A NOVEL HIGH-Q IMAGE GUIDE RESONATOR USING BAND-GAP STRUCTURES

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ABSTRACT

This paper presents a novel high-Q resonator using photonic band-gap structures in an image guide. Our initial measurement with an X-band prototype demonstrates a Q-factor of 697, which is limited by the dielectric material (Duroid) used for experiment. A new planar integration technique for image guides using Yagi-Uda slot array is also developed. This resonator structure is potentially useful for millimeter-wave integrated circuits.

INTRODUCTION

Expanding demand for wireless communication systems requires high performance for low phase-noise oscillators. Planar circuits such as microstrip resonators are not applicable at millimeter-wave frequencies because of their low Q-factor. Dielectric Resonators (DR) are used extensively to stabilize oscillating frequency in millimeter-wave range. The major problem of using DR is the compatibility with planar integrated circuits. In this paper, a new quasi-planar high-Q resonator structure is proposed to overcome this problem.

The image line has been extensively investigated for applications in millimeter-wave integrated circuits [1,2]. The use of band-stop phenomenon for periodic gratings in image guides has been realized [3,4]. A resonant cavity can be formed by introducing a defect in the periodic structure. This defect cavity allows the existence of very narrow passband within the stopband. Because of the low loss characteristics of image guides, the resonant cavity mode has very high quality factor (Q). Microstrip fed Yagi-Uda slot array has been applied to serve as a low loss transition [5]. This new resonator structure provides a solution for realizing a quasi-planar high-Q resonator in millimeter-wave integrated circuits.

RESONATOR AND TRANSITION DESIGN

Fig. 1 shows the structure of the image guide with grooves. The spacing between two center grooves is larger than the period of grating. This larger spacing introduces the cavity mode of resonance. The period of grating is chosen using guidelines available in the literature [3,6]. After the center frequency of the first stopband is chosen, the period of grating a can be obtained approximately from the following condition:

$$\beta a = \pi \qquad (1)$$

where β is the propagation constant of the unperturbed image guide. The bandwidth depends on the *g/a* ratio. Numerical method (FDTD) is applied to compute the propagation constant of the unperturbed image guide. The effective dielectric constant of the unperturbed image guide is approximated by applying volumetric principles to the image guide with gratings. The length of the defect cavity *l* determines the resonant frequency and Q-factor. Based on both simulations and experiments, the proper choice of *l* can be made to obtain a single high-Q resonant mode.

In order to realize planar excitation of the image guide we employ a microstrip-fed Yagi-Uda slot array, which has been used successfully as a surface-wave launcher for a slab waveguide [5]. A low-loss microstrip-to-image guide transition with good front-to-back ratio has been achieved by optimizing the dimensions of the Yagi-Uda slot array. This transition also serves as a band-pass filter to eliminate spurious modes generated by band-gap structures in the image guide.

NUMERICAL AND EXPERIMENTAL RESULTS

Fig. 2(a) shows the back-to-back microstrip-to-image guide transition using the Yagi-Uda slot array. The image guide sits on top of the thin substrate with slots in the common ground plane and microstrip feed line on the bottom. The measured S-parameters agrees reasonably well with FDTD simulation, as shown in Fig. 2(b) and (c). This back-to-back transition was designed to operate at the lower end of X-band. The loss of each transition is measured to be 0.35 dB. Due to the material available for experiment (RT/Duroid 6010, ε_r=10.2, tanδ = 0.002), the image guide has a measured loss of 0.34 dB/inch, which has been confirmed by HFSS simulation.

Fig. 3 shows the measured S-parameters of the resonator. The measurement was made from connector to connector. The resonant frequency is 8.276 GHz and the fractional bandwidth of the resonant peak is 0.36%. The corresponding loaded Q (Q_l) of the resonant cavity is 277. A loss budget for the resonator is presented in Table 1. The losses of connectors, feeding microstrip lines and transitions have been measured separately. The deduced insertion loss for the resonator is 4.39 dB. The unloaded Q (Q_u) of the resonator is calculated to be 697.

It should be emphasized here that the relatively large insertion loss is mainly due to the high loss of the Duroid substrate, which is used to build the circuit. Our FDTD simulations reveal that the insertion loss can be significantly improved using low-loss materials such as quartz or Teflon. We are currently working on a numerical model to characterize the relationship between dielectric loss and Q of this new resonator structure.

CONCLUSION

We have proposed a new type of quasi-planar resonator consisting of an image guide with band-gap structures. A material limited Q of 697 has been measured with an X-band prototype. We have also developed a low-loss microstrip-to-image guide transition that should facilitate the integration of image guide with planar circuits at millimeter-wave frequencies.

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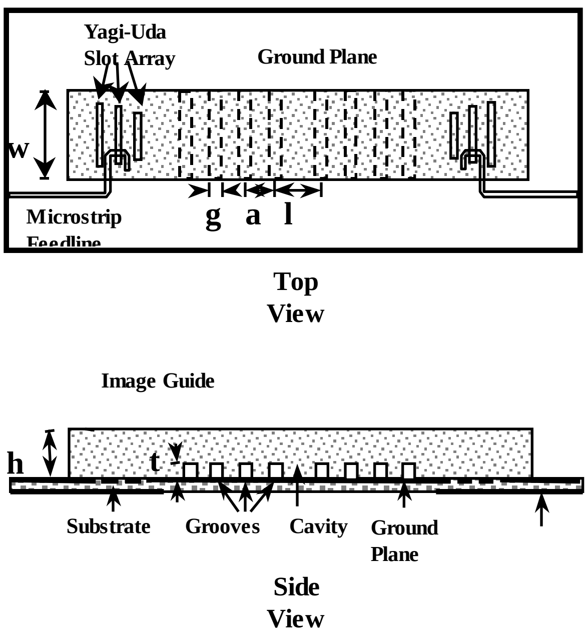
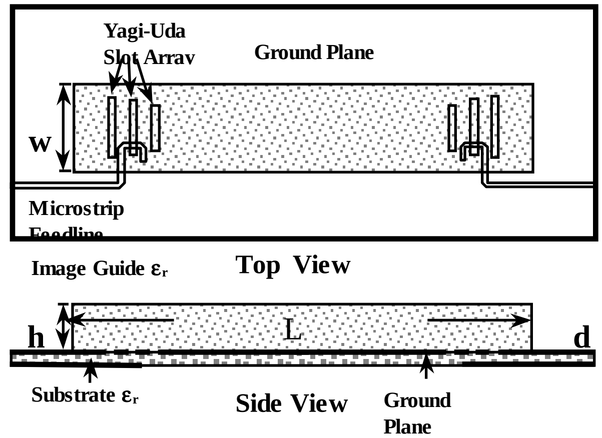
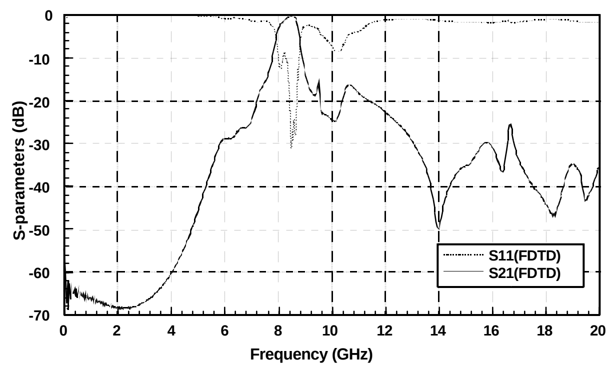


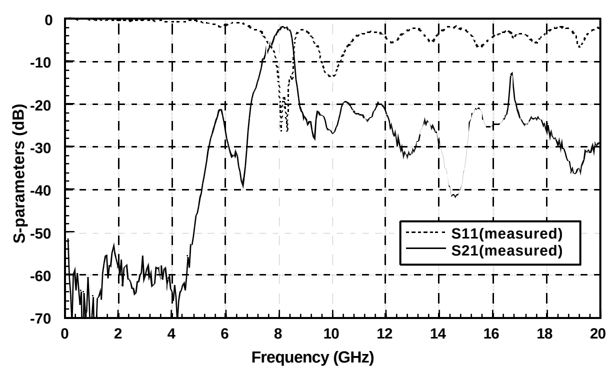
Fig. 1. The structure of the proposed image guide resonator



(a)



(b)



(c)

Fig. 2. Simulated and measured S-parameters for the microstrip-to-image guide transition with image guide length L= 1 inch. (a) Circuit configuration. (b) FDTD simulation results. (c) Measured S-parameters including connector and microstrip line losses.

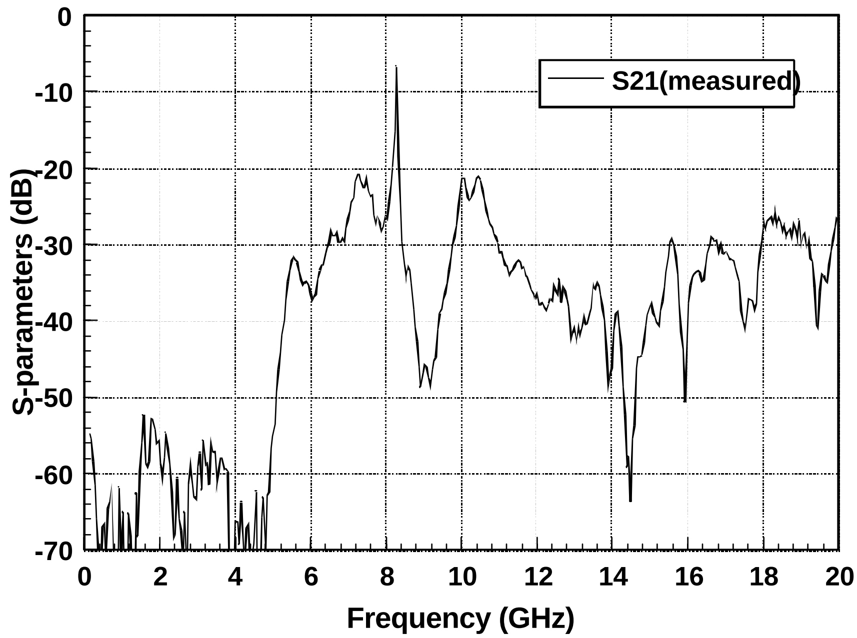


Fig. 3. Measured S-parameters for the image guide resonator with a = 380 mil, g = 180 mil, l = 570 mil and t = 60 mil.

Table 1. Losses for the image guide resonator

Total measured loss	6.7 dB
Mismatched loss (measured input return loss = 8.2 dB)	0.71 dB
Connectors and feeding microstrip lines losses (measured)	0.9 dB
Microstrip-to-image guide transition losses (measured)	0.35 dB $\times$ 2
Deduced loss for resonator	4.39 dB