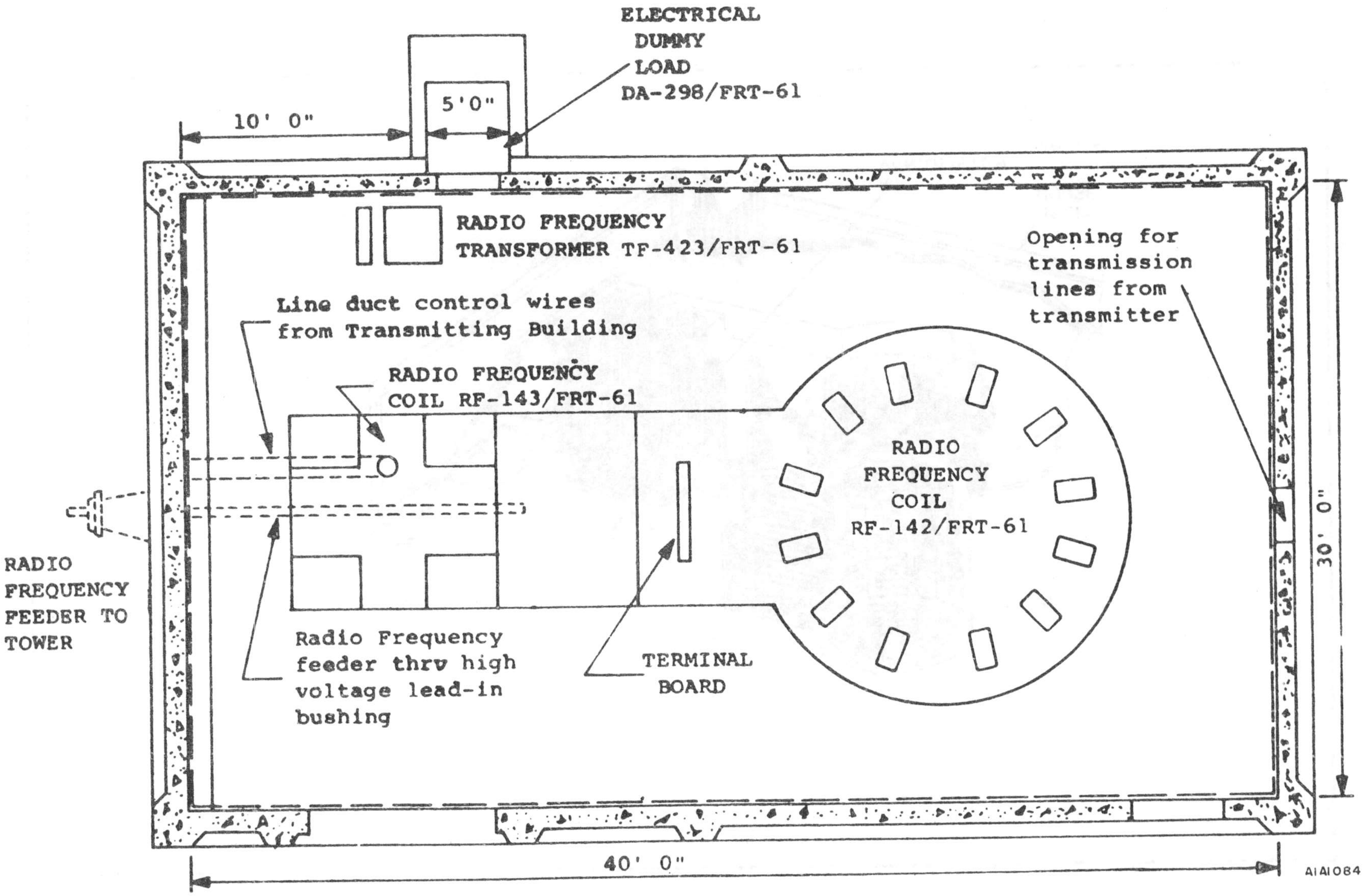


Figure 4-5. Helix House Floor Plan, Typical

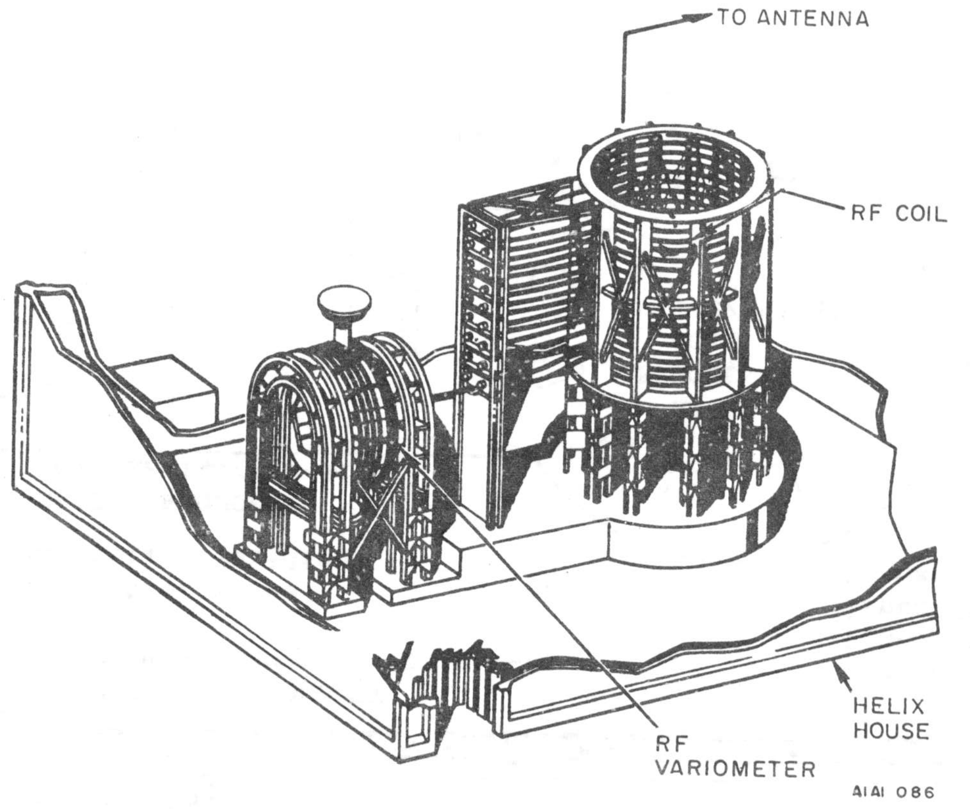
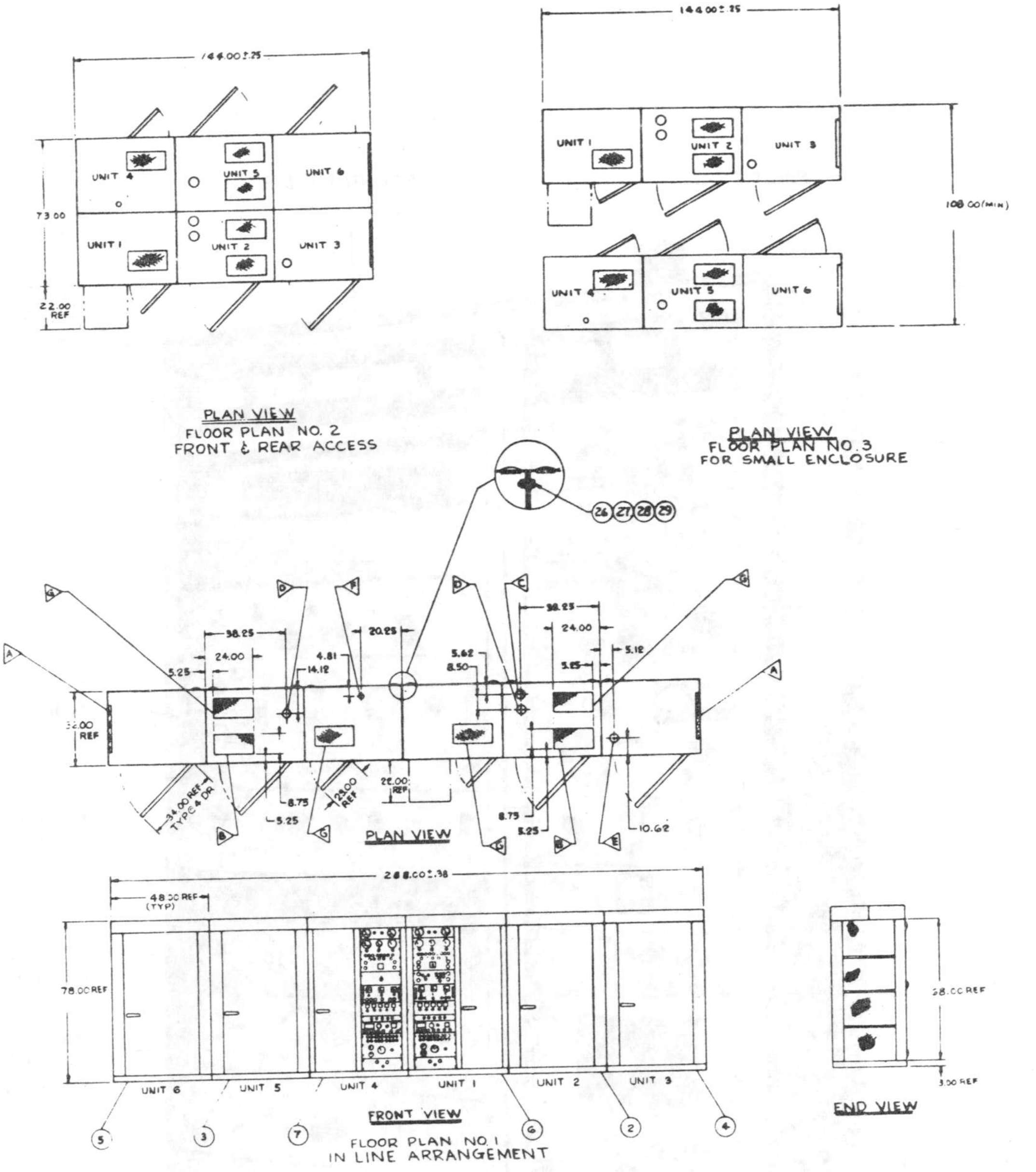


Figure 4-6. Typical Helix House Tuning Equipment



Ⓐ AIR INTAKE-26" X 68" FILTER AREA 72 LBS/MN MASS AIR FLOW. SIDES OF TRANSMITTER MAY BE PLACED AGAINST WALLS IF THRU-WALL AIR FLOW OPENING IS PROVIDED. MAXIMUM ALLOWABLE PRESSURE DROP IN EXTERNAL DUCT 0.25" WATER.

Ⓑ AIR EXHAUST-9 X 19 OPENING 1600 CFM. MAXIMUM ALLOWABLE PRESSURE DROP IN EXTERNAL DUCT 0.25" WATER HEAT EXHAUSTED IS APPROXIMATELY 120,000 BTU HOUR.

Ⓒ RF OUTPUT 3-1/8" EIA 50 OHM RIGID COAX.

Ⓓ RF INTERCONNECT-3-1/8" EIA 50 OHM COAX. (NOT FURNISHED)

Ⓔ POWER INPUT 2-1/2" OR 3-1/2" NOMINAL CONDUIT.

Ⓕ AUDIO INPUT/REMOTE CONTROL-1" CONDUIT UNIT NO. 4.

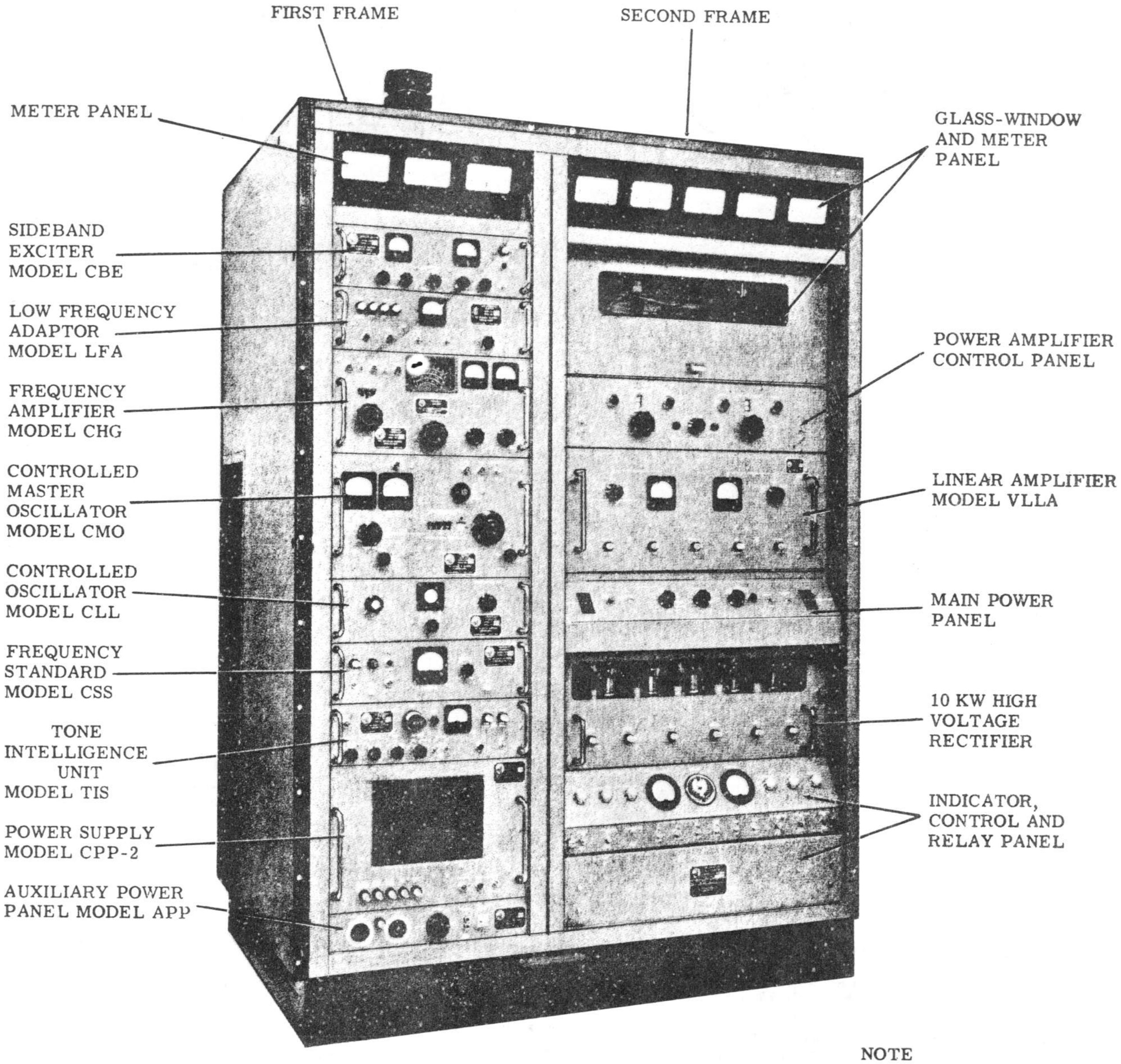
Ⓖ AIR EXHAUST-NOT DUCTED.

NOTE: TOTAL TRANSMITTER CABINET HEAT RADIATION (INCLUDING EXHAUSTS NOT DUCTED) IS APPROXIMATELY 135,000 BTU HOUR

AI AI 085

Figure 4-7. AN/FRT-72 ( ) Equipment Floor Plans

c. The AN/FRT-74 transmitter (see figure 4-8) is a conservatively rated general purpose HF transmitter. By addition of a Low Frequency Adapter the unit is converted to a LF transmitter AN/FRT-74 with the technical characteristics shown in table 4-2.



NOTE
POWER SUPPLY MODEL CPP-5 AND DIVIDER CHAIN MODEL CHL ARE MOUNTED IN THE REAR OF THE FIRST FRAME

AIAI087

Figure 4-8. LF General Purpose Transmitter, AN/FRT-74

Table 4-2. LF Transmitter Technical Characteristics

CHARACTERISTICS	PERFORMANCE
Frequency range (synthesized)	5 to 500 kHz in 100-Hz steps; 500 to 540 kHz at half power CAUTION Below 50 kHz, caution should be observed in broadband modes of operation
Modes of operation	AM, AME, CW, FAX, FSK, SSB, ISB, and pulse. (Restrictions of antenna system and bandpass limit modes below approximately 50 kHz)
Output power	a. Up to 10 kW PEP on a standard two tone test. b. Up to 25 kW peak power with up to 64-channel multitone TTY input. c. Up to 25 kW PEP on a 10%-duty cycle for pulse operation.
Output impedance	50 ohms; will match a load of 25 to 120 ohms, resulting in a VSWR (voltage standing wave ratio) of not more than 2:1
Stability and accuracy	1 part in 10^8 per day for an ambient temperature change of 59° to 15°C within the operating temperature range
Signal/Distortion ratio	Distortion products are at least 35 dB below PEP
Unwanted sideband rejection	A signal at 500 Hz is at least 60 dB down from PEP in unwanted sideband

Table 4-2. LF Transmitter Technical Characteristics (Continued)

CHARACTERISTICS	PERFORMANCE
Spurious signals	Spurious signals greater than 60 Hz removed from the carrier are at least 60 dB below PEP output.
Noise level	At least 70 dB down from either tone of a two tone test
Carrier insertion	-55 dB to full output
Harmonic suppression	Push-pull output tends to cancel even harmonics. Third harmonic at least 50 dB below PEP output when properly loaded
Audio response	Flat within ± 1.5 dB, 250 to 3300 Hz, crystal lattice filter, both upper and lower sidebands
Audio input	Two independent 600-ohm channels balanced or unbalanced, -20 to + 15 dB. Minus 20 dB input will provide full output.
Hum level	At least -60 dB below PEP
Heat dissipation	Approximately 15 kW
Operating temperature	32° to 122°F (0° to 50°C)
Humidity	Up to 95%
Cooling	Forced-air cooled
Storage	
Temperature extremes	85° to 122°F (-65° to 50°C)
Humidity	0 to 95%

d. The AN/FRT-74 transmitter is housed in two frame assemblies. The left frame houses an audio-shift keyer and an exciter. The right frame houses a driver amplifier and a 10 kW power amplifier and associated power supply.

The audio-shift keyer, TIU, accepts the inputs to the transmitter and its output is fed to the exciter which provides a highly stabilized LF output. The SBG output is fed to the broadband linear driver amplifier. The amplified LF output is applied to the power amplifier, further amplified, and applied to the antenna.

The transmitter converts audio, facsimile, telegraph, TTY, or pulse inputs into AM, CW, FAX, FSK, ISB, SSB, or pulse output in the LF range of 5 to 540 kHz. All inputs to the transmitter, foldout 4-1, are applied to the TIU. Facsimile, telegraph, or TTY inputs are converted into keyed or frequency-shifted audio tones to eliminate direct keying or frequency-shifting of the carrier. The outputs (audio or audio tones), as channels 1 and 2, are applied to the sideband exciter. Channel 1 is frequency-translated into the upper sideband and channel 2 into the lower sideband (or vice versa) of the 250 kHz carrier obtained from the frequency amplifier. The resulting 250 kHz dual-sideband output (conventional AM, CW, FAX, FSK, SSB, or pulse emission) is again frequency-translated into a synthesized dual-sideband output in the range of 1.75 to 33.75 MHz. This output is applied to the frequency converter and heterodyned with a 2 MHz signal derived from the 1 MHz signal applied by the frequency standard. Heterodyning results in a dual-sideband output within the range of 5 to 540 kHz. The linear amplifier and 10 kW power amplifier amplify the LF dual-sideband output and apply it to an output device.

The transmitter requires single and three-phase AC line voltage.

The indicator, control, and relay panel monitors significant currents and voltages in the linear and power amplifiers. Abnormal current or voltage automatically causes a signal to be applied to the main power panel to remove primary power from the linear amplifier power supply and high voltage power supply.

The transmitter contains electro-mechanical interlocks and relays for the protection of personnel and equipment. Certain interlocks reduce the possibility of personnel accidentally being exposed to lethal voltage; other interlocks and relays prevent improper initial settings, loss of air cooling, misadjustment during operation, loss of bias, and overload conditions from damaging the equipment. In all cases of an interlock or relay activating and short-circuiting the high voltage, primary AC voltage is still present.

4.3 TRANSMITTING ANTENNAS

4.3.1 Antenna Types and Characteristics

The types of LF antennas in present operation include the umbrella top-loaded monopole (Navy standard), Nord, Pan-Polar, monopole Inverted-L and TEE (the latter three are also used at MF). The main difficulty in LF and VLF antenna design is the physical disparity between the maximum practical size of the antenna and the wavelength of the electromagnetic wave it is to propagate.

The use of capacitive top-loading increases the bandwidth-efficiency product of a monopole antenna as compared to that of a non-top loaded monopole of the same tower height. Certain unique methods of feeding and loading an LF antenna of a given size may increase bandwidth, but not bandwidth-efficiency product and may thus result in lower system efficiency.

Transmitting antennas for MF (300 - 3000 kHz) are generally vertical radiators ranging in height from one-sixth to five-eighths wavelength or higher, depending on the operating characteristics desired, frequency, and economic considerations. Physical heights generally vary from about 150 to 900 feet above ground, making the use of towers as radiators practical. The towers may be guyed or self-supporting, and are usually insulated from ground at the base, although grounded, shunt-excited radiators are occasionally used. Further details on MF antenna design and theory is presented in chapter 20 of Antenna Engineering Handbook by H. Jaisk (1961), as well as other reference books.

Maximum radiation is produced in the horizontal plane, increasing with radiator height up to a height of about five-eighths wavelength. The radiated field from a single tower is uniform in the horizontal plane, but decreases with angle above the horizon and is zero toward the zenith. Radiators taller than one-half wavelength have a minor radiation lobe at high vertical angles. Figure 4-9 shows vertical radiation-patterns for several common antenna heights, both for constant power and for constant radiated field in the horizontal plane.

Current return takes place through the ground plane surrounding the antenna. High earth current densities are encountered and require metallic ground systems to minimize losses.

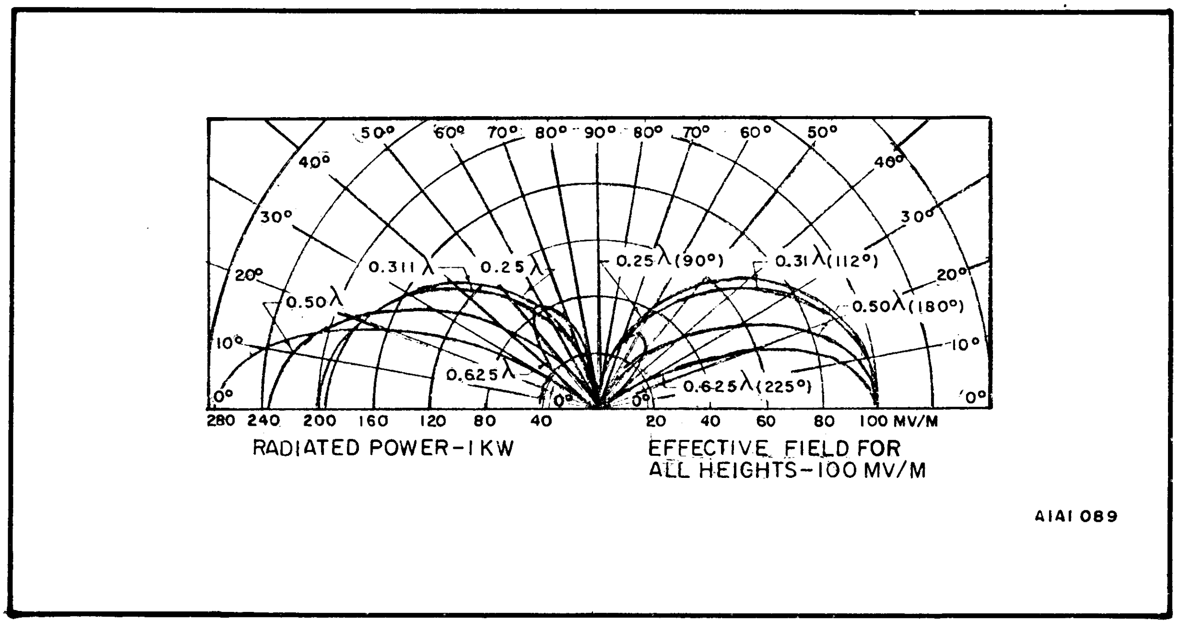


Figure 4-9. Vertical Radiation Patterns for Different Heights of Vertical Antennas

Vertical polarization is almost universally used because of superior ground-wave and sky-wave propagation characteristics. Ground-wave attenuation is much greater for horizontal than for vertical polarization, and ionospheric propagation of horizontally polarized signals is more seriously influenced by geomagnetic latitude and direction of transmission. Horizontal antennas immediately above ground produce negligible fields in the horizontal plane, but radiate relatively large fields at high vertical angles for low antenna heights. This high-angle radiation is desirable only under special circumstances.

a. Characteristics of Vertical Radiators. Characteristics of tower antennas are ordinarily computed assuming sinusoidal current distribution in a thin conductor over a perfectly conducting plane earth, with wavelength along the radiator equal to wavelength in free space. The effect of the earth plane is represented by an image of the antenna (see figure 4-10). These assumptions provide sufficiently accurate results for most purposes, but in the determination of base operating resistance and reactance and vertical radiation patterns, the finite tower cross-section must be taken into account. Except as noted, all formulas and data in this chapter are based on the assumptions stated.

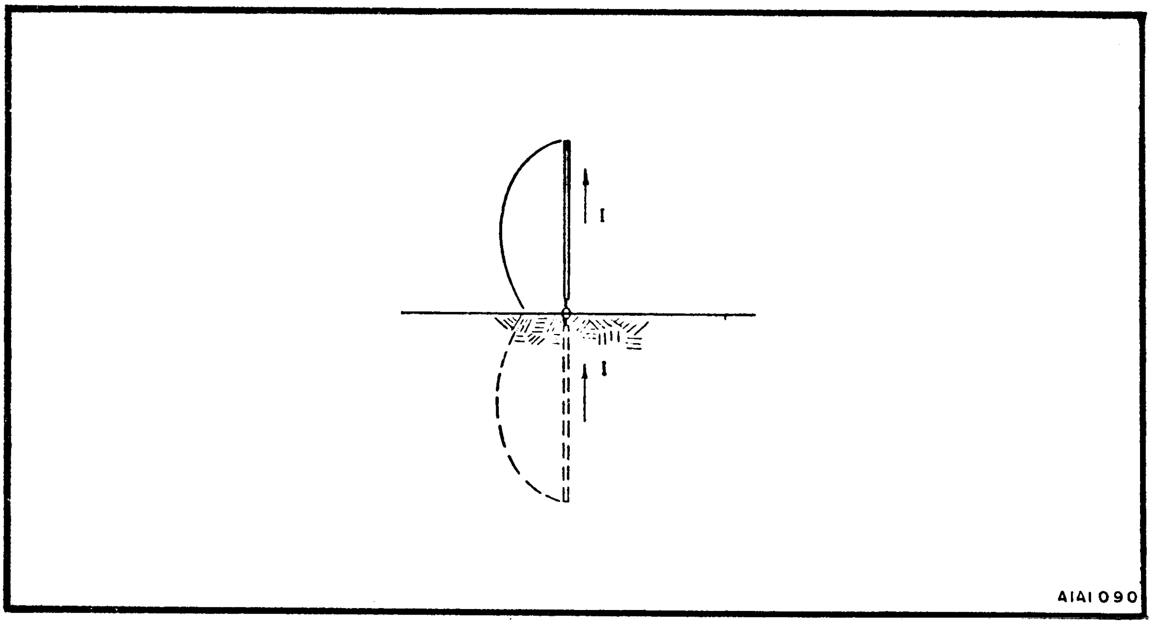


Figure 4-10. Current Distribution on Vertical Antenna and Image of Vertical Antennas Over Perfectly Conducting Plane

The field in the horizontal plane is a function of current flow and electrical height. For uniform current in a vertical radiator over a perfectly conducting plane earth, the radiated field is 0.651 MV/meter (unattenuated field at 1 mile) per degree-ampere. For other current distributions, radiation is proportional to maximum current and antenna form factor, K. For sinusoidal current distribution, the radiated field is

$$E_r = 37.251_o(1 - \cos G) \text{ unattenuated field, MV/meter at 1 mile}$$

where:

I_o = loop current in amperes

$1 - \cos G = K$, form factor for sinusoidal current distribution

G = electrical height of radiator above ground

Loop current (I_o) is related to radiated power (P_r) by the loop radiation resistance $R_r = P_r/I_o^2$. Figure 4-11 shows the radiated field for a power of 1 kW and radiation resistance as a function of antenna height G. The radiation resistance may be calculated from the following equation.

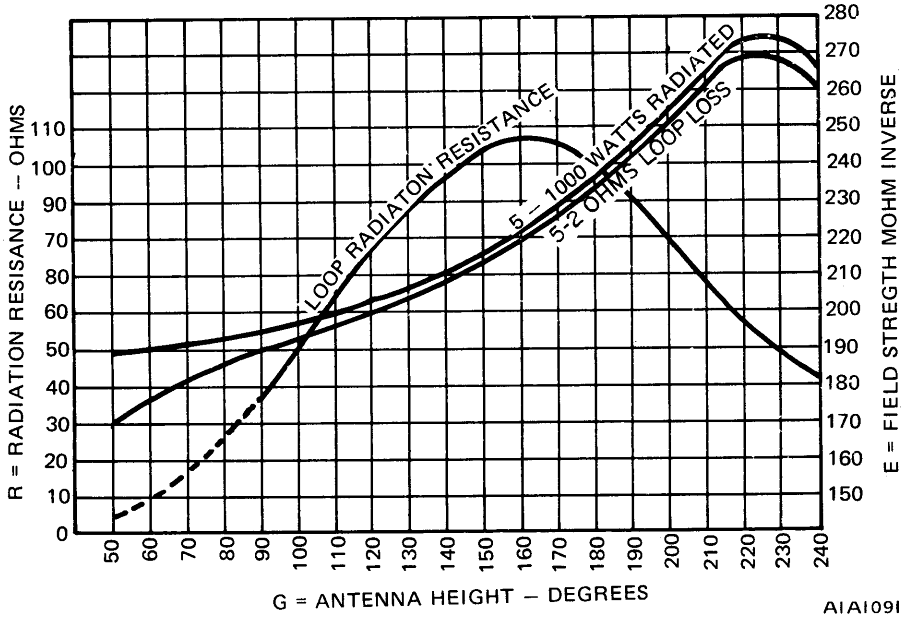


Figure 4-11. Radiated Field and Radiation Resistance as a Function of Antenna Height G

$$R_r = 15[4 \cos^2 G \,\mathrm{Cin}\,(2G) - \cos 2G \,\mathrm{Cin}\,(4G) - \sin 2G[2\mathrm{Si}\,(2G) - \mathrm{Si}(4G)]]$$

where:

$$\mathrm{Cin}\,(x) = \int_0^x \frac{1 - \cos x}{dx}\, dx \text{ (cosine integral)}$$

$$= \ln x + C - \mathrm{Ci}\,(x)$$

$$\mathrm{Ci}\,(x) = \int_x^\infty \frac{\cos x}{x} dx \text{ (cosine integral)}$$

$$C = 0.5772 \ldots. \text{ (Euler's constant)}$$

$$\mathrm{Si}\,(x) = \int_0^x \frac{\sin x}{x} dx \text{ (sine integral)}$$

For sinusoidal current distribution, base radiation resistance is related to loop radiation resistance by R_r (base) = R_r (loop)/$\sin^2 G$. However, the actual base resistance of a practical tower radiator may vary widely from this value because of the finite tower cross-section and other effects. The operating base resistance and reactance may be estimated from figures 4-12 and 4-13, which shows base resistance and reactance as a function of characteristic impedance given approximately by

$$Z_o = 60 \left(\ln \frac{2G}{a} - 1 \right) \text{ ohms}$$

where a = equivalent radius of antenna.

The relative field pattern in a vertical plane through the radiator (the vertical-radiation characteristic) is defined as having unit value in the horizontal plane ($\Psi = 0^\circ$). Based on the above assumptions, the vertical-radiation characteristic is

$$f(\Psi) = \frac{\cos (G \sin\Psi) - \cos G}{(1 - \cos G) \cos\Psi}$$

4.3.2 Antenna Configurations

a. Inverted-L Antennas. The basic inverted-L antenna is illustrated in figure 4-14. The horizontal wire portion is used for capacitive top-loading, which increases the total electrical length of the antenna and permits more current to flow in the vertical portion and increases the effective height. Radiation resistance increases with the length of the vertical part of the antenna. Antenna impedance is directly related to its total length (vertical plus horizontal portions). Antenna capacitive reactance decreases with the length of the flat-top portion of the antenna. The tuning unit also matches antenna impedance to that of balanced or unbalanced transmission lines, as required. The efficiency of a multiple-wire flat-top inverted-L antenna (see figure 4-14) is somewhat better than that of the basic single-wire type.

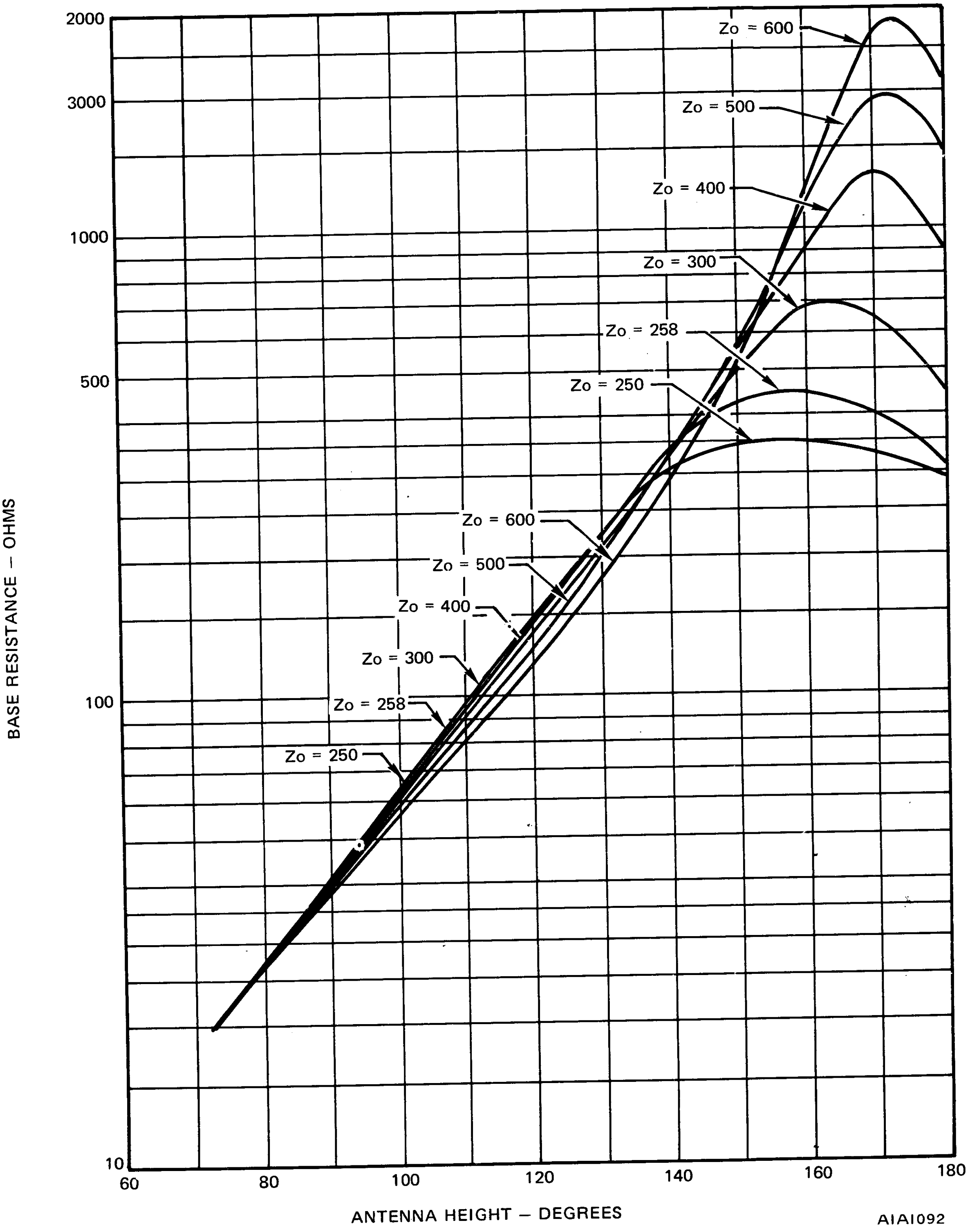


Figure 4-12. Base Resistance of Cylindrical Antennas as a Function of Characteristic Impedance

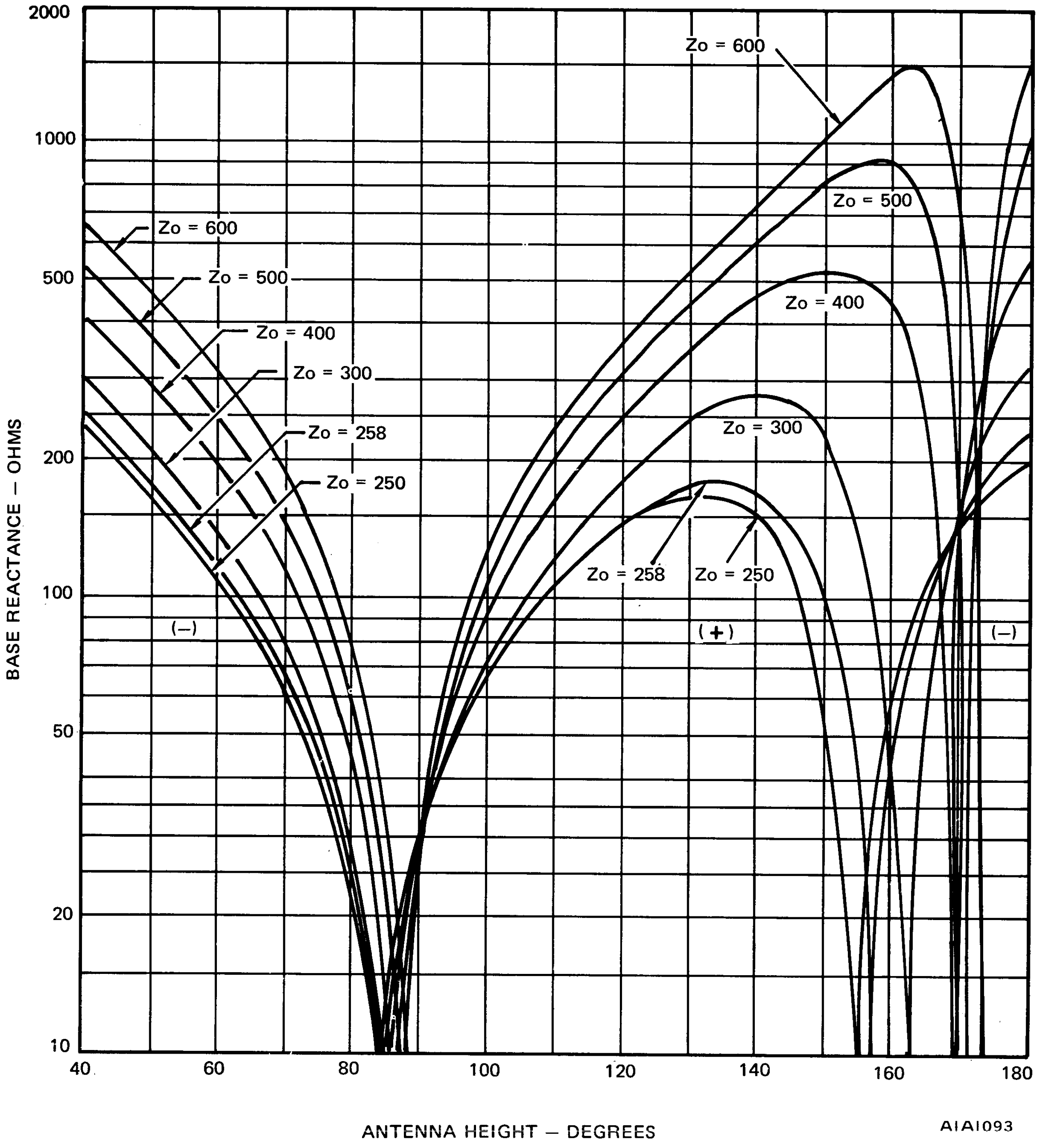
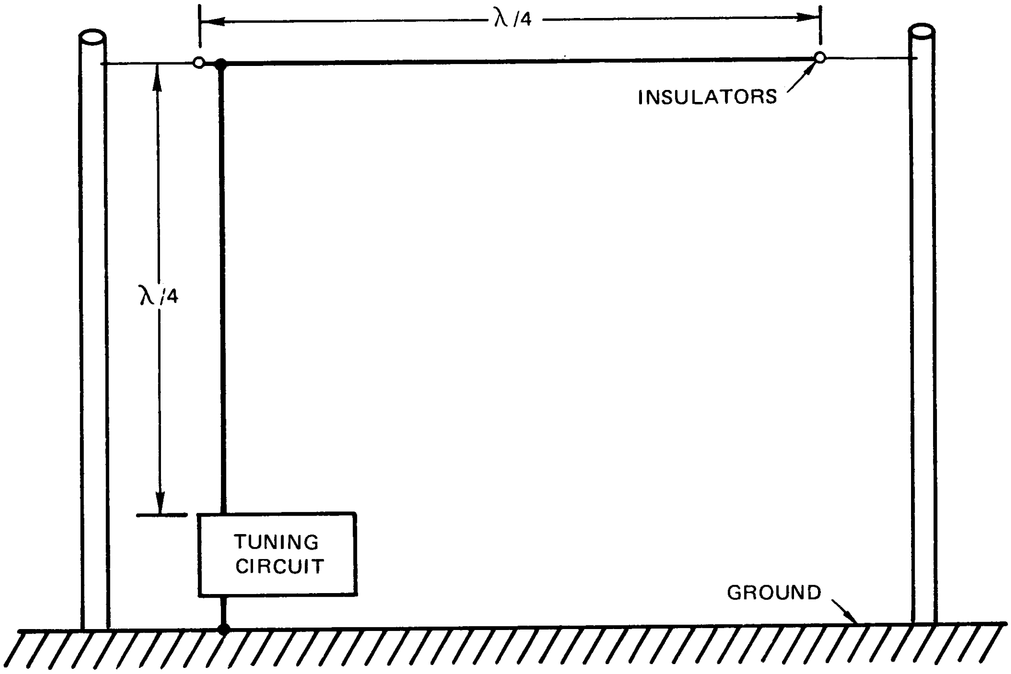
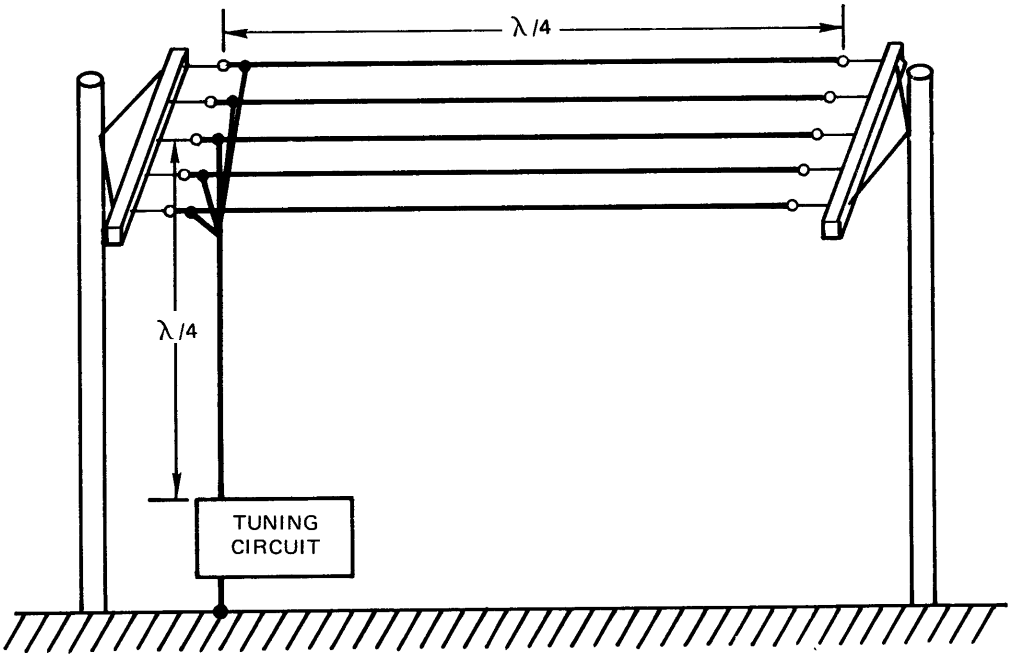


Figure 4-13. Base Reactance of Cylindrical Antennas as a Function of Characteristic Impedance



① SINGLE – WIRE FLAT – TOP (BASIC)



② MULTI – WIRE FLAT – TOP

Figure 4-14. Inverted-L Antenna Configurations

Since antenna effective height and radiation-resistance increases with antenna height, the antenna should be as high as practicable. The flat-top portion of the antenna should be as long as possible, since antenna input capacitance increases with flat-top length and a reduction in tuning coil inductance and losses can be achieved.

A typical system for the antenna consists of a minimum of 120 radials buried 10 to 12 inches below the earth's surface with a desired length of approximately 1/10 wavelength minimum. Caging of top-loading and vertical downlead and use of corona rings as appropriate will be necessary for high voltage applications. An electrically short inverted-L antenna is nondirectional in azimuthal pattern.

b. T-Antennas. The basic Tee antenna is illustrated in figure 4-15. The T flat-top, folded flat-top, and T-cage antennas (figure 4-15) have greater bandwidth efficiency products than the basic Tee antenna of the same dimensions.

c. Umbrella Top-Loaded Monopole. This is a base-insulated tower which is top-loaded with a specific number of radials, is guyed with cables insulated from the tower, has an extensive ground system, and is generally 300 to 1200 feet in height (depending on transmitter operating frequency). For a comprehensive treatment of LF top-loaded antennas, with clearly defined equations, charts, and graphs, refer to Navy Electronics Laboratory report NEL/1381 of 1966. An LF antenna design must be based on a compromise between electrical performance and structural feasibility and cost. Model-measurements may be conducted to determine the variation of effective height, static capacitance, and the resulting antenna bandwidth as a function of the number and length of radials for a given tower height. These measurements may be made for various angles between top-load conductors and the tower. A 45-degree angle represents what appears to be a reasonable compromise between electrical and structural considerations and is representative of most single-tower umbrella top-loaded antenna designs. For a 600-foot tower, the optimum length of radials is about 580 feet (this optimum is broad). The increase in bandwidth will be about 21 percent for 24 top-hat radials as compared to 12 top-hat radials. Since this is not a major gain, the increase in cost may not justify the larger number of radials. The preferred design approach would be to compare the cost of a slightly higher tower with 12 top-hat radials (to obtain equivalent performance) with that of the tower using a larger number of top-hat radials. Since bandwidth for a given frequency and efficiency is proportional to the third power of height, the relative height is the third root of 1.21 or 1.066. Thus a 6.6 percent increase in height will provide a bandwidth equivalent to that obtainable with twice the number of radials. In future designs, structural engineers should estimate the cost of the two approaches to obtain a more exact optimum. Where height is fixed, a larger number of radials is clearly indicated if lowest possible frequency of operation is imperative. For existing towers, consideration must also be given to allowable loading of the tower or base insulator when determining the number of radials to be used in a modification. It is expected that the optimum number will be very broad and will lie between 12 and 24. For an optimally top-loaded tower antenna the lowest recommended operating frequencies at each height are: 360-foot, 125 kHz; 600-foot, 85 kHz; 800-foot, 69 kHz; and 1200-foot, 50 kHz.

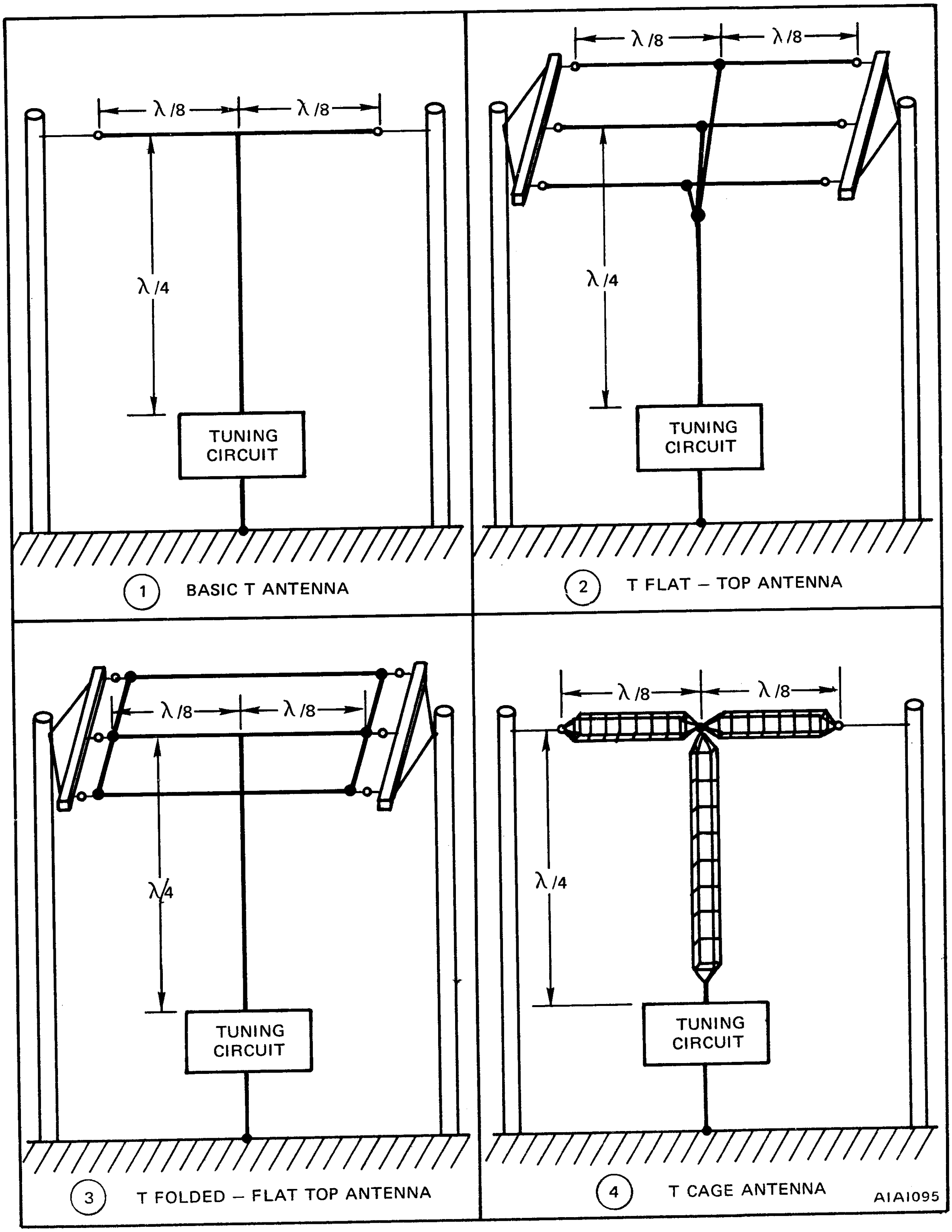


Figure 4-15. T-Antenna Configurations

d. Several other single-tower LF antennas, such as Pan Polar and the Nord, are in use. The top-load configuration of the Pan Polar is similar to that determined from model-studies to be optimum for the umbrella top-loaded monopole. It has three loading inductors (loops) spaced 120 degrees apart which are formed by interconnections between the tower guy cables, with two of these loops terminating at the ground system, and the other as a feed. This triple folding approach provides an impedance transformation. Tuning is effected by changing the loop inductor configurations, series-resonating the resultant impedance with variable capacitors, and effecting a 50-ohm transmitter-match with an iron-core transformer. A thorough evaluation of Pan Polar antenna indicates that its efficiency-bandwidth product is not as great as that of the equivalent antenna with the same top-load configuration fed through an insulated tower. An example of this type of antenna is shown in figure 4-16.

e. The Nord antenna, fed by the folded-unipole principle, is a vertical-tower radiator grounded at the base, fed by one or more wires (or folds) connected to the top of the tower as shown in figure 4-17. In addition to feeding the antenna at its base as a folded-unipole type, three wires attached to the top of the tower at 120-degree intervals are used for top-loading. The three top-loading wires extend from the top of the tower to three termination poles or towers located at a distance from its base equal approximately to the height of the tower plus 100 feet. These poles are one-third the height of the tower. At the top of each pole an insulator is inserted between the top-loading wire and ground. From the end of each top-loading wire, a connection is run down to the Guy Termination Unit (GTU) which contains lumped shunt capacitors to ground. As a result, the effective height of the antenna will be greatly reduced as the sum of the GTU shunt capacitance approaches or exceeds the capacitance of the top-loaded antenna itself. The impedance of the antenna is controlled by:

- Spacing of the fold, or folds, from the tower
- The tower diameter, as well as the diameter of the folder wire, or wires
- The angle (top-loading depression angle) or at which the guy wires and the tower, and the height of the grounded top-loading support structures
- The length of the top-loading wires
- Use or non-use of an interconnecting skirt-wire connecting the outer ends of the three top-loading guy wires to completely enclose the cone
- Use of a shorting stub connection between the fold, or folds, and the antenna
- Location of the GTU's at the termination poles, versus locating them at the tower base and returning the currents by transmission lines
- The number of folds
- The height of the grounded tower

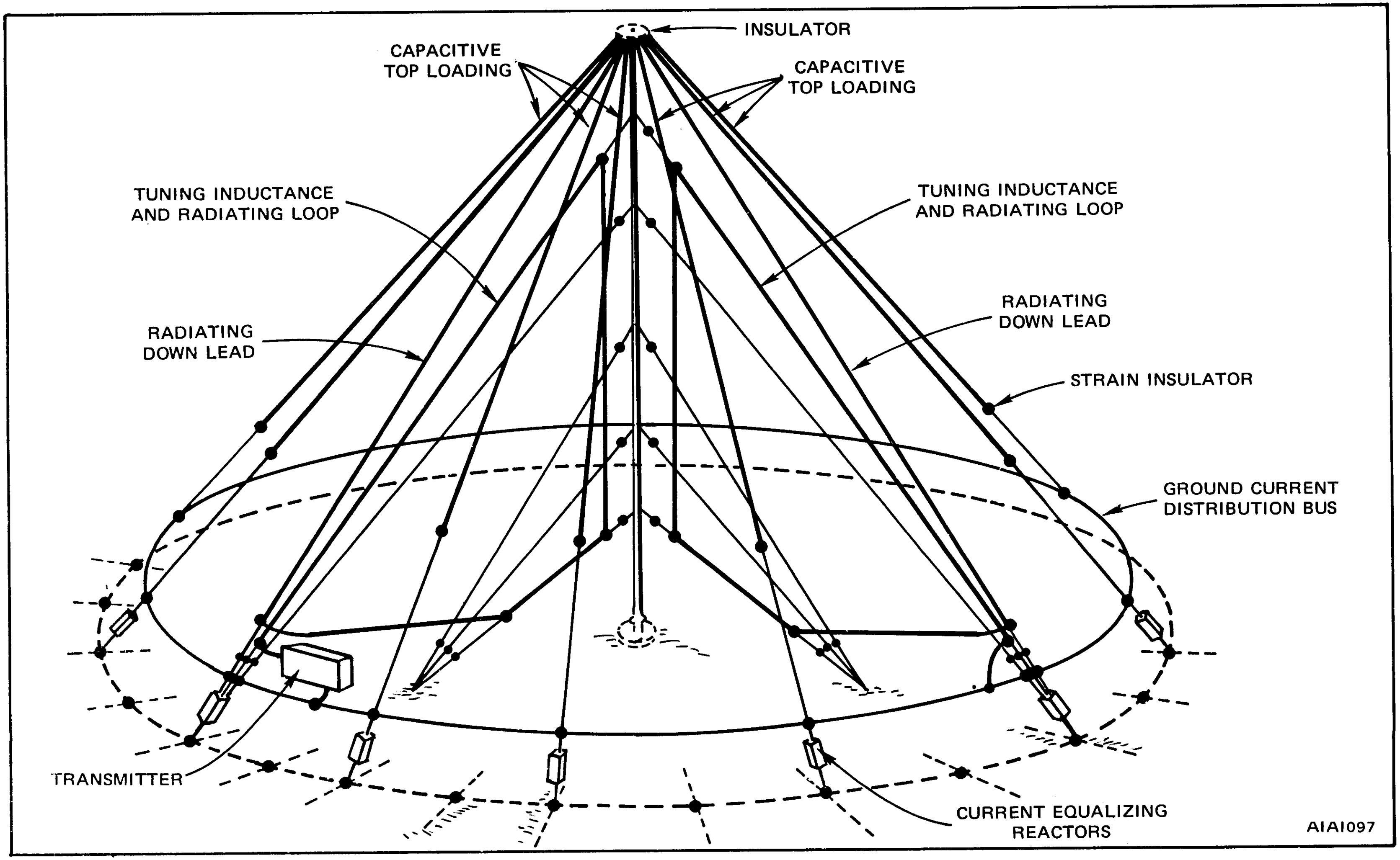


Figure 4-16. 630-Foot Pan Polar LF-VLF Antenna

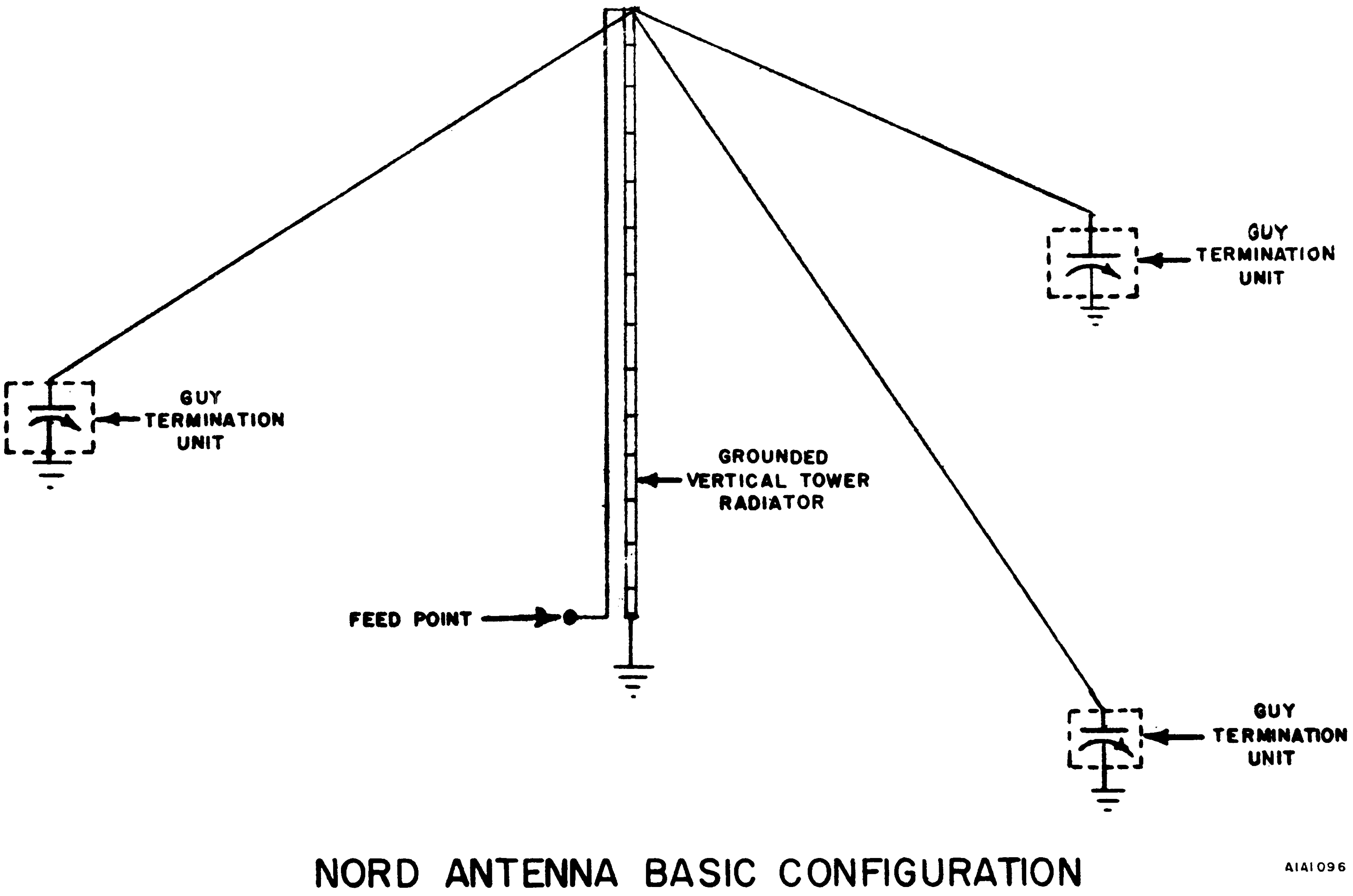


Figure 4-17. NORD Antenna Basic Configuration

- The type of ground system used

- The type of network used at the guy wire terminations.

The Nord base-resistance between 100 to 200 kHz for a short tower (300 to 400 feet) can be varied from approximately 20 to several hundred ohms. Base reactance is inductive, varying from a few ohms to approximately 1400.

All available data indicates that the limitations imposed by conventional top-load capacity and average top-load electrical height are fundamental, and that attempts to circumvent these limitations by rearranging the method of feed or tuning will not result in significant improvements.

To cover a given broadcast area it is essential that a given radiated power be available. Antenna efficiency is important, but must sometimes be sacrificed to obtain desired bandwidth (single-channel transmission may require only a 170 Hz minimum bandwidth, whereas 8-channel transmission will require 1700 to 2000-Hz bandwidth). For the transmission-ranges expected in LF, a reduction of antenna efficiency from a nominal 50 to 25 percent will reduce range to about 70 to 90 percent of that attainable with 50-percent efficiency. For an efficiency reduction of 5 percent, range will be reduced to about 35 to 70 percent of that attainable with normal efficiency. The greatest percentage reduction should be expected in the tropics, where expected range is the least.

It has been demonstrated that 50-percent efficiency is attainable with antenna-heights of 600 feet or more, even at 50 kHz. For a given antenna and efficiency, the bandwidth is proportional to the fourth power of frequency at frequencies below self-resonance. This frequency-dependence must be recognized in bandwidth-limited antennas as it provides the means to obtain acceptable bandwidth if there is a wide choice of frequency. Conversely, if a barely acceptable bandwidth is available at a given frequency, a greatly deficient bandwidth will be found at a much lower frequency. Between 50 and 120 kHz, there will be a 32:1 change of bandwidth for a given radiated power.

As pointed out above, bandwidth is proportional to the third power of height for a given form-factor and a given efficiency. For a near-optimum configuration of 24 top-load radials on a 600 foot tower, the bandwidth is about 1700 hertz at 85 kHz for 50 percent efficiency. For a 360-foot tower with the same form factor, the bandwidth is about 1700 hertz at 125 kHz for 50 percent efficiency. An 800-foot tower with the same form factor would have the 1700 hertz bandwidth at about 69 kHz. For efficient operation at 50 kHz with the required bandwidth, tower height would be about 1200 feet. For multichannel broadcast, operation at 50 kHz can be obtained with existing and planned antenna installations only at the expense of a large reduction in radiated power.

4.4 GROUNDING SYSTEM CONSIDERATIONS

Antenna systems for LF and MF are usually designed to work in conjunction with a radial-wire earth system (grid) buried just below grade. This grid provides a low-loss path for the antenna base-current and thus improves radiation efficiency.

When grounded antennas are used, it is especially important that the ground be as conductive as possible. This is necessary to reduce ground losses and to provide the best possible reflecting surface for the down-going radiated energy from the antenna. Since at LF and MF the ground acts as a sufficiently good conductor, connection to the ground must be made in such a way as to introduce minimum resistance in the connection. At higher frequencies, artificial grounds constructed of large metal surfaces are common. The ground system for an MF antenna usually consists of a minimum 120 buried copper wires, equally spaced, extending radially outward from the tower base to a minimum distance of 0.10 - 0.25 wavelength if possible. In addition, an exposed copper-mesh ground screen may be used around the tower base where high base voltages are encountered.

A less elaborate ground system may be effective in soil of high local conductivity, although adequate local-conductivity data are rarely available.

For a site located near seawater, the water provides adequate conductivity for a ground system by tension and the ground system radials may be either terminated in the water using anchors, or by radial rod end terminations driven down to water table level.

The ground connection takes many forms, depending on the type of installation and the loss that can be tolerated. For fixed stations, very elaborate ground systems are used, and often are arranged over very large areas.

Sometimes, when an antenna must be erected over soil having very low conductivity, it is advisable to treat the soil directly to reduce its resistance. Occasionally, the soil is mixed with a quantity of coal dust or treated with substances which are highly conductive when in solution. These substances (in order of preference) are: sodium chloride (common salt), calcium chloride, copper sulphate (blue vitriol), magnesium sulphate (Epsom salt), and potassium nitrate (saltpeter). The amount required depends on the type of soil and its moisture content. When these substances are used, it is important that they do not contaminate nearby drinking water supplies.

The most common ground system used with vertical grounded antennas at fixed stations is the radial ground. This consists of a number of bare copper conductors arranged radially and interconnected. Where space, economic, or other factors are involved, radials one-tenth wavelength or shorter can be used to lesser advantage, as noted in figure 4-18.

A common ground-sytem for use with short, grounded, vertical-radiators consists of 120 radials of AWG 6 copper wire. These radials, spaced every 3°, extend outward for a distance of at least 350 feet from a common terminal near the antenna base. The conductors are buried in 6- to 12-inch-deep trenches. Bonded (brazed) to the free end of each radial is a 8-foot ground rod driven into the earth. See figure 4-18.

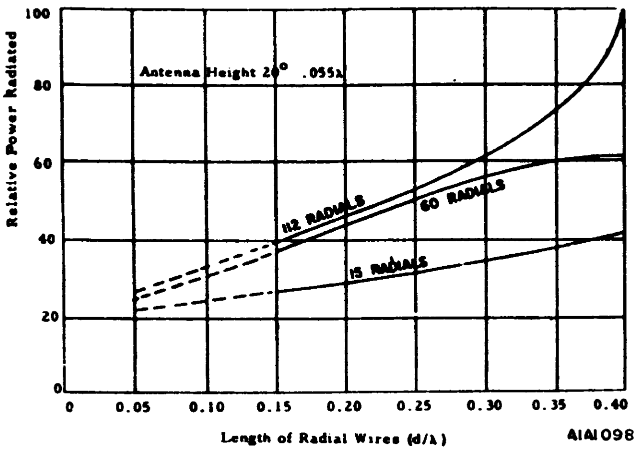


Figure 4-18. Relative Power Versus Length of Radial Wires

With a less elaborate ground system, a number of ground rods can be used. These rods usually are made of copperplated steel in lengths up to 8 feet. One end of the rod is pointed so that it can be driven easily into the earth. The other end frequently is fitted with a clamp so that the ground lead can be attached. (Some ground rods are supplied with a length of ground lead already attached.)

For simple installations, a single ground rod can be fabricated in the field from copper rod. It is important that a low-resistance connection be made between the ground wire and the ground rod. The rod should be cleaned thoroughly by scraping and sandpapering at the point where connection is to be made, and a clean ground clamp installed. A ground wire then can be bonded (brazed) to the clamp. The joint should be well covered with silicone rubber or other effective sealant to prevent resistance-increase caused by oxidation.

Wire size has negligible effect on ground-system effectiveness, and is chosen for mechanical strength; AWG 10 or larger is adequate. The wires are buried for mechanical protection; a depth of 6 - 12 inches is generally adequate.

Ground currents are conduction currents returning directly to the base of the antenna. The total earth current flowing through a cylinder of radius x concentric with the antenna, known as zone current, is a function of tower height and is calculated as follows:

$$I_{zone} = I_o[\sin r_2 - \cos G \sin x + j(\cos r_2 - \cos G \cos x)]$$

where:

I_o = loop antenna current

G = electrical height of antenna

$r_2 = \sqrt{x^2 + G^2}$

Figure 4-19 shows the variation of zone current with antenna height and zone radius.

Ground-system losses dissipate a portion of the input power and reduce the field radiated from the antenna. These losses are equivalent to the power dissipated in series with the antenna impedance.

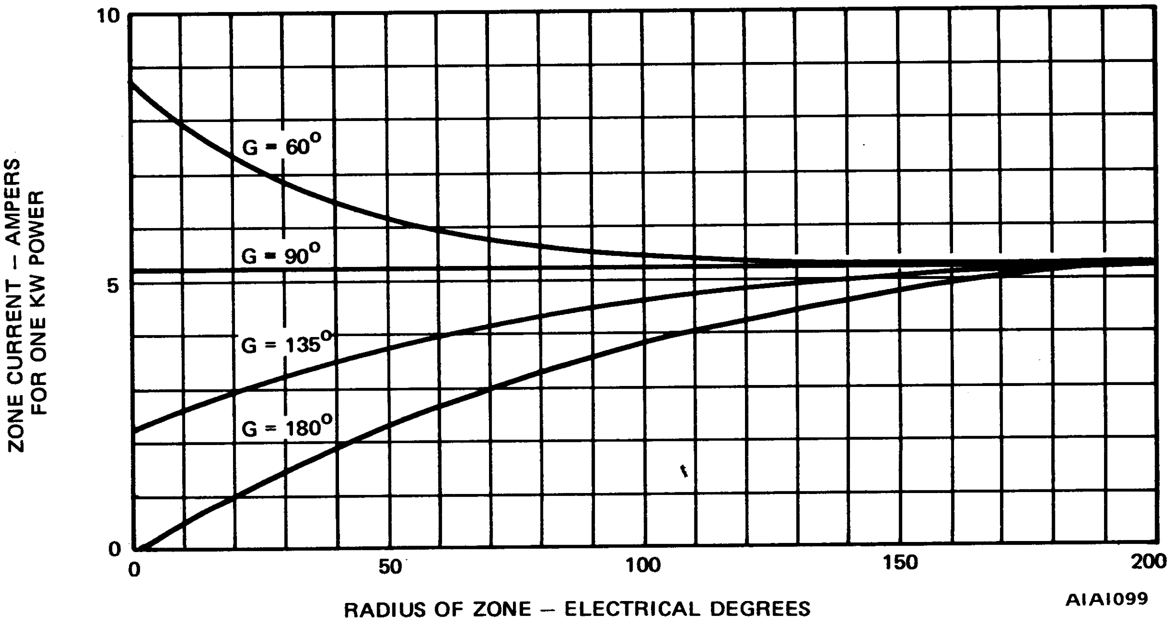


Figure 4-19. Zone Currents Returning to the Antenna as a Function of Antenna Height G

4.5 ANTENNA PROTECTION CIRCUITS

In the absence of suitable precautions, static charges accumulate on towers and guy wires and may discharge to ground. Such discharges ionize the path, and a sustained RF arc may follow. Protection can be provided to minimize the accumulation of static on the tower or to quench the arc by ensuring a good DC path to ground, but relatively little protection can be provided against direct lightning hits. A lightning rod or rods extending above the beacon on the tower top will provide some protection to the base insulator. However, the magnitude of lightning currents usually results in damage to the meters and tuning components. This is true of both insulated series-excited towers and grounded shunt-excited towers.

A DC path from tower to ground will minimize static accumulation. A separate RF choke, the tuning inductor, or the sampling-line inductor may be connected to maintain the tower at DC ground potential. Difficulty may occasionally be experienced with charges accumulating on individual guy wires and arcing across the guy insulators. This may be eliminated by installing static drain resistors across each guy insulator. These resistors may have a value of 50 to 100 kilohms, and should have an insulation path somewhat longer than provided by the guy insulator.

Horn gaps, ball (sphere) gaps and system-interlock devices which reset automatically on correction of the over-voltage condition are used to protect the antenna and transmitter from being damaged due to lightning and system-fault conditions. Horn and sphere gaps are set at specific points in the system to dissipate over voltages across the gaps. Protective sphere gaps on adjustable threaded rods are used to provide over-voltage protection for transformers, capacitors, and other easily damaged components. The spacing of these gaps is a function of voltage breakdown and must be determined by the capacity of the component to be protected. Certain components require specific voltage levels; sphere gaps may be set to proper arc over voltage using a hi-pot tester.

Interlock systems are used to protect the transmitter power amplifier tubes and other components excessive current or voltage discharges in the system. The antenna guys and horizontal supporting wire are segmented by insulators to prevent resonance effects which cause absorption of power from antennas and to insulate the antenna from ground. All radials forming the ground system are bonded together at the center and connected to the transmitter ground.

4.6 ANTENNA MATCHING COMPONENTS

4.6.1 LF Circuital Components

When vertical antennas are used in the LF range (50 to 150 kHz), the antenna height can usually be only a fraction of a quarter wavelength, and matching elements are generally required to tune out the antenna reactance and match the antenna system RF resistance to the transmitter output impedance. This is usually accomplished by use of a pair of tunable RF coils and a transformer to provide the coarse and fine adjustment required to attain good impedance match.

The RF helix coil, the RF variometer, and impedance transformer form the antenna tuning system. The fixed-inductance of the helix coil may be varied by changing the effective number of turns at the terminal block. The variometer provides continuous variable fine tuning. The helix and variometer serve to resonate the antenna, with the impedance transformer stepping up the resultant low circuit resistance to the output impedance of the transmitter.

The antenna matching components are housed in copper lined concrete building (helix house). The high levels of RF energy inside the building require no ferrous materials in the building due to the high RF induction heating of iron. Any ferrous material utilized must be shielded.

The helix coil and variometer support frames are constructed of specially treated laminated wood on which are mounted the required number of turns of Litz cable for the coil.

A brief description of the various components of the matching system follows and is presented in the order of appearance on the block diagram, figure 4-20.

Operation of the resonance indicator is based on the fact that the current and voltage of a series circuit are in phase at resonance. The resonance indicator indicates, without adjustment, circuit resonance with an accuracy of ±10° over the range of 50 to 150 kHz.

The matching transformer is a tapped primary, multiple-tapped secondary, oil-filled, iron-core RF transformer capable of matching a 50 ohm unbalanced source to an unbalanced load ranging in 90 equal-percentage steps from 0.74 to 43.9 ohms. The transformer is designed to handle continuously 50 kW average power or 100 kW PEP over the 50 to 150 kHz range. Impedance changes are effected by changing the position of links on the primary and secondary connector studs.

The toroidal current transformer has for its primary the antenna bus between the matching-transformer secondary winding and the antenna tuning inductances. The transformer secondary current heats a thermocouple generating a small DC voltage proportional to the square of the current. A vacuum tube millivoltmeter (VTMVM) calibrated in RF amperes indicates the current in the antenna bus. The Control-Indicator panel-meter is connected in series with the VTMVM indicator, and thus repeats the antenna current reading. A potentiometer is used to calibrate the antenna current indication.

The bandwidth-resistor, furnished at some sites, facilitates increasing antenna bandwidth (when operating conditions require) by lowering the antenna Q through the introduction of additional loss-resistance into the antenna circuit. The bandwidth-resistor is comprised of 50 four-kW strip-heater type resistance-elements arranged in 10 groups of 5 resistors each in parallel. The 10 groups may be connected into a number of series and parallel arrangements yielding resistance values from 0.278 to 27.800 ohms. Access to the resistor terminals (for changing resistance value) is by means of a removable cover on the terminal-board shield at the rear of the resistance bank.

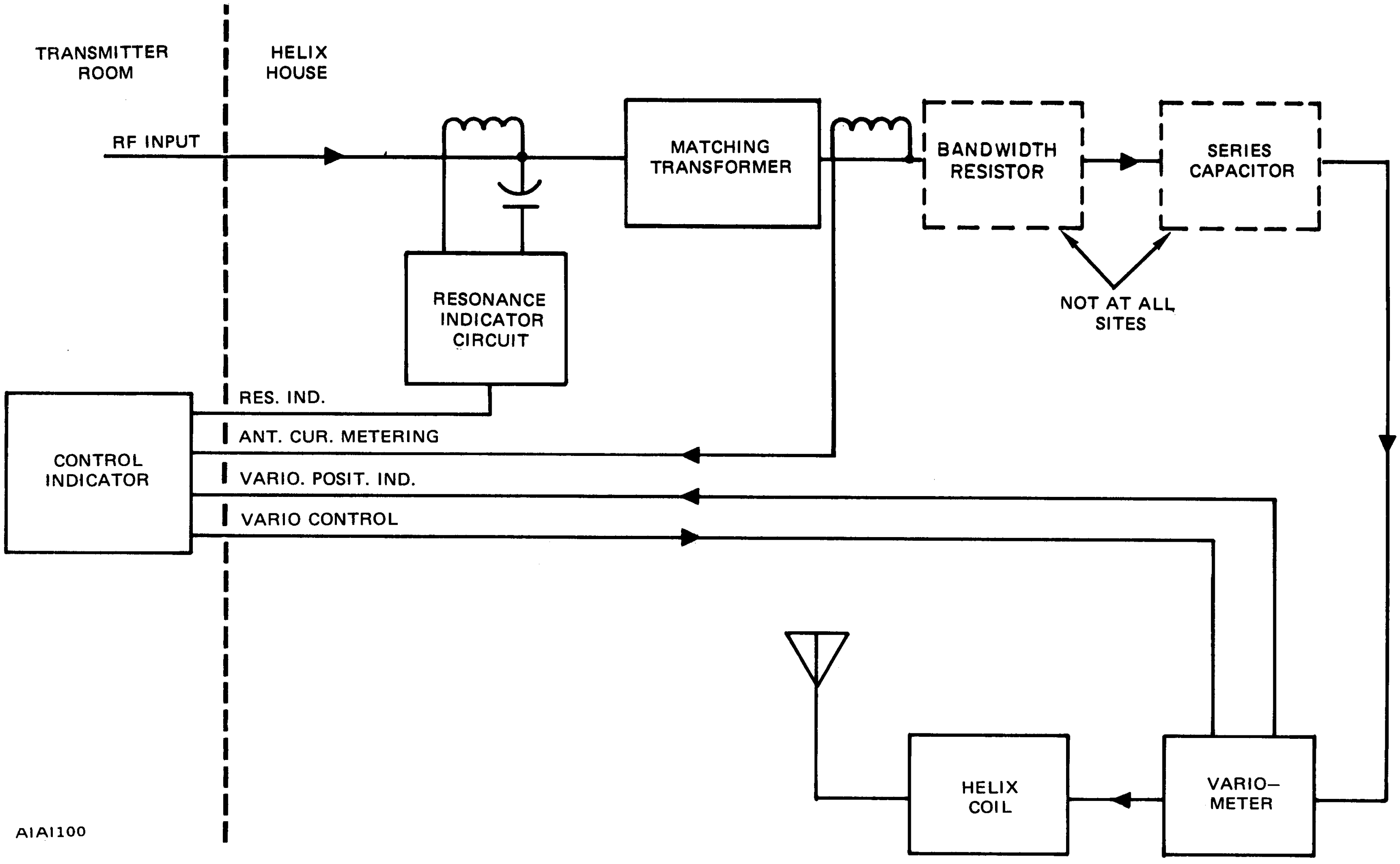


Figure 4-20. LF Antenna Matching Equipment, Block Diagram (Typical)

A link is provided inside the helix house to strap out the resistance completely when it is not to be used. Resistor-cooling is by air drawn over the finned surfaces. The blower is energized by a motor starter relay and thermal switch whenever cabinet air rises to 120°F. To prevent "short-cycling" each time the blower is started, a time-delay relay holds the motor running for a period adjustable between 2 and 60 minutes. The timer is normally set for 45 minutes. The overtemperature-switch opens the helix house interlock system to remove the RF power if cabinet air exceeds 220°F.

Series capacitance is provided at some sites to permit resonating the antenna circuit above the antenna self-resonant frequency. The capacitors provided will resonate the top-loaded antenna up to approximately 150 kHz if the variometer is connected for the lowest inductance range. The equipment consists of two high-voltage gas-filled fixed capacitors installed between the bandwidth resistor and the tuning variometer. Bus bars are provided that permit (1) bypassing the capacitors completely, (2) inserting both units in parallel, (3) inserting a single capacitor, and (4) inserting the two units in series. A high value non-reactive resistor is placed in parallel with the capacitor to aid in antenna static drain.

Adjustable threaded rods serve as sphere gaps on both primary and secondary sides of the matching transformer for over-voltage protection. The sphere gap mounted on the stud of coaxial end termination should be set for a 1/16-inch spacing. The sphere gap on the transformer secondary near the 1 5/8-inch tubing by the antenna current transformer should be set for a spacing of 1/32-inch. The high voltage ground switch in the helix house should be set at 1 inch maximum. The sphere gap on the series tuning capacitors should be set to arc over at 20 kV DC (applied to the capacitor from a hi-pot tester).

4.6.2 MF Antenna Matching Components

o Types of Circuits Used. Lumped-constant L, T, or Pi type networks are commonly used for impedance-transformation and phase-shift networks. Phase-delay networks are preferred to phase-advance networks, where feasible, because of their greater harmonic suppression. Required reactance values for the networks shown in figure 4-21 as functions of phase shift and impedance transformation, can be computed using the following formulas:

$$a = \frac{r \sin\beta}{\sqrt{r} - \cos\beta} \qquad b = \sqrt{r}\,\sin\beta \qquad c = \frac{r \sin\beta}{1 - \sqrt{r}\cos\beta}$$

$$r = \frac{R_1}{R_2} > 1 \qquad \beta = \text{desired phase shift}$$

These networks are generally used between the transmitter and transmission line for impedance transformation, harmonic suppression and phase correction.

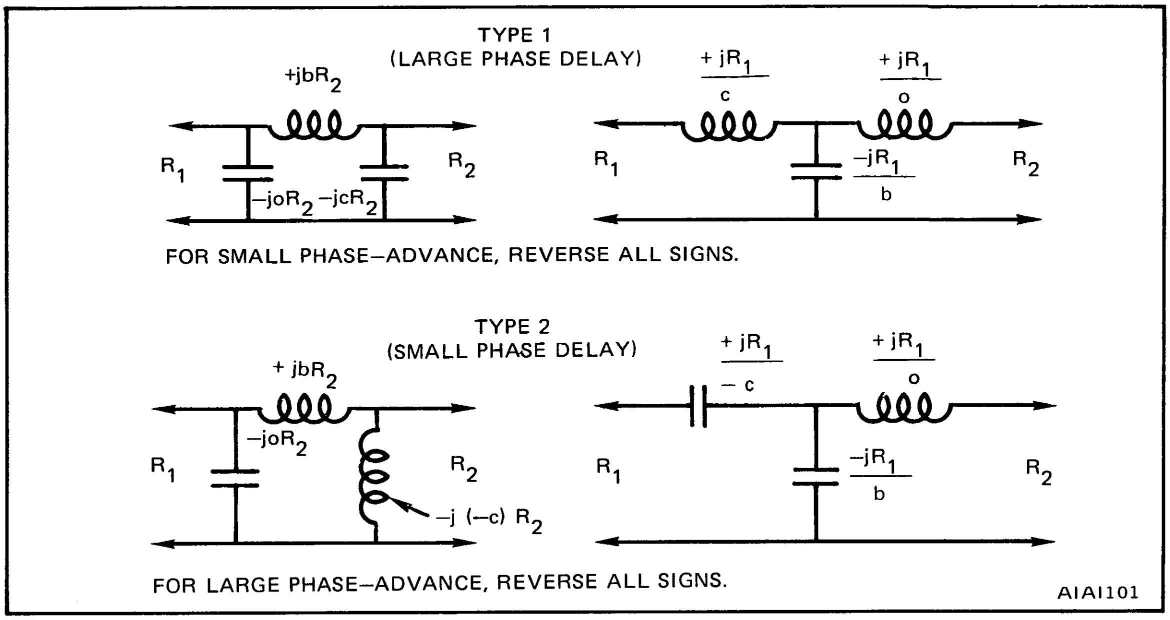


Figure 4-21. T and Pi Networks Suitable for Impedance Transformation and Phase Control

o Design of Antenna Tuning Units. Antenna tuning-unit design is based on the estimated base operating impedance of the radiators. The antenna reactance constitutes an equivalent reactance in the antenna arm of the network (the T-network is thus more convenient than the Pi network for an antenna tuning unit), but matching networks similar to those used at LF may be used.

For a nondirectional radiator, the phase shift introduced is only incidental to the impedance transformation. Since any value of phase shift may be used, an L network or a T-network with phase-shift near 90°, may be used.

o Transmission-line Requirements. Transmission lines should be unbalanced coaxial.

o Special Problems. Very High or Very Low Operating Resistances. For radiators with very low or very high base operating resistances, L, T, or Pi networks cannot conveniently provide transformation ratios exceeding about 10:1; when higher transformation ratios are required, a tank circuit (see figure 4-22) may be used. Reactance L_1 in series with the antenna is adjusted to resonate the operating base reactance and make the antenna a resistive load to the tank circuit.

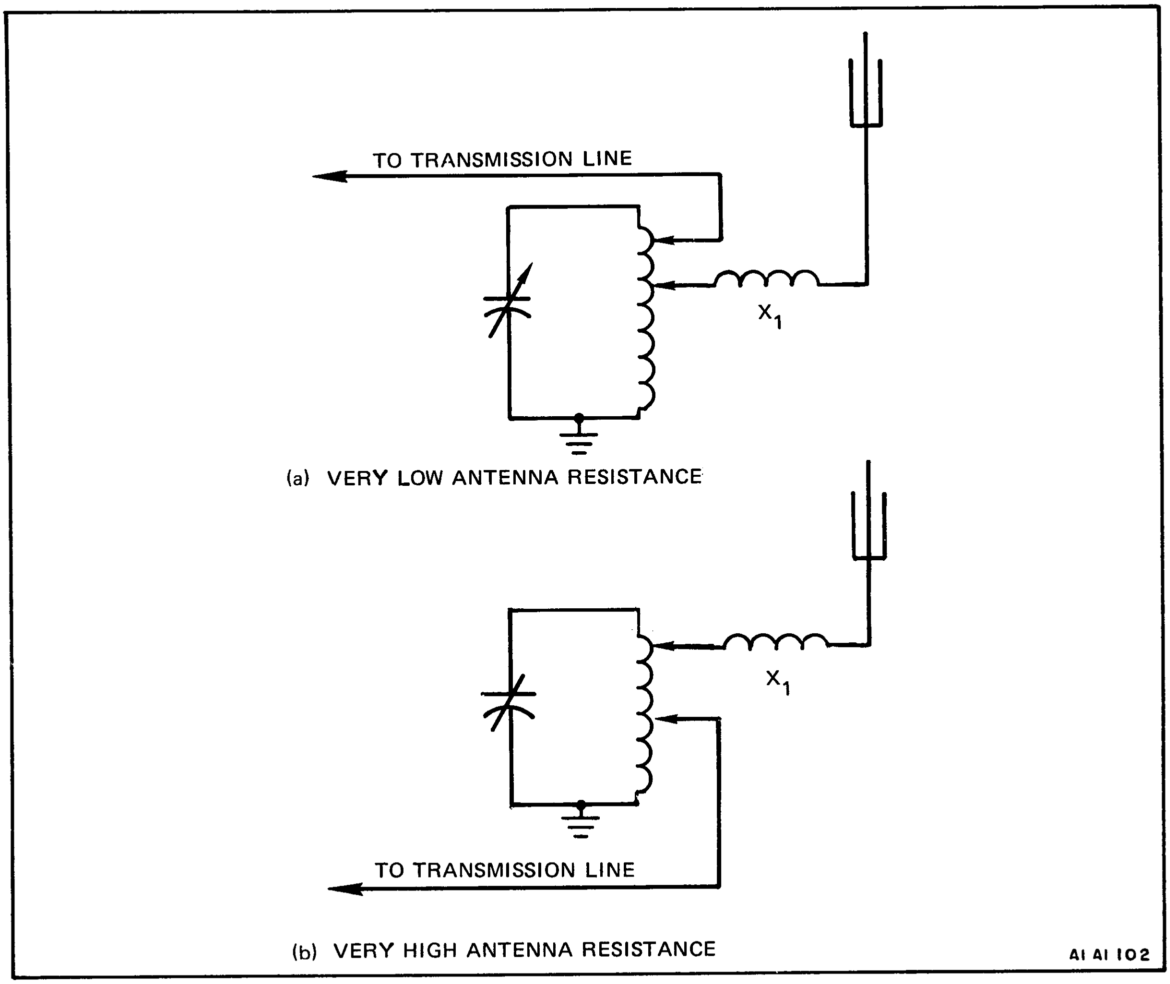


Figure 4-22. Use of Tank Circuit for High-Impedance Transportation Ratio

4.7 RECEIVING EQUIPMENT

Shore station LF receiving equipment is provided only to monitor the quality of the radiated signal; no shipboard generated message traffic is received ashore on the LF band.

To receive MF emergency communications requires a receiver capable of operating at 500 kHz with on-off keying (ICW) transmission. Three receivers, used in the VLF and LF ranges, are also capable of operating at the emergency frequency. The three units are the R-389/URR, AN/FRR-21, and AN/WRR-3 receivers.

4.7.1 Typical Receivers in Navy Inventory are:

o AN/FRP-21, which covers the 14 to 600 kHz (VLF through MF) range, is capable of receiving CW (A-1), MCW (A-2) and FSK (F-1) emissions at shore fixed installations.

- Radio Receiver R-389/URR is a stable, general purpose VLF through HF receiver for use in fixed service. The receiver provides reception of continuous-wave (c-w) and amplitude-modulated (a-m) tone radiotelegraph signals, a-m voice signals, and FSK signals in the 15 to 1500 kHz range.

- AN/SRR-19, a dual-conversion superheterodyne receiver, operates in the range of 30 kHz to 300 kHz (LF only) and will receive CW, MCW, AM, and FSK (with external equipment) emissions. This receiver is intended for reception of single sideband (SSB) fleet multichannel TTY broadcasts to surface craft.

4.7.2 Post-Receiver Equipment

Post-receiver equipment at shore LF/MF communications stations is used only to monitor the LF traffic being transmitted or the MF emergency signals being received. The LF post-receiver equipments are demultiplex equipments, telegraph terminal equipments, crypto equipment and TTY page printers.

The only required MF post-receiver equipment is a set of headphones. A speaker is usually used during listening periods, but when a message is coming through it is more convenient for the operator to use headphones. Another convenience-device, especially useful where an operator is not available 24 hours a day, is an automatic emergency alarm. When a ship operator sends an SOS, he must first send 10 four-second long dashes, each separated by one second. This signal is detected by the automatic alarm, which in turn alerts the receiving operators of the forthcoming SOS.

4.8 RECEIVING ANTENNAS

The high-sensitivity of communications receivers does not require high signal field strengths to provide good reception, and antenna matching is generally not required. Long wire, whip, and loop antennas each provide sufficient signal levels to allow receivers to drive crypto equipment and TTY printers.

The selection of a specific receiving antenna is determined primarily by the physical space available.

For most MF emergency-frequency receivers a long wire suspended vertically from a high point, such as a water tower or a high pole, will provide sufficient signal for clear reception.

Shipboard LF installations require antennas which use the least space and provide maximum signal pickup in an operational sense, but since the receiving antenna is usually non-resonant, no special problems exist. At a shore station, however, the sole function of the receiving system is to monitor transmission quality and simple long wire antennas should be acceptable.