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PROCEDURE SHEET NO. I-A:

FIELD ADJUSTMENT OF ANTENNA TUNING UNITS:

The most common network used for matching the impedance of an antenna to a transmission line is the "T" configuration. While this discussion is directed toward adjusting "T" networks, the measurement and calculation procedures are applicable to any network configuration ("L". "Pi", etc.).

CALCULATIONS:

The basic equations for "T" networks are:

$$X_1 = -j \frac{R_1 \text{CosB} - (R_1 R_2)^{1/2}}{\text{SinB}} \quad (1)$$

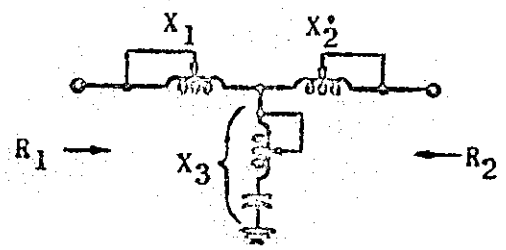
$$X_2 = -j \frac{R_2 \text{CosB} - (R_1 R_2)^{1/2}}{\text{SinB}} \quad (2)$$

$$X_3 = -j \frac{(R_1 R_2)^{1/2}}{\text{SinB}} \quad (3)$$

Where: R_1 = Transmission Line Surge Impedance (Ohms)
R_2 = Antenna Resistance (Ohms)
B = Delay Angle, i.e., angle by which phase at output of network lags phase at input (Degrees).

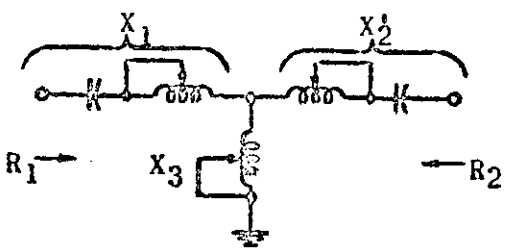
The network is of the form:

Lagging Network



B Positive

Leading Network



B Negative

Where: $X_2' = X_2 - (\pm X_{Antenna})$ (4)

This correction of X_2' is simply lumping together the value of X_2 necessary to transform R_2 to R_1 with the reactance needed to cancel out the base reactance of the tower.

For non-directional systems it is common practice to let B = 90° since this simplifies the calculations. Since Sin 90° = 1 and Cos 90° = 0. the equations (above) reduce to:

$$X_1 = X_2 = j\,(R_1R_2)^{1/2} \qquad (5)$$

$$X_3 = -j\,(R_1R_2)^{1/2} \qquad (6)$$

Example of Calculation:

Let: R_1 = 52 Ohms
$Z_{ant.}$ = 39 + j5
B = +90°

Then: $X_1 = X_2 = -X_3 = +j(R_1R_2)^{1/2} = +j[(52)(39)]^{1/2} = +j(2028)^{1/2} = +j45.3$

The values for the network are therefore:

$X_1 = +j45.3$

$X_2' = +j45.3 - (+j5) = +j40.3$

$X_3 = -j45.3$

If the value of X_3 is fixed (non-adjustable components) it is necessary to calculate the value of B from:

$$B = \text{Sin}^{-1}\ -j\frac{(R_1R_2)^{1/2}}{X_3} \qquad (7)$$

from which X_1 and X_2 may be calculated with Equations (1) and (2).

MEASUREMENTS AND ADJUSTMENTS:

Bridge Method:

The easiest method of setting up an impedance matching network is with the use of an R.F. Impedance Bridge such as the General Radio Model 1606-A. When using a bridge the method used is as follows:

1. Measure antenna base impedance.

2. Determine transmission line impedance (R_1) either from the line's specifications, calculations, or measurements (Appendix).

3. Calculate Matching Network by Equations (1), (2), (3) and (7).

4. Set network elements to calculated values with impedance bridge measurements.

5. Connect network to antenna and measure across network input terminals with the transmission line disconnected. The impedance measured should be approximately equal to the transmission line impedance.

There are two things to watch out for in following this procedure:

1. In Step 4 above have the components mounted in place. Use minimum length leads from the bridge and to ground (2" Copper strap is recommended).

   Be cautious of mutual coupling between the inductors. A good way of checking for excessive mutual coupling is to set one inductor to its desired value with the other inductors unconnected. Then short out the other inductors and remeasure. The value of inductance should not change appreciably.

   Mutual coupling is a function of the physical layout of the unit and is not readily adjustable in the field. If excessive coupling exists, it may be best compensated for by touch up after the network is set as explained below.

2. After the network elements have been set to their calculated values (Step 4)--MARK the settings (fingernail polish is handy for this), unless coil bars are numbered.

   After the settings in Step 4 are marked, a little careful touching up of the settings in Step 5 will produce an exact match and will correct for any inaccuracies in the measurements in Step 4.

   The best procedure to follow in touching up is to vary each inductor 1 or 2 turns and observe the difference this makes in the input impedance. Return to the original settings and repeat for each coil. This will provide some "feel" for the circuit and should make it apparent which components to touch up to correct the input impedance.

Voltmeter-Ammeter Method:(1)

If an R.F. Impedance Bridge is not available, the voltmeter-ammeter method may be employed for tuning the network.

CAUTION: These adjustments are made with power applied to the circuit, and some very dangerous voltages may develop in the network. Always use minimum power to give readings.

Adjustment of Network.

1. Adjust transmitter into a dummy load for proper operation. Do not retune transmitter for the following steps.

2. Connect transmitter thru transmission line to the input of the matching network. Connect the output of the network to the antenna.

3. Insert RF ammeters in series with the input and output of the network.

4. Set shunt leg (X_3) of network to the approximate value as calculated in Eqn. (6). Setting may be determined by either approximation or calculating number of coil turns necessary to produce required inductance.

5. Apply power (minimum) from the transmitter.

6. Adjust input leg (X_1) for maximum input current. (Turn transmitter off while adjusting coil tap.)

7. Adjust output leg (X_2') for proper output current as determined by:

$$I_{Out} = \frac{I_{In}}{(R_2/R_1)^{1/2}} \qquad (8)$$

8. Repeat steps 6 and 7 until the proper ratio determined by Eqn. (8) is reached.

9. If desired for greatest accuracy the accurate antenna resistance is now measured as described below and this correct value inserted into equation (8). Steps 6 and 7 are then repeated for the new value of I_{Out}.

10. The network is properly adjusted when:

    a. The ratio of I_{In}/I_{Out} agrees with the calculated value.

    b. The current at each end (or any 2 separated points) of the transmission line is equal. (Caution: The transmission line's electrical length must not equal a multiple of 1/4 wavelength for this measurement to be valid.)

Antenna Resistance Measurement:

It is necessary to know the antenna base resistance to determine the input power to the antenna. For an American Broadcast Station this value will be measured by the consultant and filed with the F.C.C. at the time of filing for the station license. This value appears on the station's license and should be used if available.

In emergency, for initial testing, or overseas where a bridge may not be available the following method may be used.

Necessary equipment:

Vacuum Tube Voltmeter (RF) such as H.P. Mod. 410 B.
Resistance Voltage Divider (56K 1/2W resistors) if needed to stay

in rage of VTVM.
Output ammeter on network.

With the network set up as described above in "Adjustment of Network", (steps 1 thru 8), and minimum power applied to the network, measure the output current I_{Out}.

With the volt meter measure and plot graphically the voltage from each turn of the output coil to ground, starting from the output end of the coil.

This plot of voltage vs. turns will show a minimum value if the network is properly set up. The minimum occurs where the output reactance exactly cancels out the reactance of the antenna and the voltage is a result of the antenna resistance only. The antenna resistance may now be calculated by:

$$R_{Ant.} = R_2 = \frac{E_{Min.}}{I_{Out.}} \qquad (9)$$

APPENDIX

Transmission line surge impedance may be calculated from R.F. Bridge measurements by:(2)

$$Z_s = R_1 = (Z_{oc} Z_{sc})^{1/2}$$

Where Z_s = Surge Impedance of Line
Z_{oc} = Impedance measurement with line open circuited at far end.
Z_{sc} = Impedance measured with line short circuited at far end.

REFERENCES

(1) Kean, "Dynamic Measurement of Base and Circuit Impedances In An Operating Directional Array", 1952 (Technical Peper).

(2) John H. Mullaney, "Procedure Sheet No. 1, Method For Determining Transmission Line Impedance and Phase Shift."