CHAPTER 6

VLF INSTALLATION-EVALUATION AND ACCEPTANCE

Evaluation of the final site configuration and installed equipment for compliance with applicable specifications and operational criteria is the last task before the station can be considered an operating facility. There are numerous acceptance evaluations and tests made from initial site development to final equipment acceptance testing. Any failures and/or non-compliance at the intermediate levels must be corrected and/or resolved before final acceptance for the entire station is given.

6.1 STATION ACCEPTANCE CONSIDERATIONS

There are at least four distinct categories that identify the various tasks and activities performed to convert a remote, undeveloped land area into a developed facility containing a self-supporting operational station. The major categories are; site development and improvement or civil works, buildings and structures or architectural, power generation and distribution or electrical, and radio transmitting equipment or electronics. These categories also help identify the nature of work performed and focus attention to specific acceptance considerations.

For each of the four categories, work evaluation and acceptance considerations will be identified for information purposes. However, the last category for electronic equipment will be expanded to provide extended coverage of the handbook subject matter.

6.1.1 Site Acceptance Considerations

The nature and type of work performed in this category may be considered primarily in the civil works or engineering field. Activities include; land surveys, land clearing and development, road construction, site surveys to stake out specific facility locations, and provision of the life support capabilities and facilities. In order to properly evaluate completed work with applicable specifications and criteria, frequent inspections, evaluations, and approval are given before proceeding with the next phase of work. Detailed acceptance criteria, standards, and tests are prepared and implemented by the cognizant Naval command. Some of the items to be evaluated for acceptance are:

- Coordinates of the site survey with original map coordinates
- Construction of roads, walks, and parking areas
- Water supply and distribution systems for potable and non-potable usage
- Water treatment systems

- Refuse and garbage disposal
- Pollution control systems
- Drainage systems
- Special protective fencing and gates
- Foundations for buildings and the antenna structure.

6.1.2 Building Acceptance Considerations

In this category the initial work entails site improvement to accommodate construction of buildings, antenna ground system, and antenna structures. Evaluation and acceptance of this initial work comes under the cognizance of civil works. From this point, the remaining work activities are considered to be architectural and entail materials, construction methods and procedures, building components, and interior finishes according to the specific building function. Detailed acceptance criteria, standards, and tests are prepared and implemented by the cognizant Naval command. Items to be considered in this category are identified by a general heading.

- Grading and drainage
- Structural compliance to horizontal dimensions and elevations
- Plumbing piping and fixtures
- Heating and ventilating piping, distribution, units, controls, equipment areas, and fire and safety features
- Electrical service for non-technical use
- Special considerations of the above applied to meet the requirements of a specific building function or equipment location on site.

6.1.3 Generating Equipment Acceptance Considerations

Power generation and distribution considerations are governed by the needs of each site and availability of commercial power. At remote locations where the station must be completely self sustaining, power generating plants capable of supplying all the stations' power needs are installed. Station locations where high voltage power can be delivered via a transmission line spur require a distribution system with emergency power generating capabilities (such as diesel power generating equipment) to maintain radio transmission in the event of a commercial power failure. Detailed acceptance criteria, standards, and tests are prepared and implemented by the cognizant Naval command. Items to be considered in this category reflect equipment compliance with operational criteria for normal and emergency conditions. Items to be examined include:

- Maintain voltage levels within tolerance for various load conditions
- Proper operation of the "no-break" automatic switch-over capability
- Proper operation of frequency control sensing circuits
- Adherence to applicable national, local, and naval specifications.

6.1.4 Electronic Equipment Acceptance Considerations

Equipment configuration, complexity, and operational functions make it desirable to subdivide the total system into smaller units, and the smaller equipment units evaluated for operational compliance prior to considering the operational acceptance of the entire transmitting system. Four categories may be used to identify the smaller equipment units and relate to the function performed.

- Signal generation
- Signal amplification
- Signal impedance matching
- Signal radiation.

The first two items identify the function performed by equipment in the transmitter building. The third item is accomplished by equipment in the helix house and the last item by the antenna system. By evaluating the smaller units, any variations from individual operational specifications may be corrected before energizing the entire system. Items to be considered at the system level are:

- Operation of interlock, protection, warning and control circuits
- Substitution of redundant equipment
- Operation in ICW or FSK mode
- Power amplifier power output
- Operation at reduced power
- Full power radiation
- Reliability.

6.2 EQUIPMENT EVALUATION AND ACCEPTANCE

The four functional categories mentioned in 6.1.4 are identified with the specific equipments that perform the particular function. Evaluation and acceptance considerations and criteria for the individual equipments are included.

6.2.1 Signal Generation

Equipments identified with this category include a frequency generator, FSK unit, and ICW Keyer. The output of the ICW Keyer must be sufficient to fully drive the pre-IPA on intermediate power amplifier, and the amplitude and frequency response should be linear over a frequency range of 14 to 30 kHz.

A simple test will provide this information. Required for the test setup is a 50 ohm resistive load and two AC voltmeters. Connect the 50 ohms and voltmeter across the ICW Keyer output jack, and the other voltmeter across the input of the keyer. Input to the keyer and the keyer are adjusted to provide the rated output across the load. Keeping the ICW Keyer input constant, vary the frequency from 14 to 30 kHz in one kHz step. Record the voltmeter readings for each one kHz step and plot the recorded data on graph paper. The resultant plot of voltage versus frequency should show the voltage as being almost constant (± 1/2 dB) over the frequency range. The output voltage should be measured at the rated input voltage to ensure the signal level is sufficient to drive the IPA to full output power.

6.2.2 Signal Amplification

Equipments that accomplish this function are pre-IPA and/or the intermediate power amplifier (IPA) and power amplifier (PA). The degree of amplification required determines the number of IPA's and PA's used. Therefore, evaluation and acceptance considerations for each type must be repeated for the number of equipments used for each amplification stage. The tests and checks conducted apply to both equipments or either one as applicable and are identified accordingly.

a. Control Circuit and Equipment Protective Circuits. All control circuits and high voltage personnel protection circuits must be checked for proper operation before energizing an IPA or PA. Overload relays must be checked and adjusted using standard ammeter and a variable AC and/or DC source to assure their proper operation and the activating of protective alarms at the specific levels. Manual and motor operated grounding circuits must be checked operationally to determine that the protective alarm circuits provide the correct indication in the event of a malfunction. The different items identified here must be operationally acceptable before proceeding further because of personnel and equipment safety considerations.

b. Equipment Cooling for Normal Operation. The water and cooling air systems must be tested to assure efficient and trouble free operation of each IPA and PA.

The air cooling system circulates air through all cubicles where heat buildup would cause equipment or piece part degradation operationally. Specifically, the temperature of certain vacuum tubes must be controlled and maintained at specified levels to optimize operating efficiency. Air velocity must be measured through all systems to assure correct air flow:

$$Qa = v\ A$$

For:

Qa = Air Flow in Cubic Feet/Minute

v = Air Velocity in Feet/Minute

A = Cross Sectional Area of the Orifice in Square Feet

A velometer is used to measure air velocity (v) at various locations in each cubicle. This test immediately focuses attention to those areas where potential equipment problems will arise and require resolution before equipment acceptance.

Testing of the water cooling system is generally conducted at a test pressure of two and one half times the normal working pressure of the system. Monitoring equipment which is an integral part of the system must be calibrated prior to testing and for subsequent operation. Water cooling systems for the IPA, PA, bandwidth resistor, and PA dummy load must be tested for flow in gallons per minute, water temperature leaving the heat exchanger, water temperature entering the heat exchanger, and the drop in the system in pounds per square inch. Checks must also be made for possible leakage at all juncture points, assuring the internal integrity of the cooling system tested.

c. Cooling Equipment Operation After AC Failure. The power amplifier rectifier unit operating temperatures are critical and emergency cooling features are incorporated at those sites utilizing mercury vapor rectifier tubes. A test should be conducted to demonstrate automatic switchover to emergency cooling system operation upon removal of AC power, and restoration of normal cooling system operation when AC power is returned. When AC power is lost, a bell should sound and a DC emergency blower system should start operating immediately. As soon as AC power is restored, the emergency cooling system should become deenergized automatically. It is very important at this point to observe the proper sequence of normal cooling and filament actuation to assure proper amplifier operation.

d. Low Level Voltages and Currents. All filament currents and voltages must be checked as being in conformance with requirements. Bias voltages must be checked and, where necessary, adjusted until correct.

e. Fault Amplifier Circuit Operation. The fault amplifier circuit is one of the most important protective circuits in the transmitter. Large, high voltage, high power vacuum tubes must be protected against damage caused by sustained gas arcs within the tube. Damage can occur before the high speed circuit breaker can open. A DC short circuit across the power supply diverting energy from the fault is the best protective device to accomplish this. An ignitron is used to apply this short and protect the tube until the high speed circuit breaker removes the input power from the system. When a fault occurs in any of the power amplifier output tubes, a voltage buildup across a series cathode resistor fires a thyratron which through associated pulse circuitry fires the ignitron. Total time from the original triggering pulse to the firing of the ignitron is approximately 8 microseconds.

A simplified test set up schematic is shown in figure 6-1. The ignitron tube is an open circuit during normal transmitter operation. When a pulse due to a tube arc is received at the ignitor, mercury vapor is generated allowing plate to cathode conduction. Since the voltage drop from a node to cathode is very low, the tube is considered as a nearly perfect closed switch. When the tube fires, the relay is pulled in and a trip signal is sent to the high speed breaker.

The fault amplifier circuit is tested by triggering the first stage of the sensing thyratron with a positive pulse that simulates the trigger generated by an amplifier tube fault. This same trigger pulse triggers a scope monitoring the ignitron current. A precision resistor is inserted into the cathode circuit of the ignitron to obtain an accurate voltage for display on the scope. Knowing the value of the resistor, it is possible to determine values for current from the scope display. Generally, the maximum total time required from the time of the fault until the breaker opens is not more than 52 milliseconds.

f. Intermediate Power Amplifier Performance. This test should demonstrate IPA operation and its ability to deliver adequate excitation power to any PA configuration. The IPA shall be evaluated on its ability to provide sufficient output power to fully excite the grids of one to four PA's (as appropriate) from a single frequency generator output. Plate voltage regulation should not exceed 10% from full load to no load conditions when measured at the filter circuits output. The plate voltage ripple should not exceed 0.5% RMS at full load.

This initial test is performed by switching the first IPA into its own dummy load. The ICW keyer output is monitored and recorded. Voltage across one resistor of the number comprising the dummy load may be measured and used to determine output power. An oscilloscope should be used to monitor the output waveform for any harmonic or parasitic oscillations (this may be done by connecting a scope to a capacitive voltage divider across the dummy load). Meters are used to measure the screen grid current (as appropriate), cathode current, and plate voltage. Plate input power, output power, amplifier efficiency, and tube dissipation are calculated using the following relations and then recorded.

$$P_i = (E_p)(\Sigma I_k - \Sigma I_{sg}) \qquad (6-1)$$

where:

P_i = plate input power in watts

E_p = plate voltage to PA Tubes measured in volts

EI_k = sum of the cathode currents of the PA Tubes in amperes

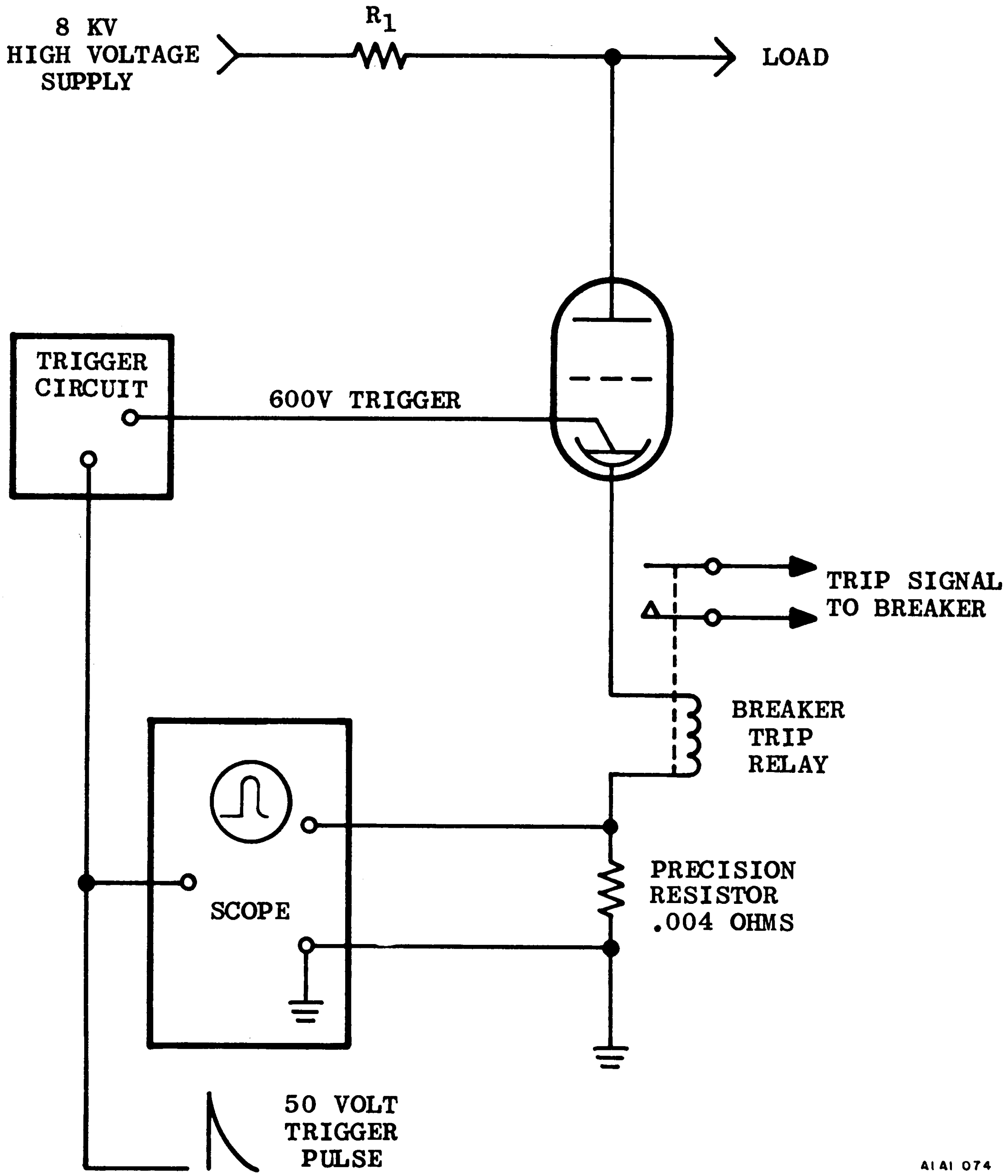


Figure 6-1. Fault Amplifier Test Circuit Simplified Schematic

ΣI_{sg} = sum of the screen grid currents of the PA Tubes in amperes

$$P_o = \frac{(E_L)^2}{R_L} \qquad (6\text{-}2)$$

where:

P_o = output power of amplifier in watts

E_L = total RMS voltage across total dummy load resistance (compute from resistive voltage divider calibration)

R_L = total dummy load resistance in ohms

$$\text{Eff}(\%) = \frac{P_o}{P_i}(100) \qquad (6\text{-}3)$$

where:

Eff(%) = plate efficiency in percent

P_o = power output in watts

P_i = plate input power in watts

$$P_{diss} = P_i - P_o \qquad (6\text{-}4)$$

where:

P_{diss} = total tube dissipation in watts

P_o = power output in watts

P_i = plate input power in watts

The per tube dissipation may be obtained by dividing P_{diss} by the total number of PA tubes active.

The second part of IPA performance testing uses all of the IPA units configured in their operational arrangement. The active IPA's will be in the operate position and the unused IPA will be terminated in the dummy load. A high voltage vacuum tube voltmeter, placed across the dummy load will measure the dummy load voltage. An oscilloscope should be used to monitor the output waveform and connected to a capacitive voltage divider placed across the dummy load. Note that the output should be a pure sine wave. Plate voltage ripple is also measured with this oscilloscope connected at another point. Plate voltage and full drive are now applied to the IPA. Peak to peak ripple voltage is read on the oscilloscope and converted to RMS voltage values. Plate voltage regulation and plate voltage ripple are calculated using the following relationships and then recorded.

$$\text{Reg}\ \% = \frac{100(E_{\text{no load}} - E_{\text{load}})}{E_{\text{load}}} \qquad (6\text{-}5)$$

where:

$E_{\text{no load}}$ = IPA plate voltage (panel meter) with key up

E_{load} = IPA plate voltage (panel meter) with key down and full drive

Reg % = plate voltage regulation in percent

$$R_{pl} = \frac{E_{\text{ripple}}\ (100)}{E_p} \qquad (6\text{-}6)$$

where:

R_{pl} = percent plate voltage ripple

E_{ripple} = AC RMS voltage in volts of ripple

E_p = DC plate voltage in volts read at IPA panel meter

Plate voltage regulation should be less than 4% which is considered within specification. Similarly, 0.3% plate voltage ripple should be acceptable.

This test and data should be conducted at various frequency settings over the transmitter frequency range. A graph of the final data should be plotted as "Kilowatt Power Output" and "Efficiency in Percent" versus "Frequency in Kilohertz." IPA performance over the operational frequency range can be readily evaluated from the graphs.

g. Power Amplifier Power Output. Each PA must be capable of a minimum power output of 500 kilowatts throughout the 14 to 30 kilohertz range. At least five specific frequencies should be picked for testing, including the lower and upper ends. The minimum power output should be maintained for one hour for each test frequency selected. Since the PA dummy load response may not be linear over the range, the PA dummy load series inductance and capacitance (if so designed) is adjusted to provide correct PA loading at each of the test frequencies. Before conducting these tests, the resistance of each PA dummy load should be determined using an impedance bridge. Knowing the resistance, power output can be calculated by measuring either the current into or the voltage across the PA dummy load. The current is read on the dummy load current meter generally located on the front panel. Alternatively, a high voltage vacuum tube voltmeter connected across the dummy load bushings will provide the voltage reading. The plate input power to the PA is calculated using the plate voltage and total power amplifier plate current readings from front panel meters. Power output, plate input power, plate efficiency, and plate dissipation can be calculated using the following relationships.

$$P_o = I^2 R_L = \frac{V^2}{R_L} \qquad (6-7)$$

where:

P_o = power output of power amplifier in watts

I = current in amperes read on PA dummy load current meter

R_L = resistance of PA dummy load in ohms

V = RMS voltage read from VTVM connector across the resistive dummy load element, or

$$P_o = \frac{(0.5)(E)^2}{R_L} \qquad (6-8)$$

where:

E = peak voltage in volts read on the high voltage VTVM

P_o = power output of power amplifier in watts

R_L = resistance of PA dummy load in ohms

$$P_i = E_p I_p \qquad (6-9)$$

where:

P_i = PA input power in watts

E_p = plate voltage in volts

I_p = plate current in amperes

$$\text{Eff}\ \% = \frac{P_o}{P_i}(100) \qquad (6-10)$$

where:

Eff % = percent efficiency

P_o = power output in watts

P_i = power input in watts

$$P_{diss} = \frac{1}{n}(P_i - P_o) \qquad (6\text{-}11)$$

where:

P_{diss} = power dissipation per tube in watts

P_i = power input in watts

P_o = power output in watts

n = number of active PA tube

Test data must be taken at each of the selected test frequencies and the appropriate calculations made. Finalized test results should indicate that each PA delivers a minimum power of 500 kilowatts into its dummy load over the specific frequencies selected in the operational range.

h. Input Impedance and Power Dissipation of Dummy Loads. It is important to verify the proper load impedance and power handling capabilities of the dummy loads of all the IPA and PA units. The basic requirement is that the impedance of the calibrated dummy loads be within ± 10% of the input impedance of the following amplifier stage. The power amplifier should include a suitable calibrated load capable of dissipating the full rated power output of any of the PA units and should be tuned to a desired frequency and checked operationally. The IPA dummy load is designed to approximate the impedance of the grid circuits of the number of PA's it is providing input to. IPA output current is calculated using data obtained from the test setup shown in figure 6-2.

$$I_g = \frac{E_r}{R} \qquad (6\text{-}12)$$

where:

I_g = current in amperes delivered to the PA grid circuit

E_r = voltage in volts across the series resistors

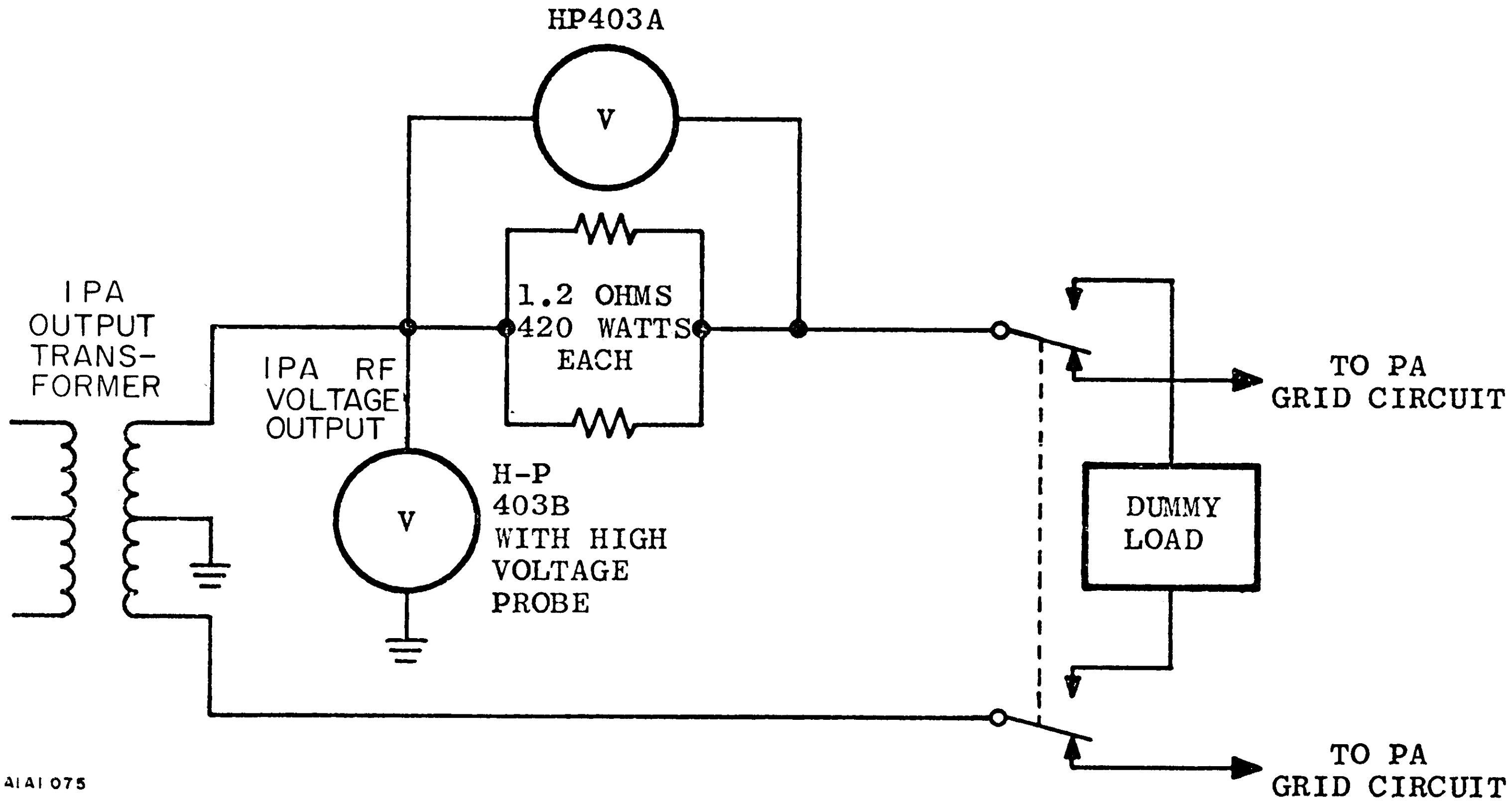


Figure 6-2. Measurement of Input Impedance of PA Grid Circuit

R = resistance in ohms of the resistors = 0.6 ohms

The impedance presented to the IPA can be calculated as follows.

$$Z_{pa} = \frac{E_g}{I_g} \qquad (6\text{-}13)$$

where:

Z_{pa} = grid impedance of PA's in ohms

E_g = RF voltage output of the IPA in volts

I_g = current in amperes delivered to the PA is grid circuits

Impedance of the IPA dummy load is measured with an impedance bridge. Percent of impedance difference between PA impedance and dummy load impedance can be calculated using the following relationship.

$$\%\ \text{Diff} = \frac{Z_{pa} - Z_L}{Z_{pa}} (100) \qquad (6\text{-}14)$$

where:

Z_{pa} = grid impedance of PA's in ohms

Z_L = impedance of load in ohms

The PA dummy load is usually designed to approximate the output impedance of a single PA. This impedance is measured in the following manner. A vacuum tube voltmeter with a high voltage probe is placed across the input to the "T" or other transmitting network to measure the voltage output of the total number of PA's. Output current is obtained from a network input current meter. Using this data, the impedance of the output of one PA is calculated using the following relationship.

$$Z_{out} = \frac{E_{in}}{nI_{in}} \qquad (6\text{-}15)$$

where:

Z_{out} = impedance in ohms seen at the output of one PA

E_{in} = voltage in volts across the matching network input

I_{in} = matching network input current in amperes

n = total number of PA's activated

Impedance of the PA dummy load is determined by measuring the voltage across the dummy load with a vacuum tube voltmeter and obtaining the dummy load current from a front panel meter on current transformer. This impedance can be calculated with the following relationship.

$$Z_L = \frac{E_L}{I_L} \tag{6-16}$$

where:

Z_L = impedance in ohms of dummy load

E_L = RMS voltage across dummy load in volts

I_L = dummy load current in amperes

From this data, the percent of difference can be obtained using previously calculated data.

$$\%\ \text{Diff} = \frac{Z_{out} - Z_L}{Z_{out}} \tag{6-17}$$

Power dissipation capability of the IPA dummy load is checked by running the IPA into its dummy load and checking the load for any signs of excessive heating. The PA dummy load power dissipation capability is checked by applying full power from one PA to the dummy load for one hour. The temperature of the input and output cooling water is obtained by attaching thermometers to the water pipes. Water flow is read from a front panel meter. This data now permits calculation of the dummy load power dissipation.

$$P_{diss} = 264\ (\text{GPM})\ (T_{out} - T_{in}) \tag{6-18}$$

where:

P_{diss} = power dissipation in watts

GPM = flow in gallons per minute

T_{out} = outlet water temperature in degrees C

T_{in} = inlet water temperature in degrees C

i. PA Rectifier Voltage Regulation and Ripple. This test is conducted to demonstrate that voltage regulation does not exceed 10% from no load to full load when measured at the filter output and voltage ripple does not exceed 0.5% at full load when measured at the output of the filter circuits. PA plate voltage regulation data is obtained by connecting the power amplifiers to one rectifier and bringing them up to full power operation. A front panel meter is used to obtain voltage readings with the key open and with the key closed. The percent voltage regulation is calculated using the following relationship.

$$\text{Reg }\% = \frac{(E_{\text{no load}} - E_{\text{load}})}{E_{\text{load}}} (100) \tag{6-19}$$

where:

Reg % = percent voltage regulation

$E_{\text{no load}}$ = PA plate voltage with key open

E_{load} = PA plate voltage with key closed

PA plate voltage ripple data is obtained by connecting an oscilloscope with a high voltage probe to the high voltage output terminal of the filter cabinet of one PA. The PA is brought up to full power and excitation is applied. Plate voltage is read on a front panel meter and recorded. The oscilloscope is used to measure peak to peak ripple voltage, converted to an RMS value and recorded. Percent ripple is calculated by substituting the record data into the following relation.

$$\text{Rpl }\% = \frac{E_{\text{ripple}}}{E_{p}} (100) \tag{6-20}$$

where:

Rpl % = percent plate voltage ripple

E_{ripple} = RMS value of ripple present on plate voltage in volts

E_{p} = plate voltage in volts

j. TEE or PI Impedance Network Component Values (when appropriate). Inductance and capacitance bridges should be used to measure for record the values of these components once optimum transmitter loading is attained.

6.2.3 Impedance Matching

a. Variometer Structure Integrity Test. The helix house contains all the equipment providing the interface between the antenna array and the power amplifier signal output. This equipment is shipped to the site unassembled because of its size and overall complexity and assembled in the helix house. The value for total antenna resistance includes the resistance of this equipment as one of the factors.

The following test must be conducted and entails visually observing that movement of all variometers is held to a minimum during keying or at any other time after the variometer is in its adjusted position. All the variometers must be checked, including the grid variometers in the power amplifiers. If any movement is observed, additional bracing on the motor drive must be supplied to eliminate the rotor movement off its axis of rotation. While this test is being conducted, all personnel must station themselves at a safe distance from each variometer.

b. Variometer(s) Inductance Range. The minimum and maximum inductance for the variometer(s) should be measured using an inductance bridge.

c. Helix Strapping and Inductance Range. An inductance bridge should be utilized to measure the inductances of the various combinations of turns of helix that can be utilized.

6.2.4 Radiation

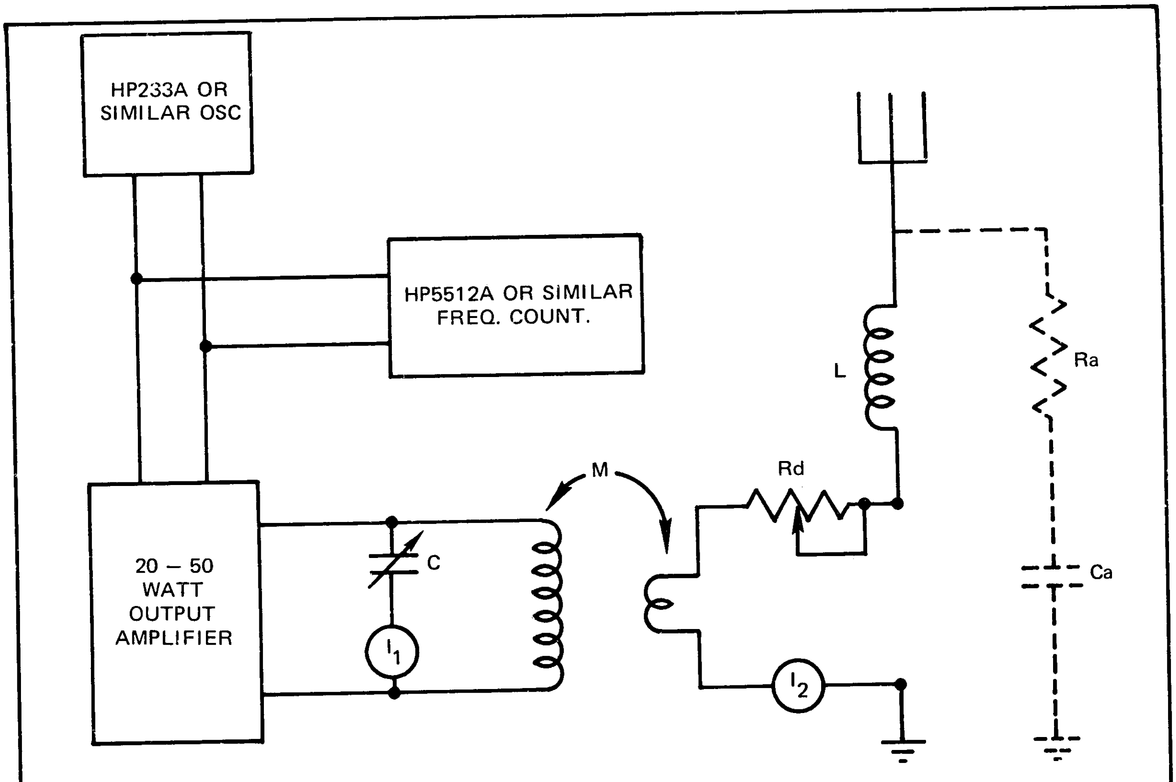
a. Antenna System Resistance. Because the VLF antenna can collect fairly substantial static discharges even in fair weather some precautions are required. For personnel safety the antenna should always be grounded when connecting a resistance test set. For equipment protection the resistance measuring scheme must not subject delicate equipment directly to antenna currents. Even in a light breeze on a fair day impulses followed by antenna resonant "ringing" show antenna currents in the order of 10-20 amperes. Antenna resistance is a function of frequency and must be measured at the frequency of interest.

(1) Pauli Method. This method is based on the fact that in a resonant antenna circuit, power lost in the antenna resistance is equal to the power coupled into the antenna. Referring to figure 6-3(a); R_a, which is to be measured, is the sum of R_c, R_r, R_{sd}, and R_i, but not R_t; and L is the sum of L_a and L_i, is to be measured. R_d is a decade resistance box which along with a small coupling coil and an ammeter are inserted in the antenna circuit for the measurement. Writing Kirchoff's Voltage Law for the antenna circuit:

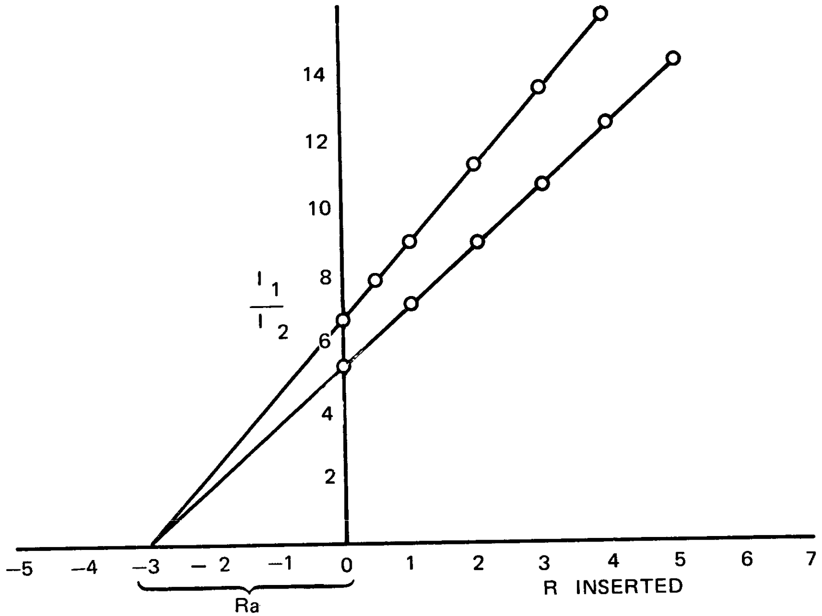
$$j\omega MI_1 = I_2(R_a + R_d) + j\omega LI_2 + \frac{I_2}{j\omega C} \qquad (6\text{-}21)$$

When the circuit is tuned to resonance at ω_o the last two terms balance and:

$$j\omega_o M (I_1/I_2) = R_a + R_d \qquad (6\text{-}22)$$



(a) SIMPLIFIED TEST CIRCUIT



(b) TYPICAL PLOT FOR TWO COUPLING VALUES

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Figure 6-3. Pauli Method of Antenna Resistance Measurement

The ratio of the primary to secondary currents is directly proportional to the total antenna circuit resistance. By varying the inserted resistance the proportionality constant, $j\omega_oM$, is determinable. The ocillator, amplifier and C are tuned to resonate with the antenna system (which is indicated by a dip in the I_1 meter). For each value of resistance R_d inserted (including zero) I_1 and I_2 are recorded and the ratio of I_1/I_2 computed and plotted for each value of R_d as shown in figure 6-3(b).

The mutual coupling of the test set is then changed from M_1 to M_2 and the process repeated. After the plots are made, the straight line curves are extended down to the R axis where they will intersect (this is a double check). If the current ratio, I_1/I_2, could be brought to zero then the antenna resistance R_a would equal zero. Therefore, the distance from the R axis intercept to the I_1/I_2 axis is the antenna resistance R_a, and values to the right of the I_1/I_2 axis represent additional resistance inserted during the measurement process. This method can be carried out at a power level of several watts. Accuracy is good and is dependent only on the insertion transformer loss, the ammeters, and the decade resistance box. All test set components can be quite rugged.

(2) Current Null Bridge. This is another effective method of measuring small values of resistance such as a VLF antenna circuit total resistance. A simplified schematic of the test set up is shown in figure 6-4. The antenna system is first tuned to series resonance using the antenna variometer in the helix house. Maintaining a constant input voltage, the resonance indication at V_1 will be maximum at this point. The resistance measurement is obtained by passing two currents through a toroid. One current passes through the toroid with a known resistance path of precision resistors and the other current is through the antenna. Since the currents are in opposite directions through the toroid a distinct null will be obtained when both currents are equal (when adjustable precision resistance equals the total antenna system resistance). Thus, the precision known resistor is adjusted for a null indication on null detector, V_2,and the value of antenna system resistance read from the dial.

b. Antenna Down Lead Current. The value for antenna down lead current is another parameter that is needed initially to accurately measure the power output of the transmitter. Antenna resistance and down lead current are essential for transmitter evaluation. A current pickup loop driving a thermocouple is usually used to measure the antenna current. The thermocouple converts the current to a voltage which is measured by a voltmeter and a remote meter on the transmitter console. The remote meter is connected in series with other voltmeter with the remote meter calibrated to read current. The test set up for the calibration circuit is shown in figure 6-5. Current for calibration purposes may be obtained by using a power amplifier output into a dummy load. A sketch of the calibration coil is shown in figure 6-6. The coil has 25 turns formed in a five-inch circle to simulate a solid copper bus. Current flows establishing a field around the circular section simulating the field established by a current of 25 times the dummy load series current. The thermocouple maximum current is generally 50 amperes which established the maximum simulated current to be 1250 amperes of bus current. Using the antenna resistance value, maximum antenna current at full power is calculated. If the calculated value is higher than the simulated current of 1250 amperes, additional turns must be added to the coil to increase its

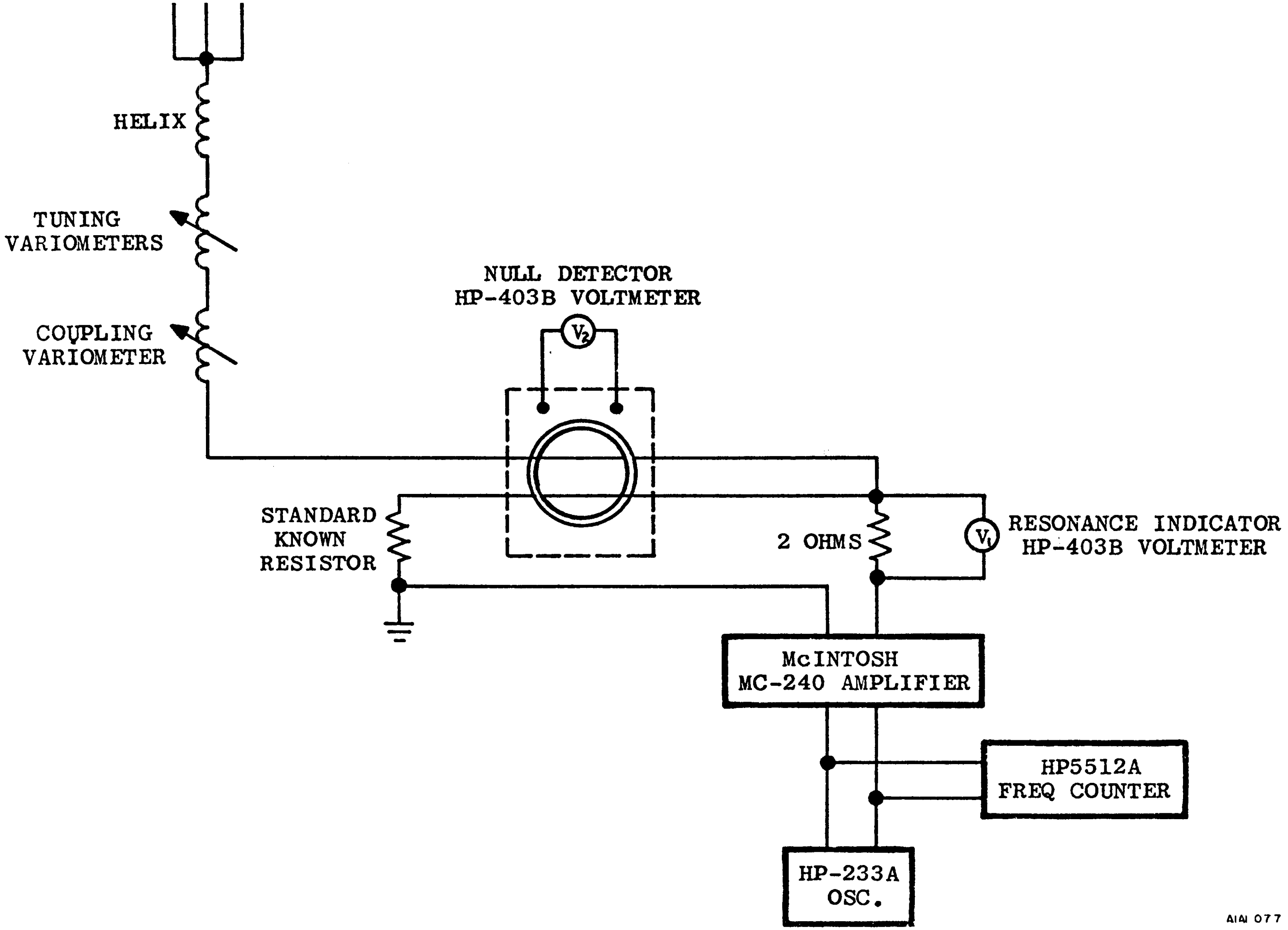

Figure 6-4. Simplified Schematic of Antenna Resistance Measurement

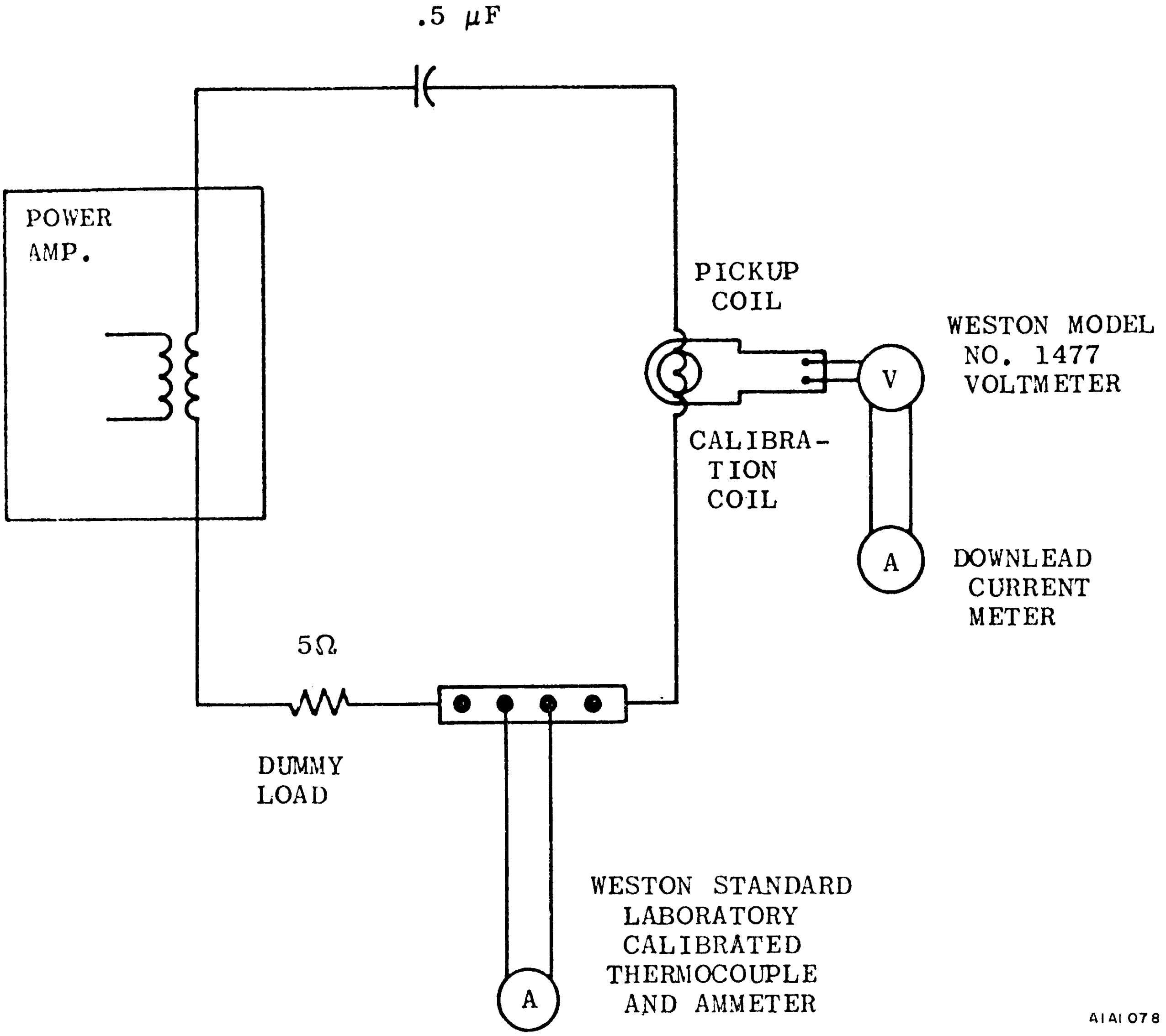

Figure 6-5. Schematic of Antenna Current Meter Calibration

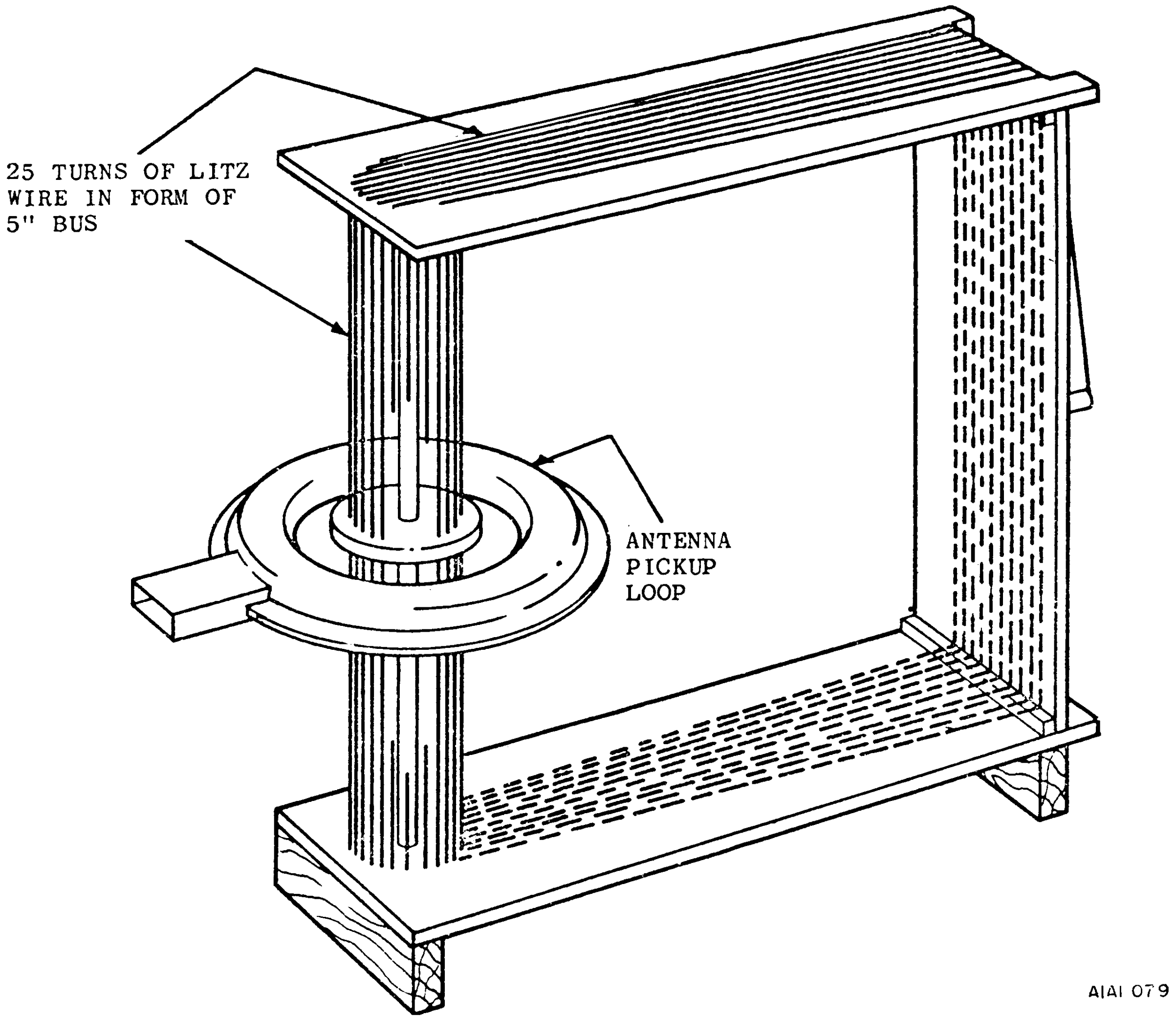

Figure 6-6. Calibration Coil

range. Data is taken and recorded at one ampere steps as indicated on the down lead current meter. The resulting table should contain: standard current in amperes, number of turns on calibration coil, standard current times number of turns, the square root of Electromagnetic Voltage (EMV), EMV, and the current times number turns divided by the square root of EMV.

An alternate method utilizes a precision antenna current transformer which is placed in series with the antenna current transformer and associated meter to be calibrated.

c. Directional Coupler Peak Transient. It should be noted that all transmitters do not have this feature. However, in the event it is supplied as part of a new antenna modification or installation, its operational capability must be tested. The test is to demonstrate that possible peak transient voltages appearing at the directional coupler will be discharged by the horn gaps across the coupler. The horn gaps are set to go over at a given voltage, V_1 kilovolts, thereby protecting the coupler from peak transient voltages such as those caused by direct lightning hits on the top hat. The directional coupler should be removed from the RF bus for ease of handling. A high voltage is brought up to $2V_1$ kV and held for a minute. This will demonstrate that the coupler is capable of withstanding a peak transient voltage of V_1 kV plus 100% of that voltage as a safety factor. The horn gaps are reset or spaced to break down at V_1 kV.

6.3 SYSTEM EVALUATION AND ACCEPTANCE

The operational capabilities of the four functional equipment groups as an operating entity must be evaluated to determine system acceptability. This entails conducting tests which demonstrate operational compliance at the system level. All of the electronic system equipment is used at various points throughout the following tests.

6.3.1 Electrical and Mechanical Interlock Circuits

This test should demonstrate that transmitter interlock system operation provides protection for personnel and equipment. The interlocks are arranged and connected so that any compartment or area may be entered by operation and maintenance personnel to make necessary adjustments and repairs without danger. Operation of other power amplifiers in use should not be interrupted when this individual compartment is deenergized. Vibrations should not interrupt interlock circuit operation. Two interlock systems are used, one is electrical and the other is mechanical. High voltage areas used both types. When an area is entered, the interlock indicator lamp on the unit and/or console lights and at the same time, a trip signal should be applied to the appropriate circuit breaker to remove the high voltage. Non-interruption of operation due to vibration is shown by striking each door or gate with a rubber mallet causing a mechanical shock at point of impact.

6.3.2 Overload Reclosure Test

Proper operation of the overload reclosure circuitry upon overload of an operating tube or associated circuit should open and reclose the breakers up to three reclosures, in some transmitters provided the overload condition does not clear. If the overload continues after the third reclosure, the circuit shall open, remain open, and give indication of a malfunction until manually reset. A bright red light located on the front panel and/or console identifies the particular part of the system at fault. The overload condition should actuate an overcurrent relay that is generally adjusted for pulling at one and one half times the normal operating current; the manufacturer's literature should be consulted to obtain the exact value. Manual simulation of an overcurrent condition by jumping a set of contacts on the breaker trip button and then on depressing it should trip the breaker (and stepped the reclose relay). Upon release of the button, the transmitter should back up. Holding the button down for a sustained time period will simulate a sustained fault activating the associated indicators and deenergizing the circuit.

6.3.3 Initial System Evaluation

The initial consideration identified here are for information purposes only. Prior to conducting system performance tests, the transmitter should be energized for short periods of time to determine if there might be problems with loading, tuning, or heating of components. Various power levels should be applied at any five frequencies over the complete frequency range. This simple test establishes the operational integrity of the total system and allows for a quick physical check for obvious hazards or potential malfunctions.

6.3.4 Full Power Operation

System operational tests are conducted at full power capacity to evaluate equipment compliance with performance specifications and criteria. Basically, they are a combination of individual and related tests to determine operational capabilities of the complete system. Specific measurements are made of transmitter output (matching network input), field intensity at two or more location, radiation efficiency, spurious radiation, and harmonic radiation. Operation in either the ICW or FSK mode is evaluated for transmitted data specification compliance. Measured antenna electrical characteristics are compared with initial theoretical calculations. Generally, five test frequencies are selected between 14 and 30 kHz for full power testing.

Stations with dual antenna arrays will have each array tested individually for compliance in addition to both antennas simultaneously.

a. Static Capacitance and Self Resonant Frequency Antenna Reactance. The antenna self resonant frequency is determined by measuring the frequency at which a minimum voltage is developed across the antenna terminal when the antenna feed point is excited by a current source. Referring to figure 6-7, V_2 is maintained constant as the signal generator frequency is adjusted for a maximum value of V_1. Antenna static capacitance is measured at a frequency of 60 hertz using an RC method. The 60 Hz signal is applied to the antenna through an adjustable series resistor. Voltage across the antenna to ground will equal the voltage across the resistance when the resistor value equals the antenna reactance. The variable resistor is adjusted until the resistor voltage and the antenna voltage are equal. The exact resistance value is determined using a simple bridge circuit and the static capacitance computed from:

$$C_S = \frac{1}{2\pi(60)\,R} \qquad (6\text{-}23)$$

where: R = resistance value for equal resistor and antenna voltages

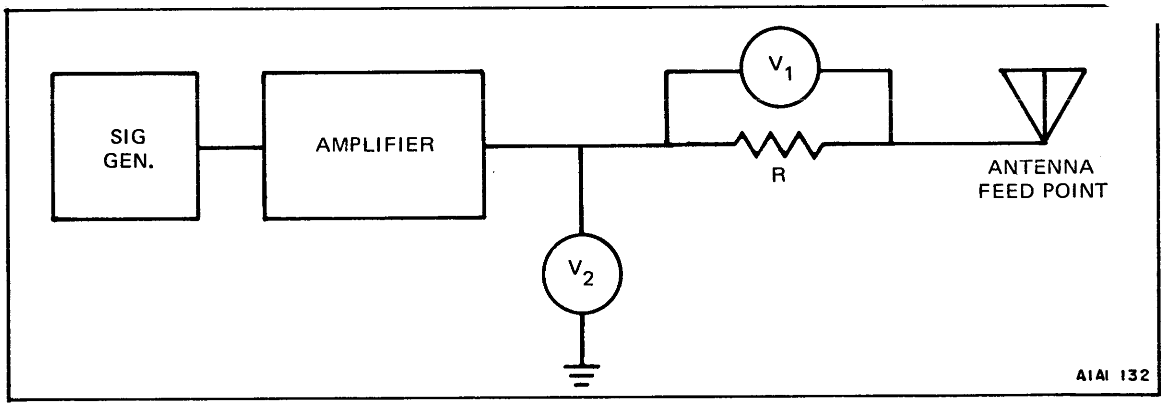

Figure 6-7. Antenna Feed Point

Antenna reactance is determined by a substitution method. The circuit for antenna resistance measurement described in 6.2.4 is brought to resonance. A low loss precision capacitor is substituted for the antenna in the series resonant circuit and adjusted to reresonate the circuit. Antenna reactance is computed from:

$$X_A = - \frac{1}{2\pi f \ CM}$$

f = Frequency of Measurement
CM= Value of capacitance required to reresonate circuit

b. Corona Check. Careful checks for indication of corona must be made during the daytime as well as the evenings. Field glasses should be used to check all insulators, down leads, and towers. These checks should be conducted under full power operation and at all test frequencies, during wet weather as well as dry and normally moist days.

Another indication of corona is a hissing sound that can be heard with sound intensifying directional microphones such as used by commercial power companies. This aural test can be done in daylight.

A black-night corona test involves a long exposure of fast film sensitive in the ultraviolet range. The individual corona streamers, even though they may be invisible to the naked eye, superimpose on the photograph to form a "fuzzy ball" appearance. Both black and white film and color film have been used to detect black corona (non-visible).

Another indication of corona that is discernible in a closed building such as the helix house is the presence of ozone, O_3. This gas and nitrous oxide, NO, are both formed by corona and have a distinctive aroma.

A popular but relatively insensitive corona test is to monitor the second or third harmonic (or other higher order harmonics) with a receiver for the presence of corona. However, substantial corona occurs before detection by this means.

c. Spurious Radiation. During full power operation at the selected test frequencies, measurements should be made to observe spurious radiation at frequencies greater than the operational frequency but less than ten megahertz. These measurements should be made at several remote locations with the transmitter operating in the dot mode. This mode permits readily identifying the signals when scanning the spectrum. Spurious radiation should be at least 60 dB below the fundamental frequency.

d. Bandwidth. The transmission bandwidths are determined for each of the selected test frequencies. One method is to match the antenna system to the transmitter and maintain the input voltage to the IPA constant while the excitation frequency is varied. Antenna current or radiated field strength as a function of frequency is plotted to determine system bandwidth.

6.3.5 On-Off Keying

This full power performance test is conducted to evaluate the radiated signal waveform. At each of the test frequencies, the antenna array transmits dots (on-off keying) at the speed appropriate to the antenna system bandwidth and/or degree of transmitter wave shaping circuit adjustment available. The signal waveform is monitored at the remote test sites on an oscilloscope and photographed for permanent records. The photographed waveforms are used to determine compliance with the specifications and should satisfy these conditions:

- Dot amplitude should reach at least 95% of the key-locked voltage
- Dot amplitude should exceed 90% of key-locked voltage for at least 50% of its duration
- Transient overshoot should be less than 5% of key-locked voltage.

6.3.6 Substitution of Units

This test is to evaluate substitution of duplicate units using the control console functioning in its normal capacity. The various important control functions are demonstrated. The maximum time limit is five minutes for correct timing and sequence of control functions. Substitution is demonstrated by bringing the transmitter up to full power with all number one units and placing all redundant units on standby status. The transmitter (on-line units) are placed in the standby condition and the standby (redundant) units are substituted for the number one units. After the substitution is completed, the transmitter is brought up to full power operational status. During this step, proper selection of local, automatic, and master operation is observed. All time delays, front panel indications, and control console operations and indications are checked for compliance with equipment operating criteria.

6.3.7 Reliability

Final system acceptance is generally contingent upon successfully completing a test to demonstrate a minimum inherent reliability level of 200 hours mean time between failures (MTBF) with a confidence level of 90%. This demonstration requires a test period of no less than 300 hours and no more than 700 hours. If no failure occurs between the official start of the reliability test and cumulative time of 300 operating hours, the test is successfully completed. If one failure occurs before the end of 300 cumulative operating hours, the reliability test must be continued for an additional 400 operating hours. If no additional failure occurs, the reliability test is successfully completed.

If more than one failure occurs before the accumulation of 700 operating hours, the test is terminated and a report made to the OICC. The accept or reject decision is made by the OICC.

A "failure" is defined as any involuntary shutdown of the transmitter following which it is found necessary to repair or replace a part or component of the transmitter, or to make an adjustment or correction to a part or component, in order to resume the full power test schedule. Any vacuum or rectifier tube failure during the test period is considered a transmitter failure. Voluntary shutdowns (e.g., to change operating mode or to change frequency) and involuntary shutdowns following which the transmitter is restored by automatic recycling or manual restart, without a repair, replacement, or adjustment being required to restore full power operation, are not considered a transmitter failure.

6.4 FIELD MEASURING TECHNIQUES

Additional information and guidance in terms of test equipment, measuring procedures and required test and data information may be found in Section 7.3 of this handbook.

6.4.1 Antenna Placement

a. Local Terrain Effects. The immediate terrain between the antenna and the station being received can have an appreciable affect on the field intensity measured. The conductivity of the terrain affects the attenuation of the ground wave and in addition introduces a receiving antenna launching loss which for arctic land and ice can amount to several dB. However, the importance of noting terrain features and if possible obtaining detailed maps of the area is to be stressed.

b. Effects of Nearby Metallic Objects. Metallic poles, guy wires, buildings, etc. should not be in the immediate vicinity of the loop. Previous tests indicate the loop should be placed at least 50 feet from buildings with metal framing or covering and this can also be assumed to be a safe value for light poles, etc. If circumstances prevent locating the loop a safe distance from metallic objects such as in a shipboard installation it is desirable to attempt getting the loop in as high an open space as possible. If possible, measurements should be made in a clear area (on the dock for example) and then with the loop mounted in position to determine what calibration factor should be applied to the shipboard antenna. Where the loop antenna is placed near vertical metal objects such as a stack or mast, this factor will exchange with bearing angle.

c. Length of Cable and Cable Placement. The cable connecting the loop to the F.I. meter should in general be short in comparison to the length that would resonate the loop at the frequency to be measured. For the 30" URM-6 loop, lengths of RG-58U of up to several thousand feet may be used when making measurements at VLF if calibration injection is near the loop. Care should be taken not to run the cable parallel to power lines or cables for long distances.

In some cases a resonated loop may be desirable (because of increased sensitivity) in which case longer cable lengths, up to that which would resonate the loop to the highest frequency to be measured, may be used.

d. Buried Cables and Conducting Objects. Buried cables with an outer metallic shield are known to have a greater effect on loop direction finders than cables on the surface of the ground. Field intensity readings and apparent signal arrival directions will thus surely be affected also. On this basis, when operating in areas likely to have buried cables or pipes, their location should be determined, noted, and avoided if possible. Location near the end of a cable will have less affect than locating the loop near the center of the cable.

Steel reinforcing in large concrete slabs or runways can also distort the electromagnetic field and as a result produce erroneous readings of the true propagated field when measurements are made near the edges of such structures. These local field distortions will frequently have differing effects on the electric and magnetic field components. In general loop antennas are less subject to local disturbing effects since the H field perturbations are less severe than those of the E field.

6.4.2 Calibration

a. Theory. Insertion of a known voltage at the antenna is a very reliable method of calibration. The schematic diagram of figure 6-8 shows the circuitry involved.

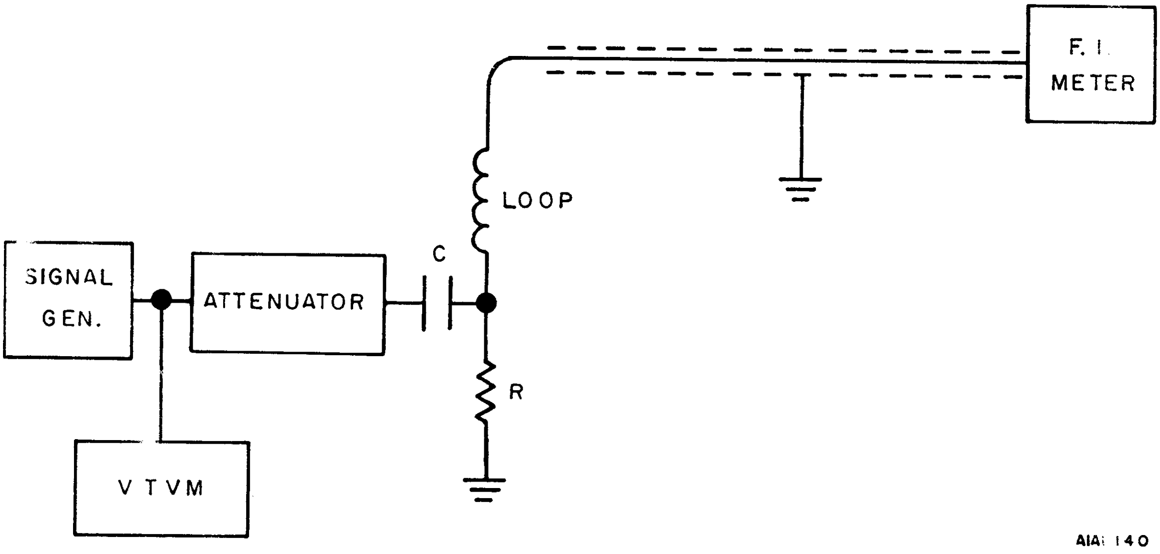

Figure 6-8. Insertion of Voltage at the Antenna, Schematic Diagram

The RC voltage divider serves to introduce an attenuation equivalent to the difference between the field intensity and the voltage induced in the loop. The voltage induced in the loop by a known field from a source in the plane of the loop may be found from:

$$V_i = \frac{E \times 2 \pi n A}{\lambda} = E \times (2.1 \times 10^{-5}) n A f$$

where:

E is field intensity in V/M
n is number of turns
A is loop area in square meters
λ is wavelength in meters
f is frequency in kilocycles/second.

For the 30" URM-6 loop

$A = 0.464$ square meters
$n = 11$ turns

Assuming a 1 V/M field at 20 kHz

$$V_i = (2.1 \times 10^{-5})\ (11)\ (0.464)\ (20)$$
$$= 0.00214 \text{ volts}$$
$$E/V_i = 1/.00214 = 467.3$$
$$= 53.4 \text{ dB}$$

Hence, at 20 kHz the RC divider should provide an attenuation of 53.4 dB. If $R = 0.5\Omega$ $X_C = 234\ \Omega$, and $C = 0.03405\ \mu$ fd. Now because of the direct relationships between f and V_i and X_c, the RC voltage divider will provide the correct attenuation at all frequencies in the VLF frequency band. If the signal generator is set at 1 or 0.1 volts and the induced voltage is varied by means of the attenuator, care should be taken to assure that the variation in loading does not introduce appreciable error. If necessary a stabilizing LC load can be employed to maintain a 50 ohm load. Thus if the VTVM indicates a voltage of 1 millivolt, the voltage inserted at the loop will be the same as would be induced in the loop by a 1 MV/m field. This system is very reliable because any cable losses, gains in voltage due to resonance, etc. will affect the calibrating signal in the same manner as the received signal.

b. Procedure. The calibration procedure is relatively simple. The loop may be positioned for a null on the station desired or the F.I. meter may be slightly detuned from the station to be received. Then insert a known voltage into the loop and tune the F.I. meter accurately to the calibration signal. Finally, adjust the gain of the F.I. meter until it indicates a field equal to the calibration voltage. The calibration is then complete for that frequency. The gain of the F.I. meter cannot be assumed to be the same at all frequencies, however, and calibration is necessary whenever a new frequency (differing from the previous calibration frequency by ±5%) is to be measured. If the loop is approaching resonance because of long cables any change in frequency will require recalibration. Stepped attenuators should be checked by calibrating at different signal levels.

c. Calibration Check. If the loop is not approaching resonance the calibration of the URM-6 may be checked by its own internal noise source. This procedure is outlined in the URM-6 instruction manual. The method outlined above is more accurate than self-calibration but self calibration will serve to check for gross errors. Calculation of expected field intensity will also serve to eliminate gross errors.

6.4.3 Operating Procedure

a. Loop Orientation. Careful loop orientation is necessary to insure accurate measurements. If the loop is turned 90^o from the position of null used for calibration it will be in line with the direction of the received signal and will be in position for maximum response. This position should be checked regularly to make sure wind or man has not changed its position.

b. Control Positions (For URM-6 or NM-10A F.I. Meters). The BFO should be off at all times except when trying to locate the desired signal. It will aid in tuning in a signal to have the BFO on but it must be off to obtain accurate field intensity readings.

The control marked CAL is simply an RF gain control and will be adjusted during calibration. It must not be changed except when calibrating.

The function control will be in the CAL position only during an internal calibration check. When making the regular calibration by inserting a signal into the loop and when measuring the field intensity of a steady carrier (locked key) the function control will be in the field intensity position. The peak position will be used only if it is necessary to make measurements as a station when it is being keyed.

The input control will be in loop operate position at all times except during an internal calibration check when it will be in loop CAL position.

The attenuator will be in the CAL position only during an internal calibration check. The field intensity to be measured will determine the position of the attenuator during measurements. During regular calibration the attenuator multiplier factor times the meter reading should be equal to the calibration voltage being inserted.

The peak control should be turned full CCW except when making peak measurements.

The audio control is simply an audio gain control and does not affect field intensity measurements or calibration.

c. Locked Key Readings. Whenever possible field intensity readings should be made with the transmitting station on locked key, otherwise, when the signal is not being keyed or amplitude modulated. The function control of the URM-6 should be in the field intensity position. Careful tuning for a maximum reading is all that is necessary for accurate results.

d. Peak (Key Signal) Readings. When the station to be measured is being keyed, it is necessary to use the peak reading function of the F.I. meter to get accurate results. The peak reading function of a F.I. meter normally involves a slide-back bias voltage arrangement. When the bias voltage is exceeded by the signal this is noted by variations of output at the keying rate. The bias voltage is adjusted until the signal just barely reaches this level. This level is then read, on a properly calibrated meter, as the field intensity of the signal. For the URM-6 the function selector is in the peak position and with the station tuned in as accurately as possible the peak control is advanced in a CW direction. As this control is advanced three effects may be noted: the meter reading will increase to a steady value and will stop fluttering with the keyed signal, the tuning eye will gradually stop fluttering, and the sound of the keyed signal will diminish until it disappears. When the peak control has just been advanced far enough to obtain the effects above, the meter should be read.

The manner in which the sound disappears can frequently cause an appreciable difference in setting and should be checked against a local calibrating signal to assure a correct threshold. If an oscilloscope is available this will provide the most accurate means of determining the true field of a keyed signal.

6.4.4 Recording Data

All data that might in any way be pertinent in analyzing the results of the measurements should be recorded. This would include always, the late and exact time, frequency, weather conditions, auroral activity for arctic measurements, loop orientation, and calibration data. Calibration data for the URM-6 should include the voltage inserted in the loop, the position of the attenuator, and the F.I. meter reading. If there is any question about the accuracy of the calibration this should be noted of course.

6.4.5 Care of Equipment

The equipment should be left on during a series of measurements even if only one reading a day is to be taken. This prevents to a great degree rapid variations of gain. If the equipment is battery operated this will not be possible and recalibration before each reading will be necessary. With equipment left running continually, calibration once or twice a day (for a given frequency) will probably be sufficient. This may be determined primarily by simply taking note of the drift or change in calibration over a given period of time.

The loop antenna and cables should be kept as dry and clean as possible. If in wet weather, the connectors should be taped with electricians tape. This is especially important when operating near to or on the sea since salt water is especially damaging.

All equipment should be handled with care and kept in as good condition as possible. Any apparent damage due to rough handling should be checked for, if possible.