Interactions Between Nested Receiving Rhombic Antennas

PETER P. VIEZBICKE, JR., MEMBER, IEEE

Abstract—In order to install as many radiating circuits as possible in a given area, consideration has to be given to the operation of antennas in proximity to one another. Therefore, mutual coupling between two nested rhombics and the effect of one rhombic on the radiation pattern of the other were measured. For a ratio of antenna sizes of 2 to 1, the presence of either a coplanar or noncoplanar antenna had no influence on the gain and radiation pattern of the reference rhombic. To determine the minimum acceptable separation, measurements were extended to include rhombics almost equal in size and as close as practicable to each other. For wire separations of 0.5λ the gain of the reference rhombic was reduced by 0.5 dB. For 0.2λ separation the gain was reduced by 1 dB, and for 0.04λ it was reduced by approximately 4 dB. Except for very close spacings, the radiation patterns remained substantially unchanged. Mutual coupling, expressed as transmission loss between the antennas in decibels, varied between -15 and -41 dB.

I. Introduction

The RHOMBIC antenna has proved to be extremely useful for general communication purposes. For efficient operation, its 2 to 1 frequency bandwidth, although wide, is not sufficient to permit communications in the HF bands at different times of day. It is, therefore, necessary either to operate the antenna outside its efficient range or to erect several rhombic antennas scaled to cover the HF spectrum. To operate over a 3 to 30 MHz range, for example, at least three antennas would be required for each circuit. The requirement for numerous circuits and the limited area available at a typical site make it necessary to consider operation of the rhombics and other antennas in proximity to each other. For improved space utilization [1] an arrangement is suggested by nesting the antennas, that is, placing one inside the other. The measurements described herein were carried out to investigate the degree of interference which one of the nested rhombics is likely to impose on the operation of the other. For this purpose, one antenna, called the reference antenna, was kept fixed in size and position, and the other, called the variable antenna, was varied in size and position with respect to the reference antenna while keeping the wires parallel. The gain and pattern of the reference antenna were measured for various configurations of the variable antenna, the latter being passive in all cases.

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The author was with the Central Radio Propagation Laboratory, National Bureau of Standards, which is now the Institute of Telecommunication Sciences, Environmental Science Services Administration. He is now with the Time and Frequency Division, National Bureau of Standards, Boulder, Colo. 80302.

The interference between rhombics may take several forms. Mutually induced currents may reradiate fields which may change the gain and radiation pattern of the antennas. This would apply to antennas used either for reception or transmission. In the case of transmission it is desirable to measure the mutual coupling between the nested antennas. With high transmitter powers, the voltages induced in adjoining antennas may be sufficiently high to warrant protective circuits for safeguarding equipment. On the other hand, if the mutual coupling between antennas is sufficiently low, consideration may be given for permitting simultaneous operation of one rhombic for transmission and the other one for reception. Since this paper considers interactions between nested receiving rhombics only, consideration should be given to the foregoing before placing nested antennas in high-power operational circuits.

Gain and radiation pattern measurements were carried out at the Table Mountain Antenna Range near Boulder, Colo. The mutual coupling measurements were carried out using an image plane at the National Bureau of Standards Laboratory, Boulder.

II. Method of Measurement

Gain and radiation pattern measurements were carried out using scaling techniques at a frequency of 2000 MHz. Since the results are to apply to HF rhombics, the scaling quoted is approximately 100. The reference antenna was designed with a leg-length $L = 6\lambda$ and a tilt angle $\phi = 68$ degrees. It was constructed of no. 40 AWG wire, mounted on nylon insulators and fastened to bakelite tubing at a height of 5λ above ground.

The variable rhombic was constructed and mounted similarly with provisions for changing its size, height h, and the spacing S between the wires of the two antennas. For convenience, the relative size of the variable antenna is expressed as the ratio l/L, where l is the leg-length of the variable rhombic. Fig. 1 shows the different nested combinations and details of the fixed and variable parameters.

Each antenna was terminated in a 600-ohm resistance. By means of balun transformers the input impedance was matched to 50 ohms. A low-loss coaxial cable connected the reference antenna to receiving-recording equipment located in a van-type vehicle off the edge of the antenna range. The variable antenna was terminated at both ends and remained passive for all measurements.

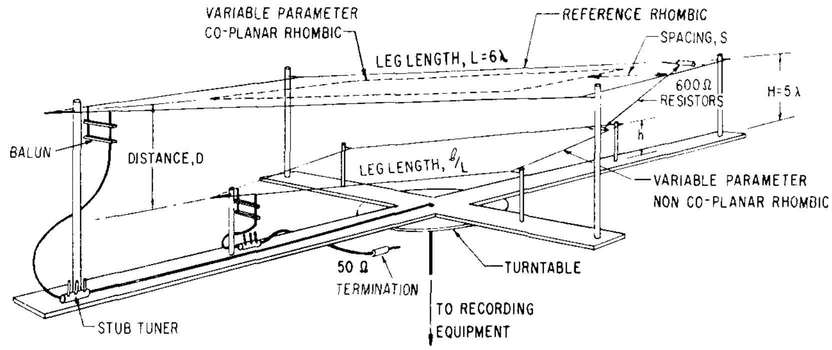

Fig. 1. Arrangement of antennas used in measuring patterns showing fixed and variable parameters.

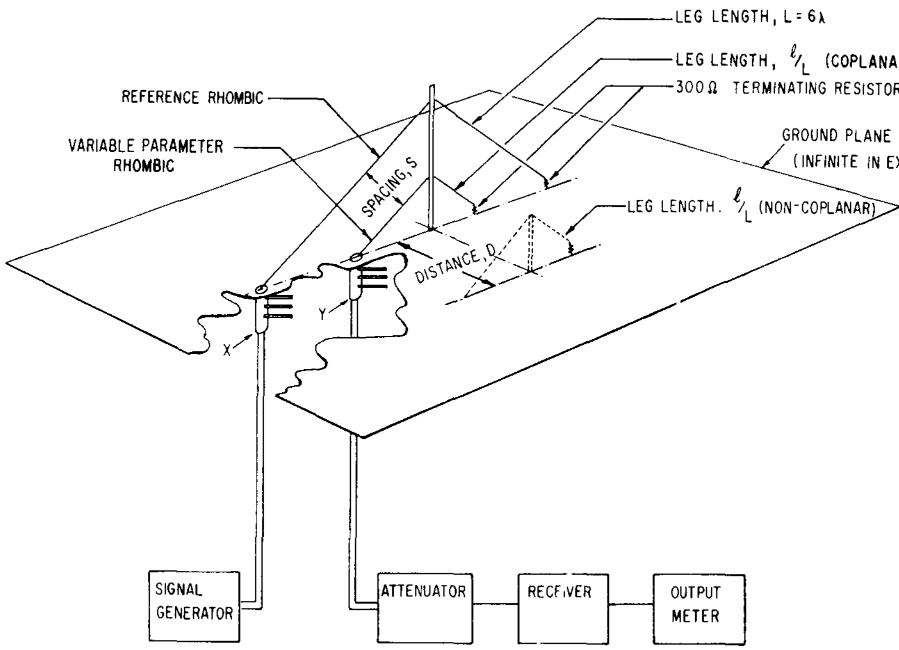

Fig. 2. Arrangement of antennas and equipment used in measuring mutual coupling.

A. Radiation Pattern Measurements

One series of measurements (coplanar) was carried out with the variable antenna in the same plane as the reference antenna. The second series of measurements (noncoplanar) was carried out with the variable antenna displaced from the plane of the reference rhombic.

For the coplanar measurements the variable rhombic was placed both inside and outside the reference antenna. In the former case the leg-length of the variable rhombic was varied from $l/L = 0.5$ to approximately 1 with corresponding spacings varied from $S = 1.1$ to 0.042λ. In the latter case the leg-length of the variable antenna was varied from $l/L = 2$ to approximately 1 with corresponding spacings varied from $S = 2.1$ to 0.042λ. When measuring the effect of a noncoplanar antenna on the radiation pattern of the reference antenna, the leg-length of the variable rhombic was varied from $l/L = 0.5$ to 2 at heights above ground ranging from $h = 2.5$ to 10λ.

To make a valid comparison of the performance of the reference rhombic in the presence of the variable antenna and by itself, two patterns were recorded on the same chart. The first pattern represented the performance of the reference antenna in the presence of the variable rhombic. The second pattern represented the performance of the reference antenna after the variable rhombic antenna was removed.

The two measurements were recorded within minutes of one another to eliminate the possibility of error introduced by equipment instabilities.

B. Measurement of Mutual Coupling

Using half-rhombics, the coefficients of mutual coupling were measured over a perfectly conducting image plane at a frequency of 2000 MHz. The half-rhombic antennas had the same basic configuration as those used in making pattern measurements. The parameters of leg-length,

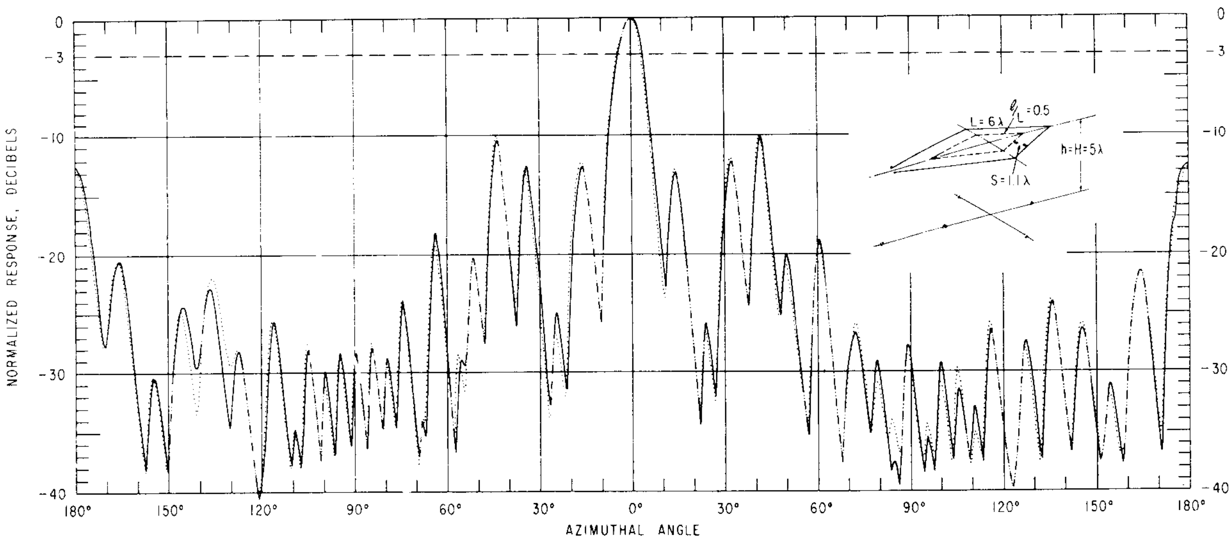

Fig. 3. Patterns of reference rhombic in presence and absence of $l/L = 0.5$ coplanar antenna spaced $S = 1.1\lambda$. Dotted line denotes variable rhombic present; solid line denotes variable rhombic absent.

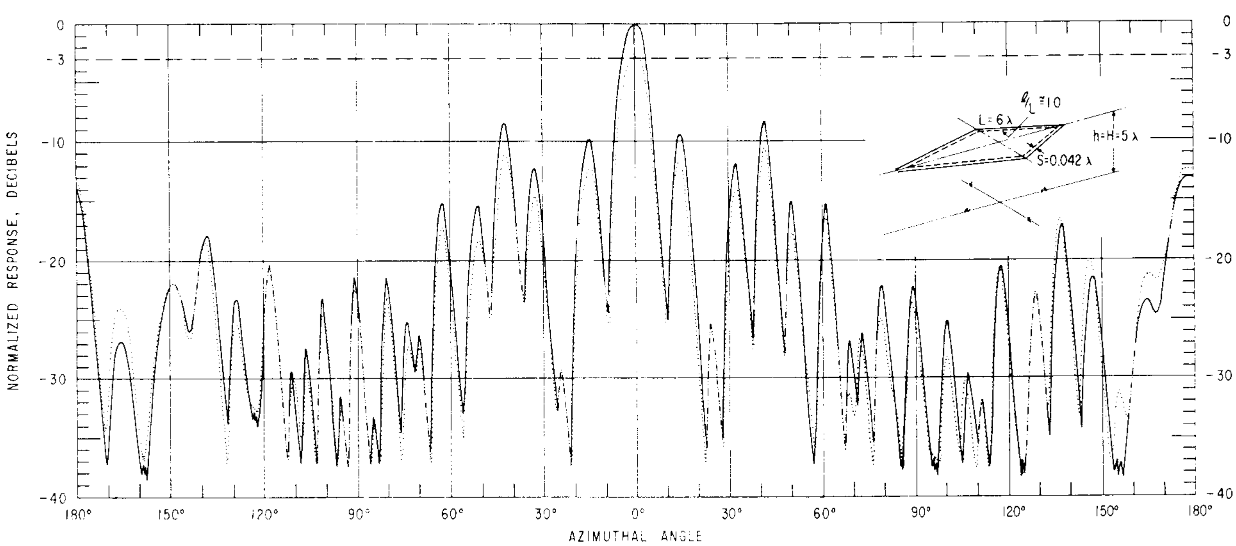

Fig. 4. Patterns of reference rhombic in presence and absence of $l/L \simeq 1.0$ coplanar antenna spaced $S = 0.042\lambda$. Dotted line denotes variable rhombic present; solid line denotes variable rhombic absent.

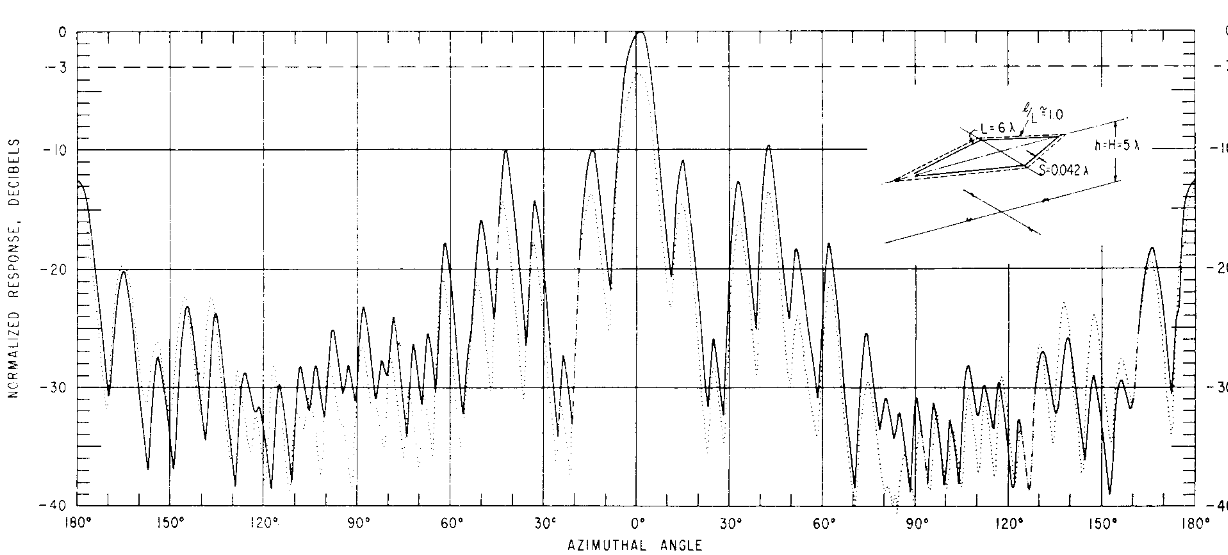

Fig. 5. Patterns of reference rhombic in presence and absence of $l/L \simeq 1.0$ coplanar antenna spaced $S = 0.042\lambda$ to the outside. Dotted line denotes variable rhombic present; solid line denotes variable rhombic absent.

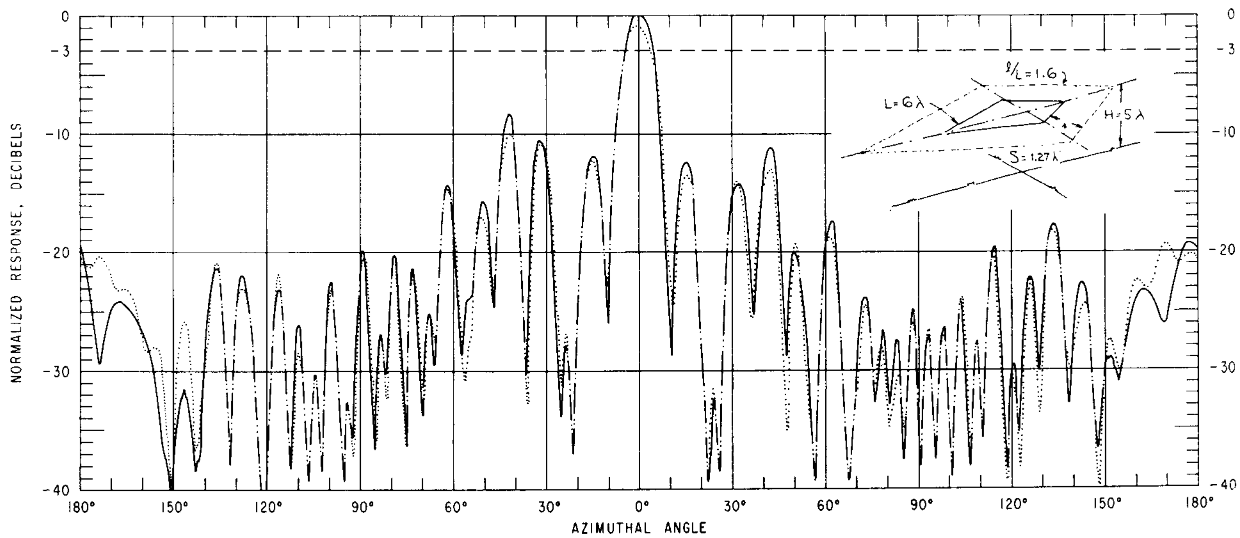

Fig. 6. Patterns of reference rhombic in presence and absence of $l/L = 1.6$ coplanar antenna spaced $S = 1.27\lambda$. Dotted line denotes variable rhombic present; solid line denotes variable rhombic absent.

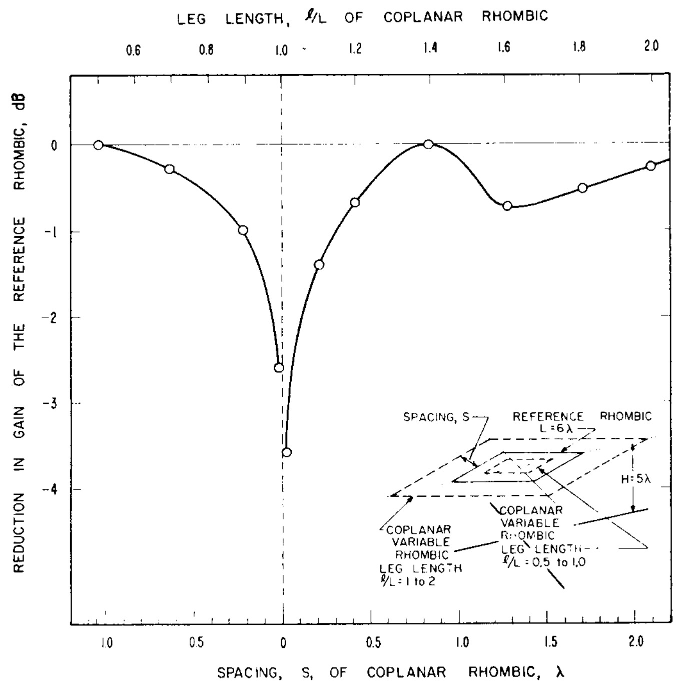

Fig. 7. Effects of different parallel coplanar rhombics on gain of reference antenna.

spacing, and height were varied as in the foregoing tests. Fig. 2 illustrates the arrangement of the antennas over a ground plane for the coplanar and noncoplanar tests and also shows interconnection of the equipment used in carrying out the measurements.

Each antenna was terminated in a 300-ohm resistance and matched to 50 ohms. A signal of known value was connected to the input of one of the antennas, and the corresponding induced voltage in the other was measured on a calibrated output indicator. Calibration included corrections for losses in the cable connecting the two antennas.

Aside from reversing the cables at points x and y (Fig. 2) to check reciprocity, additional mutual measurements were carried out by reversing the feed and termination connections of the nested antenna. This test was designed to determine values of coupling between rhombics radiating energy in opposite directions. The measured results do not include earth effects.

III. Results

The results of the measurements are represented by the radiation patterns and curves given in Figs. 3–13 and discussed in this section.

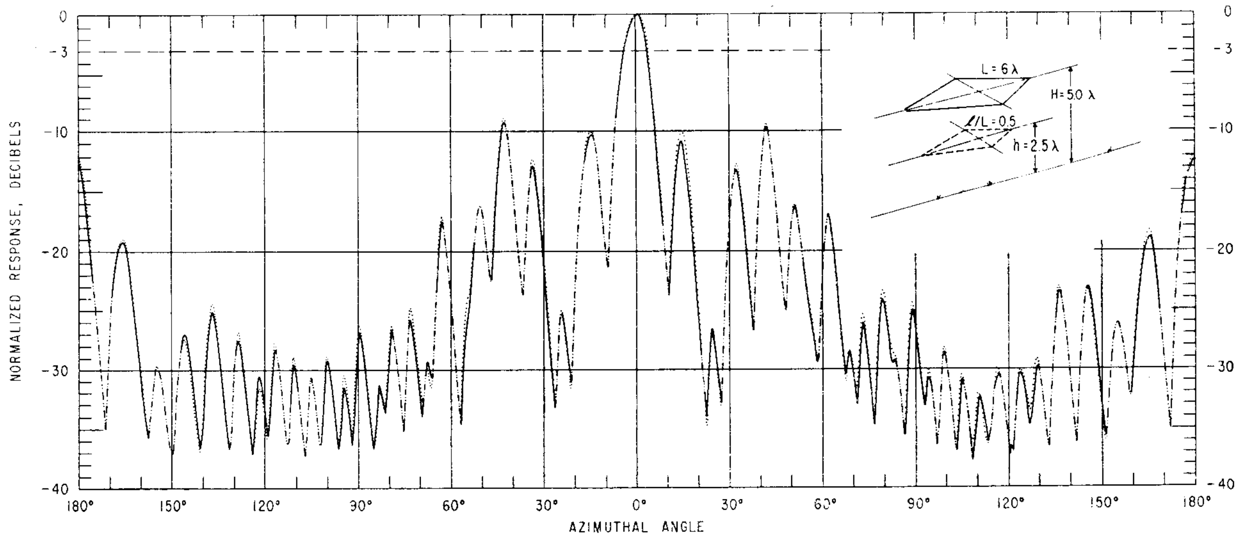

Fig. 8 Patterns of reference rhombic in presence and absence of $l/L = 0.5$ noncoplanar antenna at height $h = 2.5\lambda$. Dotted line denotes variable rhombic present; solid line denotes variable rhombic absent.

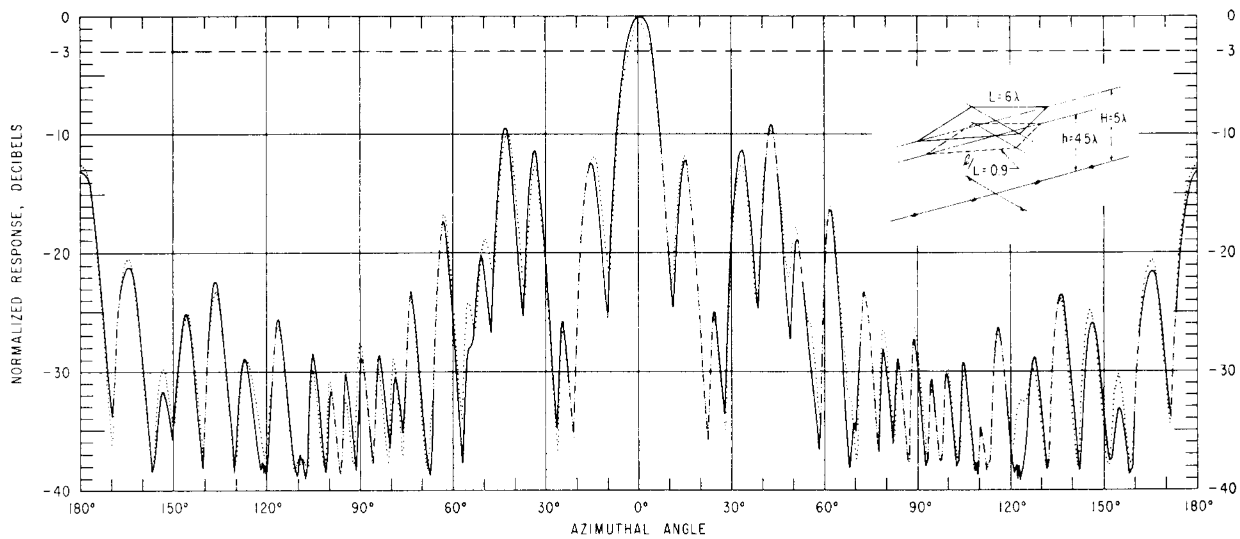

Fig. 9. Patterns of reference rhombic in presence and absence of $l/L = 0.9$ noncoplanar antenna at height $h = 4.5\lambda$. Dotted line denotes variable rhombic present; solid line denotes variable rhombic absent.

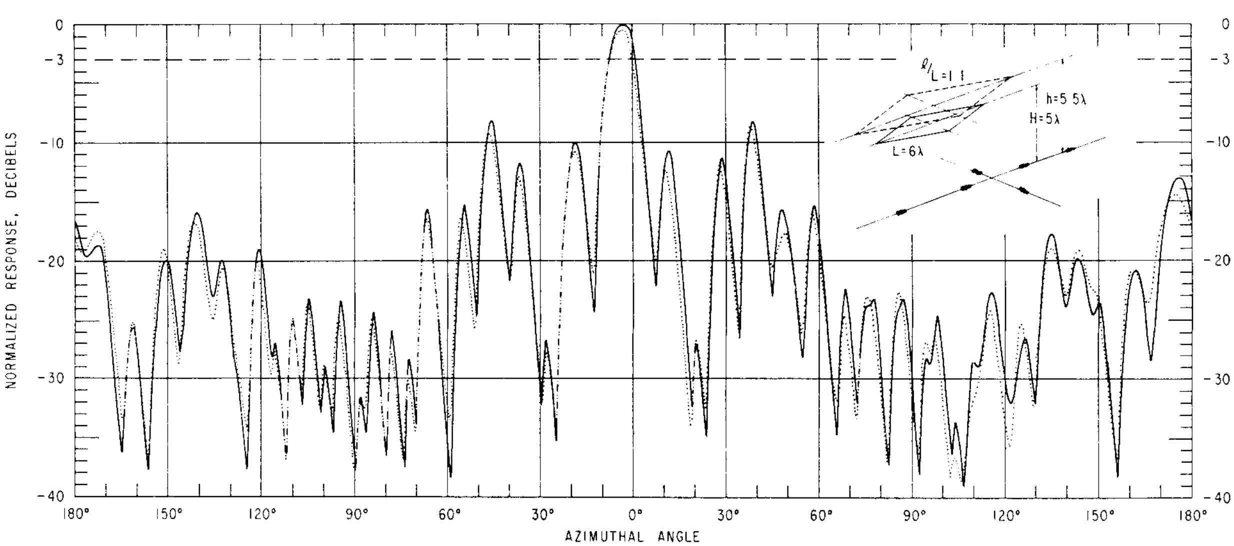

Fig. 10. Patterns of reference rhombic in presence and absence of $l/L = 1.1$ noncoplanar antenna at height $h = 5.5\lambda$. Dotted line denotes variable rhombic present; solid line denotes variable rhombic absent.

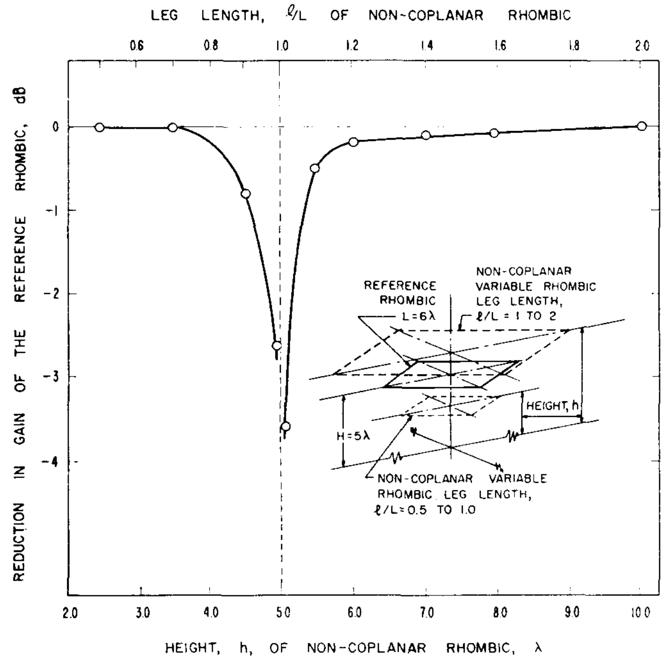

Fig. 11. Effects of different parallel noncoplanar rhombics on gain of reference antenna.

A. Interaction Between Parallel Coplanar Antennas

Radiation patterns of the reference rhombic in the presence and absence of parallel coplanar antennas of different leg-lengths l/L and spacings S are presented in Figs. 3–6. Fig. 7 summarizes results of coplanar pattern measurements and shows how the gain of the reference antenna was affected by the presence of the different antennas of various sizes. The presence of the variable rhombic with $l/L = 0.5$ and $S = 1.1\lambda$ had no influence on the performance of the measured antenna.

By increasing the leg-length of the variable rhombic to $l/L = 0.9$ and with $S = 0.21\lambda$, the gain of the reference rhombic was reduced 1.0 dB; however, the magnitude and occurrence of side lobe structure was substantially unchanged. Figs. 4 and 5 show the maximum interaction to be expected at extremely close spacings. With the variable antenna smaller and inside the reference antenna, the gain of the reference rhombic was reduced by 2.6 dB. With the variable antenna larger and located outside, the gain of the reference antenna was reduced by 3.6 dB. The difference of 1 dB in the gain reductions is believed due to shielding effects of the outer antenna. Evidence of the effect is shown in Fig. 5. The level of the entire radiation pattern of the reference antenna in the presence of the outside variable antenna was reduced over approximately 360 degrees. Unlike the pattern shown in Fig. 4 (the reference antenna inside) the level of the nulls remained at approximately the same amplitude, with the only difference being in the maximum responses of primary and secondary radiation.

The reduction in gain in the forward direction for the various combinations tested is presented in Fig. 7. At spacings of $S = 0.2\lambda$ and 0.4λ the gain of the reference rhombic was reduced 1.2 and 0.7 dB, respectively. Increasing the spacing to $S = 0.85\lambda$ with corresponding leg-length $l/L = 1.4$, the presence of the variable antenna had no effect on the gain of the reference antenna. At increased spacings and leg-lengths, however, the gain was slightly impaired, which is believed due to mutual coupling between the antennas.

B. Interaction Between Parallel Noncoplanar Rhombics

Radiation patterns of the reference rhombic in the presence and absence of parallel noncoplanar antennas of various leg-lengths and heights relative to the reference rhombic are presented in Figs. 8–10. Fig. 11 shows the effect that various configurations of the variable antenna have on the gain of the reference rhombic.

The presence of the noncoplanar variable antenna at a height $h = 2.5\lambda$ (leg-length $l/L = 0.5$) had no effect on the performance of the reference rhombic, as illustrated in Fig. 8.

Significant change in the two patterns was not readily evident until the leg-length and height of the variable antenna were increased to $l/L = 0.9$ and $h = 4.5\lambda$, respectively. While in the presence of this antenna, the gain of the reference rhombic was reduced 0.8 dB. Secondary lobe radiation was reproduced over 360 degrees in azimuth; however, variations in magnitude up to 0.5 dB occurred (Fig. 9).

Increasing the leg-length of the noncoplanar antenna to $l/L = 1.1$ and mounting it at a height $h = 5.5\lambda$ above and to the outside, the performance of the reference antenna was not significantly impaired. The gain was reduced by 0.5 dB, as shown in Fig. 10. A summary showing how the various noncoplanar configurations tested affected the performance of the reference rhombic in terms of gain is represented by the curves in Fig. 11.

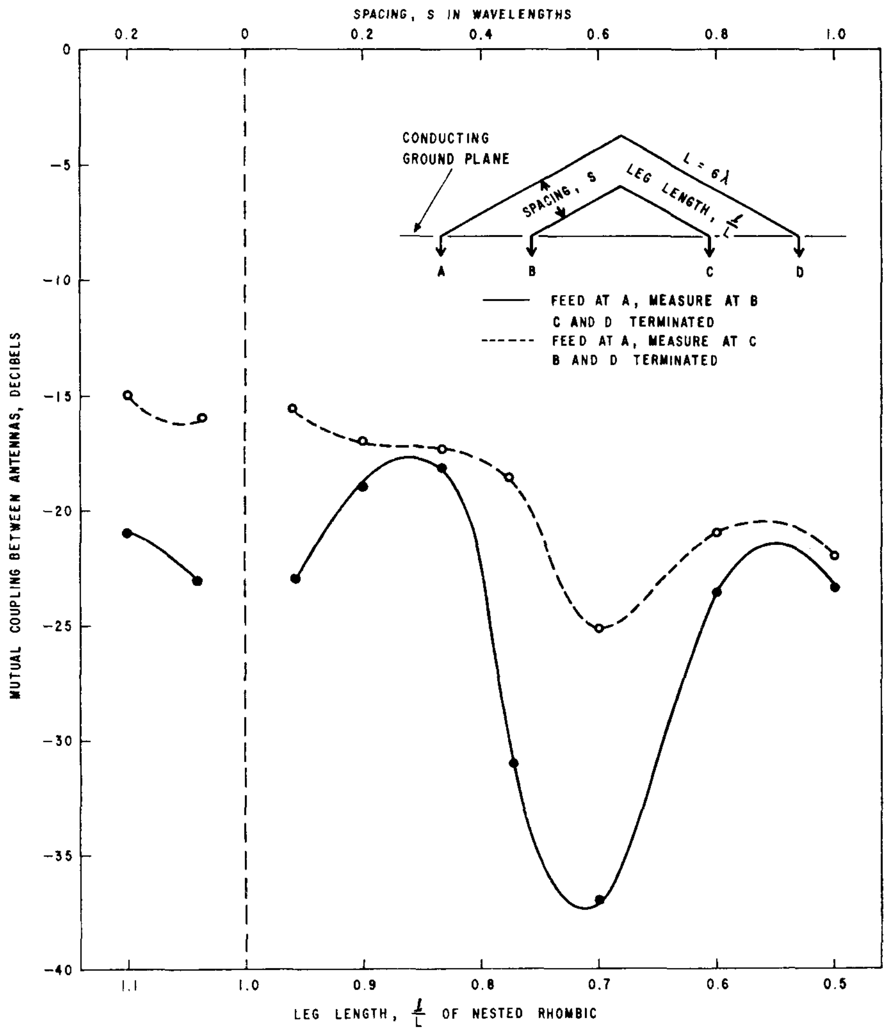

Fig. 12. Mutual coupling between parallel coplanar rhombic antennas.

C. Mutual Coupling Characteristics

Transmission loss, in dB, between different configurations of parallel coplanar rhombics is represented by the curves shown in Fig. 12. The solid curve represents values of coupling between coplanar rhombics directing radiation in the same direction. The dotted curve is the coupling measured between rhombics directing energy in opposite directions.

The magnitude of coupling while directing energy in the same direction varied from -18 dB at $S = 0.25\lambda$ to a minimum of -37 dB at $S = 0.6\lambda$. In contrast, while directing energy in opposite directions, the coupling ranged from -15 to -25 dB at spacings $S = 0.08\lambda$ and 0.6λ, respectively.

Fig. 13 shows that mutual coupling of about the same magnitude was measured between noncoplanar antennas. Since the linear displacement between comparable sized rhombics was greater than in the coplanar case, mutual effects were smaller. With each antenna directing energy in the same direction, the coupling for the different combinations tested measured from -24 to -41.5 dB. For antennas directing radiation in opposite directions, the mutual coupling between noncoplanar antennas increased and varied from -17 to -38 dB for the combinations tested.

IV. Conclusion

Parallel coplanar antennas separated by as little as 0.2λ from one another can be operated as independent systems without serious pattern distortion and with a reduction of less than 1 dB in gain.

The same conclusions are true of noncoplanar antennas with leg-length ratios up to 0.9 and with one located 0.5λ above or below the other.

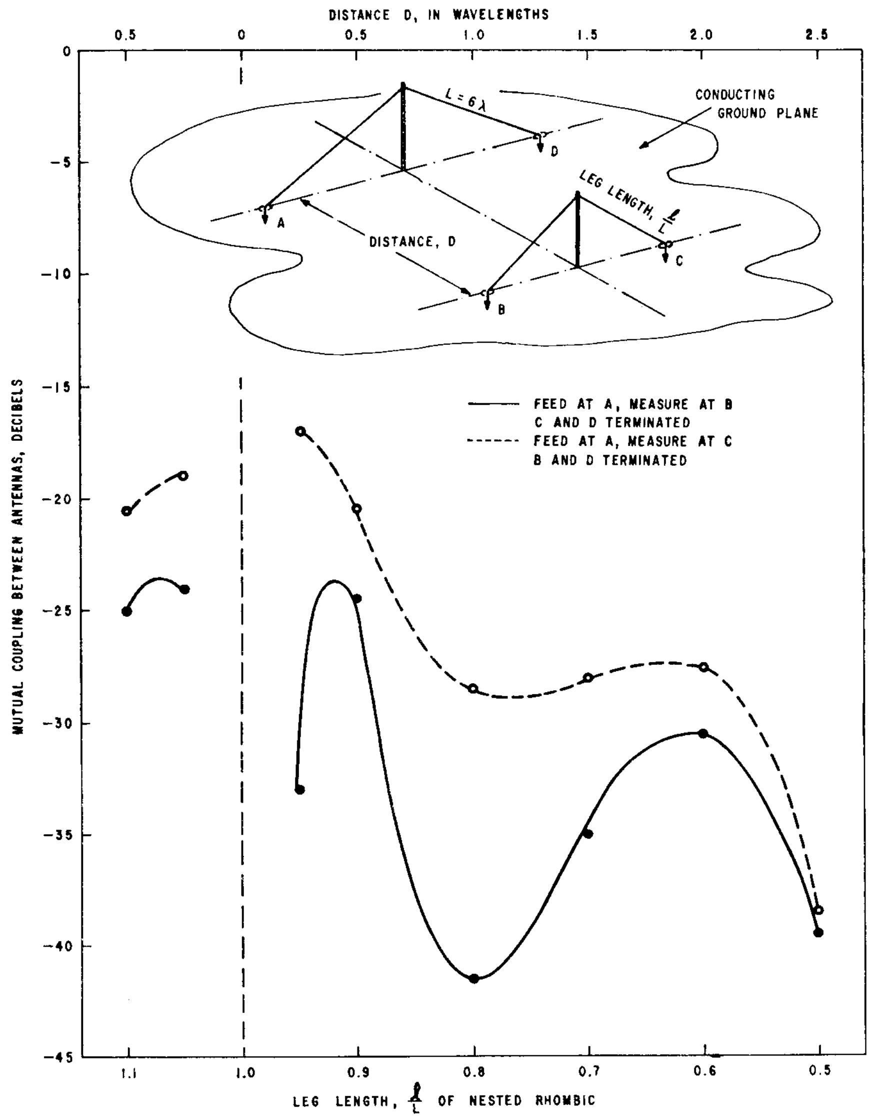

Fig. 13. Mutual coupling between parallel noncoplanar rhombic antennas.

In the coplanar case mutual coupling measured from -15 to -37 dB for the various configurations tested. In the noncoplanar case coupling varied from -17 to -41.5 dB.

For practical purposes and in agreement with the theoretical study carried out by Martin-Caloto [1], the inherent bandwidth of each antenna will permit spacings between wires which results in negligible interactions and differences in the radiation patterns between antennas.

Acknowledgment

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References

[1] A. Martin-Caloto, "A study of possibilities for improving space utilization and performance of rhombic antennas," Stanford Research Institute, Menlo Park, Calif., Tech. Rept. 67, July 1959.

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