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LOW LOSS ELECTRONICALLY CONTROLLED EHF VARIABLE POWER DIVIDERS*

David S. Besse
Lincoln Laboratory, Massachusetts Institute of Technology
Lexington, Massachusetts 02173-0073

and

Thomas E. Sharon
Electromagnetic Sciences, Inc.
125 Technology Park/Atlanta
Norcross, Georgia 30092

Summary

The development of an EHF variable power divider (VPD) using 90° phase shifters and fixed 3 dB couplers is described. The accurate characterization of individual components of the VPD's leading to the construction of a device capable of over 34 dB cancellation is discussed.

Introduction

Variable power dividers (VPDs) based on the use of phase shifters and hybrids in a bridge circuit are well known.[1,2,3,4] In this paper we describe the development and performance of this type of VPD using low loss ferrite phase shifters for use in the 43-45 GHz band. These phase shifters were designed, developed, and fabricated by Electromagnetic Sciences, Inc., of Norcross, Georgia. Figure 1 shows a diagram of the VPD described. The task was to carefully measure the transfer characteristics of a set of 90-degree ferrite phase shifters and hybrids, and using the obtained data, selectively assemble them into variable power dividers. Note that in the application described, the VPDs are actually being used as variable power combiners. This is significant because the ferrite phase shifters used are non-reciprocal. The phase shifters were selected, first, on the basis of their individual performance and then matched into pairs based on similar characteristics. This approach to construction of the VPDs provided well-defined criteria upon which to base the choice of components and eliminated trial and error. Of vital importance to this technique is the accuracy of the measurement system used to characterize the components, since one degree of phase error, or a tenth of a dB amplitude error can significantly affect the performance of the VPD. Figure 2 shows a block diagram of the measurement system used and may serve to illustrate some of its capabilities. Due to limited space, the measurement system used will not be discussed here but is documented in reference 5.

Linearization Procedure

The process of calibration (or linearization procedure) for the phase shifters and VPDs employs a digital linearization scheme orginally developed by Electromagnetic Sciences for use on the DSCS-III program. Before assembling the VPDs, each component (including phase shifters, hybrids, sidewall couplers, and adapters (refer to Fig. 1)) were measured individually. The phase shifters used are latching ferrite phase shifters where the phase shift is determined by the magnitude of a current pulse which is controlled by a twelve-bit command. The switching time of the shifters from state to state is approximately 10 microseconds. Eight bits were ultimately used to control each phase shifter. That is, 256 of the 4096 possible commands, were selectively chosen for phase shifter operation. Each of these 256 commands was assigned an address number between binary zero and binary 255. In this way, with proper selection of the 256 commands, the phase shifter could be "linearized".

The first task in characterizing the phase shifters was to calibrate them. Data was collected for each of the 4096 phase commands (12 bits) at 11 frequencies across the band. Out of 4096 phase states, the 256 states most closely corresponding to integral multiples of 90/256 were selected (8 bits). This resulted in an as close to a linearly increasing phase shift as possible with increasing state, or binary, number. A linear function was desired so that the VPD could be controlled by a computer without having to continually refer to a data base. Each of the 256 phase states was chosen such that the RMS phase error with respect to frequency and relative to the desired phase was minimized. The expression used to determine the RMS error is as follows:

$$RMS_k = \sqrt{\frac{1}{N} \sum_{n=1}^{N} (\phi_{a,n} - \psi_k)^2}$$

where N = number of frequencies

ψ_k = desired phase at k^{th} state

k = increased index (ϕ-255)

$\phi_{a,n}$ = measured phase at a^{th} (command) state, n^{th} frequency

This gives a measure of both how well the state was chosen and how constant the phase is with frequency. Refer to Fig. 3 for an example of phase versus phase state, before and after linearization. After linearization, the optimized eight-address bit to twelve-command bit conversions were burned into PROMS and placed into the driver cards for the phase shifters.

Characterizing Phase Shifters

Another important characteristic of the phase shifters is insertion loss. The insertion loss of each shifter was measured at the 0-degree phase state. The objective was not only to try to use the ones with the lowest loss but to also match the shifters and other components such that the insertion loss through the two channels of the VPD were as closely matched as possible. Equal insertion loss is important because the VPD will often be required to cancel two input signals.

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A third important factor associated with insertion loss is its variation with changing phase state. Figure 4 shows the insertion losses of a typical phase shifter at the 0-degree state and at the 90-degree phase state. In general, the insertion loss of all of the phase shifters measured varied very little with phase shift.

The other components in the VPD were also measured for insertion loss so that the total insertion loss through each channel of the VPD could be matched.

Ideally, phase shift should be independent of frequency. Therefore, it is important to have the phase shift be as constant as possible over the frequency band. Figure 5 shows the phase variation versus frequency (phase slope) of a typical phase shifter at different phase settings relative to the 0-state versus frequency. The three settings were chosen to be near 30°, 60°, and 90° and these constants subtracted for convenience in plotting. Thus the fixed phase differences for each curve have no significance; only the variation over the band is of concern. In general, the greater the phase slope, the smaller the bandwidth over which the VPD will operate as desired.

Another factor to be considered is the phase slope of the phase shifters relative to one another. This was measured using one arbitrarily selected phase shifter as a reference (set to the 0 state) and measuring each of the others (also set to the 0 state) relative to the reference. Each shifter could then be referenced to any other by direct comparison since they all had a common reference.

Assembling VPDs

The two factors discussed above, insertion loss and phase slope, had to be weighed equally when assembling VPDs. Neither one of them seemed to have more effect than the other. Once a VPD was assembled, the amount of cancellation, or attenuation, achieved when one input was turned off, was used as a criterion to evaluate the performance of the VPD. That is, an input signal was fed in on one input of the VPD, while the other input was terminated. The phase shifters were set (one at 0 degrees and the other at 90) such that the two signals were combined 180 degrees apart at the output and would cancel. If everything were ideal, there would be no signal coming out of the VPD. The actual input signal attenuation for this case was used as a measure of performance.

Some intermediate VPD states were also checked. In order to keep a constant phase output, the sum of the two phase shifter settings must always be 90 degrees, only the difference is varied. The attenuation through the VPD can be predicted for a given difference state ($\phi_2-\phi_1$) by the following equation (assuming that the sum of the two phase settings remains 90 degrees. Refer to Fig. 1):

$$E_s = E_1 \cos(\bar{\psi}) + E_2 \sin(\bar{\psi})$$

where $\bar{\psi} = \frac{\phi_2 - \phi_1}{2} + 45°$.

The signal power not appearing at the output (E_s) is dumped into the difference port of the hybrid. Theoretical attenuation was checked against the measured data for a sample VPD, at selected phase difference states, and the results are shown in Fig. 6. When both phase shifters are set to 45 degrees, the resultant output should be 3 dB down from maximum power. This was measured, and Fig. 6 shows the agreement that was obtained.

Conclusions

The approach to the development of an EHF VPD described has resulted in a broadband VPD with over 34 dB cancellation and less than 1.4 dB insertion loss. The technique of accurate determination of the frequency response characteristics of each component and the utilization of computer techniques to optimally match components has resulted in an optimum VPD with a minimum of trial and error. In addition, the method of linearizing the phase shifters has resulted in a VPD design which is readily computer controlled without the need for large look-up tables.

Little effort was made with the VPD's described here to package them for minimum volume, as is required in many applications. More recently, Electromagnetic Sciences has produced a compact version of this device using topwall hybrids. The size is such as to permit packaging compatible with an array spacing of as little as .75 inch center to center. These incorporate 360° phase shifters so that the unit can be operated as a combined phase shifter and VPD.

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6. B. Potts, private communication.

Acknowledgments

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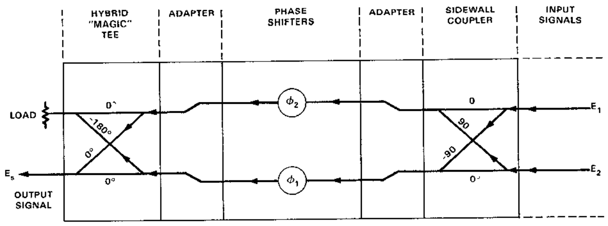

Figure 1. Schematic representation of a VPD configured as a variable power combiner.

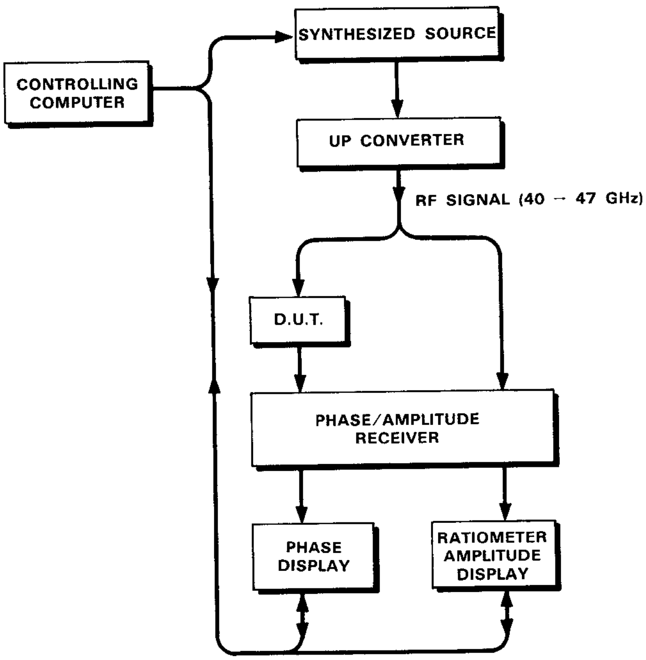

Figure 2. Simplified measurement system block diagram.

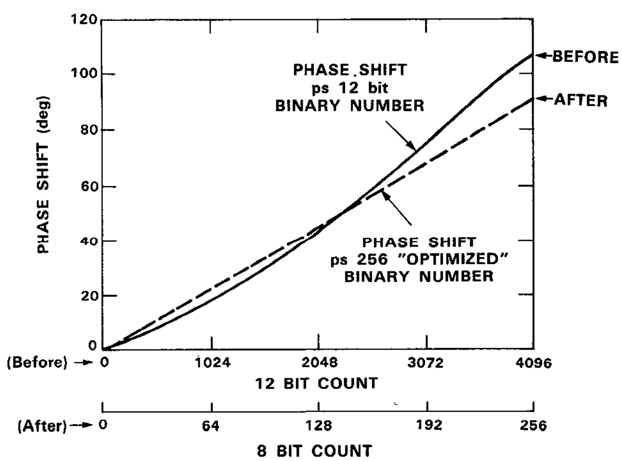

Figure 3. Results of linearizing phase shifters at 44 GHz.

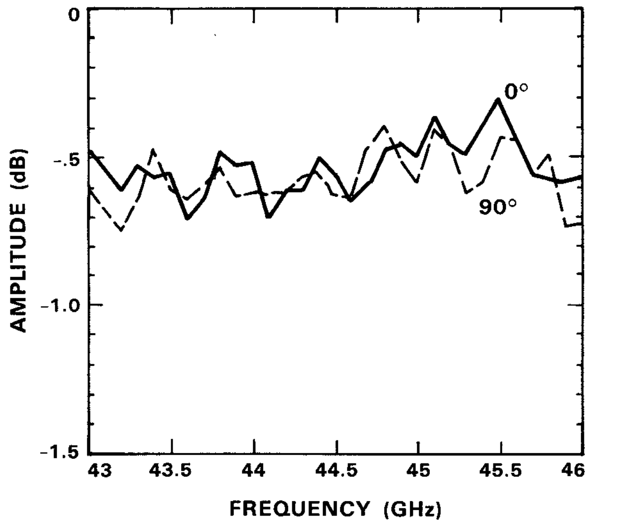

Figure 4. Insertion loss of a typical 90° phase shifter at different phase shifts (relative to 0° state)

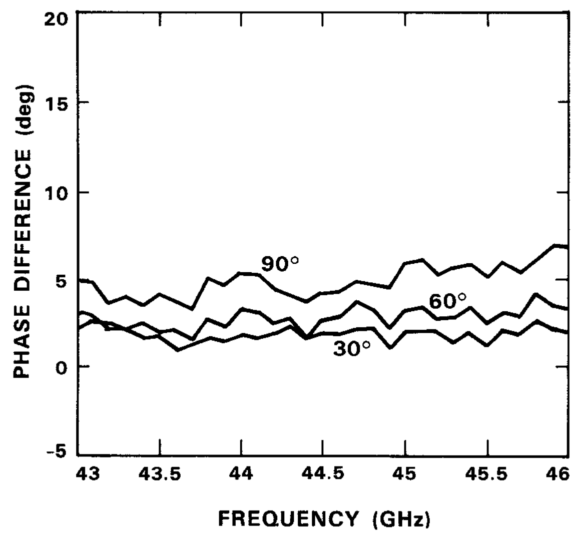

Figure 5. Relative phase variation of a typical 90° phase shifter at different phase shifts (relative to 0° state).

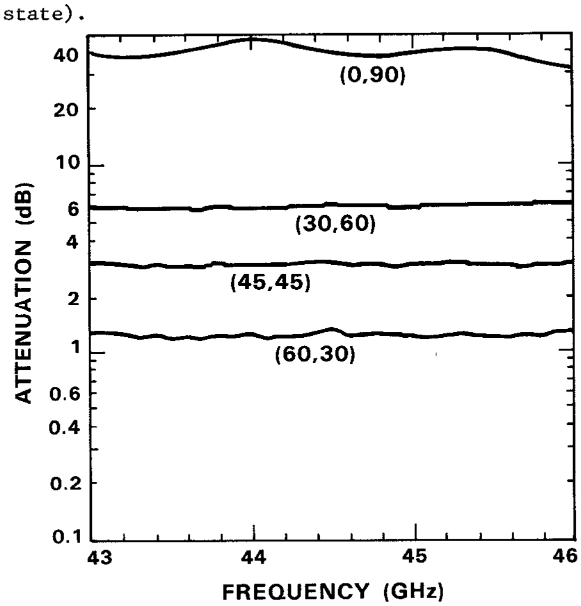

Figure 6. Attenuation of a typical VPD at various phase difference states.