Beamformers: Broadband RF Technology For Integrated Networks

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Abstract

Beamformers are used in both radiation and reception of electromagnetic energy. Beamforming networks in antenna arrays shape beams and steer their direction electronically; requiring no mechanical motion. Arrays of antennas combined with beamformers create synthetic spatial apertures. In addition, beamformers are used for spatial filtering of interference signals. Applications include: RADAR, satellite communications and remote sensing.

Introduction

Beamforming networks can be made with both time and frequency domain circuitry. Specific applications may require the advantages of one topology over another. For example, frequency domain beamforming is usually employed in broadband applications. This paper discusses frequency domain beamformers from a component design perspective. Emphasis is given to techniques utilized in broadband circuit synthesis and integration of monolithic beamforming networks.

Design

Lumped element technology is utilized for compact beamformer designs in the 1 MHz to 2.5 GHz frequency range. Broadband transmission line transformers [1]-[3] are the basis for 180 degree hybrid junctions and 90 degree quadrature hybrids. Twisted or bonded multifilar wire transmission lines are loaded with ferrite or iron cores of various shapes. The geometry of the wire as well as the core is critical to the frequency response of the transformer. The inductance/capacitance ratio of the wire must maintain the desired characteristic impedance. Stray reactance must be minimized, while enough inductive choking reactance is maintained to provide isolation for the low end frequency response. Plotted performance data for a 180 degree hybrid junction designed for the 1 MHz to 1 GHz frequency range show an amplitude balance of 0.3 dB and a phase balance of 1.5 degrees.

Elliptic functions are used to produce 4-port quadrature hybrids and 3-port hybrids of any phase. The roots of the polynomials scale the geometric mean frequency to yield inductance and capacitance values for each section. The individual specification requirements of each application drive the configuration choice: cascaded transmission line sections, or allpass networks in bridged-tee or lattice structure. Plotted performance data for a 90 degree network designed for the 500 MHz to 2 GHz frequency range show an insertion loss of 0.8 dB and a phase balance of 0.6 degrees.

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Beamformers are designed using combinations of various phase hybrids to accomplish the phase weighting requirements from each antenna to each mode. Fully symmetrical

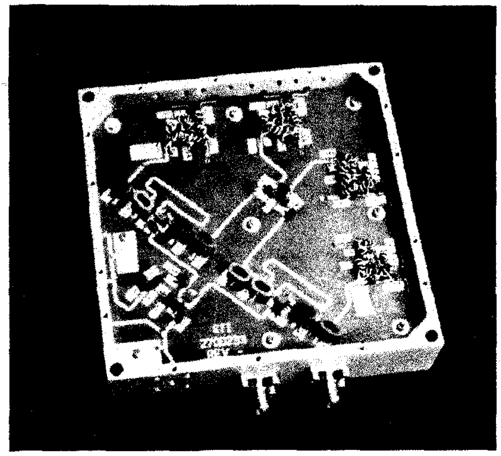

Fig. 1- 3x8 Beamformer 100-800 MHz

180 degree hybrid junctions can be utilized for vector addition, in order to create the desired phase weights. The hybrids are integrated, taking advantage of inherent impedance transformations, reducing insertion loss by minimizing the use of matching transformers. A 3x8 beamformer was designed for the 100 MHz to 800 MHz frequency band. Figure 1 shows a photograph of the assembly. Plotted performance data are given in Figure 2.

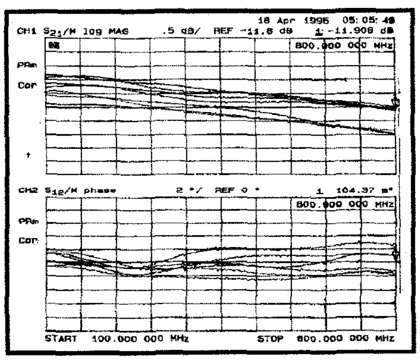

Fig. 2- Mode 1, 3x8 beamformer insertion loss amplitude balance, phase balance (offset +/- degrees: 45,90,135,180).

Although lumped element technology has the small size advantage for frequencies up to 2.5 GHz, stripline beamformers exhibit lower insertion loss, providing superior performance at higher frequencies. Typical stepped-section stripline designs achieve multi-octave bandwidths, but have a limited high frequency response. In contrast, smooth, highpass structures [4]-[8] can be used to extend the use of stripline to 65 GHz. By utilizing original, mathematical synthesis programs, various phase hybrids having a generalized

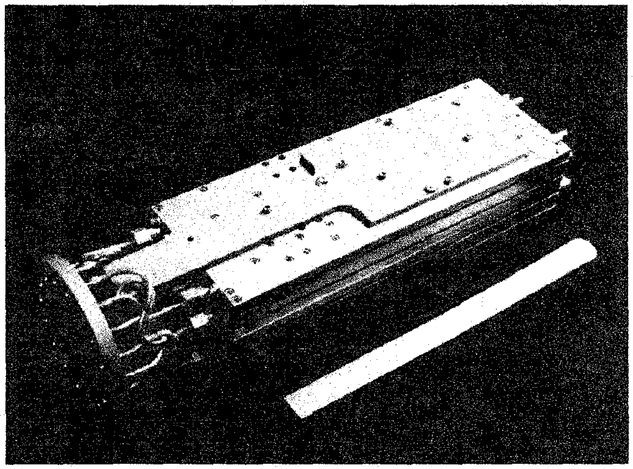

Fig. 3- 3x8 Beamformer 2-4 GHz

sinusoidal voltage coupling coefficient have been produced. This allows highpass hybrids to be produced in minimal size. The variational expression is used to compute the exact impedance of structures when striplines are offset from center. Exact mathematical analysis is used to check and iterate the synthesis process. Performance plots show the swept response of a 180 degree hybrid designed for use in the 5 GHz to 20 GHz frequency range with 0.5 dB amplitude balance and 3 degree phase balance.

One of the difficulties in creating monolithic, integrated stripline beamformers arises from the fact that 180 degree hybrids require a drastically different stripline structure than do 90 degree hybrids. Having the ability to change a hybrid's even mode impedance by adding out-of-band sidelobes, allows the production of various types of hybrids with the same spacer and ground plane spacing. The resulting stripline beamformers are truly monolithic and suitable for multi-octave performance to 65 GHz. A photograph of a 3x8, S-band beamformer is shown in Figure 3. Performance data are given in Figures 4.

Conclusion

By utilizing lumped element technology, the production of light weight, compact size, beamformers over very broad frequency bands, from 1 MHz to 2.5 GHz has been achieved. Data have been presented illustrating the performance of individual circuit elements as well as an integrated 3x8 beamformer.

By employing a generalized sinusoidal coupling coefficient theory along with the variational expression, the production of broadband stripline hybrids has been realized. In addition, original FORTRAN programs have been used to manipulate the even mode impedance by adding out-of-band sidelobes, allowing the monolithic integration of 90 degree and

180 degree hybrids. Data have been presented highlighting the frequency reponse of an individual hybrid as well as an integrated 3x8 beamformer.

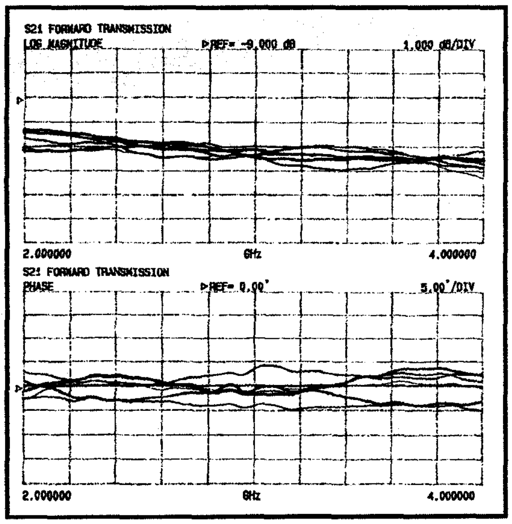

Fig. 4- Mode 2, 3x8 beamformer insertion loss and amplitude balance, phase balance (offset +/- degrees: 90,100).

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