BEAM STEERING ANTENNA CONTROL TECHNIQUE

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ABSTRACT

A technique which reduces the requirement for constructing high accuracy phase shifters for steering the main beam in a small (less than 20 elements) linear antenna array is described. The key hardware components are the phase detectors which monitor the phase difference between adjacent radiating elements and a microcomputer to read the phase differences and adjust phase shifters to obtain the desired antenna performance. This closed loop technique will also provide a means for future investigations to verify theoretical versus experimental phase distributions and other element effects in small antenna arrays.

Introduction

The development in recent years of main beam scanning phased array antenna systems has been extensive. A great deal of this development has been directed towards large aperture linear or planar arrays in which elemental thinning is applicable and/or where the hardware implementation (particularly the phase shifters) is exceedingly cumbersome. In other cases, where a small linear array (less than 20 elements) is being considered, the required phase accuracies are such that the hardware implementation often reaches the limits of component performance.

The fundamental concept of steering the main beam in a linear array relies on a progressive uniform change in the phase of a wavefront across the aperture of an array.[1] The characteristics (i.e., beamwidth, gain, sidelobe levels, etc.) of the main beam are determined primarily from the number of radiating elements in the simple array, the phase distribution, and the power distribution.[2]

Conventional (open control loop) linear arrays must provide a means to vary the phase distribution on the radiating elements to correspond to a particular scan angle. This is typically done with a "bit" phase shifter module for each element in a small array. The "bit" phase module allows 360° of phase in steps which correspond to the least significant bit. For instance, in a 5-bit phase shifter module 360° of phase shift is achieved in 11.25° steps. The "bit" phase shifter approach for controlling the phase distribution in small arrays results in unacceptable radiation patterns if low sidelobe levels or scan angle accuracy are required because the accuracy of setting the phase shifters is limited to the least significant step. Another approach for controlling the phase distribution is to vary the phase shifts continuously from 0° to 360°. In a varactor diode phase shifter, for instance, a voltage on the reverse biased diode is set to correspond to a particular phase shift. Since setting and holding a specific phase distribution or voltage settings are critical (sensitive) in a small array, a degradation in the radiation pattern is usually experienced because of variations in the voltage setting or varactor characteristics.

This paper describes a technique for controlling the phase distribution on a small (five radiating elements) linear array antenna where the scan angle (broadside to $+60^\circ$ from broadside) must be set precisely while maintaining sidelobe levels of 25 db down from the main lobe peak. This technique is centered around the development of microwave phase detectors and a microcomputer in a closed loop configuration so that the requirement for constructing high phase accuracy phase shifters is reduced.

System Configuration

The basic beam steering antenna control system will be configured as shown in Figure 1, where a four-element antenna array is the example. The following discussion will emphasize the accomplishments of the phase detector network development as well as the detailed approach for implementing the phase shifting control technique.

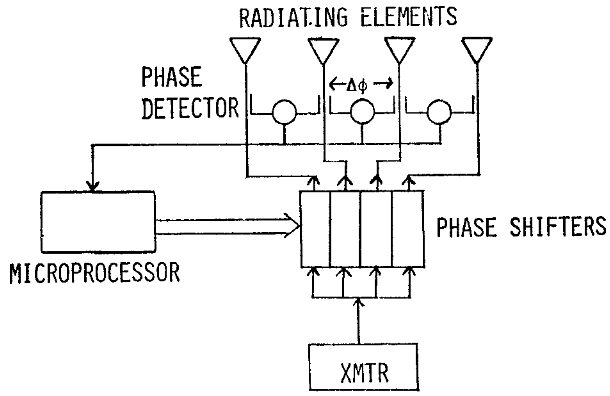

FIGURE 1: BASIC BEAM STEERING CONTROL CONFIGURATION.

Phase Detector Network

The phase detector circuit consists of a 90° branchline coupler and impedance matching transmission lines. The computer design was directed towards low power consumption with good phase detection performance. As shown in Figure 2, the microstrip circuitry uses 1/32-inch substrate material which has a dielectric constant of 2.54. Figure 3 shows the performance of the phase detector at 7.5 GHz with an input power level of -11 dbm on each port. Schottky Barrier diodes from Hewlett-Packard (HP 5082-2775) were used as the active devices.

In order to maintain uniformity in the performance of the phase detectors, it is necessary to compensate for the power level variation due to the chosen Chebyshev distribution. As shown in Figure 4, this was accomplished by selecting the proper coupling value for the directional couplers which are used to direct power from the main feed lines.

It is also necessary to provide the proper fixed phase shift at the phase detector inputs so that the optimum portion of the detector performance curve can be utilized for the given broadside to $+60^\circ$ from broadside scan angles. This means that the detector crossover (0 mV) occurs at the middle of the scan angle range. The fixed phase shift was obtained by placing the directional couplers at prescribed locations on the main feed lines.

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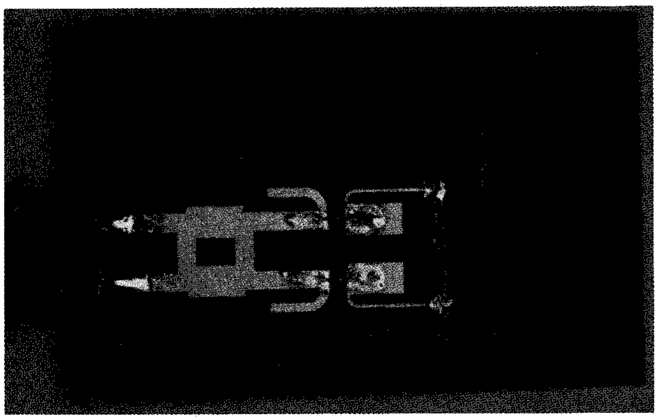

FIGURE 2: MICROSTRIP PHASE DETECTOR.

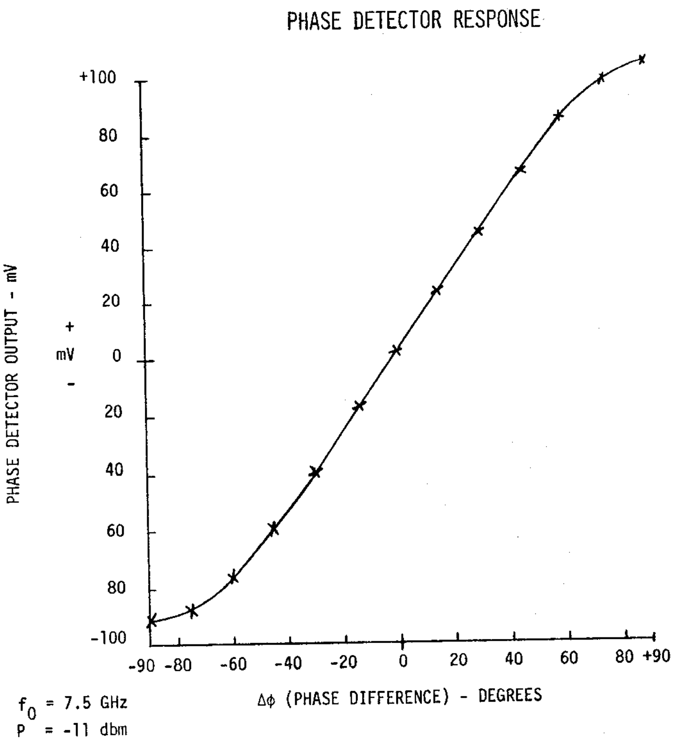

FIGURE 3: PHASE DETECTOR PERFORMANCE CURVE.

Phase Shifters

Each of the five elements are controlled by a phase shifter module. A module will consist of three simple phase shifter designs using microstrip branch-line couplers on alumina substrates.[3] Two phase shifters will be the discrete type, providing 0° and 90° phase shift and 0° and 180° phase shift. The third phase shifter will be an analog type which is varactor controlled. This phase shifter provides greater than 0° to 90° of continuous phase shift. An important factor here is that greater than 90° of phase shift is obtainable to compensate for inaccuracies in the two discrete phase shifters. The proper selection of discrete phase shifters and the voltage setting on the analog phase shifter will provide 0° to greater than 360° of phase shift from each module. The varactor phase shifter is shown in Figure 5. The diodes used are abrupt junction gallium arsenide devices from Microwave Associates (MA 46603E). The discrete phase shifters are presently in development.

Microcomputer

The heart of this beam steering antenna control technique is the microcomputer control. This consists of a 6809 microprocessor based central processing unit (CPU) with arithmetic processor, 16 K bytes of memory, and analog-to-digital/digital-to-analog converters in an SS-50 bus configuration. This type of microcomputer was selected because of the flexibility to interface with the phase detectors and phase shifters in developing and debugging the system.

The closed loop control sequence will read each phase detector voltage and make corrections based on the temperature or component variation, compare this voltage with the desired voltage determined by the phase distribution calculations, and then adjust the phase shifters accordingly. Theoretical or experimental phase distributions can be implemented to verify or investigate various effects due to mutual coupling of the elements, other element variations, or the influence of reflective irregular shaped objects.

Conclusions

A beam steering antenna control technique has been introduced which shows promise in reducing the requirement for producing high accuracy phase shifters used in controlling small linear array antennas. The performance of the key microwave component, a low power consuming phase detector, shows very good results; thus, the successful implementation of this approach is very likely.

References

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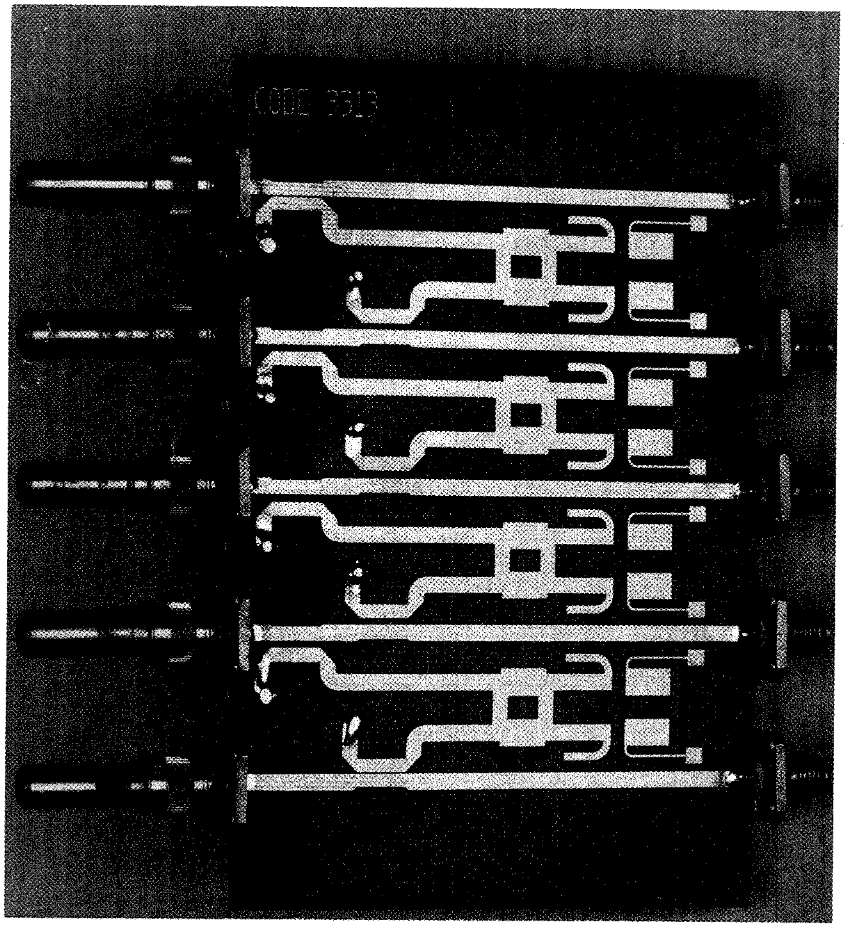

FIGURE 4: MICROSTRIP PHASE DETECTING CIRCUITRY FOR CONTROL OF A 5-ELEMENT LINEAR ARRAY ANTENNA.

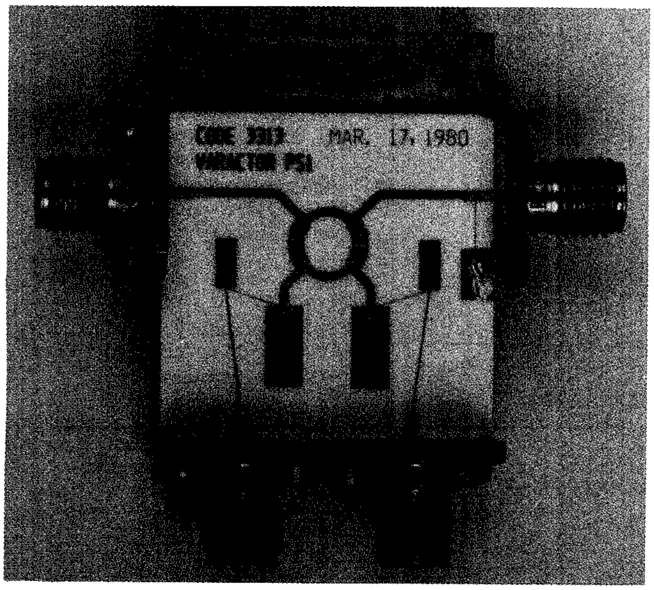

FIGURE 5: MICROSTRIP VARACTOR PHASE SHIFTER.