A BROADBAND 16 PORT MODEFORMER SYSTEM
USING COMPUTER AIDED DESIGN

N-11

G. R. Branner[*†]
E. A. Cota[†]
T. J. Minasi[†]

ABSTRACT

A 16-port broadband modeformer system has been developed to operate between C and Ku bands. The design approach is novel in that a unique computer modeling technique was developed and employed for design, optimization and integration of the system. The program employs exact analytical models for all components in the system such as 4-section tandem connected 90° hybrids, 180° hybrids, multisection phase shifters and line lengths. The overall system computer model employs special techniques to handle large (200 by 200) complex matrices. Measured data is presented which illustrates the accuracy with which the composite computer model predicts the actual hardware system performance.

I. INTRODUCTION

Increasing application of phase array antenna systems has necessitated the development of methods for employing sizeable numbers of array radiators to realize a large number of spatial field patterns. These phased array systems typically employ complex signal processing networks to combine the outputs of each individual radiator in such a manner that it is possible to form one or more independent beams simultaneously.

A highly efficient approach for realizing these patterns is through the synthesis of a lossless beamforming matrix. This approach possesses the major advantage that all beams have the full gain of the aperture.

Figure 1 illustrates a general representation for the class of 2N port beamforming systems under examination in this paper.

Power flow through this system may be represented in terms of a 2N port scatteirng matrix of the form

$$S = \left[\begin{array}{c|c} 0 & S_a \\ \hline S_b & 0 \end{array}\right]$$

where S_a and S_b are NXN submatrices. This matrix represents a system composed of N input and an equal number of output ports. An in-depth examination of this formulation reveals the property that a signal input to one of the input ports produces equal amplitude excitations at all outputs, but with a constant phase difference between radiators, thus producing radiation along a prescribed direction in space.

In the presentation to follow, the antenna array outputs of this class of network will be termed system "modes" and the overall system will be designated as a modeformer network.

Typical of such systems is the 16-port modeformer network configuration which is the topic of this paper (a block diagram of the system is illustrated in Figure 2).

*Dept. of Electrical and Computer Engineering, University of California, Davis
†ESL Inc., Sunnyvale, California

A prerequisite to the efficient physical realization of such systems containing large numbers of subcomponents is a suitable method for predicting composite system performance subject to subcomponent and interconnection network performance.

A major objective of the material presented in this paper is the description and application of a unique computer modeling technique for analysis, design and testing of large, complex systems as exemplified by the 16-port modeformer of Figure 2.

The paper describes the modeling technique in depth and the manner in which the composite computer model has been employed in optimizing the system design and actual integration and testing of the hardware system.

II. NETWORK COMPONENTS.

The modeformer network (Figure 2) utilizes 180° hybrids, 90° hybrids, and 45° phase shifters as basic building blocks. The 180° hybrids are synthesized employing 90° hybrids, reference lines and multi-section Shiffman C section networks. The following table provides a summary of the voltage phase and amplitude relationships required of the three network components.

III. SYSTEM COMPUTER MODELING.

The composite 16-port modeformer system is illustrated in Figure 2. As has been noted above, this system is composed of numerous multisection 90 and 180 degree hybrid and phase shifter networks arranged in such a manner as to provide the requisite phasings at the output ports. Furthermore, it has been stated that the 180° hybrids are synthesized, employing 90 degree hybrids, reference lines and multi-section Shiffman C section networks. All such system components are connected with finite lengths of transmission line.

The objective of the overall modeformer computer model development has been to provide a technique for realiable composite system design and performance prediction. A particularly critical design requirement concerned the specification of certain system components whose parameters could only be estimated a priori at center frequency. The computer program requirement was to ascertain exact parameter values with precision before actual system fabrication could be initiated. Such requirements dictated the development of a system model whose parameters could be directly related to subcomponent design parameters.

The general computer program which was developed to fulfill the above requirements employs basic building block 2 and 4-port scattering matrices to model specific subcomponent responses in terms of actual physical design parameters. For example, typical four-port subcomponents such as coupled line length sections are represented in terms of fundamental four by four scattering matrices involving odd

0149-645X/83/0000-0187 $01.00 © 1983 IEEE

and even mode characteristic impedances, propagation constants and device lengths. Similar analytical representations are employed for the other components utilized in the computer program. Fundamental to the program are subroutines which employ the basic 2 and 4-port building blocks to analytically realize the subcomponents such as the 180° and 90° hybrids and 45° phase shifters. These subroutines are subsequently connected through fundamental analytical techniques to form an overall system scattering matrix which provides a precision model of the system. This matrix is then evaluated subject to prescribed system parameter and response requirements over the frequency range from 6 to 18 GHz.

IV. SYSTEM REALIZATION.

A diagram of the network showing the realization of the hybrids and phase shifters is presented in Figure 3. In this figure the antenna inputs are labeled E1 through E8 and the mode outputs are designated as m = 0, ±1, ±2 and ±3. The entire network is photo-etched on three separate stripline circuit boards which are individually housed and interconnected with semi-rigid coaxial cables. A photograph of the complete assembly is shown in Figure 4.

Bandwidth requirements dictated the use of multisection hybrids and phase shifters. Relative phase dispersion arising from modal paths having unequal numbers of coupling sections are compensated for by the use of all pass C-sections of required dispersion. These sections are designated in Figure 3 as phase compensating networks.

As alluded to above, the computer network model includes the phase compensating networks. The topology of these structures was selected to provide paths of equal length and phase dispersion for all modes. The values of their coupling parameters were determined from the computer program by constraining the lengths of the sections and iterating the voltage coupling coefficients to provide optimum phase offset characteristics between the modes. This was necessary since various modes were to be compared to provide an overall bearing estimate.

The steps in the integration of the system were to trim the input cable lengths to provide the proper relative phase response among the outputs of the first network, and then interconnect the first and second board assemblies with equal length cables. The computer analysis of phase vs frequency at the second level of the system assembly was then used to adjust the interconnecting cables to their proper lengths.

As an example of this technique, Figure 5 illustrates the theoretical and measured relative phase responses at the second level of integration. The input was antenna port E4 with the outputs at points 03, 04, 07 and 08 (see Figure 3). Finally, the third network was connected through the second set of cables which were trimmed to provide the closest fit to the theoretical system response obtained from the computer program.

Figures 6 and 7 contain computer generated responses of the phase outputs of the entire system for the +2 and 0 order modes. These responses represent the overall system phase characteristics at ports 14 and 16, respectively for inputs at ports E1 through E8 with path E1 to port 16 used as normalization. As expected from theory Figure 8 shows that the phases of the responses from ports E1 and E5 to the +2 mode output are equal. Similar results are evident for input ports E2-E6, E3-E7, and E4-E8. Furthermore, as predicted by theory it may be observed that there is a constant 90° offset between the output phases for each input pair described above. Figure 7 illustrates similar results for the mode zero response.

Examples of measured system phase response are shown in Figures 8 and 9. For these graphs, modal outputs (Mode +2 and 0, respectively) are fixed while the antenna input ports are stepped from E1 to E8. As predicted, the phase offset between adjacent antenna inputs is 90° for the +2 mode output, and the corresponding phase offset for the 0 order mode is 0°.

V. CONCLUSION.

This paper presents a precision computer oriented technique for design, optimization and integration of complex microwave systems containing a variety of complex subcomponent elements. A major portion of the paper discusses the application of the technique to the design of a 16-port modeformer network, and in particular it is shown how certain subcomponent specifications are ascertained employing the computerized technique.

Data presented comparing the measured system responses with those predicted by the program, illustrates the accuracy with which the model predicts the hardware system performance.

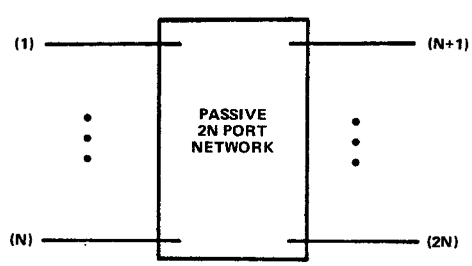

Figure 1. Beamformer System Representation

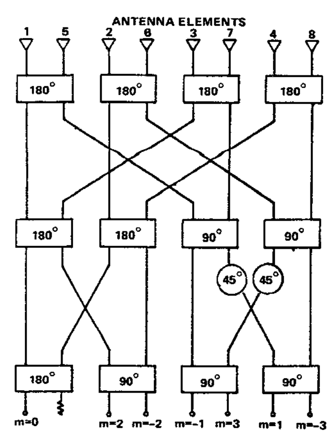

Figure 2. Modeformer Network

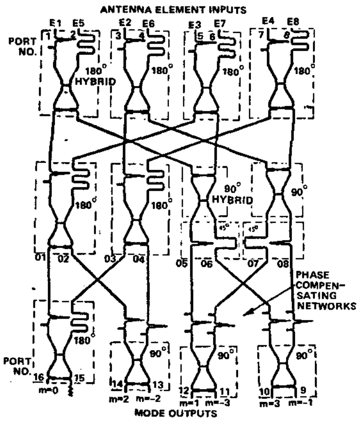

Figure 3. Modeformer Network Realization

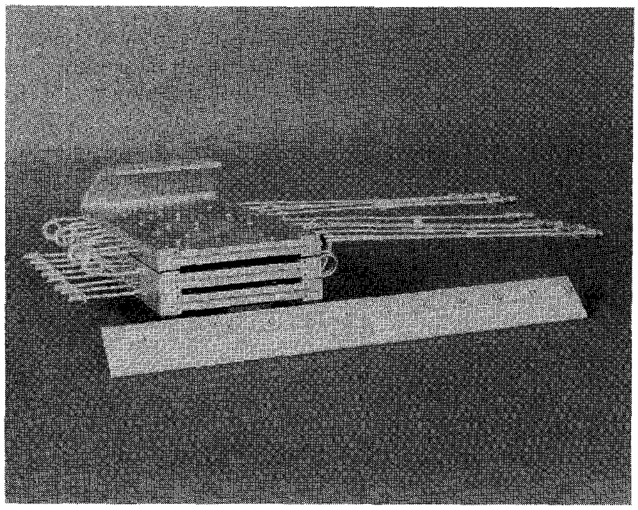

Figure 4. Modeformer Network Assembly

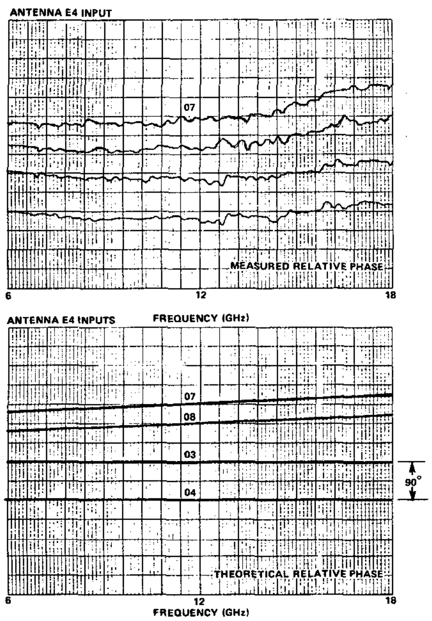

Figure 5. Phase Responses at Second Level of Integration

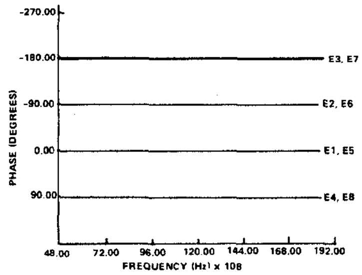

Figure 6. Computer Response for Mode 2

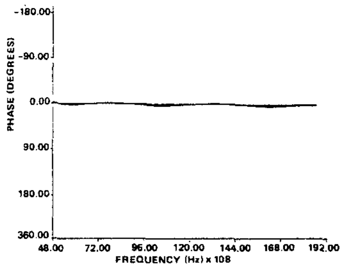

Figure 7. Computer Response for Mode 0

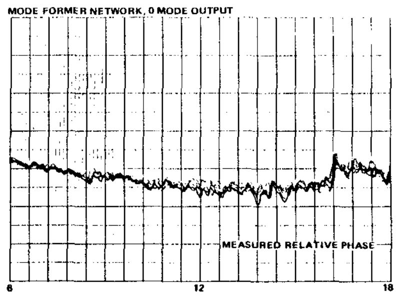

Figure 8. Modeformer Network, 0 Mode Output

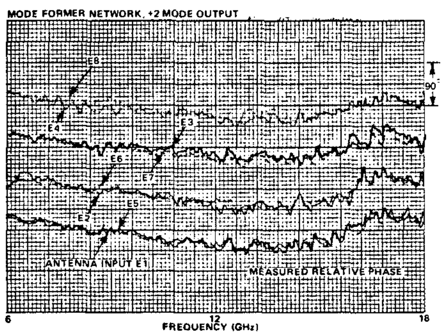

Figure 9. Modeformer Network, +2 Mode Output

Table 1. Network Components