ANTENNA ARRAY FOR LIMITED SCAN APPLICATIONS

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Abstract

An S-band line source antenna which could become the basis for a lightweight, compact, low-cost, phased array is described. The line source is a series fed array of radiating slots periodically situated in the side wall of an S-band waveguide section. The unit, which uses nonreciprocal latching ferrite phase shifters between adjacent slots, is capable of switching beam position in less than 10 μsec and is designed to operate at peak power levels >3Kw.

Introduction

The development of an S-band, 16 slot line source antenna is described which provides the basis for a compact phased array, which is particularly suited for small angle elevation scanning.

The line source consists of 16 side wall, shunt slot radiators with a nonreciprocal latching phase shifter (with matching transformers) between each of the slots. By changing the insertion phase between adjacent slots via the differential phase shift of the ferrite sections, beam scanning can be accomplished (Fig. 1). Each cell, defined as the region between two adjacent slots, is identical in physical design as well as operation. Thus, a single electronic driver can be designed to energize a number of cells using one latching-wire loop thereby reducing the required number of drive circuits as well as the system size and complexity.

Design Considerations

The line source design involved several design considerations and tradeoffs. First, the choice of the ferrite material for the phasor had to be made. For high peak-power operation it has been shown, (1) (2) (3), that the ratio, $\gamma \frac{4\pi M_s}{\omega}$, should be minimized since it is a factor that determines the peak power threshold of the device. Since the differential phase shift of the device is directly dependent on the remanent magnetization of the ferrite which, in turn, is dependent on the 4πMs of the ferrite, a compromise had to be made. Secondly, the physical configuration of the ferrite phasor must be determined, remembering that the cross-section of the ferrite phasor must be designed to produce intimate contact with the waveguide broad walls to prevent spurious mode generation. Also, the cross-section of the toroid must be designed to maximize differential phase shift, while avoiding heavy dielectric loading of the waveguide and any resulting spurious modes. Third, while attempting to achieve the desired differential phase shift, it must be kept in mind that the scan angle positions for the linear array are determined by the insertion phase between adjacent slots - in this case 360° of insertion phase represents the broadside position.

Phase Shifter Design

The basic phase shifter (phasor) cross-section is shown in Figure 2. The ferrite material utilized is Trans-Tech G-600 with Mn substitution. Trans-Tech D-16 dielectric is used to load the toroid as well as to provide the matching transformer sections. A side-view of the phase shifter situated in the line source is shown in Figure 3. Non-synchronous transformers (4) consisting of a dielectric section followed by the appropriate length air gap were designed for matching into the phasor. Figure 4 indicates the insertion loss, VSWR, and differential phase shift of the phasor. The insertion phase achieved at 3.250 GHz for each cell was measured to be 396° for the low state of ferrite magnetization and 440° for the high.

Linear Array Characteristics

A fifteen cell prototype was fabricated in a length of S-band waveguide, where each group of five cells was switched by one driver. The input VSWR of the linear array was measured to be less than 1.4:1 over an 8% bandwidth centered at 3.250 GHz. The insertion phase of each cell was measured in each state of magnetization and found to be virtually identical. Using the two values of insertion phase, the waveguide side wall slot separation, and the frequency, one can predict the two scan position extremes by using the equation for simple beam pointing for individual radiators as elements of an array:

$$\theta = \sin^{-1} \frac{\lambda_0 \Delta \phi}{2 \pi d}$$

where

θ = beam pointing angle with respect to broadside.

λ_0 = free space wavelength.

$\Delta \phi$ = phase difference between slots.

d = slot spacing or separation (2.363").

At 3.25 GHz, the measured insertion phase between adjacent elements (slots) at the low state was 396°, and 440° for the high phase state.

Therefore $\theta_{low} = 9°$

$\theta_{high} = 20°$

Figure 5 shows a set of composite antenna patterns measured for the 16 slot line source for the low and high phase states as well as some intermediate scan positions. The measured extreme pointing positions are shown to be 11° (θ_{low}) and 22° (θ_{high}), thus showing good agreement with predicted values. The calculations given above are for only center frequency of operation. Although the phasor-radiator line source is dispersive with frequency, compensation for the insertion phase variation can be achieved through the use of a portion of the differential phase shift provided by the phasor.

Figure 6 shows a photograph of a portion of the actual 15 cell array with the back wall of the waveguide section removed, while Figure 7 is an external view of the entire 15 cell array.

Conclusion

The successful design and demonstration of an S-band linear array clearly offers a technique which provides significant savings in cost, weight and size when compared to conventional methods for performing small-angle, elevation scanning. This is evidenced by the fact that 15 phasor elements are driven, identically and simultaneously, by a common electronic driver whereas conventional phased arrays require that each phasor be driven by its own driver. Hence, the linear array approach facilitates the integration of the phasors and radiating elements into a common transmission line that results in a compact, simplified and cost effective structure. Further design improvements in such areas as ferrite material, dielectric loading, cell cross-section, and slot design could make this unit more efficient and more versatile.

References

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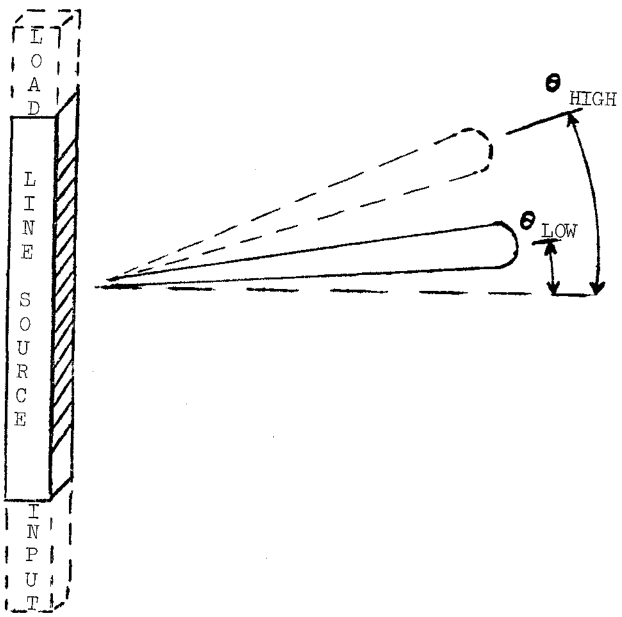

FIG 1 BEAM STEERING BY LINE SOURCE ARRAY

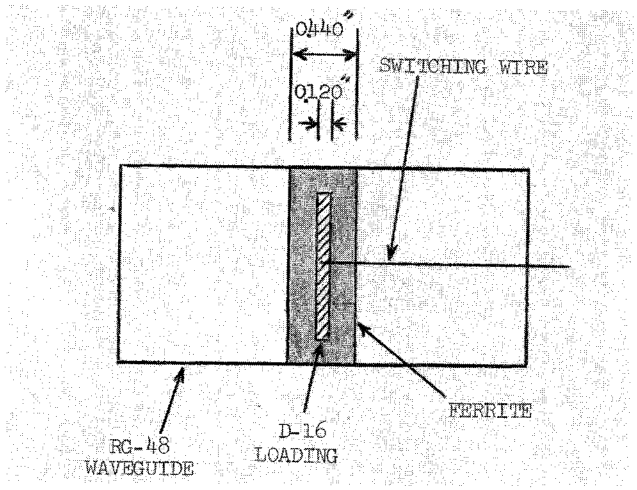

FIG 2 CROSS SECTION VIEW OF THE PHASOR

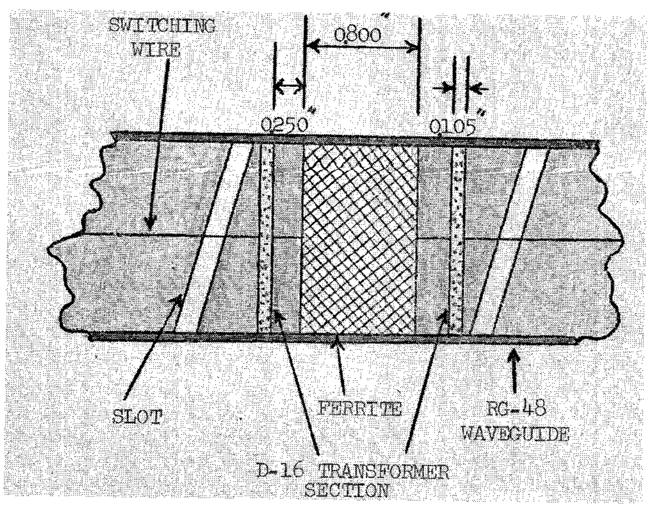

FIG 3 SIDE VIEW OF PHASOR SITUATED IN LINE SOURCE

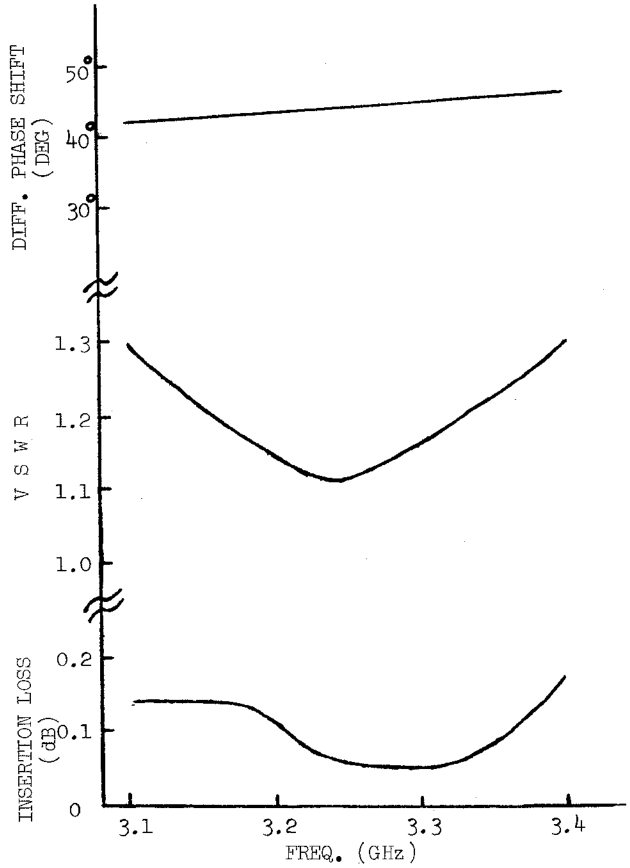

FIG 4 OPERATING CHARACTERISTICS OF ONE PHASOR

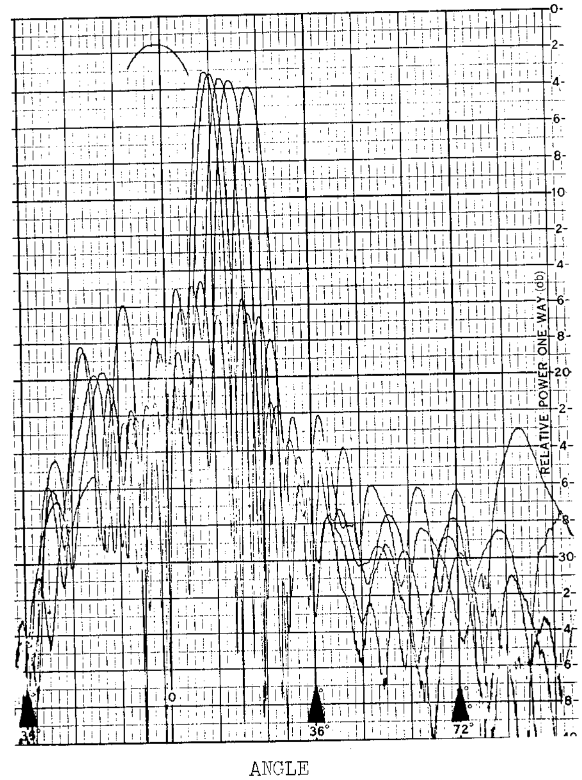

FIG 5 ANTENNA PATTERNS TAKEN FROM LINEAR ARRAY

FIG 6 INTERNAL VIEW OF A PORTION OF THE LINE SOURCE

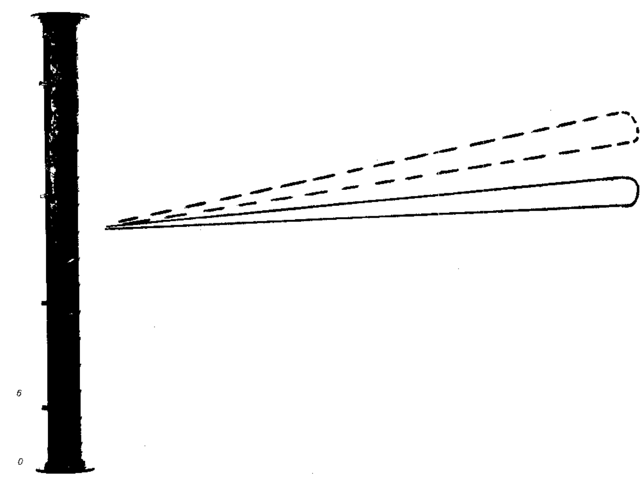

FIG 7 EXTERNAL VIEW OF THE LINE SOURCE ARRAY