A COMPARISON OF COPLANAR WAVEGUIDE AND MICROSTRIP FOR GaAs MONOLITHIC INTEGRATED CIRCUITS*

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ABSTRACT

Conductor and dielectric losses are lower in microstrip than in coplanar waveguides (CPW) when the substrate height is equal to the ground plane spacing in CPW. When radiation loss is included and the ground plane spacing is allowed to increase in the CPW, the guides are comparable.

Introduction

Coplanar waveguides (CPW) are often suggested as an alternative to microstrip lines in GaAs monolithic microwave integrated circuits, especially when the active elements include planar diodes and GaAs FETs. The present paper compares losses in coplanar waveguides with those in microstrip lines to provide a basis for the choice of the guide. Calculations have estimated conductor and dielectric losses in each case and have also obtained the radiation losses from respective half-wavelength resonators, and the results are presented in terms of the quality factor Q of these resonators. When the ground plane spacing (see Figure 1) of the coplanar waveguide is identical to the substrate height of the optimum microstrip line, then the CPW Qs are lower. But when the ground plane spacing is allowed to increase the Q factors approach that of the microstrip line. Increasing the ground plane spacing in coplanar waveguides is possible since the radiation losses are much less due to the anti-phase excitation of the adjacent radiating slots. Thus, in the cases considered, the choice of guide may be resolved by considerations other than loss.

Calculations of Q

The conductor and dielectric loss constants α_c and α_d respectively are estimated, and from these the circuit quality factor Q_o is obtained. Note that the stored energy in a $\lambda_g/2$ resonator, with the voltage distribution of $V \sin \beta_g z$, is given by:

$$U = \frac{V^2}{8 Z_o f} \tag{1}$$

and the power loss by:

$$W_\ell = \frac{1}{4} \frac{V^2}{Z_o} \lambda_g (\alpha_d + \alpha_c) \tag{2}$$

Thus, the circuit Q is given by:

$$Q_o = \frac{2\pi f\, U}{W_\ell} = \frac{\pi}{\lambda_g(\alpha_c + \alpha_d)} \tag{3}$$

The radiation Q is estimated by calculating the total power radiated W_r and then evaluating the ratio

$$Q_r = \frac{2\pi f\, U}{W_r} \tag{4}$$

The total Q_t is given by:

$$\frac{1}{Q_t} = \frac{1}{Q_o} + \frac{1}{Q_r}$$

Calculation of Losses

Coplanar Waveguide

The coplanar waveguide impedance, velocity and effective dielectric constant for different a/b (strip width to ground plane spacing) ratios are calculated assuming quasi-static TEM propagation. The Green's function approach is used, and for computational convenience a secondary ground plane is assumed to exist some large distance from the guide. Even and odd mode calculations and subsequent subtraction ensures that the presence of this ground plane does not have any affect. Results obtained by computer calculations agree with those of Wen[1]. The impedances, however, are higher by a few percent due to the finite thickness of the substrate[2].

The conductor loss factor is estimated using the equation:

$$\alpha_c = \frac{R_s}{2 Z_o I^2} \left[\int_{-a}^{+a} J_s^2 \, dx + 2 \int_b^{\infty} J_{gp}^2 \, dx \right] \text{ neper/m} \tag{5}$$

and the dielectric loss factor by:

$$\alpha_d = \frac{q \varepsilon_r \tan\delta}{\varepsilon_{eff} \lambda_g} \text{ neper/m} \tag{6}$$

where J_s is the strip longitudnal current distribution

J_{gp} is the ground plane current distribution of the CPW

Z_o the impedance

I the total strip or ground plane current

ε_r the substrate relative dielectric constant

ε_{eff} the effective dielectric constant

λ_g the guide wavelength

tan δ the substrate loss factor

The current distributions, impedance and the effective dielectric constant estimated from the computer calculations are used to obtain α_c, α_d and subsequently Q_o, for different a/b ratios.

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Radiation from a half-wavelength resonator is calculated by assuming that the electric fields in the gap between strip and ground plane (see Figure 1) give rise to magnetic currents which radiate. The standard formula[3] for radiation from a resonant slot is used, with corrections for the resonant length which is reduced due to the substrate and the presence of the pair of slots excited in antiphase. The radiated power into the air and dielectric regions are estimated seperately and summed, and the radiation Q estimated from equation (4). Results have been obtained for both open and short circuit resonators.

Microstrip

The microstrip loss calculations follow well documented methods[4,5] for conductor and dielectric loss factors. The radiation loss is estimated following the approach of Easter and Roberts[6]. The Q factors follow those observed by others[7].

Results

Since the purpose here is to try to resolve the choice of guiding structure for GaAs monolithic circuits, all results have been obtained for $\varepsilon_r = 13$ and $\tan \delta = 10^{-3}$. No surface roughness factor has been included. Calculations have been performed at 8 GHz, assuming gold metallization $\sigma = 4.1 \times 10^7$ mhos/m, thickness 3 μm.

Figure 2 summarizes the results for half-wavelength open circuit coplanar waveguide resonators with ground plane spacings of 0.5, 1.0 and 2.0 mm for different impedances. (Note that the impedance variation with a/b is available in the literature[1,2].) The highest Q_t is obtained for a ground plane spacing of 1.0 mm, and reaches a value of 160. Figure 3 compares the microstrip Qs of $\lambda_g/2$ resonators for h = 0.25, 0.5 and 1.0 mm with those of the CPW resonators. The Qs of the 0.5 mm substrate microstrip resonators are similar to those of the CPW resonators with ground plane spacing of 1.0 mm, but the CPW resonators with 0.5 mm ground plane spacing show much lower Q_s.

Thus it appears that the choice between the guides is not clear on the basis of loss. Other considerations may determine the choice, and some of these are as follows. The CPW, as a planar structure, allows shunt and series elements to be incorporated with ease, though some care needs to be exercised with shunt elements to retain symmetry to prevent the excitation of spurious slot modes. Microstrip shunt elements require the drilling of holes in the substrate and subsequent processing or alternatively the use of wrap around ground planes. The packaging of the CPW circuits in principle require that the enclosures provide space both above the metallization and also below the substrate, and omission of the latter for reasons of convenience and cost may result in the excitation of spurious circuit responses. Microstrip enclosures require air space only above the substrate. To retain comparable loss performance the CPW ground plane spacing has to be over twice the equivalent microstrip substrate height, and circuits, in general, may require larger substrate areas when compared to equivalent circuits in microstrip. Realization of complex circuits in CPW may result in isolated ground plane regions, with associated problems. Thus, the choice of guiding structure is determined by the designer.

References

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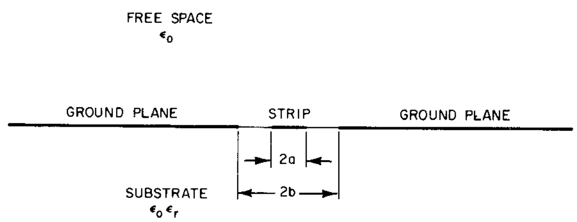

Figure 1: Geometry of coplanar waveguide

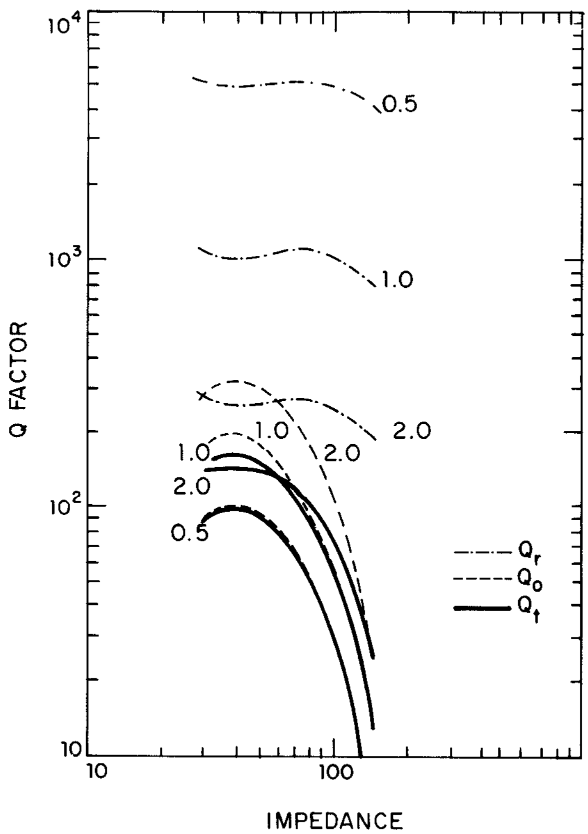

Figure 2: Quality factor against impedance for CPW $\lambda_g/2$ open-circuit resonators for 2b = 0.5, 1.0 and 2.0 mm.

$\varepsilon_r = 13$, $\tan\delta = 10^{-3}$, f = 8 GHz

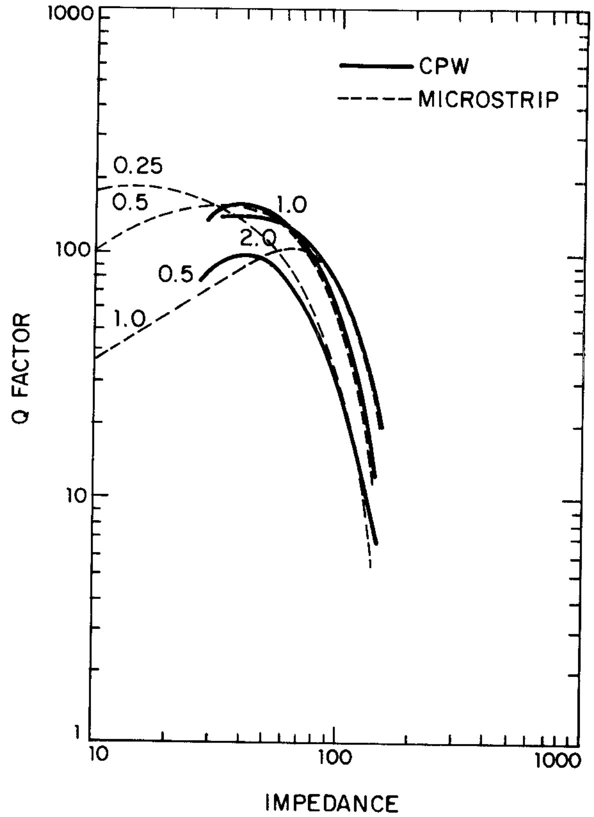

Figure 3: Comparison of Q_t factors of microstrip and CPW $\lambda_g/2$ open circuit resonators for h = 0.25, 0.5 and 1.0 mm and 2b = 0.5, 1.0 and 2.0 mm respectively

$\varepsilon_r = 13$, $\tan\delta = 10^{-3}$, f = 8 GHz