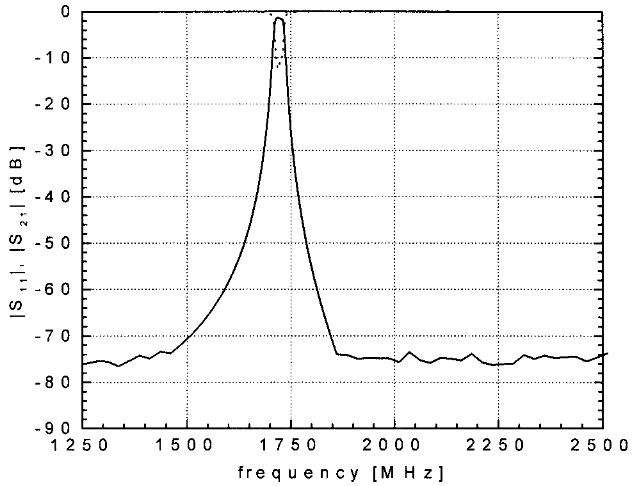

Figure 4 Measured frequency response of realized lumped-element filter at 20 K. ---- $|S_{21}|$, dB. —— $|S_{11}|$, dB

EXPERIMENTAL DETAILS

The filter was realized from a single-sided YBCO thin film on a 10 × 10 × 0.5 mm MgO wafer. During fabrication, all sides of the substrate were covered by silver with annealing. After patterning, only the inner ends of coils and the corresponding contact pads of capacitors, and 50 Ω feedlines, together with the bottom surface of the substrate, were still covered by silver. These pads have teen used for ultrasonic bonding of 40 μm gold wires. Connections between cryostat cables and filter feedlines were also made with 40 μm gold wires using ultrasonic bonding. The connection between the ground plane and mounting plate was made with silver epoxy.

RESULTS

Figure 4 shows the measured frequency response of the fabricated filter with one gold wire per connection. All measurements were performed at 20 K temperature using a scalar network analyzer. However, calibration of the cables was performed at room temperature; the resulting error due to increased dissipation in the cables is about 0.3 dB. Figure 5 shows a comparison of the frequency responses of filters with two versus one 40 μm gold wire per connection. The unloaded quality factor of each resonator can be estimated as being about 3000–4000. Such a Q-factor was obtained for extremely narrow conductors for this type of HTSC application. But more importantly, it has been obtained in a non-HTS (normal metal) interconnection structure, and with only one side of the substrate coated with YBCO. A comparison between simulated and measured results shows good agreement, although a frequency shift of about 55 MHz exists. This shift can be explained by the nonideal knowledge of the parameters of the substrate (thickness and permittivity) and the influence of underetching or overetching in the wet chemical processes.

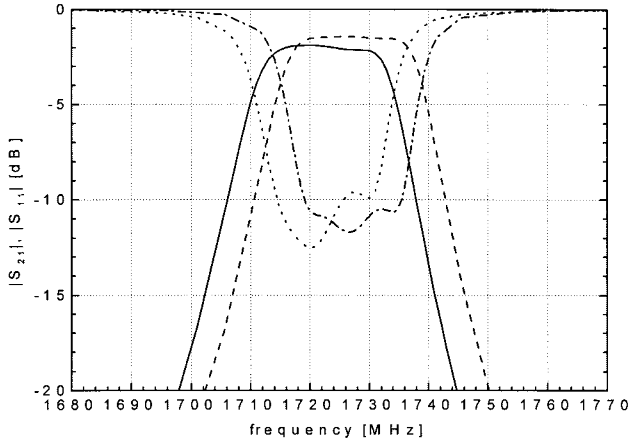

Figure 5 Measured frequency response of a filter with one wire per connection (solid line $|S_{21}|$, dotted line $|S_{11}|$) versus measured response of a filter with two wires per connection (dashed line $|S_{21}|$, dashed–dotted line $|S_{11}|$)

CONCLUSION

We have presented a novel lumped-element third-order bandpass filter with planar spiral inductors. This structure is very small, and our filter is suitable for a 10 × 10 × 0.5 mm MgO substrate. The measured filter exhibited 1.5 dB insertion loss at a quite narrow bandwidth of 0.84%. Filter measurements are in good agreement with theory.

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A COMPACT MICROSTRIP ANTENNA WITH MEANDERING SLOTS IN THE GROUND PLANE

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ABSTRACT: *A novel compact microstrip antenna design is demonstrated. By embedding meandering slots in the antenna's ground plane, it is observed that the resonant frequency of the microstrip antenna is* *significantly lowered, which can lead to a large antenna size reduction for a fixed frequency operation. In addition, enhanced impedance bandwidth and antenna gain are also observed for the proposed antenna. Details of the proposed design and experimental results of the constructed prototypes are presented and discussed.* © 2001 John Wiley & Sons, Inc. Microwave Opt Technol Lett 29: 95–97, 2001.

Key words: *compact microstrip antenna; slotted ground plane*

1. INTRODUCTION

The technique of meandering an antenna's radiating patch has been shown to be an effective method for achieving compactness of microstrip antennas [1–3]. This meandering technique is achieved by inserting slits at the nonradiating edges of the antenna's radiating patch. Owing to the meandering slits, the excited patch surface current paths can be lengthened, which results in a lowering of the antenna's resonant frequency; that is, a reduced antenna size at a fixed operating frequency can be achieved for such microstrip antennas with a meandered patch. However, similar to many other compact microstrip antenna designs such as using shorting-pin loading, a high-permittivity substrate, and so on, the impedance bandwidth and antenna gain are also decreased as compared to conventional microstrip antennas.

In this paper, we propose a new design of a compact microstrip antenna with meandering slots in the antenna's ground plane (see Fig. 1). It is found that the proposed design can also cause significant lowering of the antenna's fundamental resonant frequency, similar to the design of embedding meandering slits in the antenna's radiating patch. Moreover, it is found that, probably owing to the embedded slots in the antenna's ground plane, which effectively reduces the quality factor of the proposed design, the impedance bandwidth and the antenna gain as well are greater than those of the corresponding conventional microstrip antenna. Prototypes of the proposed design have been successfully implemented, and experimental results are described in detail in this paper.

2. ANTENNA DESIGN

Figure 1 shows the configuration of the proposed compact microstrip antenna. The rectangular radiating patch has dimensions of $L \times W$, and is printed on a microwave substrate of thickness h and relative permittivity ε_r. Three identical slots are embedded in the antenna's ground plane, and are aligned with an equal spacing of $L/4$ and parallel to the patch's radiating edges or the y-axis. The embedded slots have a narrow width (1 mm in this study), and have a length of $l_o + l_i$, where l_o and l_i are, respectively, the slot length outside and inside the projection image of the radiating patch in the ground plane. A probe feed is placed along the patch's center line (x-axis) at a position d_p from the patch center.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Prototypes of the proposed antenna (antennas 1–4) were constructed and experimentally studied. Figure 2 shows the measured return loss of the constructed prototypes, and the corresponding measured data are given in Table 1 for comparison. In the study, inexpensive FR4 substrates ($\varepsilon_r = 4.4$, $h = 1.6$ mm) were used. The dimensions of the rectangular radiating patch were chosen to be 30 mm × 20 mm ($L \times W$). The slot lengths l_o for the prototypes were all fixed to be 10 mm, and the slot length l_i was varied from 8 to 14 mm. The reference antenna ($l_o = l_i = 0$) is also shown for comparison. First, note that the embedded slots in the ground plane have very small effects on the feed position d_p for achieving good impedance matching of the prototypes; all d_p were chosen to be 5 mm in the study.

For the reference antenna, the fundamental resonant mode TM_{10} is excited at 2387 MHz with a 10 dB return-loss bandwidth of 2.0%. With an increase of the slot length l_i, it is seen that the fundamental resonant frequency is quickly

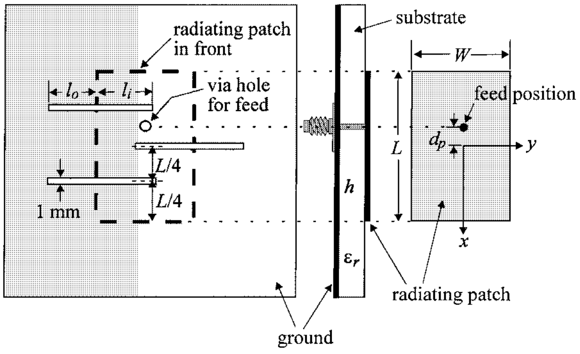

Figure 1 Geometry of the proposed compact microstrip antenna with meandering slots in the ground plane

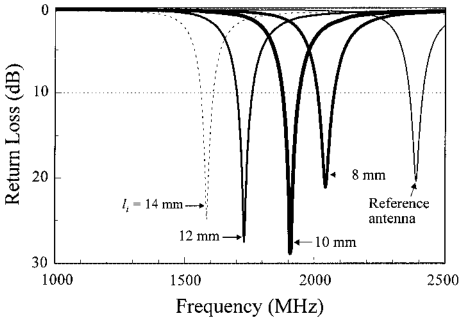

Figure 2 Measured return loss against frequency; antenna parameters are given in Table 1

TABLE 1 Performances of the Proposed Antenna; $h = 1.6$ mm, ε_r 4.4, $L = 30$ mm, $W = 20$ mm, $l_i = 10$ mm, Ground-Plane Size = 50 mm × 50 mm; the Bandwidth is Determined from 10 dB Return Loss

	l_o, l_i (mm)	d_p (mm)	f_c (MHz)	Bandwidth (MHz, %)	Gain at f_c (dBi)
Antenna 1	10, 8	5	2043	64, 3.1	4.1
Antenna 2	10, 10	5	1907	67, 3.5	4.1
Antenna 3	10, 12	5	1723	64, 3.7	4.6
Antenna 4	10, 14	5	1587	50, 3.2	3.9
Reference	0, 0	5	2387	48, 2.0	3.0

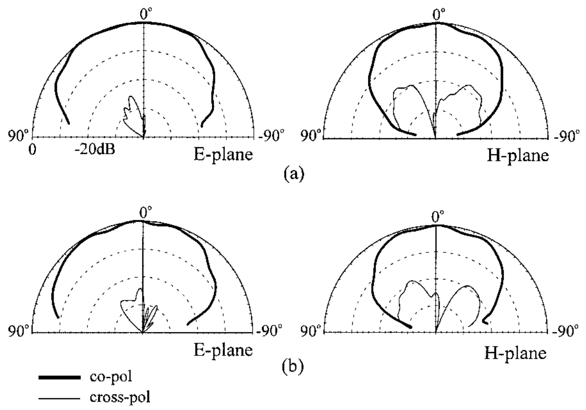

Figure 3 Measured E-plane (x–z plane) and H-plane (y–z plane) radiation patterns for the proposed antenna shown in Figure 2. (a) Antenna 3 ($l_i = 12$ mm) at 1723 MHz. (b) Antenna 4 ($l_i = 14$ mm) at 1587 MHz

lowered. For the case of antenna 4 ($l_i = 14$ mm), the resonant frequency is at 1587 MHz, which is only about 0.66 times that of the reference antenna. This suggests that an antenna size reduction as large as about 56% can be achieved for the proposed antenna for operating at a fixed frequency. Moreover, it is clearly seen that the impedance bandwidths of the prototypes (antennas 1–4) are all greater than that of the reference antenna. This behavior is largely owing to the meandering slots embedded in the antenna's ground plane, which effectively lowers the quality factor of the proposed antenna.

Figure 3 plots the measured E- and H-plane radiation patterns for antennas 3 and 4. Good broadside radiation patterns are observed. Also, the measured antenna gain (see Table 1) is seen to be greater than that of the reference antenna. From the IE3D$^{\text{TM}}$ simulation results, the radiation efficiency of the proposed antenna with an FR4 substrate is greater than 80%, which is much greater than that (less than 40%) of the reference antenna with the same FR4 substrate. The increase in the radiation efficiency is probably associated with the embedded slots in the ground plane, which lowers the quality factor of the proposed antenna, and may account for the observed antenna gain enhancement for the proposed antenna. Also, from the obtained results, it is suggested that, for obtaining optimal bandwidth and gain enhancement, the slot length l_i should be slightly greater than half the patch width ($W/2 = 10$ mm in this study) in the proposed design (see antenna 3 in Table 1).

4. CONCLUSIONS

A novel design of a compact microstrip antenna with a slotted ground plane has been proposed and experimentally studied. Prototypes has been successfully implemented, and experimental results show that, in addition to a large antenna size reduction obtained at a fixed operating frequency, the impedance bandwidth and antenna gain can also be enhanced. For the case of using an FR4 substrate studied here, the obtained impedance bandwidth of the constructed prototype can be about 1.85 times that (3.7 versus 2%) of a corresponding conventional microstrip antenna without embedded slots in the antenna's ground plane, and a gain enhancement of 1.6 dBi (4.6 versus 3.0 dBi) is also observed.

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CHARACTERIZATION OF POLYPROPYLENE THIN-FILM MICROSTRIP LINES AT MILLIMETER AND SUBMILLIMETER WAVELENGTHS

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ABSTRACT: *We report on the characteristics of thin-film microstrip lines with adhesive polypropylene tape as dielectric. The attenuation and dispersion have been measured in a frequency range between 30 and 800 GHz by electro-optical sampling. A 31-μm-wide PP microstrip line exhibits a low attenuation of 0.09 dB/mm and an effective permittivity* $\varepsilon_{r,eff}$ *of 1.85, both at 30 GHz. Both the excellent dielectric properties as well as the high planarity appear very attractive for future waveguide structures.* © 2001 John Wiley & Sons, Inc. Microwave Opt Technol Lett 29: 97–100, 2001.

Key words: *millimeter wavelengths; electro-optic sampling; transmission-line characteristics; low-k dielectrics*

1. INTRODUCTION

In recent years, the millimeter-wave regime has attracted more and more attention with a rising number of applications like local multipoint distribution service (LMDS), satellite communication, or wireless local-area network (WLAN). Since passive components play an essential performance-limiting role, especially in Si- and SiGe-based millimeter-wave integrated circuit systems, it is of great interest to find new efficient *and* low-cost solutions [1]. Several types of transmission lines have been designed and investigated for application at millimeter-wave frequencies [2–4]. The maximum frequency of operation of a microstrip-line configuration is limited by the excitation of spurious modes, surface waves, and radiating waves. The cutoff frequency $f_{c,\mathrm{HE1}}$ of the first-order hybrid microstrip mode HE$_1$ is given by [5]

$$f_{c,\mathrm{HE1}} = \frac{c_0 Z_0}{2\eta_0 h} \tag{1}$$

where c_0 is the free-space light velocity, Z_0 is the characteristic impedance of the microstrip line, and η_0 is the characteristic impedance of free space. Conventional (thinned) substrates for microstrip lines usually have a minimum thickness of 100 μm. Therefore, a 50 Ω microstrip line on a 100-μm-thick silicon substrate yields a cutoff frequency of 200 GHz with a pronounced dispersive behavior starting above 30

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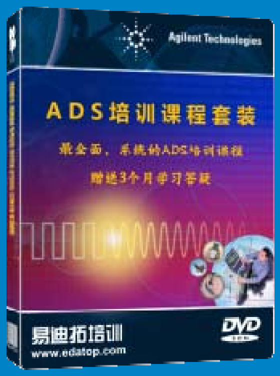

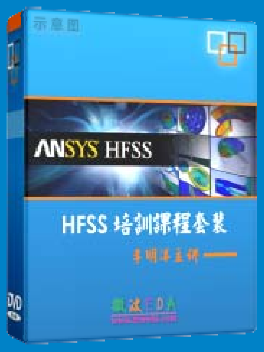

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