Broad-Band Impedance Matching a Shunt Slot Radiator Using an Improved Computer-Aided Technique

R. S. GORDY, MEMBER, IEEE, AND
G. P. RODRIGUE, MEMBER, IEEE

***Abstract*—A broad-band computer-aided impedance-matching technique using a comparison reflectometer [1] has been established. The technique is capable of resolving points in a waveguide which generate reflected energy. The comparison reflectometer determines the mean amplitude of the reflection coefficient as a function of distance along the guide and the complex-reflection coefficient of a specific discontinuity in the guide as a function of frequency. A computer program has been developed which is capable of impedance matching the characteristics of each disturbance independent of other reflections in the guide.**

A shunt slot radiator was fabricated and its complex-reflection coefficient measured with a comparison reflectometer. Application of the computer-aided matching technique resulted in a VSWR of less than 1.16 to 1.0 for the slot radiator over the frequency band from 8.5 to 10.5 GHz.

INTRODUCTION

A recognized need has existed for an automatic broad-band impedance-matching technique. The technique reported here is capable of electrically locating a discontinuity in a waveguide and measuring the complex-reflection coefficient of the disturbance as a function of frequency. Furthermore, the method reported determines the physical location and dimensions of a matching element which will provide an impedance match over a predetermined bandwidth.

THEORETICAL CONSIDERATIONS

A comparison reflectometer measures the total reflection coefficient of a standard and an unknown mismatched device [2]. Two sets of measurements are needed to characterize a discontinuity, one with a standard mismatch terminated in a matched load and a second set with the standard mismatch terminated in the unknown disturbance. Measurements are taken at 50-MHz intervals with phase-lock accuracy from 8.0 to 12.4 GHz. The first description of the comparison reflectometer was given by Holloway [1].

When the location of the "unknown" discontinuity is established and its complex voltage-reflection coefficient Γ is found, a matching element is selected. The matching elements considered as part of this research and tabulated in [2] are the solid metal inductive post, dielectric post, capacitive iris, and inductive iris. The complex-reflection coefficients of these matching elements were programmed using well-established equations from [3]. The impedance-matching computer program calculates the total reflection coefficient[1] of both the unwanted disturbance (as characterized by the comparison reflectometer) and the matching element according to:

$$\Gamma_{It} = \frac{\Gamma_{Ia} \exp[-j2\beta L] + \Gamma_{Ib} - 2\Gamma_{Ia}\Gamma_{Ib} \exp[-j2\beta L]}{1 - \Gamma_{Ia}\Gamma_{Ib} \exp[-j2\beta L]}. \quad (1)$$

These terms are identified with the aid of Fig. 1. The derivation for (1) is given in [2, Appendix C].

The rms of the magnitude $|\Gamma_{It}|$ is calculated over the specified bandwidth and minimized by varying the physical dimensions of the matching element and the relative location of this element with respect to the reflection point. The waveguide is thus impedance matched by using a three-dimensional iterating technique described in detail in [2].[2] The output of this computation is a listing of the physical dimensions of the matching element, location of the matching element relative to the mismatch (either toward or away from the generator), and two superimposed curves—one curve of the unmatched disturbance and the second of the matched response.

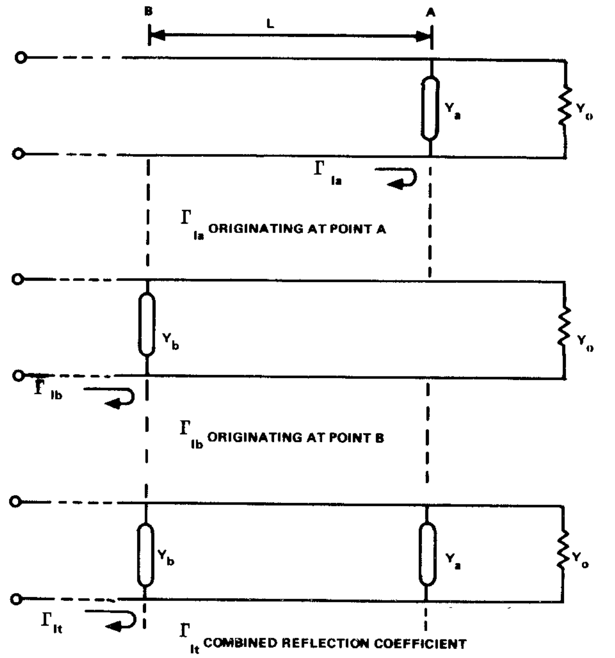

Fig. 1. Current-reflection coefficients generated by disturbances on otherwise matched transmission line.

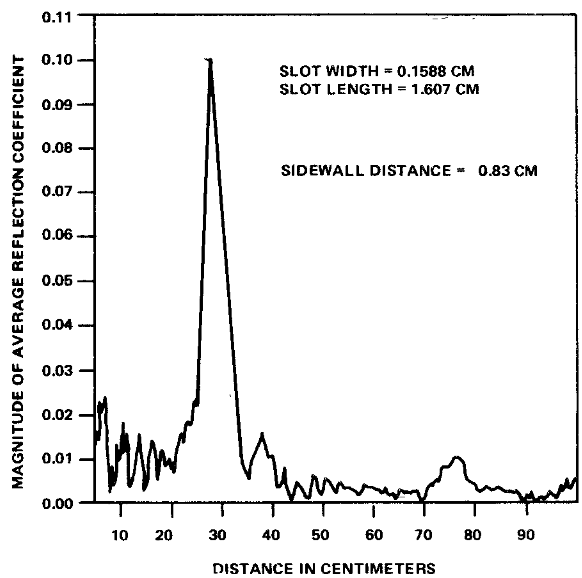

Fig. 2. Distance plot of the shunt slot radiator.

EXPERIMENTAL RESULTS

While this impedancing-matching technique is primarily concerned with in-guide disturbances, the radiating slot provides an interesting application of the technique. Interest in the slot radiator was primarily motivated by the need to broad-band impedance match this element when it is used in a broad-side steerable array.

From the comparison reflectometer measurement the apparent *electrical* location of the slot was established as 28.68 cm from the reference step as shown in Fig. 2. The *geometrical* center of the slot

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R. S. Gordy is with Electronic Communications, Inc., St. Petersburg, Fla. 33733.

G. P. Rodrigue is with the Department of Electrical Engineering, Georgia Institute of Technology, Atlanta, Ga. 30332.

[1] The complex current-reflection coefficient Γ_I is equal to the negative of the complex voltage-reflection coefficient Γ, i.e., $\Gamma_I = -\Gamma$. (This was done so that points on the Smith chart could be read as admittance or Γ_I.)

[2] This reference is available from University microfilms.

was actually located 27.0 cm from the reflectometer reference step. Therefore, the electrical center is located 1.68 cm on the load side of the physical center of the slot. The shunt slot is a radiating device with surface currents on the outer surface of the waveguide in the vicinity of the slot. These surface currents and the disturbed surface currents on the inner wall influence the electrical location of the slot as measured by the comparison reflectometer. Unlike the nonradiating elements measured, the shunt slot radiator showed a marked separation between the electrical location and the geometrical location.

The magnitude and phase of the complex-reflection coefficient of the shunt slot at the apparent electrical location are given in Fig. 3(a) and (b).

It is possible to calculate the complex-reflection coefficient in two different ways at the physical location. The complex-reflection coefficient can be calculated at the apparent *electrical* location and multiplied by $\exp[-j2\beta(1.68)]$ resulting in the correct magnitude and phase at the physical center of the slot. On the other hand, the complex-reflection coefficient can be calculated directly at the physical location by specifying $L_t = 27$ cm when integrating over overlapping intervals of wavenumber [2]. This latter direct calculation at the geometrical location results in an erroneous result. The error stems from the fact that the locating nature of the transforms

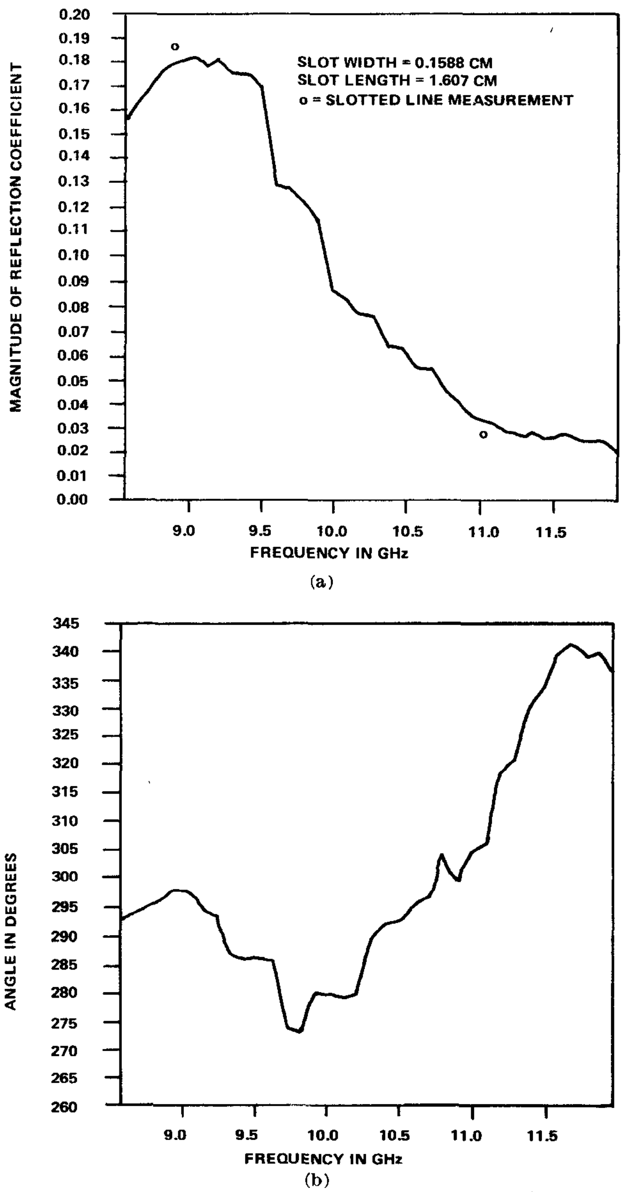

Fig. 3. Magnitude and phase of the reflection coefficient of a shunt slot radiator at the apparent electrical location. (a) Magnitude-reflection coefficient. (b) Phase at electrical location.

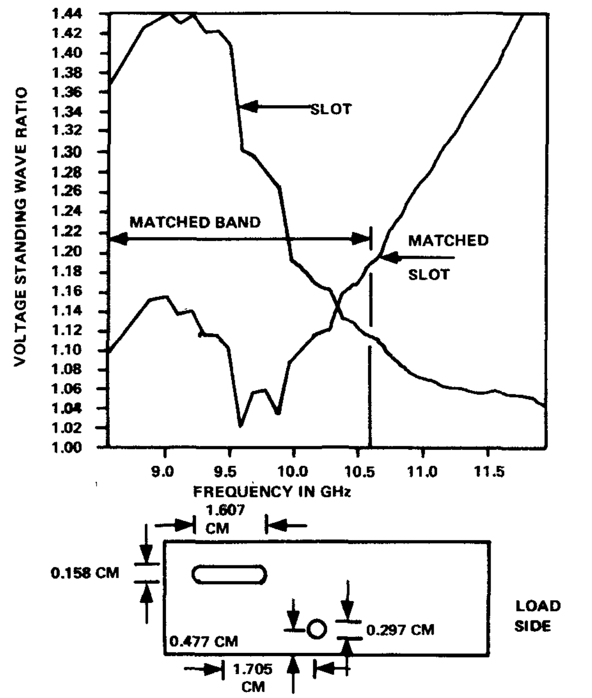

Fig. 4. Slot radiator impedance matched by a dielectric post.

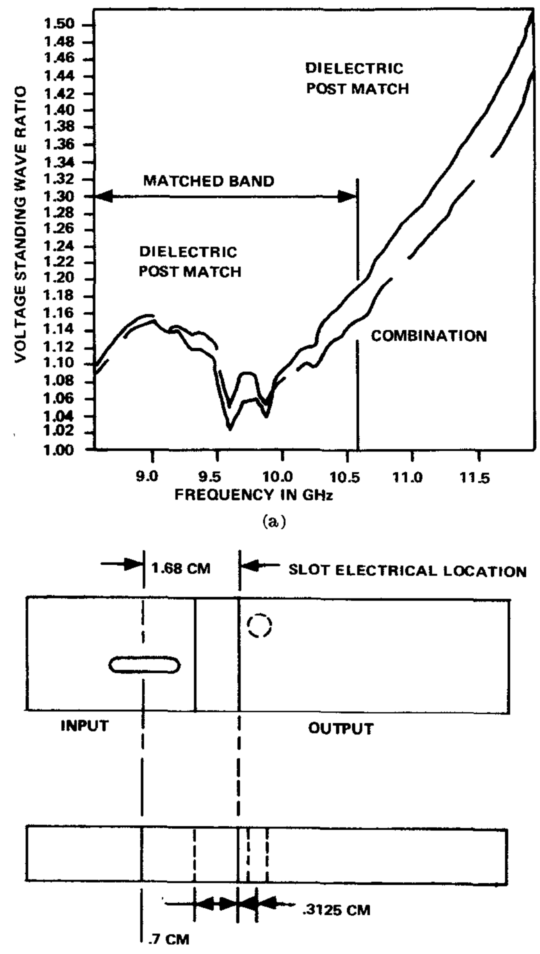

Fig. 5. Shunt slot radiator impedance matched by a dielectric post and by a dielectric post–capacitive iris combination. (a) Response of a slot matched by a dielectric post and by a dielectric post–capacitive iris combination. (b) Location of matching element dielectric post. Diameter: 0.2975 cm; dielectric post sidewall distance: 0.4755 cm; capacitive iris thickness: 0.035 cm; capacitive iris height: 0.060 cm.

attenuate the magnitude of the reflection coefficient at distance points not equal to the electrical location, shown in Fig. 2.

The characteristics of the slot, Fig. 3(a) and (b), were impedance matched according to (1) by a dielectric post. The relative dielectric constant of 4.07 was used to characterize the post [3]. The results of the optimized impedance match using the dielectric post are given in Fig. 4. The calculated physical parameters of this dielectric post are as follows: diameter: 0.297 cm; sidewall distance: 0.477 cm; distance from center of slot 1.705 cm toward the load.

In order to improve the impedance match of the slot and dielectric post, the resulting complex reflection coefficient was again used as a discontinuity in the matching computer program. During this iterative calculation a capacitive iris was the matching element for the resultant mismatch of slot and dielectric post. The result of this effort is shown in Fig. 5. The symmetrical capacitive iris with thickness 0.035 cm and height 0.06 cm was located 0.7 cm toward the generator from the *electrical* location of the slot. The dielectric post was located 0.312 cm toward the load from the *electrical* location of the slot.

Boron nitride was machined into a post with a diameter of 0.117 ± 0.002 in and inserted between the walls of the waveguide to the position given in Fig. 5. The final location of the dielectric post was within 0.002 in of the calculated location. The symmetical capacitive iris was machined to fit two slots sawed through the broad wall of the waveguide. The slots were 0.014 ± 0.002 in wide and 0.074 ± 0.002 in deep. The dielectric post was positioned in the guide, and the capacitive irises were fitted into the respective slots. A silver-based conductive paint was painted on the outside wall of the waveguide over the ends of the irises and on the intersection of the iris and the inside waveguide walls.

The impedanced matched shunt slot radiator was then measured by the slotted line at 100-MHz intervals from 8.575 to 10.875 GHz. The results of these measurements, seen in Fig. 6, show excellent agreement between the computer calculated VSWR and the experimentally measured VSWR.

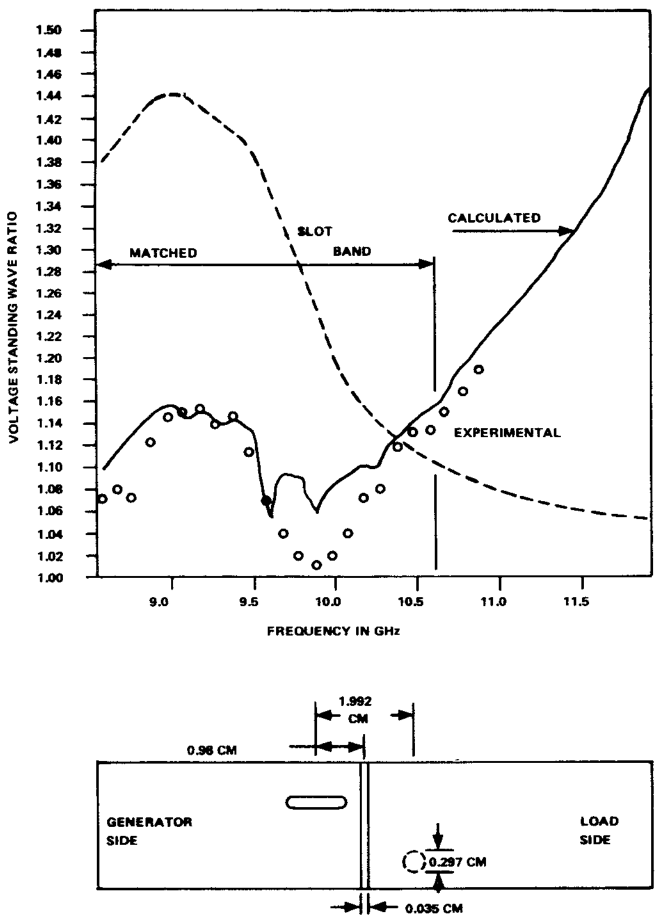

Fig. 6. Comparison of calculated mismatch and measured mismatch.

CONCLUSIONS

The combined use of the comparison reflectometer and the computational procedure developed in this study makes it possible to resolve individual sources of reflections in a waveguide and to synthesize waveguide obstacles that are capable of matching the original discontinuity. The computational time required is short (approximately 100 s on a Univac 1108) and the output includes both the parameters of the matching structure and the expected final performance. Experimental verification of the technique corroborates the theory. Due to approximations in the theory at its present state of development, its application is limited to original discontinuities having VSWR's less than approximately 1.5.

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Modal Characteristics of Quadruple-Ridged Circular and Square Waveguides

M. H. CHEN, MEMBER, IEEE, G. N. TSANDOULAS, MEMBER, IEEE, AND F. G. WILLWERTH

***Abstract*—A theoretical study, backed by experimental verification, was undertaken to determine the modal characteristics of quadruple-ridged circular and square waveguides. Field lines for the first few important modes and cutoff frequencies were determined. It is shown that for square waveguides quadruple-ridge loading always decreases the TE_{10}–TE_{11} bandwidth whereas for circular waveguides only a small amount of additional separation between the first two fundamental modes may be obtained over a limited parameter range. Symmetrical excitation will not excite the asymmetrical higher-order modes. This feature makes these waveguides acceptable as feeds for wide-band reflector antennas and for similar applications but raises a question mark regarding their use as radiators in wide-band phases arrays.**

I. INTRODUCTION

Phased array antennas operating in the *L*-band or higher frequency regions, commonly use waveguide radiating elements. To provide dual-polarization capability, it is natural to use circular or square waveguides as radiators because they can support two orthogonal modes [1].

Based on the cutoffs of the first two (TE_{10},TE_{11}) waveguide modes, maximum available bandwidth for square waveguides is about 34 percent of center frequency [1]. For circular waveguides the TE_{11}–TM_{01} bandwidth is only about 26.5 percent of center frequency. Thus circular waveguides compare unfavorably with square waveguides as far as maximum bandwidth is concerned. The first higher order mode limitation on bandwidth has been shown to be valid in order to avoid mode resonance effects that may give blind spots in the array scan pattern [1], [2].

In many phased array applications, the circular radiator shape is advantageous for symmetry and other reasons. If bandwidths much in excess of about 17 percent (maximum bandwidth reduced by about 10 percent to allow good matching to the exciter at the low end of the frequency band) are required, some way of increasing the available bandwidth is desirable. It has been known that ridged rectangular waveguides exhibit greatly enhanced bandwidth [3].

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M. H. Chen was with the Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, Mass. 02173. He is now with COMSAT, Clarksburg, Md.
G. N. Tsandoulas and F. G. Willwerth are with the Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, Mass. 02173.