PLANAR RADIAL RESONATOR OSCILLATOR

by
Michael Dydyk

Motorola Inc., Government Electronics Group; Scottsdale, Arizona

ABSTRACT

The input and output coupling coefficients associated with planar radial resonator oscillator having two degrees of freedom are derived. It is shown, that (a) the input coupling coefficient can be controlled by the separation between the centers of the radial disk resonator and the active device and (b) the output coupling coefficient is controlled by the amount of overlap between the radial disk resonator and the inner conductor of the microstrip transmission media.

SUMMARY

This paper deals with the theoretical analysis of a planar radial resonator oscillator having two degrees of freedom, i.e. the ability to satisfy oscillation conditions and providing desired external quality factor (Q_{ext}). The contribution contained in this paper is significant in that it enables theoretical design of the aforementioned oscillator which was never before possible.

The oscillator circuit, shown in Figure 1, consists of a radial disk resonator, output and bias connections realized in a microstrip transmission media. The input coupling to the active device (Gunn or IMPATT diode) can be controlled with the separation between the centers of the radial disk resonator and the active device. The output coupling coefficient, in turn, is controlled by the amount of overlap between the radial disk resonator and the inner conductor of the microstrip transmission media. The validity of the above statements and the dependency of both coupling coefficients will be determined analytically.

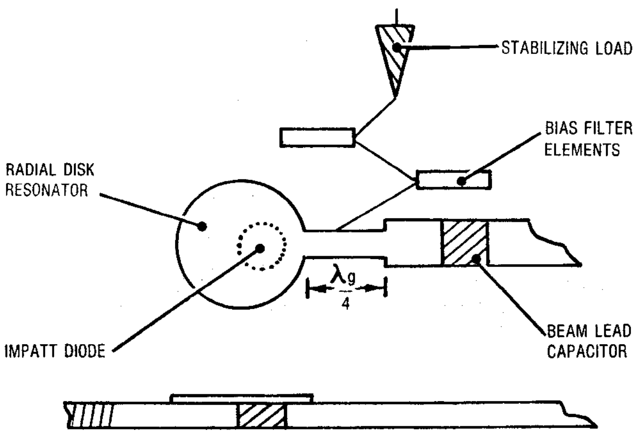

Figure 1. RADIAL DISK RESONATOR OSCILLATOR

The geometry of the radial disk resonator is shown in Figure 2 with diameter (D) and quality factor (Q_o) determined, respectively, by

$$D = \frac{1.84\lambda_o}{\pi\sqrt{\varepsilon_R}} \quad [1]$$

and

$$Q_o = \frac{1}{\left(\frac{\pi}{\lambda_o}\frac{\eta h}{R_s}\right)^{-1} + \tan\delta} \quad [2]$$

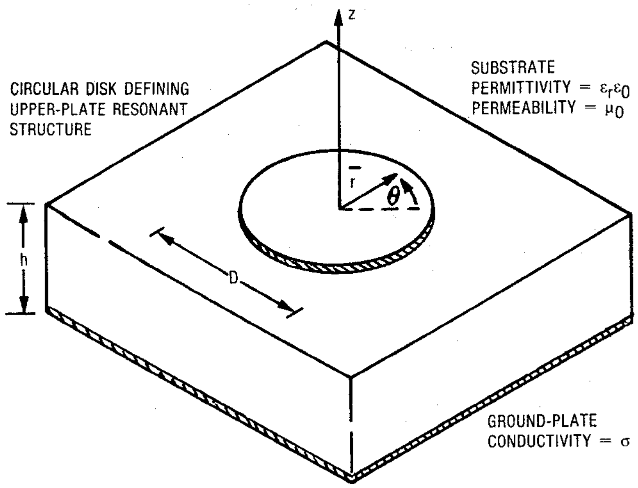

Figure 2. RADIAL DISK RESONATOR

To determine the input coupling coefficient of the radial disk resonator, let the inner conductor of a coaxial transmission media extend into the resonator as shown in Figure 3.

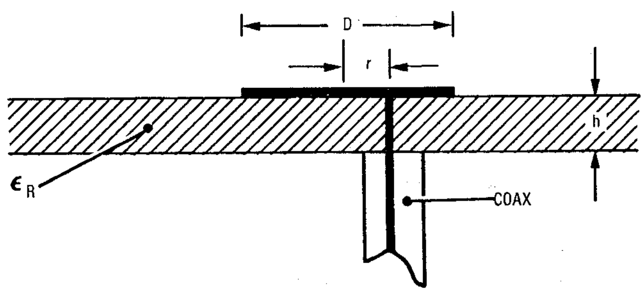

Figure 3. GEOMETRY FOR DETERMINATION OF INPUT COUPLING COEFFICIENT

At frequencies for which h is substantially smaller than a quarter-wavelength, the current in the inner conductor is practically uniform and hence in the direction parallel to h the field is substantially uniform. Under these conditions the resonator will operate in the dominant mode. The field configurations in this mode have no variation in the axial or azimuthal directions and are given by:

$$E_z = k^2 J_1(kr)\cos(\theta + \varphi) \quad [3]$$

$$H\varphi = j\omega\varepsilon k J_1'(kr)\cos(\theta + \varphi) \quad [4]$$

Assuming a shunt transformer coupled representation with dissipation, the input impedance to this resonator is:

$$Z_{in} = \frac{j\omega}{n_1^2 C_o\left[\omega_o^2 - \omega^2 + \frac{j\omega\omega_o}{Q_o}\right]} \quad [5]$$

where

$$n_1^2 C_o = \frac{2E}{V^2} \quad [6]$$

For the mode of interest

$$E = \varepsilon k^4 h\pi \frac{R^2}{2} J_o^2(kR)\left[(kR)^2 - 1\right] \quad [7]$$

and

$$V = hk^2 J_1\left(k\frac{r}{R}\right)\cos(\theta + \varphi) \quad [8]$$

Substituting [6], [7], and [8] into [5] and evaluating at $\omega = \omega_o$ we get

$$Z_{in}\Big|_{\omega = \omega_o} = \frac{R_o}{n_1^2} = \frac{Q_o\lambda_o h\eta\cos^2(\theta + \varphi)}{2\pi^2 R^2\left[(kR)^2 - 1\right]}\left[\frac{J_1\left(k\frac{r}{R}\right)}{J_o(kR)}\right]^2 \quad [9]$$

To relate $\frac{R_o}{n_1^2}$ to the coupling coefficient β_1, it is necessary to make use of a simple equivalent circuit shown in Figure 4.

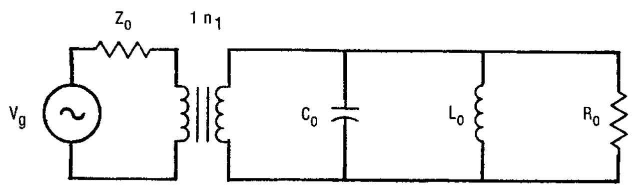

Figure 4. EQUIVALENT CIRCUIT OF A RESONATOR LOADING A GENERATOR

The loaded quality factor, Q_L, for this system is

$$Q_L = \frac{\omega C_o}{\frac{1}{R_o} + \frac{1}{n_1^2 Z_o}} = \frac{Q_o}{1 + \frac{R_o}{n_1^2 Z_o}} \quad [10]$$

By definition

$$\beta_1 = \frac{R_o}{n_1^2 Z_o} = \frac{Q_o\lambda_o h\eta\cos^2(\theta + \varphi)}{2\pi^2 R^2 Z_o\left[(kR)^2 - 1\right]}\left[\frac{J_1\left(k\frac{r}{R}\right)}{J_o(kR)}\right]^2 \quad [11]$$

This equation states that β_1 will be minimum when

$$r = 0 \quad [12]$$

i.e., at the center of resonator.

Let us now consider the output coupling coefficient β_2, which is realized via an overlap between the radial disk resonator and the inner conductor of microstrip transmission media as shown in Figure 5. Based on previous discussion, it is assumed that the electric field E_z has a cosinusoidal distribution with one period around the periphery of the disk. At the edge of the disk, the electric field is given by

$$E_z = A_1 J_1(kR)\cos\varphi$$

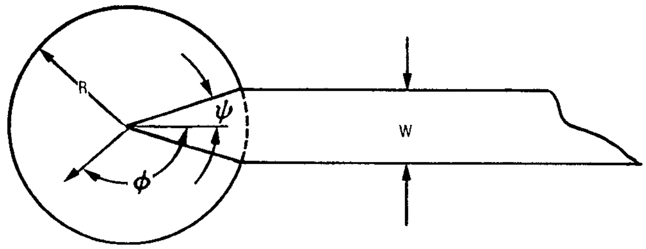

Figure 5. GEOMETRY OF THE OUTPUT COUPLING MECHANISM

Further, we assume that the tangential component of the magnetic field at radius r = R is a constant over the width of the microstrip inner conductor, W, and zero elsewhere. This permits representation of the tangential component of magnetic field with a Fourier series,

$$H(R,\varphi) = \frac{H_1\psi}{\pi} + 2H_1\sum_{n=1}^{\infty}\frac{\sin n\psi}{n\pi}\cos\varphi \quad [14]$$

where

$$\sin\psi = \frac{W}{2R} \quad [15]$$

Another solution for H_φ is deduced from Maxwell's equations and is given by

$$H_\varphi = \frac{j}{\omega\mu_o}\frac{\partial E_z}{\partial r} = jY_e J_1'(kR)\cos\varphi A_1 \quad [16]$$

where

$$Y_e = \sqrt{\frac{\varepsilon_o\varepsilon_R}{\mu_o}} \quad [17]$$

Comparing Eq. [14] (for n = 1) with Eq. [16], coefficient A_1, becomes

$$A_1 = -j\frac{2H_1\sin\psi}{\pi Y_e J_1'(kR)} \quad [18]$$

Substituting Eq. [18] into Eq. [13] reduces E_z to

$$E_z = \frac{-j2H_1\sin\psi}{\pi Y_e}\left[\frac{J_1(kR)}{J_1'(kR)}\right]\cos\varphi \quad [19]$$

The input-wave admittance at $\varphi = 0$ is therefore given by

$$Y_{in} = \frac{H\varphi}{E_z} = j\frac{\pi Y_e}{2\sin\psi}\left[\frac{J_1'(kR)}{J_1(kR)}\right] = jB_{in} \quad [20]$$

This result can then be used to determine the external quality factor (Q_{ext}) via

$$Q_{ext} = \frac{\omega_o}{2Y_o}\frac{\partial B_{in}}{\partial\omega}\Big|_{\omega = \omega_o} = \frac{\pi Y_e}{4Y_o\sin\psi} \cdot \frac{(kR)^2 - 1}{kR} \quad [21]$$

Finally, we recognize that

$$\beta_2 = \frac{Q_o}{Q_{ext}} = \frac{4Q_o Y_o\sin\psi}{\pi Y_e}\left[\frac{kR}{(kR)^2 - 1}\right] \quad [22]$$

Armed with the results of this paper, specifically Eq. [11] and [22], it is possible to theoretically design a planar radial disk resonator oscillator. For detailed relationships between coupling coefficients, active devices, parameters and oscillator requirements, refer to the author's previous paper (1).

Reference

(1) Michael Dydyk, "Efficient Power Combining", IEEE Trans. Microwave Theory Tech., Vol. MTT-28, pp. 755-762, July 1980.