HARRIS

Engineering Report

PHASING SYSTEM NETWORK SENSITIVITIES

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PHASING SYSTEM NETWORK SENSITIVITIES

by

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R. F. Feeder Systems for directional antennas are systems of networks so designed and connected to control the phase and amplitude of currents flowing in the individual towers or antennas. This is a basic statement and is made here to stress the fact that there are two (2) and only two parameters that a phasing or feeder system is required to control. Furthermore, proper design and adjustment of feeder systems require sufficient knowledge of the networks used that these two antenna parameters can be adequately controlled. Conversely, inadequate knowledge of the networks often leads to much effort expended in the adjustment of the networks rather than the adjustment of the antenna parameters.

Figure 1 shows the basic arrangement of networks in a general directional antenna feeder system. Antenna Coupling networks, Phase Shift networks, and Input Matching networks are usually of the so-called "T" configuration while the Power Dividing network may take several different forms.

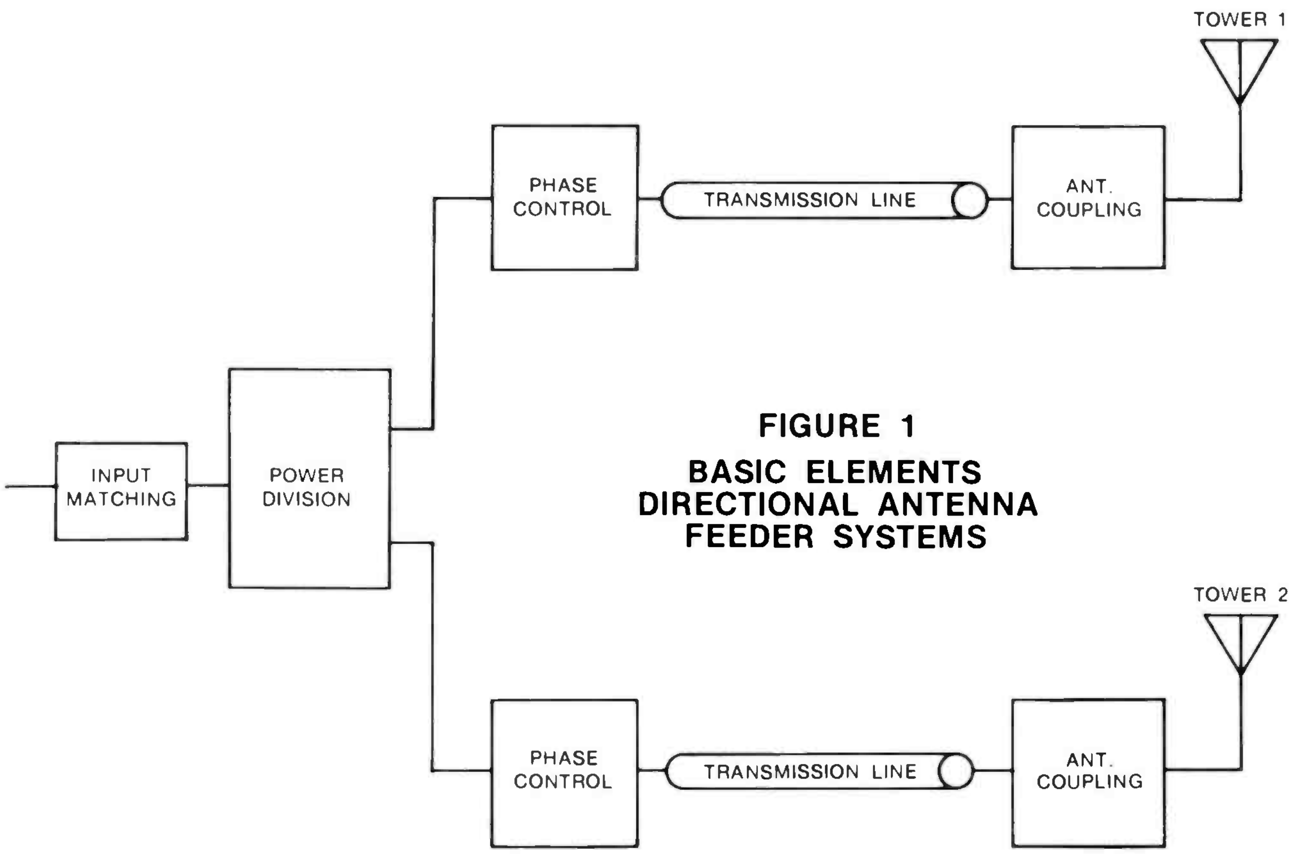

FIGURE 1
BASIC ELEMENTS DIRECTIONAL ANTENNA FEEDER SYSTEMS

If any of these networks are constructed, for instance, with a variable control in each leg of the network and adjusted without knowledge of the constraints of each leg or the sensitivity of each branch of the individual network, the adjustment process easily degenerates into a problem of network adjustment rather than the control of one of the antenna system parameters.

It is the purpose of this paper, then, to show how proper knowledge of network element sensitivity can be of considerable help in system adjustment rather than network adjustment.

THE COMPLICATED "T" NETWORK: The following discussion applies primarily to the commonly used "T" network—the complicated "T" network—which provides an excellent example.

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The "T" network, probably very familiar in appearance to most engineers engaged in antenna systems, has been demonstrated by many otherwise very competent engineers to be highly complicated in its adjustment when its basic principles are not thoroughly understood. As will be shown, the adjustment of one branch may require a compensating adjustment of a second branch for one parameter of interest while at the same time causing the exact opposite results to those desired of the second antenna parameter, if done—without information of the sensitivity of the arm being adjusted to the system parameter of interest.

The "T" network is considered complicated by the writer in the sense that in many years of designing and adjusting them, there always appears to be something more to be learned.

This discussion is begun with a simple sensitivity analysis run on a computer using a standard well known computer program. The analysis does not present a startling new development but does point up at least one aspect of the use of this network where customary and traditional practices have caused it to be used inefficiently for many years.

The analysis is based on the use of the usual Phase Shift network which is designed to operate between two equal resistances and whose sole purpose in the system is to provide a phase adjustment in each individual tower feed. It is a lagging network such as is shown in Figure 2. The results of the analysis, however, may be applied to a "T" network used for another purpose, if qualified for that purpose.

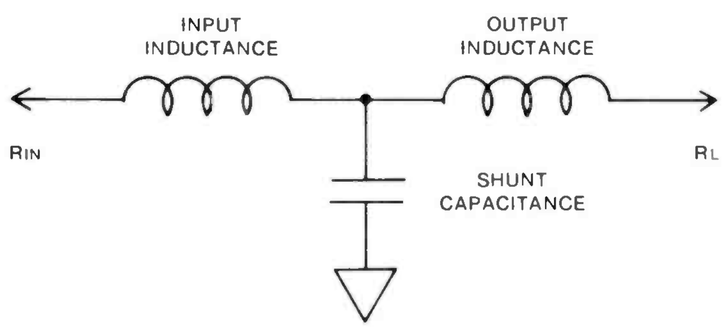


FIGURE 2
BASIC "T" NETWORK

In this analysis each leg is changed, one at a time, one-percent. The change in phase shift through the network and the ratio of the input resistance exhibited by the network to the load resistance is then noted. For example, if the input leg is changed one-percent and the phase shift through the network changes one-percent, then the effect of the input leg on the phase shift of the network is considered 100%. If the input leg changes one-percent and the phase shift changes one-half percent, then the effect of the input leg is 50%, and so on: A negative sign simply indicates that the change in the phase or resistance ratio is opposite to the change made in the network branch.

Results are shown in Table 1 of networks designed for a nominal phase shift of 30, 60, 75, and 90 degrees. Table 1A provides similar results of networks designed for nominal phase shifts of 90, 105, 120, and 150 degrees.

TABLE 1
ANALYSIS
"T" NETWORK COMPONENT SENSITIVITY

NETWORK DESIGN	INPUT INDUCTANCE		SHUNT CAPACITANCE		OUTPUT INDUCTANCE		LOAD RESISTANCE	
ø	$\frac{R_L}{R_{IN}}$ %	ø %	$\frac{R_L}{R_{IN}}$ %	ø %	$\frac{R_L}{R_{IN}}$ %	ø %	$\frac{R_L}{R_{IN}}$ %	ø %
-30°	-0.05	51.17	13.4	6.86	-11.61	38.34	24.96	-82.9
-60°	-0.17	55.12	50.19	27.69	-24.95	13.76	75.46	-41.67
-75°	-0.3	58.91	74.49	43.75	-19.16	3.96	94.14	-19.29
-90°	-0.5	63.66	100.49	64.30	-0.00	0.00	101.0	-0.00

TABLE 1A
ANALYSIS
"T" NETWORK COMPONENT SENSITIVITY

NETWORK DESIGN	INPUT INDUCTANCE		SHUNT CAPACITANCE		OUTPUT INDUCTANCE		LOAD RESISTANCE	
ø	$\frac{R_L}{R_{IN}}$ %	ø %	$\frac{R_L}{R_{IN}}$ %	ø %	$\frac{R_L}{R_{IN}}$ %	ø %	$\frac{R_L}{R_{IN}}$ %	ø %
-90°	-0.5	63.66	100.49	64.30	-0.00	0.00	101.00	- 0.00
-105°	-0.72	70.96	126.12	90.36	32.48	4.72	94.24	13.69
-120°	-1.28	82.61	149.03	125.73	75.38	20.75	75.60	20.81
-150°	-5.65	142.48	167.08	270.50	160.93	108.41	25.27	16.67

THE INPUT BRANCH: First, it should be noted that the input leg adjustment has very little effect on the input/output resistance ratio, but produces substantial changes in the network phase shift. In a practical network these results would not be strictly true since the loss resistances of the input leg would enter the picture, but since these losses are indeterminate and generally small, the results give a very clear picture of the sensitivity of the input branch.

It should also be noted that the effect of the input leg on the phase shift of the network increases as the design center phase shift increases. In other words, the higher the nominal phase shift design of the network, the more sensitive the phase shift of the network to the adjustment of the input leg.

THE SHUNT BRANCH: The shunt leg, as might be expected, has a very substantial effect on both phase and resistance ratio except possibly at very low phase angles. This is a good illustration why in any given "T" network regardless of end purpose, the shunt leg should always be adjusted or established first, and once established, determines the adjustment center of the network.

The results relating to this branch of the network cannot be emphasized too strongly for if any branch of the "T" is misadjusted more often it is certainly the shunt leg. As can be seen from the accompanying tables, an adjustment of this leg produces very substantial effects on both parameters of the antenna system such that one parameter must receive a corresponding compensation if the shunt leg has been changed to produce a single desired parameter change in the system. Furthermore, as will be shown later, this branch of the network has definite limitations which if exceeded prevents any possibility of a desired input/output impedance relation.

THE OUTPUT BRANCH: The output leg is interesting in that for all phase shifts other than 90 degrees, this leg controls input impedance as well as phase shift. Incidentally, the zero results shown at 90 degrees does not indicate that the output leg has no effect in the network, but merely that its effect is extremely small throughout the range of this analysis—10% for each component.

The important consideration here is simply that the output leg of the "T" cannot be adjusted simultaneously with the input leg to vary the phase shift through the network without also causing a change in the input impedance of the network which, in turn, in a phasing system, causes a change in power division. In other words, the output branch, like the shunt branch, will change both the phase shift of the network and the input/output resistance ratio, although to a lesser degree, except when the adjustment center of the network has been made at 90 degrees.

THE LOAD RESISTANCE: The effect of the load resistance on the performance of the network is extremely important in that it shows a measure of the stability of the system adjustment versus the network phase shift design.

As can be seen from the tables, the load resistance into which the network operates has an increasing effect on the phase shift of the network as the design center phase is reduced. For example, in a network design of a nominal phase shift of 30 degrees, the one-percent change in the load resistance produces an 82.9% of one-percent change in the phase shift of the network. This is accomplished while it also produces a 25% of one-percent change in the input/output resistance ratio.

This simply means that in a system employing "T" networks designed with low phase shift angles, slight changes in the antenna resistance values, transmission line characteristics, or other causes of network load resistance changes because of weather, temperature changes, etc., both the phase and amplitude system parameters will vary as a direct result of the network design.

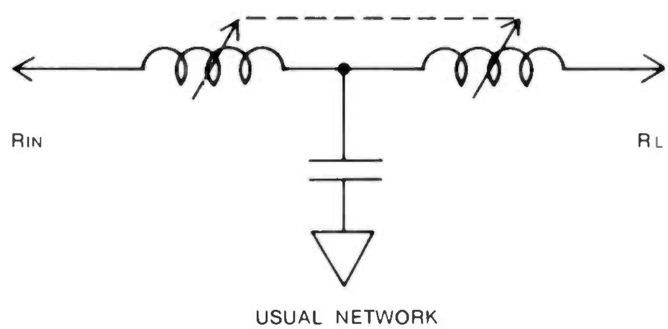
Conversely, a phasing system employing networks designed and adjusted very nearly 90 degrees will maintain its phase relations more closely and will only vary in amplitude with changes in the load resistance of the networks. Such a system would, of course, be much more stable.

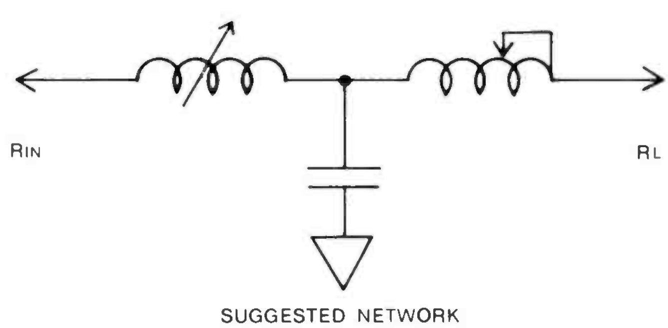
CONCLUSIONS: There are many conclusions that may be drawn from this analysis—too many to be included in the scope of this paper. It is hoped, however, that those discussed will provide much assistance in the design and adjustment of "T" networks in the future.

The first conclusion of importance is that phase shift networks as used in feeder systems should not have the two series legs ganged to control phase as we have so long thought in the past. Changing the input; leg or branch controls the phase shift, but changing the output leg means that the resistance ratio will also be changed, which in turn, causes a change in power division. In other words, if we want a phase shift network to control phase and not be a factor in the power division of the system, we must vary only the input control.

The customary design of the phase shift network is shown in the upper network in Figure 3, while the suggested design is shown below.

FIGURE 3
PHASE SHIFT
NETWORK DESIGN





Phase shift networks as suggested have been in use by some antenna engineers for some time and who, apparently, are already acquainted with much of the information presented here. The majority of system designs in use today, however, still employ networks using ganged series inductors because of custom or because the design engineers are not familiar with the design considerations.

A second and very important point to be made as a result of this analysis is the proper procedure for setting up any "T" network regardless of the purpose for which it is to be used. First, adjust the shunt leg for the desired impedance transfer and/or the desired phase shift. As demonstrated, this must be done to establish the design center conditions for the network since the shunt leg has such a pronounced effect on both phase shift and impedance relations.

Once the shunt branch is fixed, the input and output series arms are adjusted for the correct or desired impedance relations, adjusting, in general, the input arm for reactance control and the output arm for resistance.

NETWORK FORMULAE: The "T" network is seldom found in the literature discussed in terms particularly applicable to the engineer who must wade out to the tower in the middle of the night and adjust the antenna coupling network with one hand while he swats mosquitoes with the other. For this reason, a few network design formulae are given here simplified for this purpose in Table 2.

TABLE 2
SIMPLIFIED "T" NETWORK DESIGN FORMULAE

$$\text{MIN. SHUNT REACTANCE} = \sqrt{R_{IN} R_L}$$

or

$$\text{MAX. SHUNT CAPACITANCE} = \frac{0.159}{f_{(MHZ)} \times \sqrt{R_{IN} R_L}} \quad (\text{IN } \mu f.)$$

FOR ANY PHASE SHIFT

$$X_{SHUNT} = \frac{\sqrt{R_{IN} R_L}}{\sin \phi}$$

or

$$C_{SHUNT} = \frac{0.159 \times \sin \phi}{f_{(MHZ)} \times \sqrt{R_{IN} R_L}} \quad (\text{IN } \mu f)$$

$$\text{INPUT INDUCTANCE} = \frac{X_{SHUNT} \pm R_{IN} \times \cot \phi}{6.28 \times f_{(MHZ)}} \quad (\text{IN } \mu h)$$

$$\text{OUTPUT INDUCTANCE} = \frac{X_{SHUNT} \pm R_L \times \cot \phi}{6.28 \times f_{(MHZ)}} \quad (\text{IN } \mu h)$$

The minimum possible shunt reactance—or maximum capacity—that may be used in a "T" network and still obtain a match between the input and output resistance is equal to the square root of the product of the input and output resistance. This value must include any reduction in the capacitive reactance resulting from lead inductance.

The above statement simply means that the shunt reactance of a "T" network can never be less than the geometric mean of the two impedances between which it is to be connected.

This can also be computed in terms of capacity expressed in microfarads as shown. Knowledge of this reactance or capacity is usually very helpful in adjusting the network because it places an important constraint on the adjustment of the shunt leg.

This fact about the "T" network is the principle reason why a variable control in the shunt branch which can be adjusted without knowledge of the actual reactance being produced can easily lead to very difficult network adjustments.

The figure 159 used in the capacity formula is one that should be indelibly inscribed in the minds of every engineer working in medium frequencies. It is the reactance of a .001 mfd. capacitor at 1 MHz. From this value, the reactance of any capacitor at any frequency can be easily obtained simply by dividing 159 by the frequency in megahertz and comparing the relation of the capacitor of interest to a .001 mfd. capacitor. This is the basis for the capacity formulae used here.

The minimum shunt reactance or the geometric mean between the input and output resistances provides a 90 degree phase shift network if the input and output arms are also made this value but opposite in sign. The balance of the formulae in this table give the reactances or element values for the "T" network at other phase shift angles. The numerators for the input and output inductance formulae give the inductive reactances for these arms.

The plus and minus signs between the two terms of the numerators have been used to call attention to the fact that there are always two solutions for the series arms for any given shunt reactance. The minus sign gives the value for a phase shift less than 90 degrees while the plug sign provides a value for angles greater than 90 degrees.

The plus sign results from the fact that the cotangent of any angle between 90 and 180 degrees is negative.

SYSTEM IMPEDANCE COMPONENTS: An often abused concept of feeder system design is the relation of the real and the imaginary part of any impedance occurring within the network or the feeder system.

The only power passed on from one part of the system to another is that power which is dissipated in the real part of the impedance at that point. However, many times systems and networks have been designed or adjusted to deliberately increase the reactive to resistance ratio at various points. This is especially true in power divider circuits. It has the effect of increasing the reactive currents in this portion of the circuit which, in turn, give an apparent greater adjustment control per turn of the crank. The final result, however, is to provide a system which is or can be very unstable and difficult to maintain because the system parameters are more subject to non-controllable variations, such as temperature, weather, etc.

This is another way of saying that the system "Q" is increased at this point. A higher "Q" also means a narrower bandwidth and if the "Q" is made sufficiently high the entire system can be made unusable for AM broadcasting—a condition which has happened in at least three systems of record.

The above information provides a very useful method of checking a phasing system for stability and sensitivity to non-controllable variations due to weather, etc. The lower the reactance to resistance ratio measured at any point in the system, the more stable the system. This is especially true for a measurement of the impedance presented by the power divider at its input following the input matching network.

COMPONENT SELECTION: A brief statement about component selection for a phasing or feeder system is in order in a discussion of system sensitivity. Many otherwise excellent designs have been seriously impaired by poor component selection resulting from an inadequate knowledge of the components themselves.

Inductances, for example, are severely influenced by their surroundings and it is next to impossible to accurately predict their actual inductance or even their voltage and current capabilities until after their installation, yet an empirical or experienced idea of what may be expected is vital to the successful system design.

An excellent illustration of this point is in the choice of large tubing coils where perhaps a small ribbon coil is normally more than adequate. This is often done on the theory that if a small coil is adequate for carrying the expected circuit current, a larger coil will provide a larger safety factor. Quite often the exact reverse may be true. The larger the physical size of a coil, the greater are its stray capacities to its surroundings. The larger these stray capacities, the higher will be the stray currents within the coil. If carried to the extreme, the stray currents may exceed the circuit currents for which the inductor is used. When this occurs, circuit control is lost because the inductor is now being adjusted for stray currents rather than its circuit purposes.

A good rule of thumb is to select the smallest coil that will adequately provide for the circuit requirements with a modest safety factor. Then, if in practice, additional current is found in the coil, determine the cause and correct it.

Knowledge of network and system sensitivities is obviously important in good system adjustment. This paper, then is an attempt to put the emphasis on the control of antenna parameters as the first consideration of phasing system adjustment—not the adjustment of the networks that make up the system.

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