CHAPTER 7

LF/MF INSTALLATION-EVALUATION AND ACCEPTANCE

Each LF or MF transmitter system, upon installation-completion, should be evaluated to insure that the system is performing properly, efficiently and radiating sufficient power to satisfy the facilities mission. This performance evaluation is conducted on all transmitting stations prior to being assigned full operating status (commissioned) by the Navy. These acceptance tests should include field intensity measurements which are taken at intervals of less than 10 wavelengths on certain radials, to determine the radiation pattern of the antenna, system radiation efficiency, and radiated power. This test will provide an indication of signal reliability and the maximum range at which the signal is strong enough to provide a total printout with no loss of message. To augment the data from actual tests and test procedures, the proof of performance reports on the various transmitter facilities are excellent references. Significant factors which are peculiar to LF/MF systems are discussed in the following paragraphs.

7.1 ANTENNA MATCHING

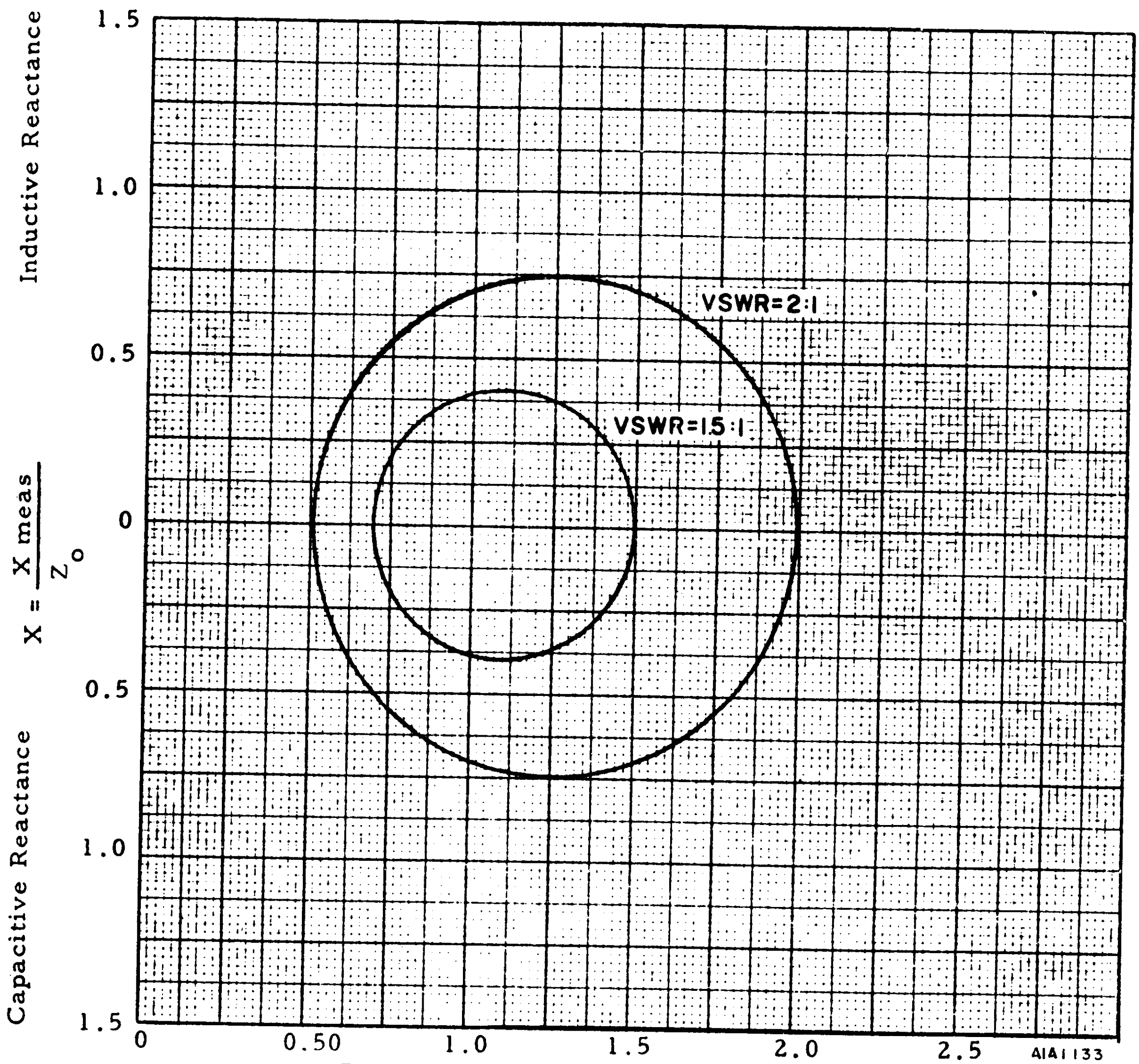
In the LF/MF range the problems of connecting the antenna transmission line to the antenna must be solved by using lumped circuit parameters. At these frequencies large high-Q inductances can be constructed, gas filled high voltage capacitors are available, and lead inductance and stray capacitance can be minimized by good design practices.

7.1.1 Transmitting Antenna Matching

The transmitter mismatch should not have a VSWR in excess of 1.5:1. Table 7-1 illustrates the losses due to mismatch for varying degrees of mismatch. In this table no consideration has been given to any other losses. At the desired frequency the input impedance of the transmission line load should be measured using an RF bridge. The measured resistance and reactance should be divided by the characteristic impedance of the transmission line and the results plotted on a Smith Chart similar to the one in figure 7-1. If the value is within the 1.5:1 VSWR circle on the chart, the VSWR is less than 1.5:1.

7.1.2 Receiving Antenna Matching

The surface may utilize the AN/SRA-17 antenna tuning group for VLF through 600 kHz reception; this group consists of a tunable 10-foot whip antenna. Other surface ships utilized a non-tuned long-wire antenna and a bandpass multicoupler to divert the LF/MF signal to the desired receiver. Monitor sites may utilize various types of long wire antennas (untuned); since atmospheric noise is generally so much greater than receiver noise, large amounts of VSWR mismatch can generally be tolerated without degradation of signal-to-noise ratio.



$R = \frac{R\ meas}{Z_o}$

Z_o = Characteristic impedance of transmission line in ohms

X meas = Measured reactance of antenna feed in ohms

R meas = Measured resistance of antenna feed in ohms

Figure 7-1. Impedance Diagram to Determine if Antenna Feed VSWR is Within Limits

Table 7-1. Losses Due to Mismatch of a Transmission Line and its Load

INPUT POWER (kW)	LOSSES DUE TO MISMATCH (kW)				
	VSWR				
	1:1	1.5:1	2:1	3:1	9:1
1	0.0	0.039	0.111	0.250	0.64
10	0.0	0.39	1.111	2.5	6.4
50	0.0	1.95	11.111	12.5	32.0

7.2 TRANSMISSION LINE CHARACTERISTICS

Transmission lines for RF, regardless of type, have certain characteristics which must be taken into consideration.

7.2.1 Characteristic Impedance

The characteristic impedance of a line is the impedance it would present to a source if the line were infinitely long. Where a line is terminated in its characteristic impedance, the line regardless of length will present this impedance to the source. Theoretically, the characteristic impedance of a line is usally dependent on frequency and will have reactive as well as resistive components. In practice, lines that have small attenuation over the desired frequency range will have an almost constant characteristic impedance that is essentially resistive.

a. Measurement. Actual measurement of line characteristic impedance is difficult to achieve.

b. Approximation. An approximation-method that can be used for low-attenuation lines is: (see figure 7-2).

Step 1. The line is terminated with a known-value nonreactive load whose value is less than the expected value of Z_o.

Step 2. At the desired frequency, using a directional wattmeter, measure the power being sent to the load (forward power) and the power returned by the load (reflected power) is measured using a directional wattmeter and VSWR computed from:

$$\text{VSWR} = \frac{1 + \sqrt{\dfrac{\text{reflected power}}{\text{forward power}}}}{1 - \sqrt{\dfrac{\text{reflected power}}{\text{forwarded power}}}}$$

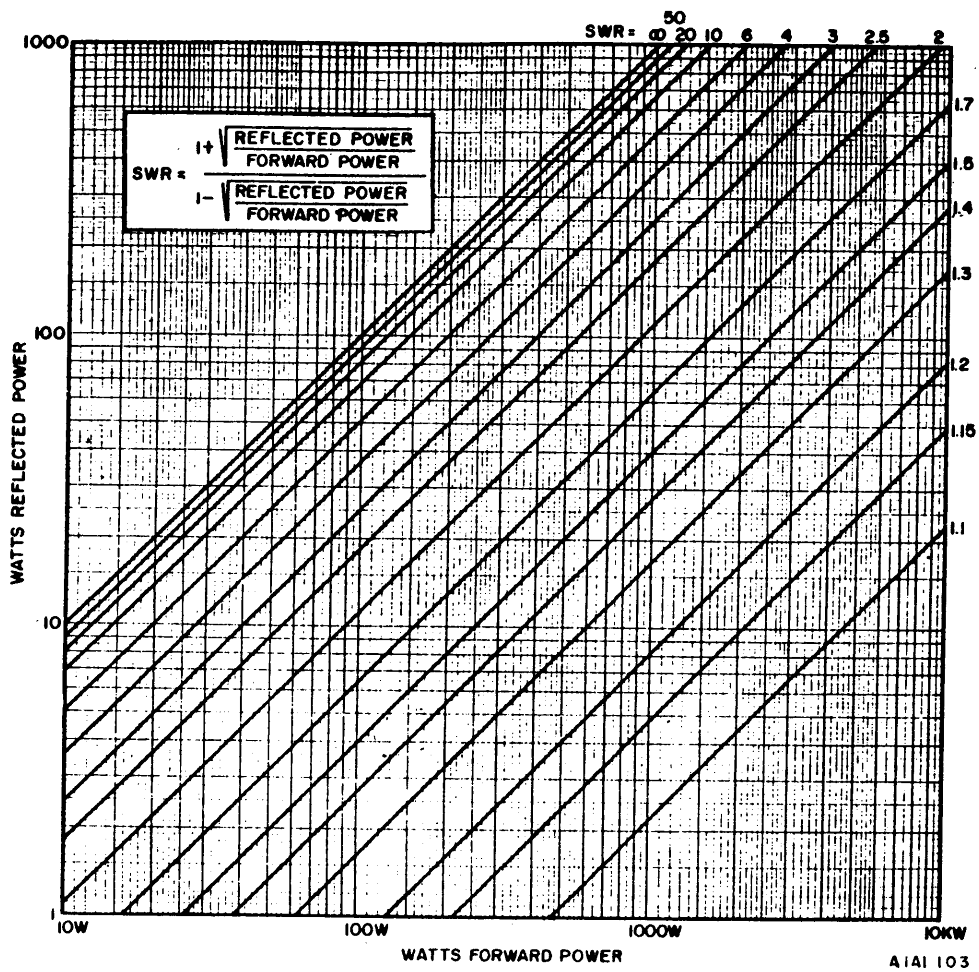


Figure 7-2. Plot of SWR Versus Forward and Reflected Power

(If available, a VSWR bridge may be used in lieu of the directional wattmeter and the VSWR reading taken directly.)

Step 3. Z_o is computed from:

$$Z_o = Z_L \text{ (VSWR)}$$

where:

Z_L = known load

If it is necessary to use a Z_L whose value is greater than the expected value of Z_o, then use the formula

$$Z_o = \frac{Z_L}{\text{VSWR}}$$

7.2.2 Attenuation

The attenuation of a line is dependent on the distributed parameters of the line. The formula for calculation of the attenuation instant of a line is

$$\alpha = 8.686 \{1/2[\sqrt{(R^2 + W^2L^2)(G^2 + W^2C^2)} + RG - W^2LC]\}^{1/2}$$

where:

α = Attenuation constant in dB/unit length

R = line resistance in ohms/unit length

L = line inductance in henrys per unit length

G = line conductance in ohms/unit length

C = line capacitance in farads/unit length

W = 2π (frequency in hertz)

a. Measurement. The line is terminated in its characteristic impedance. A signal of known level is inserted at the input to the line. The voltages at the line input and at the load are measured and attenuation is computed from

$$\text{Attenuation (dB)} = 10 \log_{10} \frac{\text{power in}}{\text{power out}} \text{ dB}$$

$$\text{Attenuation(dB)} = 20 \log_{10} \frac{E_{in}}{E_{out}} \text{dB}$$ (providing no impedance transformation has taken place)

b. Alternate Method "A" of Measurement

Step 1. The line is terminated in a resistance (R) substantially different from Z_o and the input VSWR measured. (See paragraph 7.2.3.)

Step 2. The load VSWR is calculated.

$$VSWR = \frac{R}{Z_o} \quad (\text{for } R > Z_o)$$

$$\text{or } VSWR = \frac{Z_o}{R} \quad (\text{for } R < Z_o)$$

Step 3. The nomograms in figures 7-3 and 7-4 are used to calculate the line attenuation.

c. Alternate Method "B" of Measurement

Step 1. The line is terminated in a short circuit.

Step 2. The input impedance of the line is measured using an RF bridge.

Step 3. The input impedance is plotted on a Smith Chart and the line attenuation read off the appropriate radial scale.

7.2.3 Voltage Standing-Wave Ratio

When a transmission line is not properly terminated, it will not deliver all of the power carried by it to the load. Part of this power is reflected back toward the source. This reflected power interacts with the power traveling toward the load and a standing wave appears on the line. Line losses are increased by the presence of standing waves because of the increase in voltage and current on the line. The voltage standing wave ratio (VSWR) is equal to:

$$\frac{V_{max}}{V_{min}} \text{ or } \frac{I_{max}}{I_{min}}$$

There are several methods for measuring SWR. One method is to use a direct-reading VSWR bridge or reflectometer. Another method of measuring the SWR, with a line of known characteristic impedance, is to measure the input impedance. (This must include both the resistive and reactive components at the desired frequency.) The VSWR may be computed as follows:

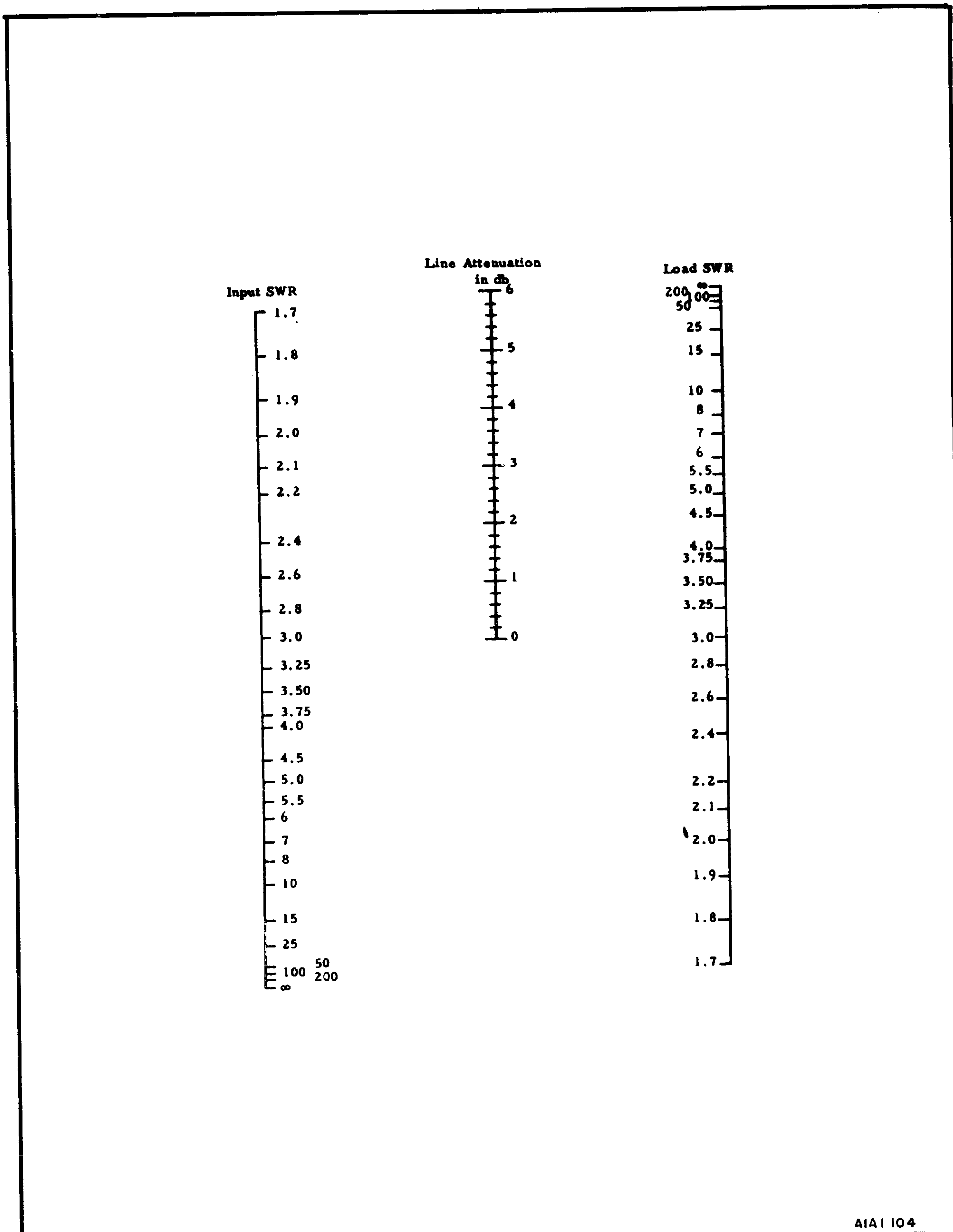


Figure 7-3. Nomogram Relating Input and Output VSWR to Line Loss for Low-Loss Lines

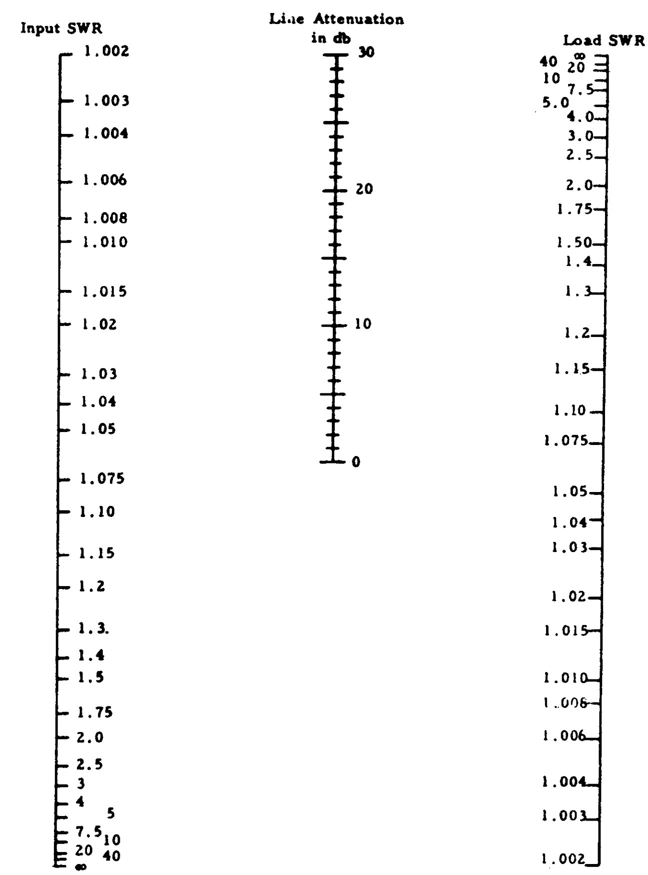


Figure 7-4. Nomogram Relating Input and Output VSWR to Line Loss for High-Loss Lines

$$\text{VSWR} = \frac{1 + \left|\frac{Z_o - Z}{Z_o + Z}\right|}{1 - \left|\frac{Z_o - Z}{Z_o + Z}\right|}$$

where:

Z_o = Characteristic impedance of the transmission line

Z = Input impedance of the transmission line with load

Alternatively, the input impedance may be plotted on a Smith Chart and the VSWR read off the appropriate radial chart.

7.3 LF FIELD INTENSITY MEASUREMENTS

7.3.1 Measurement Site Selection

Antenna field intensity (FI) measurement site selection should include the following considerations:

- The site should be located along an antenna radial between three and six wavelengths from the transmitting antenna.

- The site should not be near any abrupt ground conductivity change region, e.g., near a stream or lake. The site should be at least two to three wavelengths from any major land-water boundary (e.g., land-sea).

- Sites chosen should generally be in flat areas. Gently rolling hilly areas are acceptable but extremely high elevations (mountain tops) and deep depressions (valleys) are to be avoided.

- The site should not be located near magnetic ore areas nor near any conducting materials such as buried cables, overhead conductors, metallic posts and guys, reinforced concrete structures (buildings, roads), etc. Minimum separation from overhead lines should be 900 feet; from all other conducting objects 200 feet should be sufficient.

- Final site acceptability should be determined from the results of a measuring loop pattern taken at the site. Pattern nulls should be a minimum of 40 dB (60 dB recommended) down from pattern maximum and pattern nulls should be located 180 degrees from one another. Insufficient pattern null depth indicates reflections from nearby conducting objects (or low signal to noise ratio), and pattern null tilt indicates measuring system unbalance.

o Sites should be chosen with a view to equalizing the azimuthal distribution of the sites. Ideally, eight equally spaced antenna radials would be determined with a minimum of two to three measurement sites along each radial chosen. In a practical situation this is sometimes impossible to achieve.

7.3.2 Transmitting and Monitoring Site Considerations

In determining the efficiency of an LF antenna, three quantities must be accurately determined: Distance of FI measurement site from transmitting antenna, measured FI at site, and power into the antenna or antenna system. If the power is measured at the transmitter output, the value of efficiency computed will include transmission line and matching circuit losses. If antenna efficiency alone is required the power into the antenna must be determined; this power is generally computed from accurate measurements of antenna base current and resistance. Since output power from certain transmitters may drift with time, it is advisable to establish a FI monitor site to continually monitor the signal during the measurements in order to maintain transmitter output power constant or apply a correction factor to the site FI readings.

For all FI and power measurements the transmitter must be in the CW (locked key) mode. The transmitter should be tuned to the desired measurement frequency and the antenna matching network tuned for minimum VSWR. Procedures for determining input power at various points in the system are given below:

o Terminate transmitter in resistive dummy load equal to transmission line characteristic impedance (generally 50 ohms) and calibrate transmitter forward and reflected power meters.

o Calibrate antenna current meter.

o Measure system resistance looking toward antenna on the antenna side of the antenna current meter (the line to the meter must be broken for this measurement), R_i. In many cases the antenna current meter is installed between the antenna matching transformer and the matching circuit components and the resistance (R_i) and efficiency so measured for this case will include some matching circuit losses. Use of the measured antenna resistance, R_a, with the current value obtained with the current meter in the foregoing location to comput input power to the antenna may introduce appreciable error if the antenna impedance is heavily shunted.

o Measure transmission line input impedance on the antenna side of the transmitter reflectometer at the FI measurement frequency and determine voltage reflection coefficient, P_{tl}.

o The following definitions apply:

$P_{in(1)}$ = Power (rms) delivered to load at transmitter reflectometer.

P_f = Forward power (rms) read from transmitter forward power meter.

P_r = Reflected power (rms) read from transmitter reflected power meter.

$P_{in(2)}$ = Power (rms) delivered to antenna matching network.

$I_{i(2)}$ = Current (rms) at input to matching network.

$R_{i(2)}$ = Resistance at input to matching network.

$P_{in(a)}$ = Power (rms) delivered to antenna.

I_a = Antenna input current (rms).

R_a = Antenna input resistance.

o Terminate transmitter with antenna load and increase transmitter output power to desired value. This value should be maintained as nearly constant as possible.

o Compute the desired system input power(s) from the following formulas:

$$P_{in(1)} = P_f - P_r = (1 - |P_{in(a)}|^2)\, P_f$$

$$P_{in(2)} = (I_{i(2)})^2\, R_{i(2)}$$

$$P_{in(a)} = (I_a)^2\, R_a$$

Establishment of a FI monitor site two to three wavelengths from the transmitting antenna will generally enable more accurate monitoring of transmitter power than readings obtained from the transmitter power meter. The field strength at the monitor site is initially measured for a given transmitter power output. Any change in transmitter power level or radiated power may be referenced to this level and appropriate corrections made to site FI measurements. Radiated power may change because of transmitter output or transmitter input power drift, antenna matching circuit detuning (accidental or due to antenna impedance change caused by ground conductivity change), or change in antenna efficiency (due to ground loss resistance change caused by ground conductivity change).

After the initial reference field strength, E_r is measured, the indicated FI meter indication at the monitor site must be calibrated using the series injection method (described in the FI measurement site test procedure section) each time a FI measurement is made at a site. The transmitter may be keyed continually or as is often the case keyed for a given period of time at regularly spaced intervals (e.g., 10 minutes twice an hour). At the center of the transmission interval the FI at the monitor site, E_m, is measured. The following correction factor should then be added to the measurement site FI measurement in dB above one microvolt per meter to determine the corrected field strength:

$$F = 20 \log (E_r/E_m)$$

The monitor site chosen should be located near a source of ac power. A loop antenna and FI meter should be used and site selection considerations contained in FI Measurement Site Test Procedure followed. The exact loop location and bearing orientation for maximum signal should be noted so that the same antenna situation can be returned to on succeeding days.

7.3.3 Measurement Site Test Procedure

a. Equipment. The following equipment is recommended for Field Intensity measurements at the designated sites:

- o Portable source of AC power - AC generator and voltage regulator or battery/inverter to provide power for FI meter, signal generator, and VTVM. Operation of this equipment on internal batteries is not recommended.
- o Signal generator.
- o VTVM - (high input impedance, 1/2 percent accuracy desirable).
- o Loop calibration network.
- o Shielded loop antenna with tripod mount.
- o FI meter.

b. Procedures. Details of the calibration circuit (figures 7-5 and 7-6) for unbalanced and balanced loop antennas. The equivalent circuit for a loop antenna is shown in figure 7-7. The voltage induced in the loop by a given electric field, E, is:

$$Vi = hE \text{ for:} \qquad (7\text{-}1)$$

$$h = (2.1 \times 10^{-8}) \text{ NAf} \qquad (7\text{-}2)$$

N = Number of turns of loop antenna

A = Area of loop antenna in square meters

f = Frequency in Hz

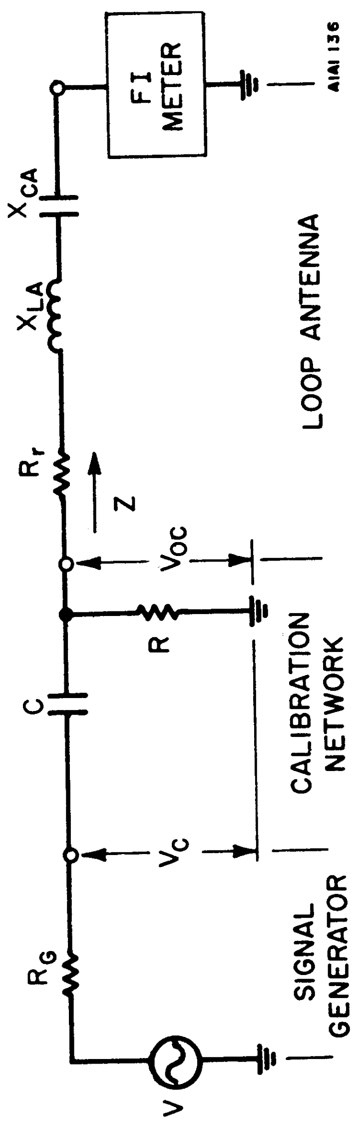


Figure 7-5. Calibration Circuit, Schematic, Unbalanced Loop Antenna

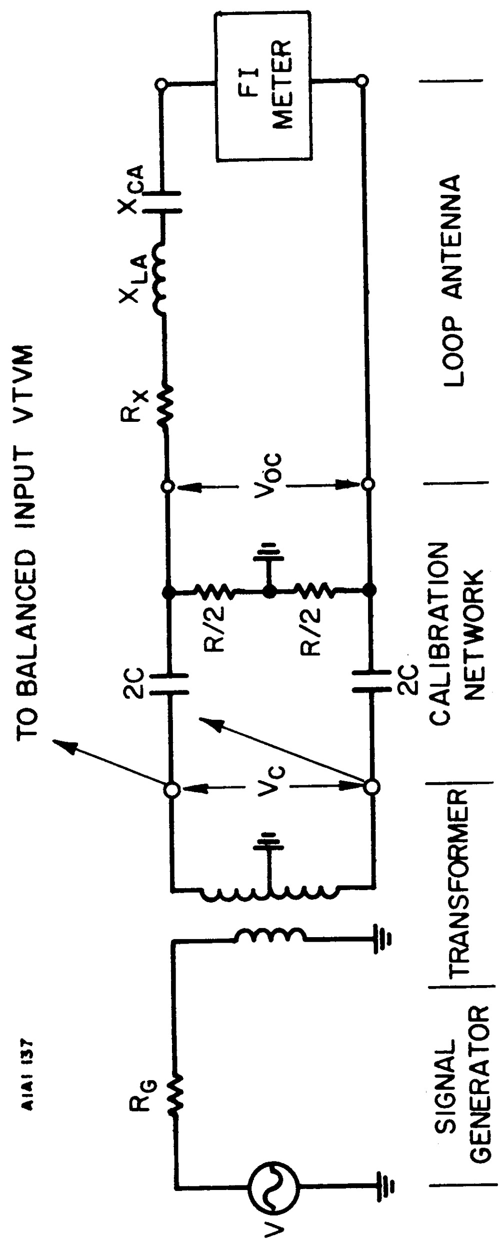


Figure 7-6. Calibration Circuit, Schematic, Balanced Loop Antenna

If the impedance, Z, to the right of the resistance, R, in the circuit of figure 7-1 is very high compared to R and if R ≪ Xc, the voltage across R, Voc, will be given by:

$$Voc \cong \frac{R}{Xc} V_c = 2\pi R\, fC\, V_c \qquad (7\text{-}3)$$

In order for a signal generator to induce the same indication level on the FI meter as the electric field at the site (refer to figures 7-5 and 7-7):

$$Vi = Voc \text{ or} \qquad (7\text{-}4)$$

$$(2.1 \times 10^{-8})\, NA\, E = 2\pi RC\, V_c \qquad (7\text{-}5)$$

The VTVM indicates V_c, and the magnitude of V_c in volts will equal the field intensity for a given radiated power from the transmitting antenna at the site, E, in volts/meter if:

$$RC = (3.34 \times 10^{-9})\, NA \qquad (7\text{-}6)$$

In order to minimize the loading effects of Z, R is usually a non-inductive resistor with a value near 0.5 ohms. The capacitor, C, should be relatively high Q and frequency and temperature stable. The calibration network should be installed in a shielded box with coaxial input and output connectors and the components precisely adjusted to yield the measured voltage relationship computed from equation (7-3) before field measurements are taken. It should be noted that the calibration network constructed should be valid for the loop antenna for which it was computed at all frequencies for which the measured and computed voltage relationships expressed in equation (7-3) correspond.

Figure 7-8 shows the equipment arrangement for the FI measurement calibration. Do not rely on FI meter internal calibration. For initial system check out the equipment should be set up as shown with the exception that the loop should be detached from the calibration circuit and oriented for maximum received signal from the transmitting antenna. All equipment should be located a minimum of approximately 50 feet from the antenna and the equipment and connecting cables should be positioned in the pattern null region. Proper grounding and AC isolation should be checked by noting any instability in FI meter reading as equipment cases are touched, 60 Hz background noise in FI meter audio, etc. Ensure that system connection points are clean and moisture proof. Avoid laying cables parallel to power lines for long distances.

After checking grounding, check the acceptability of the site by measuring a loop pattern using the transmitted signal. The FI meter should be in the field intensity, CW, carrier, or RMS mode with minimum bandwidth. The BFO should be off at all times except when trying to tune in the signal. Rotate the loop antenna and note FI meter levels every 45 degrees or so and the position and depth of the pattern nulls. The pattern should be figure eight with no null tilt (indicates good system balance); depth of nulls should be at least 40 dB (preferably 60 dB) relative to pattern maximum (indicates low reflection level from surrounding metallic objects).

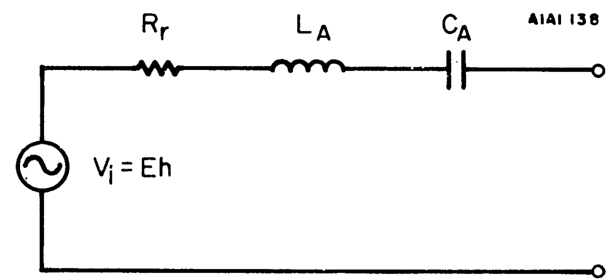


Figure 7-7. Equivalent Circuit for Loop Antenna Oriented for Maximum Pick-Up in Electric Field

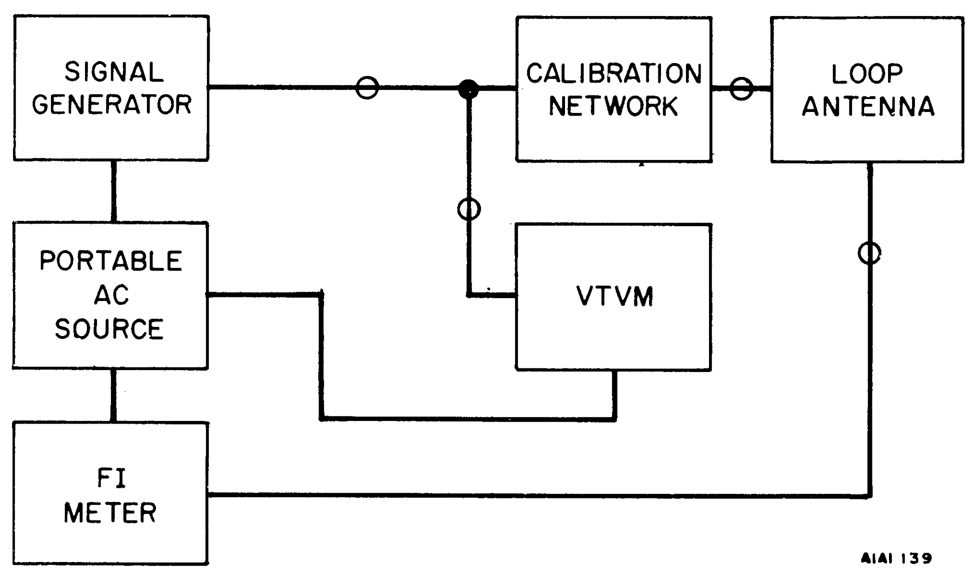


Figure 7-8. Arrangement of Equipment for FI Measurement Calibration

After locating a suitable measurement site, record the information listed in FI Measurement Test and Data Sheet Information as it becomes available. The distance of the measurement site from the transmitting antenna base must be accurately determined (to three places); appropriately scaled topographic maps may be utilized. A rough estimate of the field strength at the measurement site for checking purposes may be determined from:

$$E = \frac{300\sqrt{nP_{in}}}{d} \qquad (7\text{-}7)$$

n = Estimated antenna system efficiency

P_{in} = Power input to antenna system (kW)

d = Distance of measurement site from transmitting antenna base (km)

E = Electric field intensity (MV/M)

Extremely high or extremely low measured FI values as compared with the expected values may be caused by unknown site anomalies.

For FI measurement, rotate loop for a null and note bearing. Then rotate loop 90 degrees from null; this position should correspond to maximum received signal, and the bearing should correspond to the correct bearing of the transmitting antenna from the site. Note FI meter indication (should be midscale or higher). Rotate loop back into received signal null. Connect calibration circuit as shown in figure 7-8. Signal generator cable losses must be low in order that the calibration circuit be accurate. This will require calibration network and VTVM placement near the loop. Measuring cables and equipment near the antenna may have to be rerouted to ensure that they are in the antenna null for the new loop position (for calibration). Tune signal generator frequency for maximum signal on FI meter; do not change any FI meter switch settings. (These should be the same as for the initial indication from the transmitted signal.) Adjust signal generator output level to give the same FI meter indication as when the transmitting antenna FI level was obtained. Note and record VTVM reading; this level in volts is the field intensity at the measurement site in volts/meter (uncorrected for transmitter power level change).

Immediately after initial measurement, move loop antenna position 10 to 20 feet and verify value obtained by remeasurement. Compare measured value with expected value.

Also compare measurements on the same transmitting antenna radial to determine if the inverse distance relationship obtains:

$$\frac{E1}{E2} = \frac{d2}{d1} \qquad (7\text{-}8)$$

for:

E1 = Corrected FI at site 1

E2 = Corrected FI at site 2

d1 = Distance of site 1 from transmitting antenna base

d2 = Distance of site 2 from transmitting antenna base

If the two measurements do not correlate, take a third measurement and use the two measurements that most closely follow the inverse distance relationship. (The FI ratio that most closely equals the distance relationship as given above.)

It is good practice to repeat measurements previously recorded at one site before taking additional measurements when these must be made on other days.

7.3.4 Measurement Test and Data Sheet Information

To assist in the interpretation and evaluation of antenna system efficiency measurements the following information should be obtained and recorded:

- o Date of FI measurement.
- o Time at which FI measurement obtained.
- o Site information:

Number of designation.

Latitude and longitude.

Distance from transmitting antenna.

Weather and surrounding ground conditions; e.g., measurement made after rainstorm, in rice paddy, etc.

Check-out information from loop antenna pattern:

Bearing of transmitting antenna.

Depth of pattern nulls relative to pattern maximum.

Departure of pattern from figure eight pattern, i.e., position of pattern nulls relative to one another.

- o Equipment used:

Antenna type and nomenclature, including area of loop and number of turns.

FI measurement and ancillary equipment nomenclature.

Indicated setting of FI meter switches, etc. (e.g., meter mode, bandwidth, etc.).

Calibration method used including circuit schematic and description.

o Measured field strength at measurement site and results of remeasurement after quickly moving loop antenna location 10-20 feet from initial measurement site.

o Transmitted signal information:

Transmitter frequency and mode (mode should be CW - locked key).

Transmitter forward and reverse power meter readings. Power input to antenna may be computed from measured antenna base current and antenna input resistance.

Transmitter power output correction factor obtained from monitor station FI reading at time of FI measurement at site.

7.3.5 System Efficiency

These measurements will be used to calculate the radiated power and antenna efficiency using the following procedure:

a. Plot the locations of each measurement site accurately on a map. Measure the exact distance of each location from the antenna.

b. Calculate the F x D (field strength times distance) for each location. Calculate the root mean square F x D for each radial using the following formula:

$$F_{\text{at 1 mile}} = \left[\frac{(F_1D_1)^2 + (F_2D_2)^2 + \ldots. + (F_ND_N)^2}{N}\right]^{1/2}$$

where:

D = miles

F = millivolts per meter

N = number of measurements

c. Calculate the root mean square value of F x D for all measurements on all radials. This is the "unattenuated field" at one mile for the given transmitter output.

d. Plot a radiation pattern of the antenna, using the root mean square value of F x D on each radial as the unattenuated field value at one mile. Use polar graph paper, with 0^o indicating true north from the antenna.

e. Calculate the radiated power as follows:

$$P_r = P_{in} \left(\frac{E_\mu}{E_t}\right)^2$$

where:

P_r = radiated power in kilowatts

E_μ = (measured unattenuated field intensity at one mile in millivolts per meter for 1 kW) = $E_m/\sqrt{P_{in}}$

E_t = (theoretical unattenuated field intensity at one mile in millivolts per meter for input power of 1 kW) ≅ 186.3 MV/m

E_m = measured unattenuated field at 1 mile with P_{in} system input power.

f. Calculate the antenna system efficiency using the following formula:

$$\text{Efficiency percent} = 100 \frac{P_r}{P_{in}}$$

where:

P_r = power radiated

P_{in} = power input.

7.3.6 Impedance-Resistance, Reactance, VSWR

Most LF antenna impedance-measurements may be made directly with an RF bridge. The exact location of the measurement depends on the purpose of the measurement. For example, if the antenna impedance is desired so that the helix (and/or impedance transformer) may be properly designed, then the measurement would be made at the point where the helix would be connected. (A large value non-inductive static drain resistor should be connected from measuring point to ground).

Further consideration includes steps to be taken to avoid experimental errors. Generally these can be avoided by taking a series of measurements. The test frequency should be varied, both above and below the desired operating frequency. This multiplicity of measurements tends to show up errors due to miscalculation, bridge maladjustment, etc.

The VSWR measurements depend on the characteristic impedance of the feeder line and are made at the line termination with the matching network with the line disconnected.

7.4 MF INSTALLATION REQUIREMENTS

MF antenna installation criteria, especially at the low end of the band, is similar to that specified for LF antennas.

- o Guy-wire Insulation. Guy wires supporting tower radiators must be insulated from the tower and from ground and must be broken up into sections sufficiently short so that the induced currents do not distort the radiation pattern. Strain insulators are installed at the guy anchor, the point of attachment to the tower, and at intervals along the guy wire. The maximum length of any individual guy-wire section should not exceed one-tenth wavelength.

- o Voltages in High-power Arrays. The voltages commonly encountered in MF antennas are rarely high enough to present corona or insulation problems. The voltages on guy-wire insulators may be roughly estimated for a typical system as having a maximum value of 30 volts per wavelength for one watt of power in the antenna.

- o Circuits Across Base Insulator, AC Power Supply. It is often necessary to cross the base insulator of a tower antenna with AC power circuits. Power for aeronautical obstruction lighting or other purposes may be supplied by means of high impedance shunt chokes with AC lines internal to tubular windings or by transformers especially designed for the purpose (air gap type).