Automatic Tuning of Antennae

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The impedance of a transmitting antenna varies considerably with frequency and environment. To maintain maximum transfer of power a transmitter must be matched into this varying impedance. A network used for this purpose is conventionally referred to as an 'Antenna Tuner'. This article describes a technique for automatically adjusting the three components of a pi-network antenna tuner.

In an automatic tuner the tuning elements are adjusted by a motor (or some other actuator) by amounts which depend on the relationships between various voltages and currents in the tuning network. The way in which tuning information is derived from measurements and the way the results of these measurements are applied are important; they must be correctly chosen to ensure that automatic tuning is always successful.

In the 1·5 to 30MHz radio band the resistive component of a "typical" antenna impedance can vary between 3 and 2,000Ω and the reactive component between −2,500 and +500Ω; the antenna may have a Q of 500. The output impedance of a transmitter may be typically either 50 or 75Ω.

A single L network can deal with the range of impedance involved provided that the input and output can be interchanged by switching, but for technical reasons it is better not to do this. In practice it is best to use a pi configuration (Figure 1) in which one or the other capacitor is adjusted to be as near as possible to zero capacitance. Resonance effects can create very high voltages in antenna tuners, but using this type of network not only are these voltages minimized but the LC configuration provides low pass filtering of any harmonics from the transmitter.

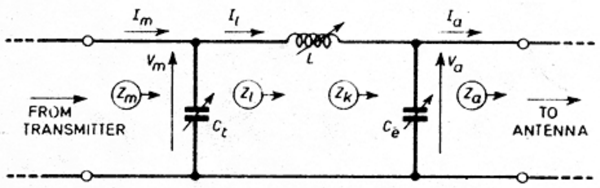

Fig. 1. Pi network.

The impedance transformation of each element in the pi-network is indicated in Figure 2. Capacitor C_e transforms the antenna impedance Z_a along a circle of constant conductance to Z_k. The inductance L transforms Z_k to Z_l along a line of constant resistance and capacitor C_t changes Z_l along a circle of constant conductance to the matched impedance Z_m.

Although a pi-network is simple and effective, it is difficult to adjust not only because the effects of the component values (and therefore their adjustment) are interdependent, but also because an infinity of sets of component values can match a particular pair of impedances, each set having a different value of loaded circuit Q. Thus, if the standing wave ratio (SWR) on the line connecting the antenna tuning unit

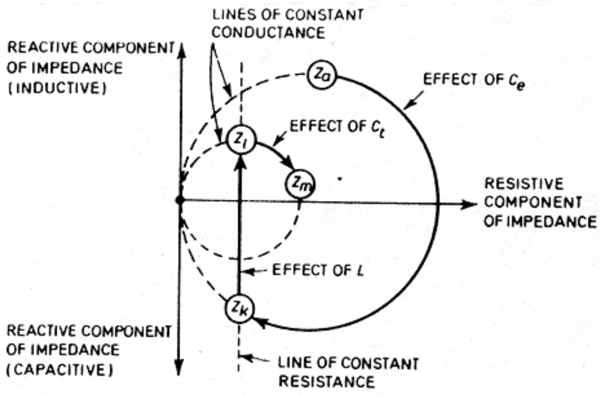

Fig. 2. Impedance transformation.

(ATU) to the transmitter is used as a tuning indicator the ATU might be adjusted (incorrectly) to match all the transmitter power to the loss resistance of the inductance instead of to the antenna. Even if antenna currents and voltages are also used it is a lengthy process to ensure that the pi-network is adjusted correctly. Ideally indicators used for automatic tuning should show unambiguously which circuit element needs to be adjusted and in which direction, and should indicate when each element has been adjusted well enough. So far as possible, indicators should be independent of the output power of the transmitter; this enables adjustments to be made either at low power levels or during transmission when (particularly for single sideband working) the output power can vary rapidly.

In the system described here, specially developed power independent detectors compare the voltages and currents at various parts of the network in a way which enables each element in the network to be adjusted unambiguously. Three kinds of detectors are needed; phase detectors to indicate the sign of the phase difference, resistive match indicators to show whether the resistive component of an impedance is above or below a desired value and conductance match indicators to show whether the conductive component of an admittance is above or below a desired value.

The method developed for tuning the pi-network automatically is indicated diagrammatically in Figue 3. This relates to a 50Ω transmission line and an SWR of 1·2:1. The network is adjusted as follows:

Adjustment of C_e (Figure 3a)

If the reactance of Z_k (see Figure 1) is positive (i.e. inductive) and its conductance less than 22·5 milli-Siemens, or if the reactance is negative (i.e. capacitive) and the resistance is greater than 56Ω, C_e is increased.

If the reactance is negative and the resistance less than 45Ω, or if the conductance is greater than 22·5 mS, C_e is decreased. (In this process C_e may reach zero).

If the reactance is negative and the resistance is between 45 and 56Ω, C_e is not altered.

For the adjustment of C_e one phase indicator together with

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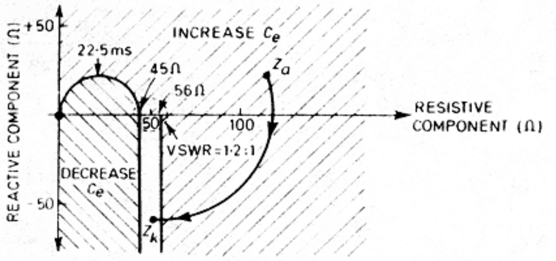

Fig 3a. Adjustment of C_e.

one conductance and two resistance match indicators are needed; these operate on V_a and I_l in Figure 1.

Adjustment of L (Figure 3b)

Firstly C_e (see Figure 1) is adjusted (by which time the resistive component of Z_l will be less than 50Ω).

If the reactance of Z_l is negative or if its reactance is positive and with a conductance greater than 22·5 mS, L is increased. If the reactance is positive and the conductance less than 17·5 mS, L is reduced. If the reactance is positive and the conductance is between 17·5 and 22·5 mS, L is not altered.

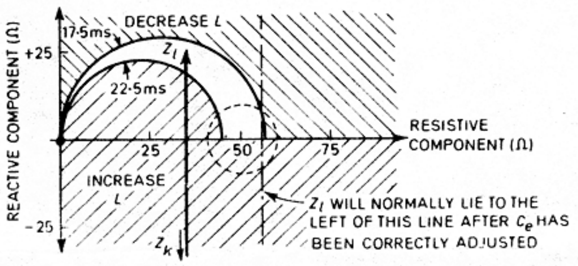

Fig. 3b. Adjustment of L.

For the adjustment of L, one phase indicator and two conductance match indicators are needed; these operate on V_m and I_l in Figure 1.

Adjustment of C_t (Figure 3c)

First C_e and L are adjusted (by which time the conductive component of Z_m (see Figure 1) will lie between 17·5 and 22·5 mS).

If the phase angle of Z_m is greater than $+7°$, C_t is increased. If the phase is less than $-7°$, C_t is decreased. If the phase angle is between $+7°$ and $-7°$, C_t is not altered.

For the adjustment of C_t two phase detectors are needed; these operate on V_m and I_m.

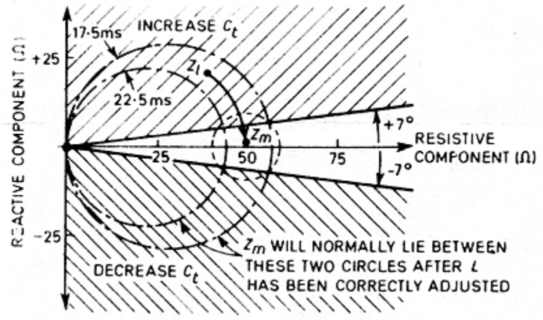

Fig. 3c. Adjustment of C_t. Impedances lying within the dotted circles will match 50Ω with a VSWR of less than 1·2:1.

Although C_e, L and C_t must be adjusted in that order, each adjustment does not affect the settings for the others; the measurements which define the adjustment of each element were deliberately chosen to meet this requirement.

The adjustments are made automatically and rapidly during the tranmission of any form of modulation and can deal with sudden changes of antenna impedance which result from a change of frequency or of antenna location. Although designed for mobile transmitters operating in the h.f. band the technique can be applied at other frequencies and with fixed antennae.

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