with frequency. This effect may be attributed to discontinuity effects at the junctions between the re-entrant and strip line sections. In view of the large plate spacing compared to wavelength ($b/\lambda=0.405$ at 5.0 Gc in the re-entrant section), it is not surprising that discontinuity effects are severe. The poor directivity is also attributable to the discontinuities.

In order to decrease the coupling of the re-entrant section, the outer characteristic impedance, Z_{o1}, was reduced from 84.7 to about 76.3 ohms by reducing the plate spacing from 0.956 inch to 0.832 inch. This produced the desired triple loop appearance of the coupling and main line response curves. The center loop was 0.75 db, the lower loop 0.3 db, and the upper loop 0.7 db. The directivity was almost unaffected, however.

A number of changes were then made in the end sections to cancel discontinuity effects and increase the directivity. The final data for the 1–5-Gc hybrid coupler is shown in Fig. 10. Photographs of the coupler disassembled and assembled are given in Figs. 11 and 12.

Conclusion

The advantages of the re-entrant cross section have been verified experimentally in both single-section and three-section 3-db hybrid-coupler models. For cross-section heights in the range of 0 to 0.16λ, the simple design formulas have proved to yield very good accuracy. Beyond 0.16λ the coupling appears to increase gradually, but nevertheless good performance was achieved even with a cross section height as large as 0.4λ, after a minor adjustment of dimensions.

In the case of a three-section design for 5:1 bandwidth, a center section coupling of -1.28 db is required. This very strong coupling is easily achieved by the re-entrant cross section, and may be maintained accurately in production.

Correspondence

On the General Relation Between α and Q*

The relation between the quality factor Q and the attenuation constant α of a transmission line has been known as follows:

$$\alpha = \frac{\beta}{2Q}$$

where β is the phase constant. Recently from the following relation of propagation constant at resonance

$$\Gamma(\omega_0) + \frac{\partial\Gamma}{\partial\omega}\Delta\omega \simeq i\beta(\omega_0),$$

where

$$\Gamma(\omega_0) = \alpha(\omega_0) + i\beta(\omega_0).$$

Yeh[1] derived a general relation between Q and α, namely,

$$\alpha = \frac{v_p}{v_g}\,\frac{\beta}{2Q},$$

where v_p, and v_g are the phase velocity and group velocity of the wave respectively. This general relation can be derived very simply from the generally accepted definition of α and Q.

General definition of Q applicable to waveguide as well as to ordinary transmission line is as follows:

$$Q = \omega\,\frac{\text{energy stored per unit length}}{\text{power lost per unit length}}.$$

The attenuation factor α in the range of propagation is given by

$$\alpha = \frac{1}{2}\,\frac{\text{power lost per unit length}}{\text{power transmitted}}.$$

If we realize that the power transmitted is equal to the energy stored per unit length multiplied by v_g (group velocity) instead of v_p (phase velocity) then it is readily seen that

$$\alpha = \frac{1}{2}\,\frac{\omega}{v_g Q}.$$

Then from the relation

$$v_p = \frac{\omega}{\beta},$$

we obtain

$$\alpha = \frac{v_p}{v_g}\,\frac{\beta}{2Q}.$$

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* Received February 26, 1963.

[1] C. Yeh, "A relation between α and Q," Proc. IRE (*Correspondence*), vol. 50, p. 2145; October, 1962.

A Varactor Frequency-Modulated AFC Reference Cavity*

Summary

A varactor frequency-modulated microwave cavity is described where the application of a periodic square wave voltage to a varactor serves to electronically detune the cavity. There results a discriminator characteristic which makes the device applicable as an AFC reference. Experimental results are given and discussed.

Introduction

When an AFC loop is used to stabilize the frequency of a microwave signal source, a stable frequency reference is needed. A frequency modulated (periodically detuned) microwave cavity has been developed which performs this function by giving an AC error voltage whose magnitude and phase are proportional respectively to the magnitude and direction of the frequency shift of the source from the reference frequency of the cavity. The cavity thus has a discriminator characteristic. The periodic detuning of the cavity is accomplished through the application of a square wave voltage to a nonlinear reactance device (a varactor[1] or *pn*-junction diode) coupled to the cavity.

The varactor frequency-modulated microwave reference cavity is basically a high-Q

* Received February 26, 1963.

[1] A. Uhlir, Jr., "The potential of semiconductor diodes in high frequency communications," Proc. IRE, vol. 46, pp. 1099–1115; June, 1958.