EFFICIENT, HIGHER ORDER MODE RESONANCE COMBINER

MICHAEL DYDYK
MOTOROLA, INC., GOVERNMENT ELECTRONICS DIVISION
SCOTTSDALE, ARIZONA 85252

ABSTRACT

This paper will discuss a power combining approach that uses a higher order mode cavity resonance without mode suppressors to achieve a highly stable and efficient combiner. This is made possible by proper handling of the undesirable resonances.

The application of this approach to a Ku-band 12 GaAs IMPATT diode combiner will be discussed.

SUMMARY

This paper discusses a power combining approach that uses a higher order mode cavity resonance for the purpose of increasing the number of active devices to be combined. Contrary to previous approaches, this approach does not use mode suppressors to prevent spurious frequency generations. This means high efficiency combining. Also, in previous approaches to power combining, the efficiency suffered because each coaxial module of the power combiner had a matched or mismatched load which dissipated a percentage of the power.

Recently Dydyk (1), in his paper, described an efficient power combiner in which he introduced a second cavity tuned to the same desired frequency. This second cavity in conjunction with a quarter wave length of transmission line, between cavities, presents a virtual short circuit at the desired frequency and a stabilizing load at all other frequencies. This improvement made the approach superior in efficiency and frequency control. It is important to note that Dydyk (1), in his approach, considered only dominant mode operation which limits the number of active devices to be power combined.

Extension of this concept to higher mode resonant cavity power combining, which is the subject of this paper, is not trivial.

To assure single frequency of operation of this combiner, it is essential to establish a viable approach to handling the undesirable resonances. To accomplish this it is necessary to take a look at some basics of the cylindrical cavity operating in the TMono higher order mode (n > 1). Let us take, for example, the case of TM020 mode. The electric field behavior of this cavity is shown in Figure 1.

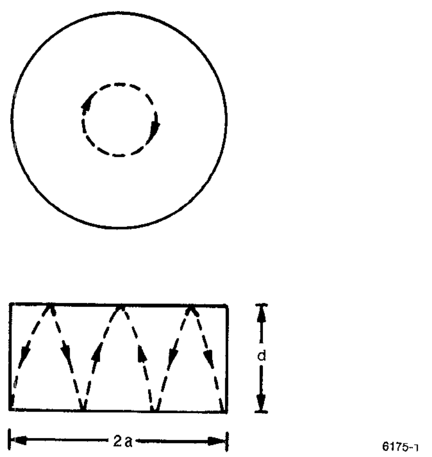

Figure 1. Cylindrical Cavity Operating in the TM020 Mode

The input coupling to the cavity (for power combiner application) is executed in the usual manner as shown in Figure 2.

Maximum coupling occurs wherever there is maximum electric field. In addition to coupling to the desired resonance, this mechanism also couples to other resonances. In fact, within an active band, there are a total of five including the desired resonance.

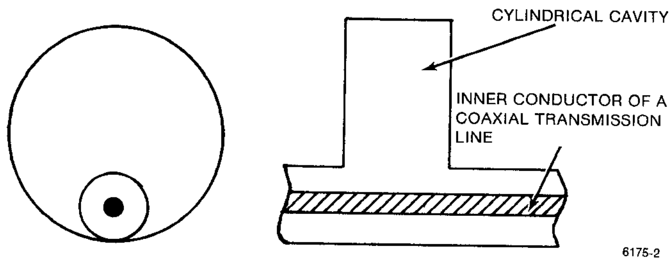

Figure 2. Input Coupling to the TMono Mode

The output coupling to this cavity combiner can be executed in several different ways. However, the optimum position is the center of the cylindrical cavity because, of the five resonances indicated above, only the desired resonance couples to the output probe at that location. Any other technique of output coupling will couple to all five resonances.

To clarify the significance of this output coupling, let us plot the real part of the impedance seen at the plane of the cavity (with the output as well as the other side of the coax transmission line terminated in matched loads) as a function of frequency as shown in Figure 3.

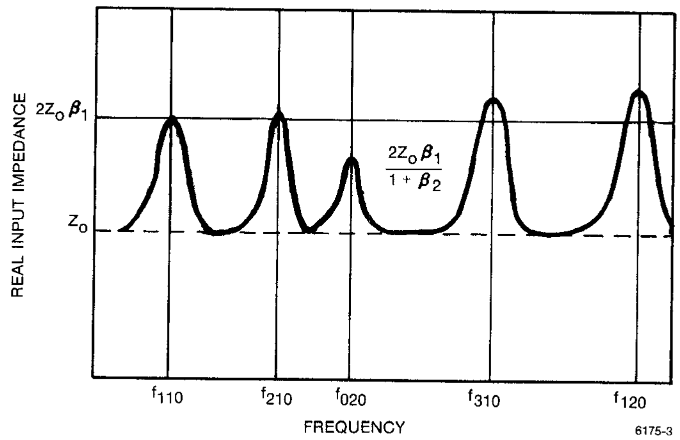

Figure 3 Cavity Real Impedance versus Frequency

In developing Figure 3, the equivalent circuit shown in Figure 4 was assumed.

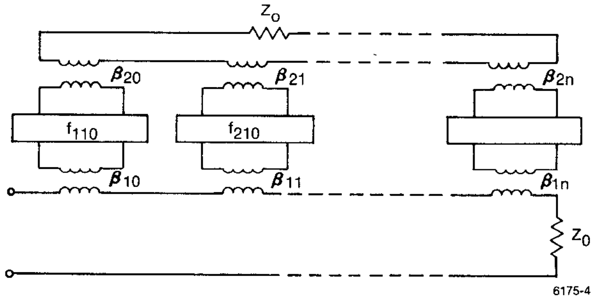

Figure 4. Equivalent Circuit of Higher Order Mode Cavity

The standard synthesis of an oscillator using the Kenyon technique (2), is to maximize the ratio of cavity impedance at resonance (R_c) to stabilizing impedance (Z_o) which would minimize the amount of power dissipated in the stabilizing load (Z_o). Unfortunately, when this technique is applied to the cavity operating at a higher order resonance, this ratio (R) is higher at all except the desired resonant frequencies. To overcome this problem, other investigators in this field introduced mode suppressors that reduce the cavity impedance and therefore, the ratio R, at all except the desired frequency. The disadvantage of this approach is oscillator combiner inefficiency.

An alternate solution to power combining using the higher order cavity resonance is to select the cavity impedance R_c at the desired frequency such that it will be the lowest impedance of all other frequencies including the stabilizing impedance (Z_o) In other words, the opposite from previous approaches. This can be accomplished with proper selection of ($2Z_o\beta_1/1+\beta_2$) and the introduction of the second cavity. Keeping in mind the ultimate application, this second cavity also will operate at the same higher order mode as the first cavity. The equivalent circuit including the second cavity is shown in Figure 5.

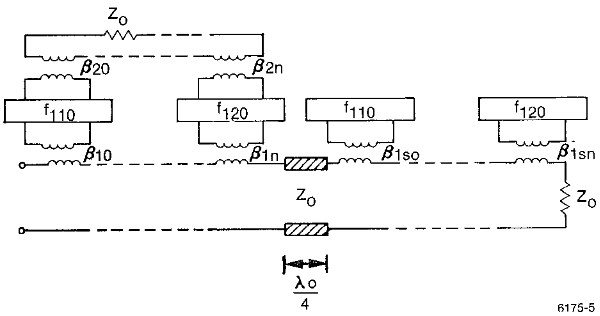

Figure 5. Equivalent Circuit of Two Cavities

The real part of the input impedance of the circuit as a function of frequency is shown in Figure 6. As observed in Figure 6, the desired effect has been achieved; i.e., lowest real part only at the desired frequency.

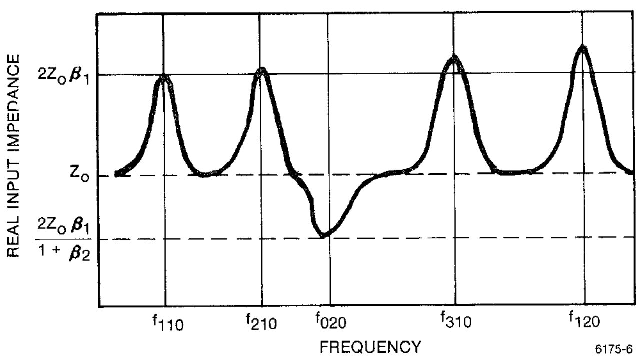

Figure 6. Real Impedance of Two Cavities versus Frequency

Selection of the various coupling coefficients for a practical realization of the combiner under discussion is not trivial. To aid in this selection, let us introduce the equations for the input resistance to the two cavities

$$(1) \quad R_{in} \quad \frac{2Z_o\beta_1}{1+\beta_2} + \frac{Z_o}{1+2\beta_{1s}}$$

and the expected insertion loss

$$(2) \quad IL = 10\log_{10}\left[2\beta_1 + \frac{1+\beta_2}{1+2\beta_{1s}}\right]\left(\frac{1+\beta_2}{2\beta_1\beta_2}\right)$$

Further, let us first consider the case where $\beta_{1s} = \beta_1$. With this constraint (based on Eq. (2)), it is necessary to choose β_1 very large in order to minimize power dissipated with the stabilizing impedance. With large β_1, and the condition that

$$(3) \quad R_{in} < Z_o$$

Eq. (1) requires β_2 to be also large. For single active device application, large β_2 is permissible. However, where multi-active device power combining is considered where

$$(4) \quad \beta_{2N} = N(1+\beta_{21}) - 1$$

it is not possible to realize such a large output coupling coefficient. Therefore, the first conclusion that is reached is that β_{1s} has to be larger than β_1. Upon taking a closer look at the implication of this requirement, what shall be called a "γ effect" takes place as shown in Figure 7.

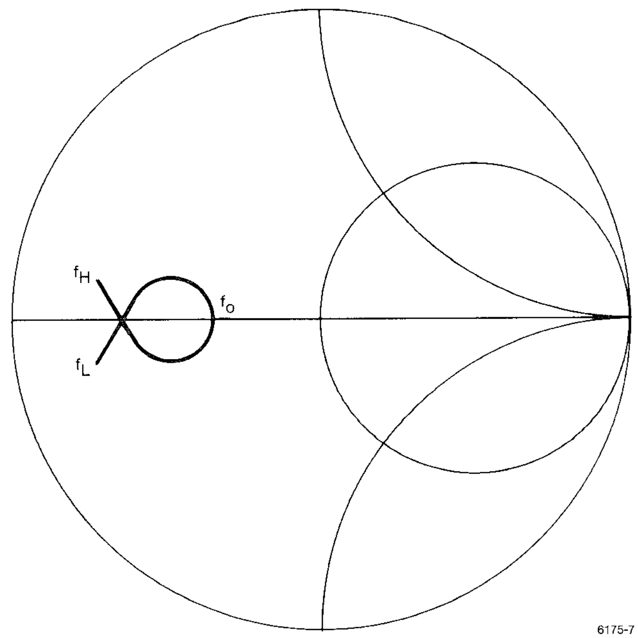

Figure 7 Two Cavity Input Impedance with Different Input Coupling Coefficients

This means that a lower real part of the input impedance occurs at other than desired frequency, hence the oscillator will exhibit frequency switching and large output power gyrations as a function of frequency. Naturally, this is not a desirable characteristic. The "γ effect" can be eliminated by choosing the output coupling coefficient β_2 such that

$$(5) \quad \beta_2 = (1+2\beta_{1s}) \times \sqrt{\frac{\beta_1}{\beta_{1s}}} - 1$$

This comes from demanding that the two undesirable resonant frequencies in the "γ effect" occur at the desired frequency

Now, let us turn our attention to the realization of a larger β_{1s}. Since both the main and second cavities have to be of the same diameter, then in order to increase β_{1s} the height of the second cavity has to be increased. Based on previous experience the height of a cylindrical cavity was never made larger than $\lambda_o/8$. This was done to reduce the possibility of exciting additional higher order mode resonance and also minimize the input coupling inductance, a subject that we shall address presently. Using this as an upper criteria limit to cavity height, and considering practical realization on lower limit, a two-to-one ratio to cavity heights was established. This translates to

$$(6) \quad \beta_{1s} = 4\beta_1$$

It is now possible to determine explicitly the value of β_1 with the aid of Eq. (1), (6) and (7), which is

$$(7) \quad \beta_1 = \frac{1 - R_{1n}/Z_o}{4\left[\frac{2R_{1n}}{Z_o} - 1\right]}$$

Here, another constraint is imposed on the design of the oscillator/combiner; i.e.,

$$(8) \quad \frac{2R_{1n}}{Z_o} > 1$$

Up to this point it was assumed that the two cavities were ideal (other than Q_0) and the realization of the input coupling coefficient introduced no discontinuities. The real world is somewhat more difficult, as can be seen from a more complete equivalent circuit of the two cavities shown in Figure 8

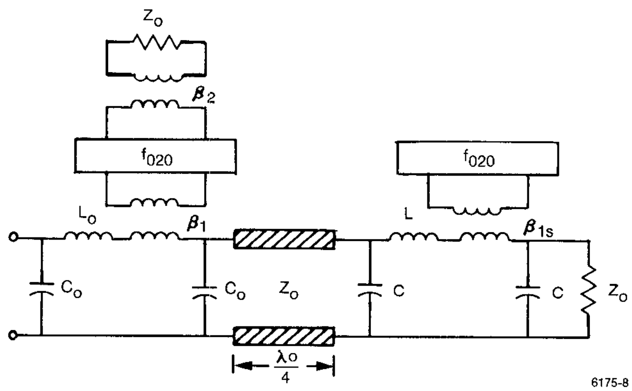

Figure 8 Complete Equivalent Circuit of Two Cavities

The inductances L_0 and L are due to the manner by which the coupling coefficients are realized while the capacitances C_0 and C are the discontinuities caused by the variations in the outer conductor as the inner conductor passes through the cavities Based on experimental evaluation these reactances are of sufficient magnitude to be of concern. It is, therefore, mandatory to minimize/eliminate their effect. A viable approach of doing just that will be described.

The equivalent circuit of Figure 8 suggests, and experiments verify, that the input impedance to the two cavities will be complex; i.e.,

$$(9) \quad Z_{in} = R_{in} \pm jX_{in}$$

This will have to be considered in synthesizing an equalizing network to satisfy oscillating conditions between the active device and the input to the two cavities. The choice of this equalizing network that will satisfy the requirements is one where the input impedance at the plane of the cavity is directly proportional to the impedance at the plane of the first (main) cavity. Several equalizing networks were considered, but the one that has the greatest potential is shown in Figure 9.

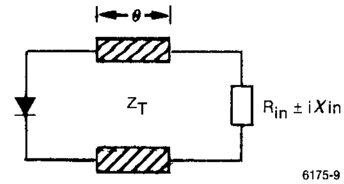

Figure 9. Equalizing Network with Active Device and Load

Most of the comments have been addressed to a single active device oscillator and its realization using a higher order resonance in both the main and second cavities. To extend this concept to multi-active device oscillator is a matter of simply adding more coaxial modules with the active devices. The number of active devices to be combined in this manner is unlimited. This is primarily due to the built-in capability of switching to higher and higher order mode resonance operation as more surface area is needed for combining additional active devices. The discussion, in this paper, was limited to TM020 mode, however, the same technique can be applied to any TMono mode.

Using this approach, 12 GaAs IMPATT diodes have been combined to generate 100 watts peak at Ku-band with 16.7 percent duty factor and 125 nanosecond pulse width under injection locked condition.

REFERENCES

(1) Michael Dydyk, "Efficient Power Combining," 1979 G-MTT Symp Digest, pp. 309-310.

(2) N D Kenyon, "A Circuit Design for MM-Wave IMPATT Oscillators," 1970 G-MTT Symp Digest, pp 300-303