Electromagnetic Coupling Reduction Techniques

Seventh Quarterly Report
15 May - 14 August 1967

By

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FOREWORD

This report was prepared by The University of Michigan, Ann Arbor, Michigan, under the direction of Professor Ralph E. Hiatt and Professor John A. M. Lyon and on Air Force Contract AF 33(615)-3371 under Task No. 435709 of Project 4357 (U) "Electromagnetic Coupling Reduction Techniques". The work was administered under the direction of the Air Force Avionics Laboratory, Electronic Warfare Division, Research and Technology Division, Wright-Patterson Air Force Base Ohio. The Task Engineer was Mr. Olin E. Horton, the Project Engineer Mr. Herbert Bartman.

This report covers the period 15 May through 14 August 1967.

ABSTRACT

Further work and improvements on various decoupling methods developed earlier for this project is the subject of this report. The method employing the RF bridge has been improved and a new circuit has been designed which minimizes loss. Depending upon the system this loss may be restricted to only 0.1 db.

The possibility of combining different decoupling methods to achieve higher isolation was investigated and the necessary conditions stated. A number of experiments are reported to indicate how the methods can be combined and what levels of isolation can be expected.

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I

INTRODUCTION

The coupling reduction methods in this report are applicable to the problem of a receiving system with its antenna and a transmitting system and its antenna. Quite obviously, the methods can be extended to interference problems involving more systems and, correspondingly, more antennas.

Information is provided showing that the RF bridge link method can provide cancellation of unwanted electric fields in a receiving antenna due to a transmitting antenna located nearby. The bridge circuit has been modified to minimize the power loss in the compensating link. This very useful modification has been made while still retaining the high level of isolation provided by the RF bridge over the entire X-band. It is believed that this modification makes the RF bridge link a most desirable method of coupling reduction. The work of this project appears to be different from any similar uses of bridges for reduction of interference. The difference lies in the extension of the bridge method to a broad frequency range. The present circuit could give a much higher level of isolation for narrower bands of frequency with a fairly simple modification. Emphasis has been given to broadband compensation in the belief that this represents one of the greatest needs in combating power interference coupling.

Also, in this report is presented a detailed explanation of results of cascading coupling reduction methods. A simple analysis is given on the change of the coupling factor when two methods of decoupling are used. It is shown experimentally that there will be some situations where the isolation obtained by one decoupling method will simply add to the isolation obtained by another decoupling method. In other situations it is shown both experimentally and analytically that the simple addition of the individual isolations will not correspond to the actual isolation achieved by two decoupling methods. An explanation of the electromagnetic field problem is given. It is shown that the scattered field from one method will modify the influence of a second decoupling method. Both phase and amplitude aspects are important in the overall consideration of the coupling reduction problem.

II

PROGRESS IN DECOUPLING METHODS

2.1 RF Bridge

2.1.1 New Design of RF Bridge

As mentioned before in the Sixth Quarterly Report under this Contract (7692-6-Q), the major problem remaining with the RF bridge method of decoupling was the unnecessary loss of 3 db of power both at the transmitting and receiving feed junctions. This loss was due to the use of the hybrid tees as feed elements. At the transmitting junction, one-half of the transmitted power was being fed to the bridge link. This link actually requires far less power than this, on the order of -30 db instead of -3 db. This is because the power levels in the bridge link and in the coupled path must be equal for optimum decoupling performance, and the E-plane slot coupling level is approximately -30 db for the spacing considered. All of the additional transmitter power in the bridge link was being wastefully dissipated in the bridge link attenuator. At the receiving junction, one-half of the power from the receiving slot antenna was being dissipated in the hybrid tee's resistance card and never reaching the receiver.

A new type of bridge circuit was designed using multihole directional couplers in the place of hybrid tees (Fig. 2-1). The lower waveguide circuit is the transmitting slot feed. From right to left is the directional coupler used to feed the bridge link, a 16" piece of waveguide, a 50 db precision attenuator, an isolator and the transmitting slot antenna mounted in the ground plane. Behind the ground plane is the anechoic chamber. The upper circuit is the bridge link. From right to left is a waveguide-to-coaxial adapter, a 24" piece of RG-55 coaxial cable, another waveguide-to-coaxial adapter, the squeeze guide section, a 50 db precision attenuator, and the directional coupler used as the receiving feed junction. Also visible is the receiving slot antenna, mounted in the ground plane and feeding into the directional coupler. The RG-55 cable is used to match the slope of the attenuation vs frequency curve in the bridge link with that of the coupled path, while the squeeze guide matches the

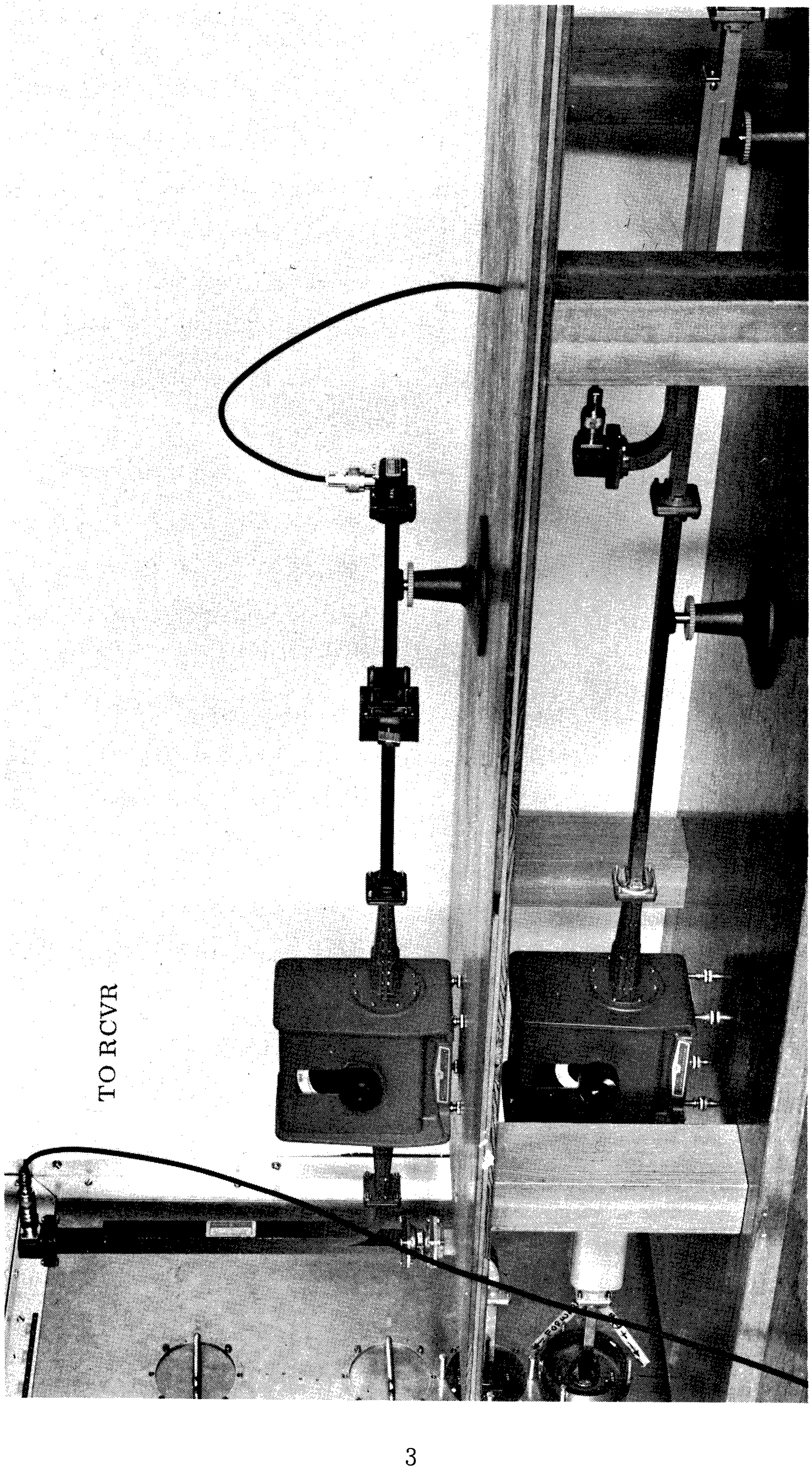

FIG. 2-1: RF BRIDGE CIRCUIT

phase dispersions of these two paths as functions of frequency. The bridge and coupled path have been chosen to be very nearly of the same electrical length at all frequencies. The 180° phase shift necessary for decoupling is produced by proper orientation of the waveguide to coaxial adapters.

For convenience, a 10 db and a 20 db directional coupler were used. While the hybrid tees had a loss of +3 db, a 10 db coupler has a loss of only +0.46 db, while a 20 db coupler has a loss of +0.04 db. This is a significant improvement. This bridge circuit is now considered practical for use.

A sample decoupling curve is shown in Fig. 2-2. The upper curves show how closely the coupled power is matched by the bridge power . The lower curve is the decoupled power level. It is below the -47.5 db level from transmitter power for all of X-band. The decoupling achieved is approximately 17 db.

2.1.2 System Demonstration

A demonstration was prepared to show the effectiveness of the RF bridge in reducing interference. The equipment layout is shown in Fig. 2-3. The idea was to first receive a desired signal, then "jam" the receiver with a nearby transmitter, and then finally use the RF bridge to reduce the interference so the desired signal could once again be received. The desired signal source was an X-band sweep generator, labeled No. 1, feeding a horn antenna. This was located inside the anechoic chamber, 22 feet away from the ground plane. The receiver used a slot antenna mounted in the ground plane, while the interfering source was another X-band sweep generator, labeled No. 2, feeding a second slot antenna mounted in the same ground plane. The coupling was the strong or E-plane case and the interfering slot was spaced 11.4 cm away from the receiving slot. The RF bridge was connected as usual between the interfering transmitter and the receiver.

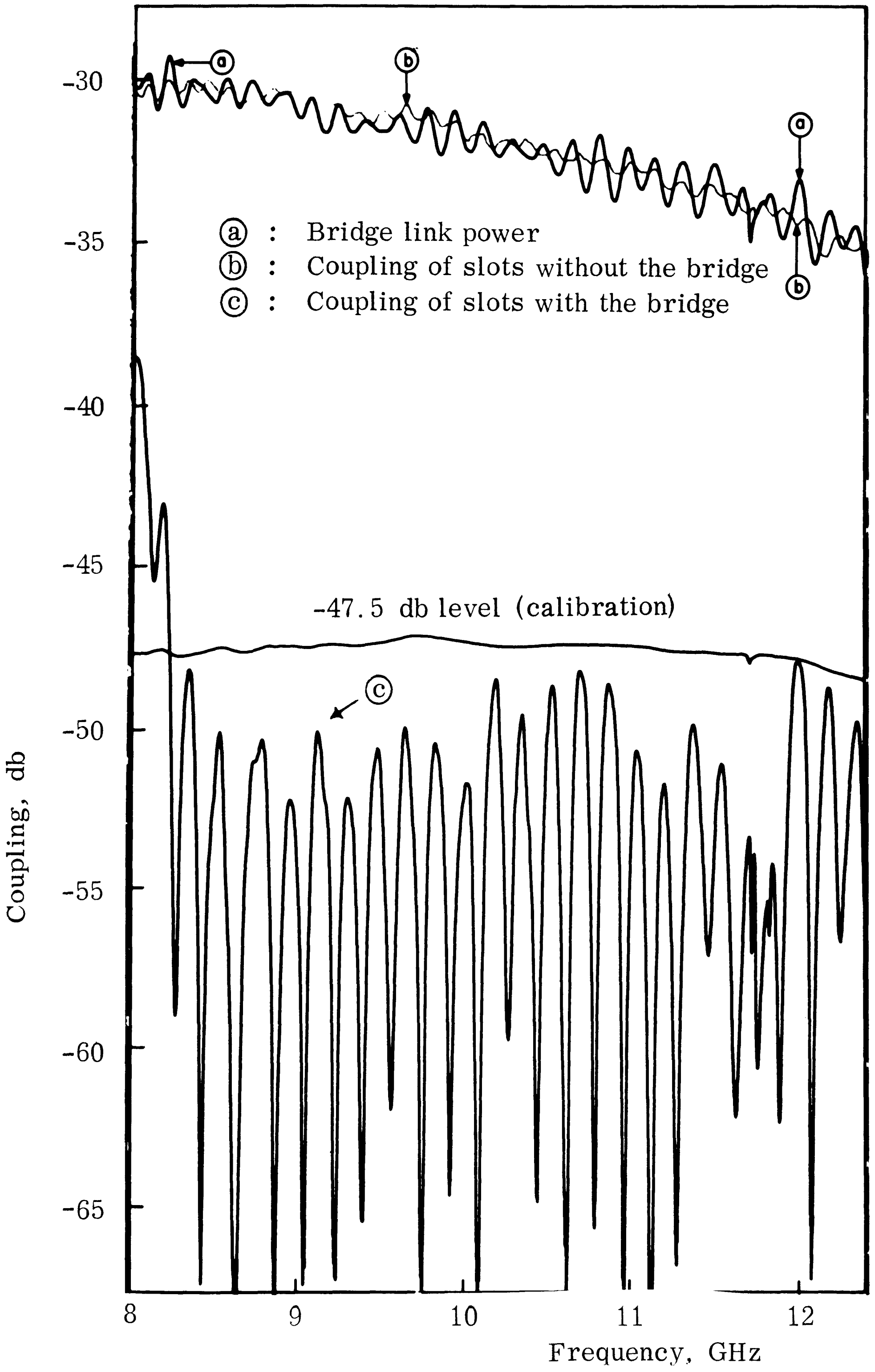

FIG. 2-2: REDUCTION OF THE E-PLANE COUPLING OF TWO SLOTS SPACED 11.4 cm BY THE RF BRIDGE

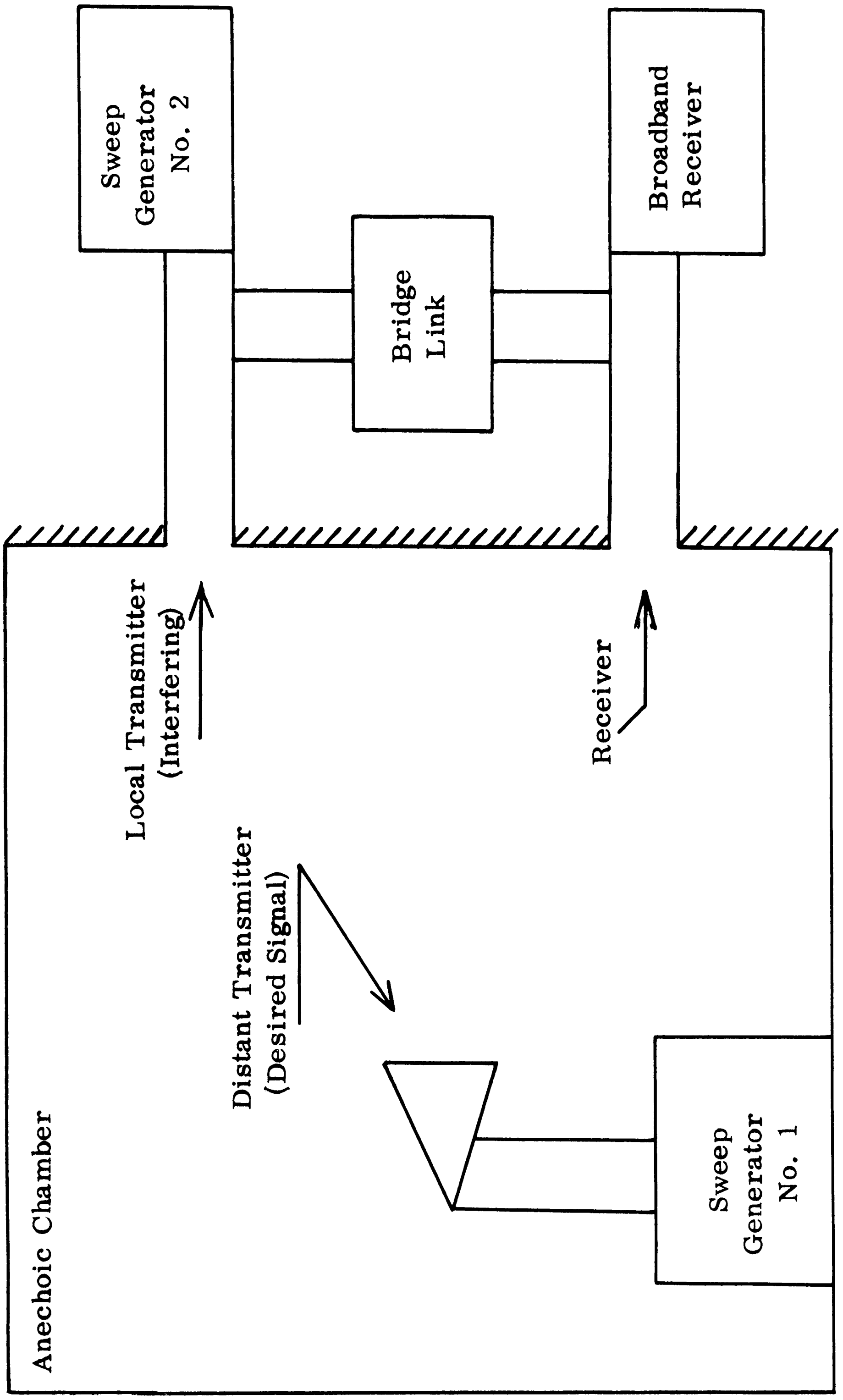

FIG. 2-3: EQUIPMENT LAYOUT FOR BRIDGE DEMONSTRATION (NOT TO SCALE)

The results of this demonstration are shown in Fig. 2-4. The frequency scale is for the desired signal. The interfering sweeper, No. 2, was running four times as fast, and sweeping from 12.4 to 8.0 GHz in each sweep, rather than from 8.0 to 12.4 GHz. Curve (b) shows the remote or desired signal with the local interfering transmitter off. Curve (a) shows the desired signal jammed by the local transmitter. Finally, curve (c) shows how the interference is reduced by the RF bridge. Note how closely curve (c) matches curve (b).

2.2 Combination of Decoupling Methods

2.2.1 Preliminary Considerations

In previous reports under this contract a number of decoupling methods have been described. Most of these methods (absorbing materials, corrugations, RF bridge) do not require any protrusions above the ground plane and they offer an additional amount of isolation to a system of the order of 16 to 20 db over the entire range of a waveguide band of frequencies (i.e. a 1.5 to 1 bandwidth). One of the methods (fences) capable of creating much greater additional isolation, of the order of 30 db over a waveguide band, requires the use of pins erected above the ground plane to a maximum height of half a wavelength. All methods can offer a considerably greater amount of isolation over a narrower frequency range.

In some systems the need arises to create additional isolation of up to 40 db. Therefore it was decided to investigate the feasibility of combining various decoupling methods to obtain greater isolation. In such an attempt one has to deal with two obstacles. First, due to physical limitations, a method that requires a certain modification of the ground plane near the antenna aperture (e.g. creating corrugations) cannot be combined with another method involving a different modification of the ground plane (e.g. substitution of absorbing material for part of the metal surface). To that extent it appears that combinations involving the RF bridge on one hand, which consists of a link between

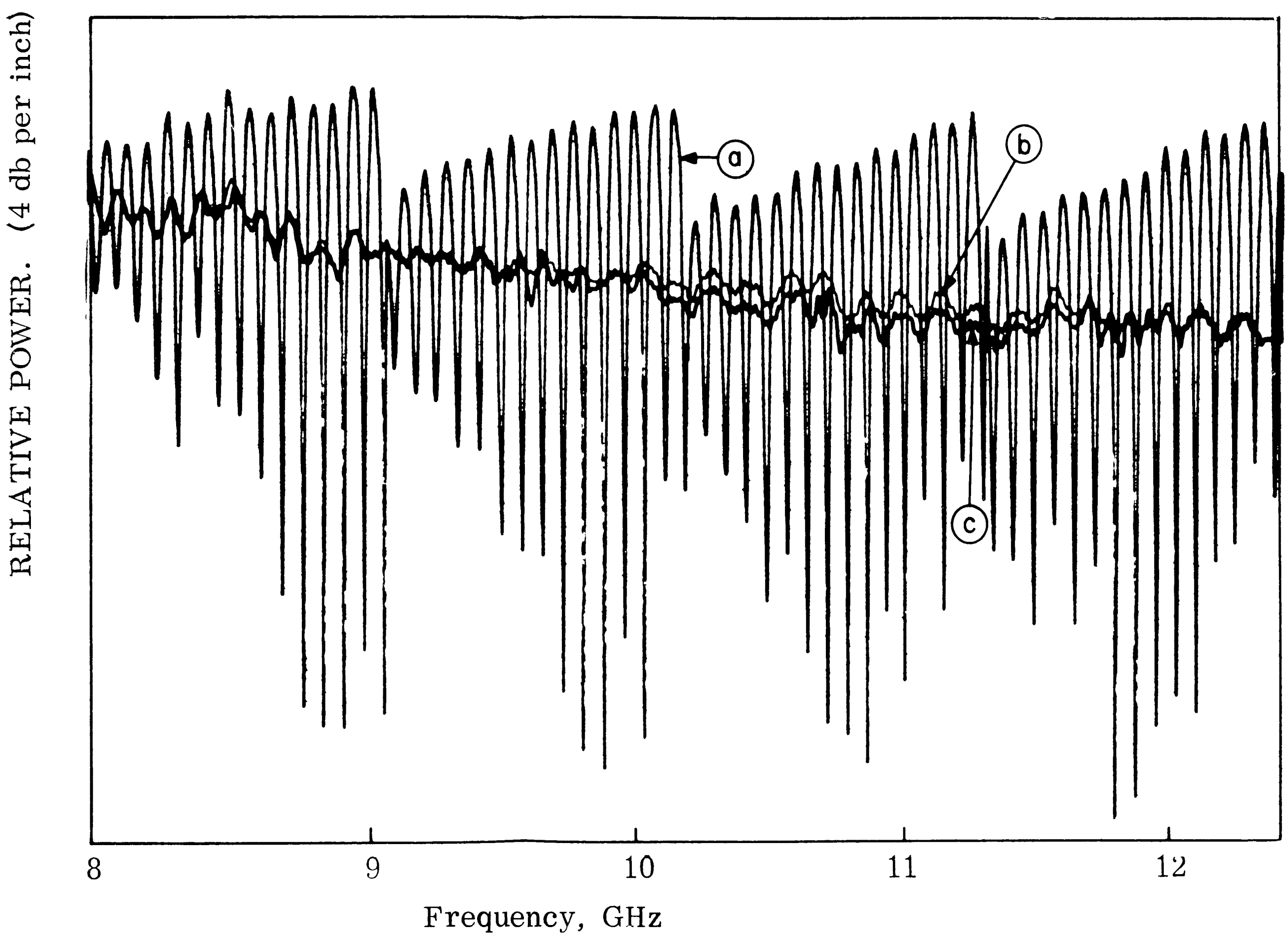

FIG. 2-4: DEMONSTRATION OF BRIDGE EFFECTIVENESS IN REDUCING INTERFERENCE

ⓐ Remote transmitter signal with interference from a transmitter near the receiver.

ⓑ Remote transmitter signal with local transmitter off.

ⓒ Remote transmitter signal with local transmitter on. Interference reduced by the RF bridge.

transmitter and receiver entirely behind the ground plane, and any one of the methods of modifying the ground plane surface on the other, would be both physically realizable and fruitful. Secondly, each decoupling method has an effect on the phase of the coupled signal. So, when two different methods are combined the respective phase variations have to be taken into account and proper modifications have to be made when one or both methods depend partly or wholly upon a phase cancellation scheme. Such is the case for the fences and the RF bridge.

Consider the field coupling factor given by

$$c = \sqrt{\frac{W_R}{W_T}}\, e^{j\alpha} \tag{2.1}$$

where W_T is the transmitted power, W_R is the received power and α is the phase difference between the principal mode components in each aperture. Let the original coupling c be reduced to c' by a decoupling method I and to c'' by a decoupling method II. Then one may write

$$c' = \sqrt{\frac{W'_R}{W_T}}\, e^{j\alpha'} = c\sqrt{\frac{W'_R}{W_R}}\, e^{j(\alpha' - \alpha)} \equiv k'c \tag{2.2}$$

where the complex factor k' expresses the change in the field at the receiving aperture both in amplitude and phase. A similar relation exists for c''.

Now if the two decoupling methods are applied simultaneously and the assumption is made that they are independent of each other, one may write

$$c''' = k'k''c \tag{2.3}$$

and for the power coupling

$$C''' = |k'|^2\, |k''|^2\, C \qquad \text{with} \qquad C = |c|^2.$$

Expressing all terms in db one has

$$(C''')_{db} = 20 \log |k'| + 20 \log |k''| + (C)_{db}$$

and for the (power) decoupling:

$$(\Delta C''')_{db} \equiv (C)_{db} - (C''')_{db} = (\Delta C')_{db} + (\Delta C'')_{db} \tag{2.4}$$

where

$$(\Delta C')_{db} = -20 \log |k'| \tag{2.5}$$

and similarly for $\Delta C''$. Note that normally $|k| < 1$ and therefore the decoupling, as introduced in (2.5), would normally be a positive quantity.

2.2.2 Experimental Studies

The antennas used for the experimental investigation were two waveguide fed slots mounted in a large (12 feet by 12 feet) aluminum ground plane. The slots were oriented for strong or E-plane coupling. The experiments were conducted in X-band (8.2 to 12.4 GHz) using a swept-frequency technique. An oscilloscope display was used to make certain critical circuit adjustments but all the figures in this report were obtained through a pen recorder.

The first combination involved two sets of corrugations each surrounding one of the slots and flush with the ground plane. Strictly speaking, this case is not a combination of two different methods. However, the two sets of corrugations had a completely different profile; consequently each set had different attenuation and phase characteristics. These sets of corrugations have been completely described in the previous quarterly report under this contract (7692-6-Q, p. 17) so here they will be simply referred to as R1 and R6. It suffices to note that each set extends on the ground plane from the slot aperture for a radial distance of approximately one wavelength. The decoupling obtained when each set was used alone and when they were used simultaneously is shown in Fig. 2-5. From this figure it can be verified that the total decoupling is equal to the sum of the decouplings obtained by each method individually (when all quantities are expressed in db) exactly as predicted by (2.4). This leads to the conclusion that the assumption under which (2.4) was obtained, i.e. that the two decoupling methods do not affect each other noticeably is valid for center-to-center spacings of the two apertures of at least as small as 6λ.

The second type of combination investigated was that of a fence and one set of corrugations. The parameters of the fence used were as follows: $h = 1.7$ cm, $s = 1.2$ cm, $2a = 1/16'' = 0.16$ cm (see 7692-6-Q, p. 20). In one series of experiments one slot was surrounded by corrugations (set R1) and the fence was placed on the ground plane near the trenches while the second slot was left unmodified. The position of the fence was changed and for each position a swept-frequency pattern was recorded. The best result obtained this way was an 18 db additional isolation over a forty per cent bandwidth. This result is not considered satisfactory since the use of the same fence has produced the same decoupling over a wider frequency range without the corrugations. Radiation patterns taken for this case indicate that while corrugations alone create a sidelobe reduction (E-plane) along the ground plane of 9 db, and the fence alone a reduction of 16 db, when the two methods are combined in the fashion described above the sidelobe reduction is only 15 db. The explanation for this is that the corrugations preventing the propagation of a surface wave, reduce the energy radiated along the ground plane to such an extent that a fence in the vicinity of the corrugations cannot reduce the coupling nearly as much as when acting alone.

In another series of experiments one slot was surrounded by corrugations while the fence was placed in the vicinity of the second slot. By taking a number of charts for different positions of the fence it was found that a distance of $d = 3.0$ cm

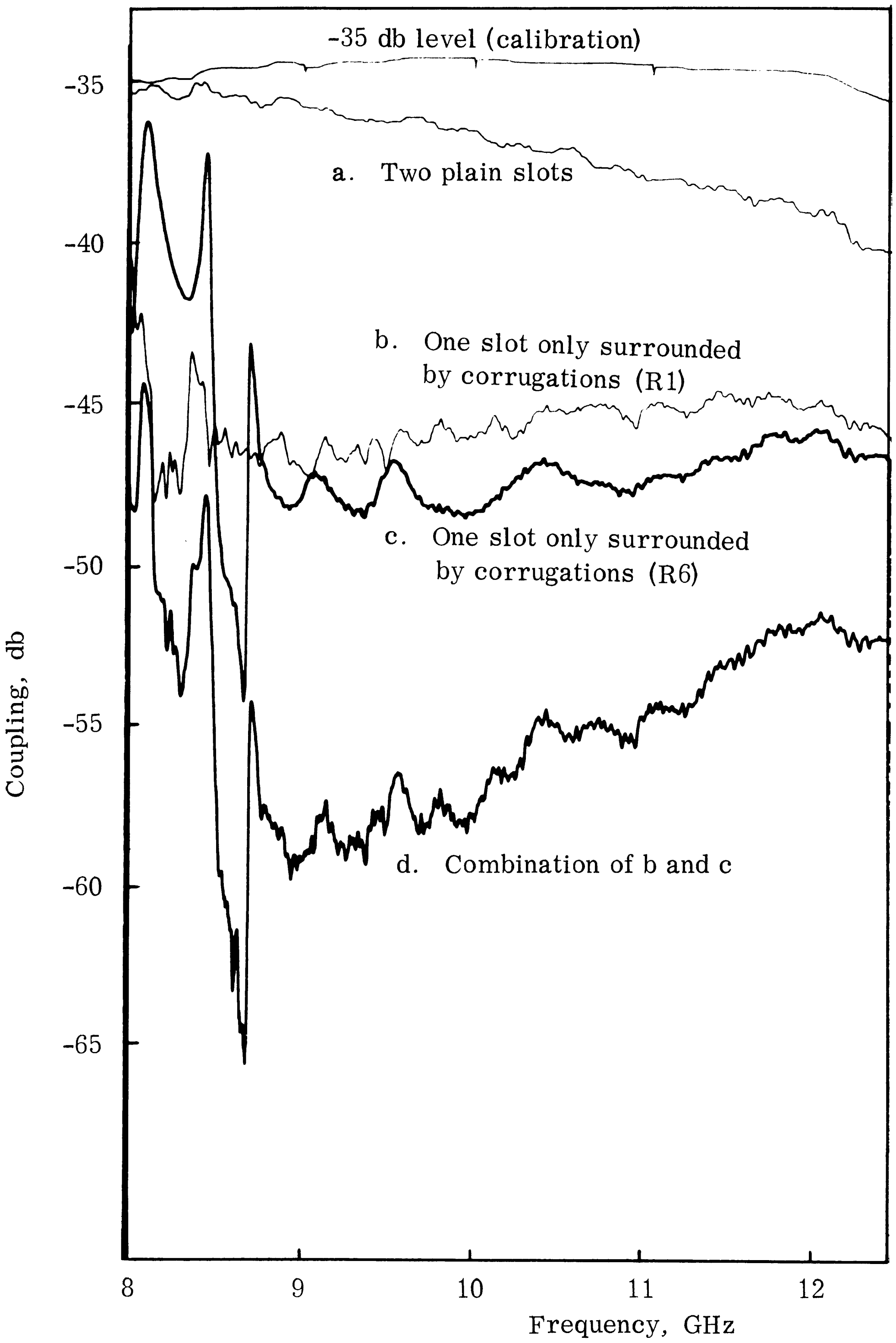

FIG. 2-5: REDUCTION OF THE E-PLANE COUPLING OF TWO SLOTS SPACED 22.8 CM BY MEANS OF CORRUGATIONS

between the fence and the center of the closest slot gave the best results. Fig. 2-6 shows that a decoupling of at least 27 db was obtained over the entire X-band. In this case the individual isolations offered by each method add according to (2.4).

In yet another combination of decoupling methods an RF bridge was formed for two slot antennas one of which was surrounded by circumferential corrugations. It was stated earlier that the bridge effectiveness depends upon how close the signal in the bridge link remains to the coupled signal in both amplitude and phase as the frequency is swept. In Figs. 2-7 and 2-8, obtained for two different settings of the bridge link for both attenuation and phase, the bridge and the coupled signal without the bridge are shown for comparison. To approximate the variation of the coupled signal with frequency a piece of RG -9 coaxial cable and a squeeze guide were used. Still the matching is only fair resulting in a reduction of maximum coupling to a level below -68 db for a 17 percent bandwidth (Fig. 2-7) or to a level below -57 db for the X-band (Fig. 2-8). Both levels are with respect to the transmitter power. It is expected that different waveguide components can be used for a closer match of curves (a) and (b) of Figs. 2-7 and 2-8 thereby producing even lower levels of coupling.

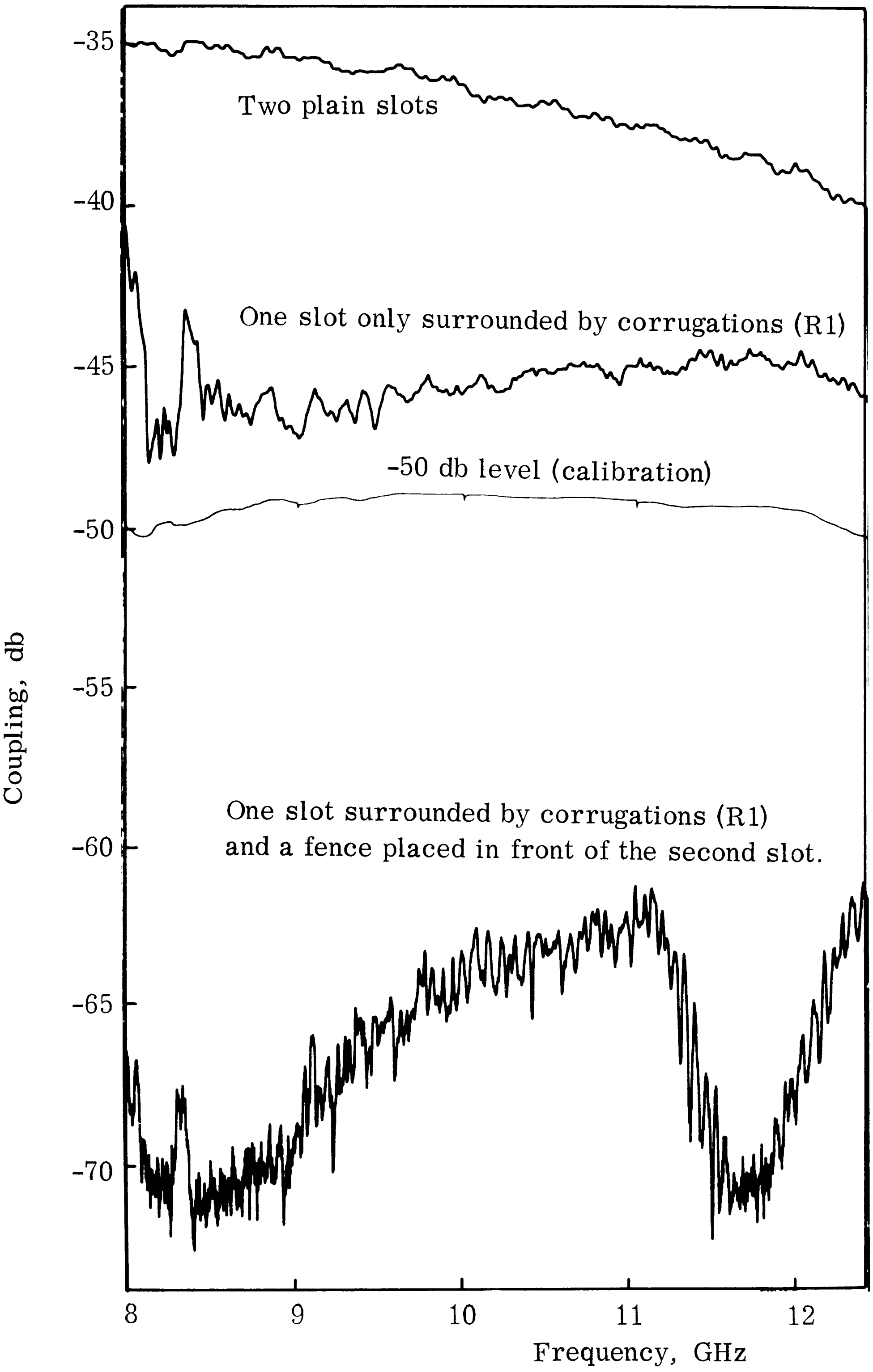

FIG. 2-6: REDUCTION OF THE E-PLANE COUPLING OF TWO SLOTS SPACED 22.8 CM BY MEANS OF ONE SET OF CORRUGATIONS AND ONE FENCE.

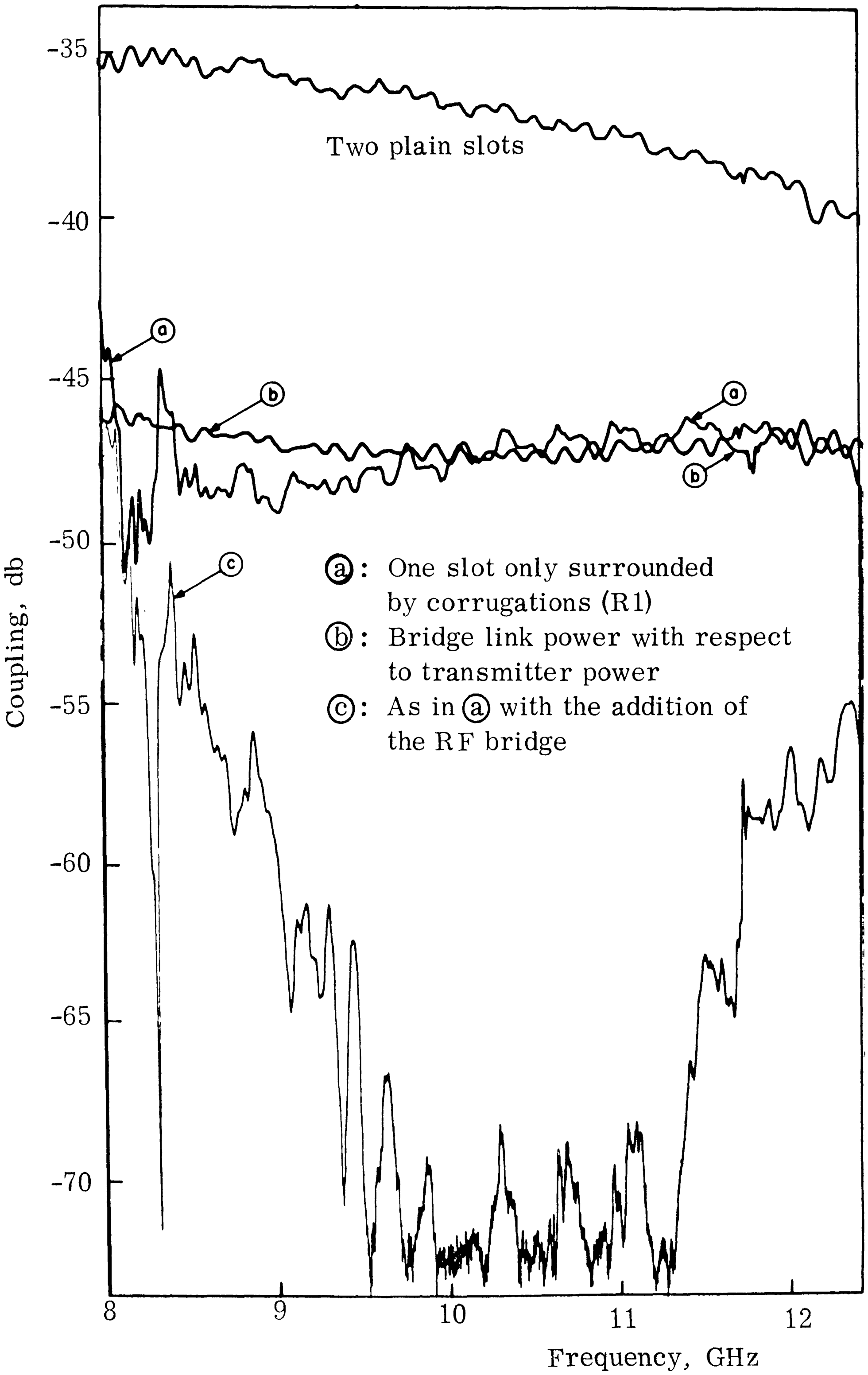

FIG. 2-7: REDUCTION OF THE E-PLANE COUPLING OF TWO SLOTS SPACED 22.8 CM BY COMBINATION OF THE RF BRIDGE AND CORRUGATIONS

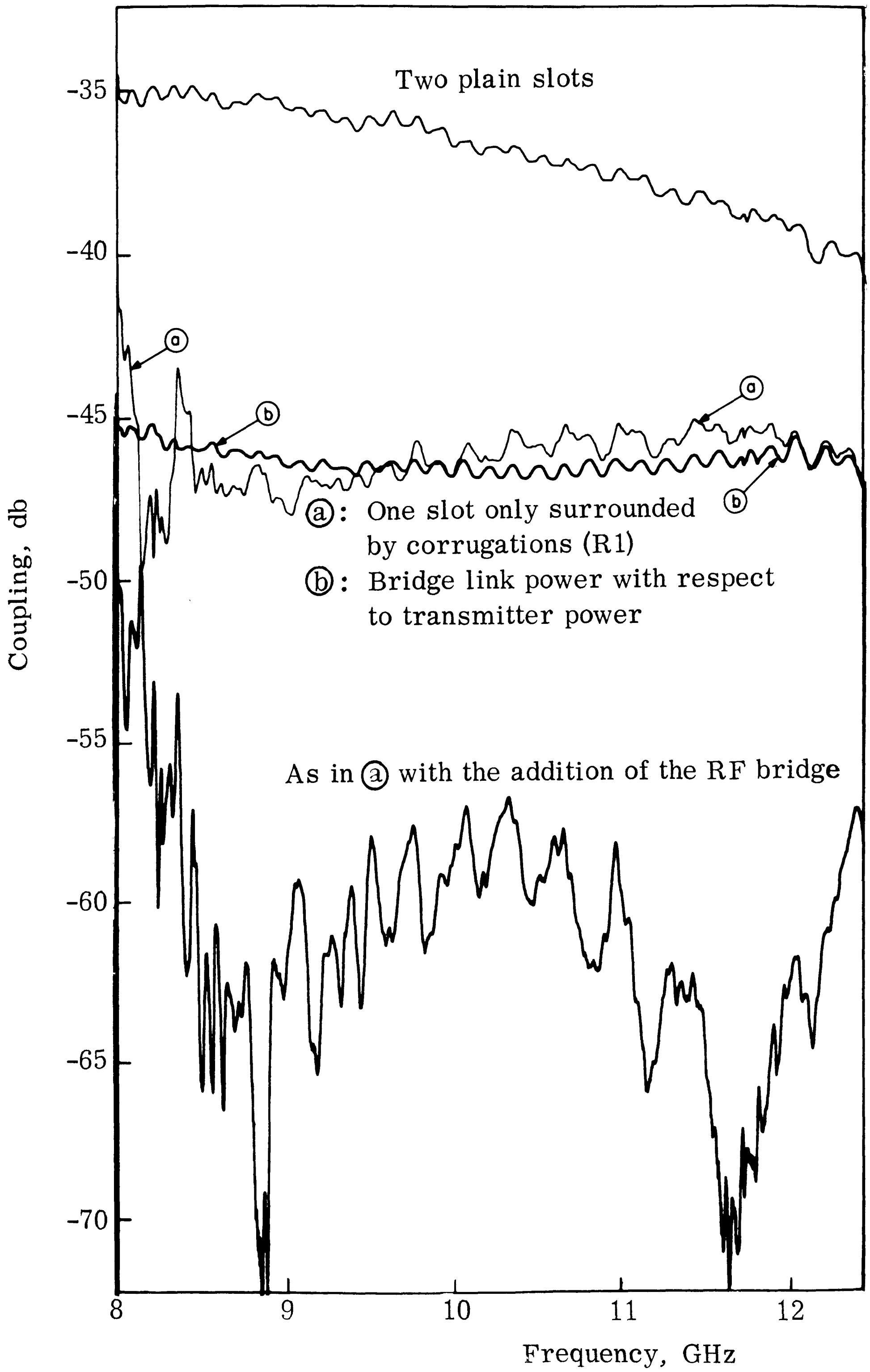

FIG. 2-8: REDUCTION OF THE E-PLANE COUPLING OF TWO SLOTS SPACED 22.8 CM BY COMBINATION OF THE RF BRIDGE AND CORRUGATIONS

III

CONCLUSIONS

The RF bridge or compensating method has been shown to be a practical means of mitigating power interference coupling. This compensating link method can be applied between any two systems. It can also be effectively applied between one system and each of a number of offending systems. With the improvement of the RF bridge system involving the demonstration of a system which utilizes only negligible power and does not detract from either the transmitted or received power in any considerable amount, it is believed that this bridge method has been amply proved as a valuable coupling reduction method suitable for adaptation at all frequency ranges. With this recorded success it will be noted that further work on the bridge compensation method is not included as future effort, except possibly for modifications of the present circuit which may be necessitated by combination with other decoupling methods. Any resumption of work on this method would depend upon additional needs as supplied by the contract monitor.

The cascading of two or more methods of coupling reduction has been studied. It can be concluded that two methods can be used with an overall reduction of coupling corresponding to the sum of the coupling reductions by each of the two methods provided that certain conditions are met, as described in this report. These contentions are supported by experimental results. The results show that two methods cannot be applied blindly to power interference problems with expectations of achieving the sum of the benefits for both methods.

IV

FUTURE EFFORT

4.1 Corrugations for S-band

A new ground plane with circumferential corrugations has been designed. The dimensions of these corrugations have been chosen so as to create a stop band for surface waves (i.e. a capacitive surface impedance) at frequencies in the S-band. The beginning of the stop band was placed at 2.75 GHz and calculated using a theory developed for periodic structures in general and based on Floquet's theorem. The corrugations extend for approximately one wavelength in the radial direction and have twelve trenches per wavelength.

It is contemplated that a number of S-band antennas will be used with the new ground plane including spirals, slots and monopoles. Information regarding the radiation characteristics of these antennas in the presence of the corrugations will be obtained. Also the coupling to other similar or dissimilar antennas on the same ground plane will be investigated and it is expected it will be reduced.

The corrugations are inherently effective in reducing the coupling at the third harmonic frequencies of the band for which they were originally designed. To investigate this the S-band corrugations will also be used with X-band antennas. Also an S-band slot may be excited by higher frequencies such as X-band and its behaviour studied both with and without surrounding corrugations.

4.2 Coupling under a Dielectric Layer

Work has begun on determining the coupling between two slot antennas covered by a dielectric layer. This is a very important case as many space vehicles are coated with an ablative material, designed to burn off during the re-entry phase of flight. This material protects the metal skin of the space vehicle. Results which were valid for flush-mounted antennas in a ground plane will, in general, be different for the ablative coated vehicles.

It is anticipated that results will be derived for different thicknesses of coating, and also for varying types of dielectric material. As usual, the spacing and orientation of the slot antennas will be important parameters in the coupling. The analytical work will begin as soon as the literature search, now well underway, is finished.

Backing up the analytical effort will be an experimental program. Coupling will be measured, and radiation patterns taken for various cases. The anechoic chamber will be used for this set of experiments. For preliminary tests, available fiber, plastic and glass sheet materials are being considered as dielectric layers; those with tabulated properties are preferred.

Because dielectric layers have been used to simulate a plasma environment, this work should have some relationship to coupling in a plasma. However, no plasma experiments are contemplated at this time.

REFERENCES

Lyon, J.A.M., D.R. Brundage, A.G. Cha, C.J. Digenis, M.A.H. Ibrahim and W.W. Parker (June 1967), "Electromagnetic Coupling Reduction Techniques," The University of Michigan, Radiation Laboratory, Report 7692-6-Q, AD 817354.

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