

# Resonance Analysis of the Leaky-wave Antenna

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**Abstract**—The resonance analysis of the leaky-wave antenna with the microstrip feeding has been presented in this paper. Owing to an open-end structure of the leaky-wave antenna, we analyze the antenna by using the cavity-mode technique. Two conventional leaky-wave antennas with two different lengths, defined by the short and long cases, are shown to examine their radiation mechanism and frequency characteristics. Without using commercial EM simulation tools, the location of the resonance modes of the leaky-wave antenna can be predicted.

**Index Terms** — Slot antenna, resonance condition, spurious response.

## I. INTRODUCTION

Menzel had proposed the beam-scanning leaky-wave antenna by using an asymmetrically feeding structure [1] in 1979. The microstrip leaky-wave antenna is one of antennas which radiate a leaky-wave along a guiding transmission line. The propagation of the first higher order mode is operated in the radiation region where most of the guided power gives off in the form of the space wave. The theory of the leakage from the first higher order mode on the microstrip line was derived by Oliner in 1986 [2]. However, it is known that the resonant modes of the leaky-wave antenna are very complex and hard to explain them. Few studies discuss the impedance frequency response on the leaky-wave antenna.

In this work, the cavity analysis is utilized to understand radiation modes of the leaky-wave antenna. We used two traditional leaky-wave antennas of different lengths (short and long) and obtained their impedance-matching characteristics. Through simulation results, the current distributions of the leaky-wave antenna are discussed to realize the resonant behavior.

## II. ANTENNA DESIGN

As shown in Fig. 1, the configuration of the leaky-wave antenna was designed on a printed-circuit board (PCB) with a dielectric constant of 4.4 and substrate thickness of 1.6 mm. To excite the first higher order mode within the operating range of frequency, this microstrip leaky-wave antenna was fed asymmetrically, and the width  $W$  of the microstrip transmission line was empirically chosen to be 20 mm. The lengths of the transmission line were set 15 mm and 70 mm, respectively, and the two lines were defined as the short and long leaky-wave antennas. In order to observe the original resonant modes of the leaky-wave antenna, no matching circuit is added for the feeding structure of the antenna. In order to obtain the better impedance matching condition, a feedline with the dimensions of 1 mm  $\times$  20 mm is used.

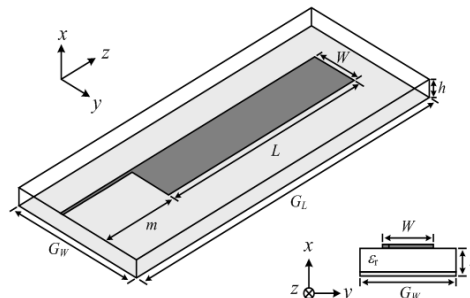


Fig. 1. Configuration of microstrip leaky-wave antenna. ( $G_L=150$  mm,  $G_W=60$  mm,  $L=15$  and 70 mm,  $W=20$  mm,  $h=1.6$  mm,  $m=30$  mm,  $\epsilon_r=4.4$ ).

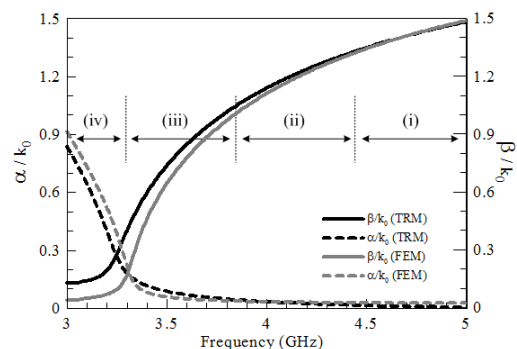


Fig. 2. Normalized complex propagation constant of the leaky-wave antenna.

## III. ANALYSIS OF THE LEAKY-WAVE ANTENNA

### A. Propagation constant and reflection coefficient

Fig. 2 shows the comparison of complex propagation constant of using the transverse resonance method and simulating the structure by Ansoft HFSS. As observed from the results, in order to radiate in the leaky wave of the first higher mode, the leaky-wave antenna should operate in the range of 3.25 – 3.85 GHz. Fig. 3(a) shows the comparison of the reflection coefficient of the short and long antennas ( $L=15$  mm and 70 mm). From 1 to 8 GHz, there are four and fifteen resonant modes for the short and long leaky-wave antennas, respectively. The frequencies of the resonant modes of the two leaky-wave antennas are shown in Fig. 3(b). It can be observed from the figures that the resonant modes and the impedance bandwidth increase with a large propagation path ( $L$ ). The bandwidth enhancement results from the merging of multiple resonant modes. Moreover, the reflection coefficients of the short antenna are worse than those of the long one because of little power leakage, which is dominated by the leaky-wave -wave propagation.

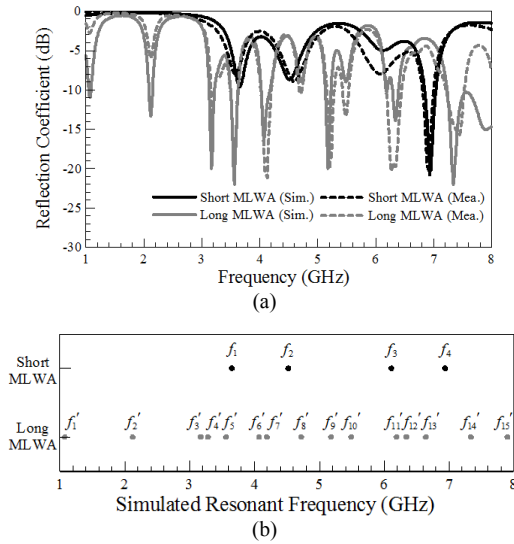


Fig. 3. Comparison of reflection coefficient of the leaky-wave antenna between  $L=15$  mm and  $L=70$  mm. (a) frequency response (b) resonant frequency.

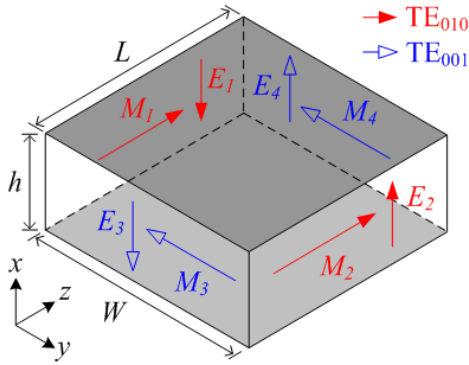


Fig. 4. Equivalent cavity model of the leaky-wave antenna.

### B. Modal Analysis

Fig. 4 is the schematic diagram of the microstrip leaky-wave antenna. The dielectric substrate is treated as a cavity, which is bounded by perfect electric conductors above and below it, and by perfect magnetic walls along the perimeter of the leaky-wave antenna. Because of the small thickness of the substrate, the fringing effect of the electric fields along the four edges can be ignored, and the electric fields are normal to the leaky-wave antenna. The tangential components of the magnetic fields vanish along the four magnetic walls. The resonant frequencies for the cavity of the leaky-wave antenna can be derived by

$$f_{0mn} = \frac{1}{2\pi\sqrt{\mu\epsilon}} \sqrt{\left(\frac{m\pi}{W}\right)^2 + \left(\frac{n\pi}{L}\right)^2}, \quad (1)$$

where  $m$  and  $n$  represent, respectively, the number of half-cycle field variations along the  $y$  and  $z$  directions. For the short leaky-wave antenna, since  $W$  (20 mm)  $>$   $L$  (15 mm)  $>$   $h$  (0.8 mm), the mode with the lowest frequency (dominant mode) is the  $TE_{010}$  whose resonant frequency is given by

$$f_{010} = \frac{1}{2W\sqrt{\mu\epsilon}} = \frac{c_0}{2W\sqrt{\epsilon_r}}, \quad (2)$$

where  $c_0$  is the speed of light in free space. Moreover, the next higher mode (second) mode is the  $TE_{001}$  whose resonant frequency is given by

$$f_{001} = \frac{1}{2L\sqrt{\mu\epsilon}} = \frac{c_0}{2L\sqrt{\epsilon_r}}. \quad (3)$$

Based on eq. (1), the third and fourth resonant mode are  $TE_{011}$  and  $TE_{020}$ . After calculation, the operated frequencies of the first four resonant modes for the short leaky-wave antenna are 3.57, 4.76, 5.96, 7.15 GHz, which agree with the frequencies by the measurement (3.58, 4.58, 6.09, and 6.91 GHz) and EM simulation (3.65, 4.52, 6.11, and 6.94 GHz) in Fig. 3.

Figure 5 shows the variations of resonant frequency with frequency for various lengths ( $L$ ) of the leaky-wave antenna. As shown in the figure, the resonant frequencies of the  $TE_{010}$  and  $TE_{020}$  only have slight variation due to a fixed width ( $W$ ) of the antenna. On the other hand, the resonant frequencies of the  $TE_{001}$ ,  $TE_{002}$ , and  $TE_{003}$ , which are controlled by the lengths ( $L$ ) of the leaky-wave antenna, shift down by increasing the length ( $L$ ). For the two cases of the short and long leaky-wave antennas, the resonant frequency of the  $TE_{001}$  drastically changes from  $f_2 = 4.52$  GHz to  $f_2' = 1.07$  GHz. As similar as the  $TE_{001}$ , the resonant frequency of the  $TE_{011}$  decreases from  $f_3 = 6.11$  GHz to  $f_3' = 3.55$  GHz.

### IV. CONCLUSION

The microstrip leaky-wave antenna by utilizing the cavity-mode theory has been analyzed. The resonant modes of the leaky-wave antenna can be predicted theoretically. With aid of the complex propagation constant, the radiation mechanism of the leaky-wave antenna is presented.

### REFERENCES

- [1] W. Menzel, "A new traveling wave antenna," *Proc. 8th European Microwave Conf.*, pp. 302-306, 1978.
- [2] A. Oliner, "Leakage from higher modes on microstrip with application to antennas," *Radio Science*, vol. 22, no. 6, pp. 907-912, Nov. 1987.

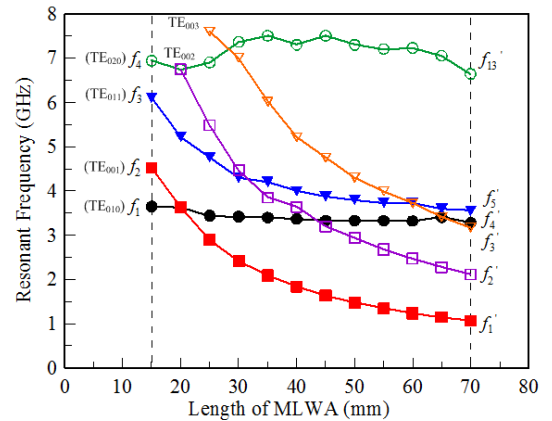


Fig. 5. Variations of resonant frequency with frequency for various lengths .