GATES
ENGINEERING
REPORT

QUANTITATIVE PHASING SYSTEM SPECIFICATIONS

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Quantitative Phasing System Specifications

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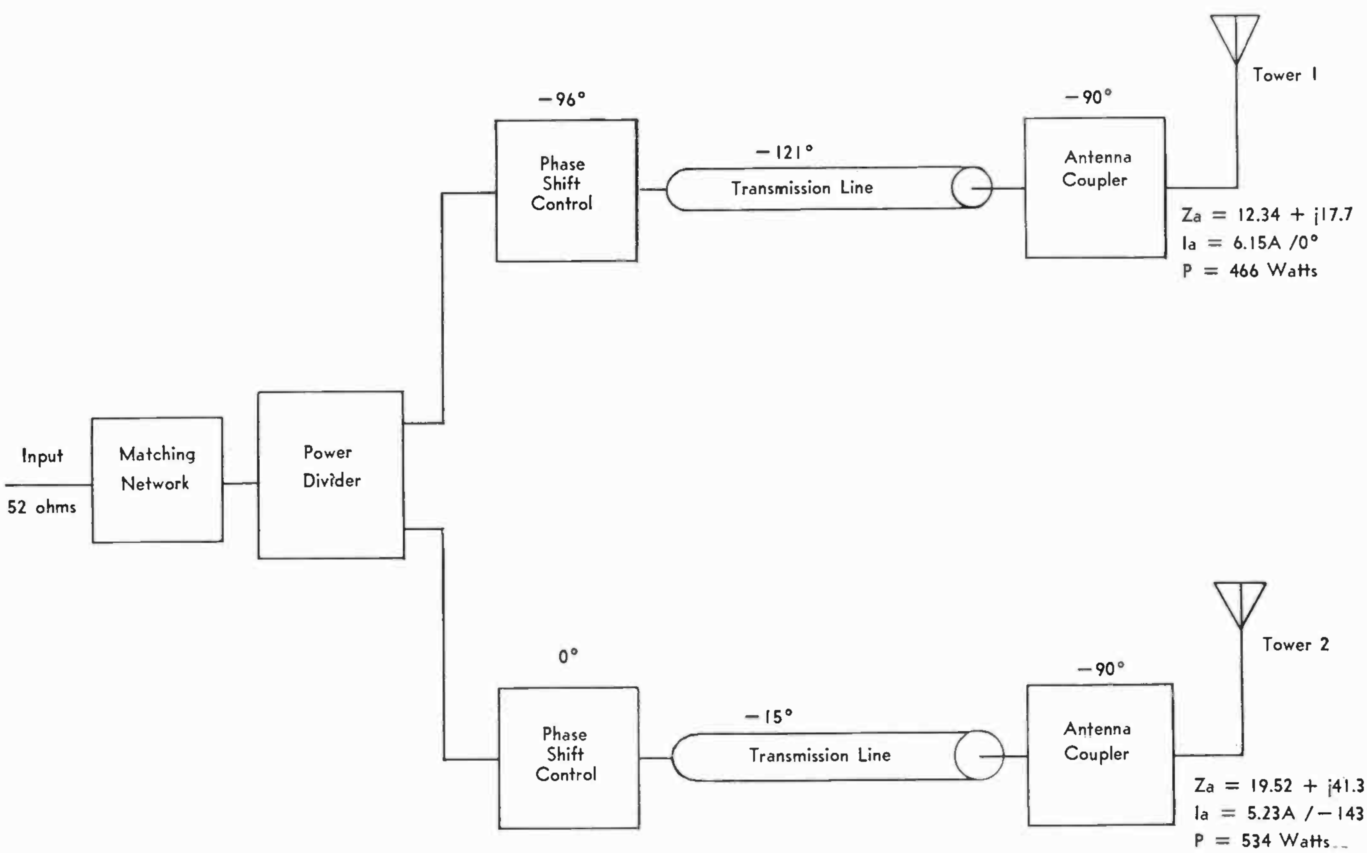
A vital requirement of directional antenna planning is the establishment of requirements and the precise definition of the capability of the system

For most electronic equipment certain exact specifications can be written. Phasing systems for directional antennas are unique in this respect in that they are designed to be adjusted in the field. Until this adjustment is made, actual performance characteristics of the system cannot be known.

Customarily, phasing system designs have been made using single valued transfer functions. Components are then selected slightly larger than required on the premise that the added size will allow sufficient variation of the networks to account for expected differences between design assumptions and actual field conditions. Such methods of design never define exactly what may be expected in the way of actual ranges of adjustment possible. It does not specifically spell out what the manufacturer is supplying either to the adjusting engineer or to the purchaser of the equipment. All too often such designing methods have resulted in either an over design, which is needlessly expensive, or an insufficient design, which seriously interferes with the proper adjustment and operation of the system.

Differences of opinion exist among

Figure 1. Block drawing of proposed phasing problem



engineers as to methods of design, desirable networks, and requirements which a phasing system should meet. Varied experience sometimes leads to good, practical reasons why some requirements are particularly desirable, but often there are opinions expressed which are the result of inaccurate information or of insufficient information. This latter condition leads to system designs which are inefficient, unnecessarily complicated with too many components, and, of course, expensive.

It is the purpose of this article to establish a set of specifications, applicable to any phasing system, which will, in each instance, precisely define what the system is at least capable of, in performance and adjustment. Further, it is a purpose to clarify and define specific functions of a phasing system, leading to more pertinent requirements written for particular systems. Looking to these ends, every effort is made to consider all factors arising in any practical adjustment of the equipment.

Antenna Driving Point Impedances

A familiarity with the relative values of the antenna driving point impedances is a pre-requisite to the adjustment of any antenna system. For this reason, a knowledge of the factors used in their computation is needed by the adjusting engineer.

The first specification is, then:

The antenna self base impedances and the values of mutual impedances used for the computation of the antenna driving point impedances shall be clearly stated.

Antenna Coupling Networks

The antenna coupling network always has three functions to perform in any phasing system.

1. Matching the antennas to the transmission line.

2. Provide a portion of the phase difference between the currents fed to the various towers.

3. To provide a conjugate reactance to the reactance portion of the antenna driving impedance. This latter function is in reality a part of the first requirement. However, since it must be considered separately in the design of the coupling units, it is included here as a separate function.

Antenna base impedances are always complex and effected by their surroundings, ground systems, etc. Base impedances may differ over quite wide limits between identical physical structures located in different surroundings. Consequently, a very generous allowance is required by the coupling networks to assure that they will perform their functions under actual field conditions. This allowance must consider the resistance and the reactance portion of the driving impedance as two independent variables.

The second requirement of antenna coupling networks, providing a portion of the phase difference between the currents fed to the various towers, is automatically fulfilled whenever a network of any kind is inserted in the system. However, in the case of the antenna coupling network, it is desired that the phase shift be controlled so that the balance of the system can be adjusted to include this phase shift. The phase transfer function of the coupling network thereby becomes a particular function of the network.

With the previous considerations in mind, the second specification is written:

Antenna coupling networks shall provide a specific phase shift and at the same time be capable of matching the transmission line to antenna base resistances at the computed base reactance of from 50% to 200% of the computed base resistance; and, shall also be capable of matching the transmission line at the computed base resistance but with a base reactance of from 50% to 200% of the computed value. The exact computed ranges of the networks shall be specified with each design.

Figure 2 illustrates this specification very clearly.

Phase Shift Network Ranges

These networks are the controlling elements for determining the phase relations between currents fed to the various towers.

They are usually considered as equal input and output impedance networks, their phase transfer functions being the prime consideration. Computation over a range of phase shifts is required to assure components of a sufficient range and to assure that the components used will be capable of handling currents and voltages throughout the range considered. The voltage and current encountered can vary quite rapidly as the transfer function of these networks is changed.

The third specification:

Figure 2.
Sample phasing system design specifications

ANTENNA DRIVING POINT IMPEDANCE CALCULATIONS:
Z11 = 27 + j20 = Z22
Z12 = 19.8 to / —29°

ANTENNA COUPLING UNIT RANGES AT INDICATED PHASE SHIFTS:
Tower No. 1:
5.2 to 26 + j17.7
Tower No. 2:
10.4 to 41.6 + j41.3
or
Tower No. 1:
12.338 — j30.7 to + j49.8
Tower No. 2:
19.523 — j 7.4 to + j73.1

PHASE SHIFT NETWORK RANGES:
Line 1:
—80° to —110°
Line 2:
—15° to +15°

OVERALL TRANSMISSION LINE EFFICIENCY:
95.1%

POWER DIVIDER DRIVING POINT IMPEDANCE RANGE:
11.154 to 22.308 ± j22.46 ohms

MATCHING NETWORK RANGE:
Matching 52 ohms
to 11.154 — j34.38 to + j46.12
to 22.308 — j30.01 to + j50.44

COMPONENT RATINGS THROUGHOUT ABOVE RANGES:
CURRENT:
Greater than 1.414 × max. RMS
VOLTAGE:
Greater than 4.0 × max. RMS

Phase shift networks shall be capable of phase adjustment of 15° above and below the design center phase shift required.

Overall Transmission Line Efficiency

This is not a specification of the phasing system since the length or type of transmission line used is determined by considerations other than the parameters of the antenna system. However, line efficiency is of utmost importance to the adjusting engineer and to the station operator. Power supplied to a directional antenna system can only be determined, accurately, at the input to the system. Power lost in the transmission lines is, therefore, a measure of the possible overall efficiency of the system, because it usually accounts for the greatest loss.

Overall transmission line efficiency can only be computed after the antenna driving point impedances and the power division between towers is estimated. The fourth specification is added as a convenience factor, easily determined by the phasing system design engineer as he makes his system design.

The overall transmission line efficiency shall be computed and supplied with the phasing system design.

Power Divider Driving Point Impedance Range

The design of power dividing circuits is of the utmost importance in the design of any phasing system, for in general, larger and more expensive components are required than are needed for any other portion of the system.

Power divider design, unfortunately, has not received much attention in literature. Many methods of design and adjustment are in current use, some of which are good and others which are inefficient, expensive, and difficult to adjust properly.

Regardless of how the design is made or the actual circuit configuration used, the desired end result is the same — the input or driving point impedance.

By replacing the power divider circuit with a Thevenin equivalent circuit, it can be shown that the real or resistance part of the power divider driving point impedance uniquely determines all current and voltage requirements of the network components comprising the power divider. This is true since this resistance portion of the impedance represents the real load to the transmitter at this point in the system. Because of this, the real part, therefore, determines the efficiency of this circuit, its cost, the band-width of the system, and the requirements of the required matching network between this point and the transmitter.

The determination of the driving point impedance is made by consideration of the following factors:

1. The power division required between the several transmission lines.
2. The input impedance to each transmission line.
3. The method to be used to divide the power.
4. An assumed practical adjustment of the power divider.

The first of these is, of course, fixed by the antenna system. The second has, for the most part, been assumed equal to the characteristic impedance of the transmission lines used. This assumption, however, is seldom if ever valid, for in the process of adjusting the antenna system full attention must be paid to securing the desired results at the towers themselves, and because of this, transmission lines within a phasing system are almost always mismatched to a greater or less degree. Good design of the power divider, therefore, dictates the necessity of considering the input impedance of the transmission lines over a range of possible values. A VSWR of 2 to 1 restricts the range to a practical limit and is suggested in connection with the specification for the power divider circuit.

The method selected for dividing the power should be determined from a consideration of the number of towers, the total power, its division, and the type of adjustment desired. It should be kept in mind, however, since the efficiency of the circuit is directly proportional to the real part of the driving point impedance, that a method should be chosen that will result in a real part that is as high as possible.

A practical power divider adjustment selection, for the purpose of design, is one requiring experience in power divider design, preferably a

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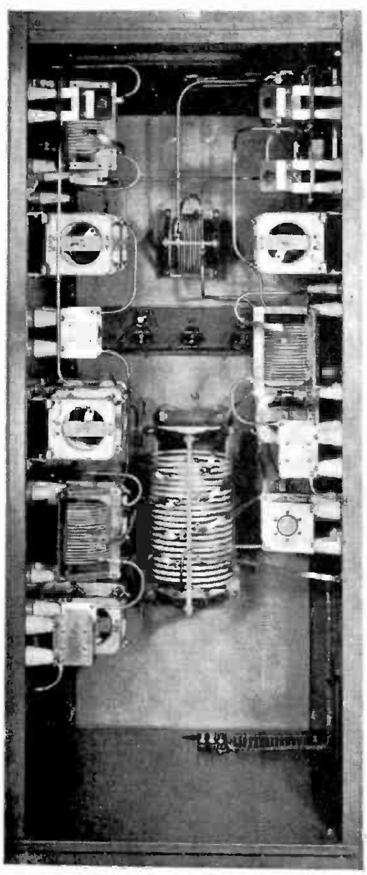

Photo A. Rear inside view of typical phasor. Note the ample space layout of components.

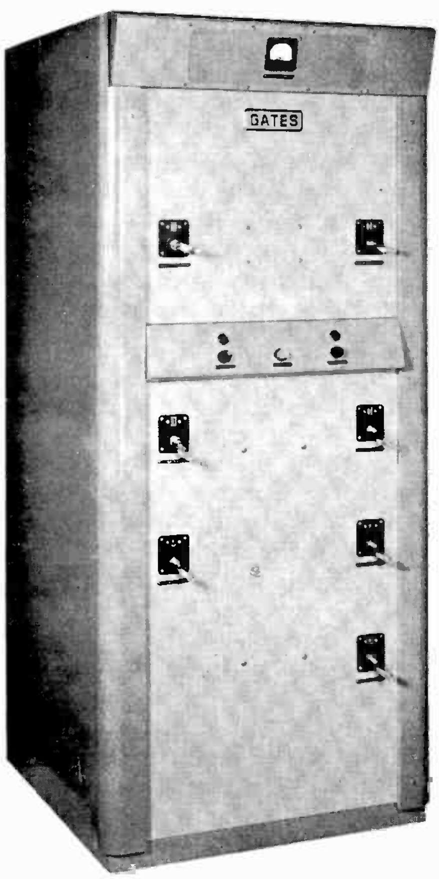

Photo B. Front view of phasing control cubical designed for station WJBO, Baton Rouge, La.

Quantitative Phasing

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knowledge of the adjusting engineer's techniques, and a knowledge of practical components available. Whatever the choice, no design can be considered complete unless all of the above discussed factors are carefully weighed and included within the actual computations. This results in a range of impedance values that should be clearly stated as a part of the phasing system specifications and completely defines the requirements of the subsequent matching network.

The fifth specification follows:

The power divider driving point impedance shall be computed over a range that will include a possible standing wave ratio at the input to each transmission line of 2 to 1. In no event shall the real part of this impedance be considered over a range less than maximum to ½ maximum. The actual range of this impedance shall be clearly stated with every system design.

Matching Network Range

The driving point impedance of any power dividing network is the impedance that appears at that point in the circuit where the full power of the transmitter is immediately distributed between the various lines feeding the antennas. All circuits preceding this point, or between this point and the transmitter output, serve only one purpose, to match the transmitter to the power divider.

This singularity of purpose for this network suggests, at once, that it be as simple as possible. The more components used to accomplish this purpose, the greater the expense, and each additional component added, in turn, adds to the system losses.

The matching network range, of course, must equal or exceed the power divider driving range. However, knowledge of the full range of the matching network is of interest to the adjusting engineer in order that he know the actual maximum limits he can tolerate in the adjustment of the power divider.

The sixth specification:

The matching network preceding the power divider shall be designed to match the input resistance of the system to greater than the stipulated range of resistance and reactance of the power divider driving point impedance. The computed range of this network shall be included with the design.

Component Ratings and Selection

In any circuit handling large amounts of radio frequency power, the ultimate design limits are the practical current and voltage ratings of available components. Consequently, if the foregoing specifications hold, every component selected must be capable of withstanding the maximum current or voltage it will encounter throughout the complete range it is expected to operate.

It goes without saying that a safety factor must be applied as a matter of good engineering practice. A factor of 1.414 is chosen as an economical value, since, to overcome this factor, the power would have to double or the impedance of the circuit would go to ½ its estimated value.

A voltage factor of $2 \times 1.414 \times 1.414 = 4$ is used to convert RMS voltages to peak voltages.

So with these factors the seventh and last specification is written:

All components shall be selected such that their current ratings shall be greater than 1.414 times the maximum RMS current occurring in the circuit at any point within the above specified range.

All components shall also have a voltage rating at least 4.0 times the maximum RMS voltage occurring across the component throughout the above range.

Conclusion

A complete set of quantitative specifications for all directional antenna phasing systems has long been needed to provide a clear cut guide for design and consideration. Antenna systems are becoming increasingly complicated and exacting in their requirements.

Smaller stations are required to install more elaborate and more costly antennas as the frequency spectrum becomes more crowded. Phasing systems must, therefore, be better designed, easier to adjust, more stable and reliable, and as economical as possible.

The phasing specifications as outlined here and as exemplified in Figure 2 are believed to assure this type of system. Certainly, they provide a very effective means of evaluating any system design and should, at least materially, assist in providing the best possible directional antenna phasing system at the lowest possible cost.

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