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A VERY COMPACT ELECTROMAGNETIC BANDGAP STRUCTURE FOR SUPPRESSING SURFACE WAVES IN INTEGRATED CIRCUITS

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ABSTRACT: A very compact electromagnetic bandgap structure is presented for integrated-circuits applications. This structure, which is one kind of high-impedance surface with periodic interdigital elements, is adopted to increase the fringe capacitor in order to compress the overall size of the high-impedance surface. Its design uses the effective-circuit model. The measured results show that a 30% to 40% size reduction can be obtained. This will be very valuable for practical applications. © 2004 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 41: 455–457, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20169

Key words: EBG; interdigital capacitor; high-impedance surface; surface-wave

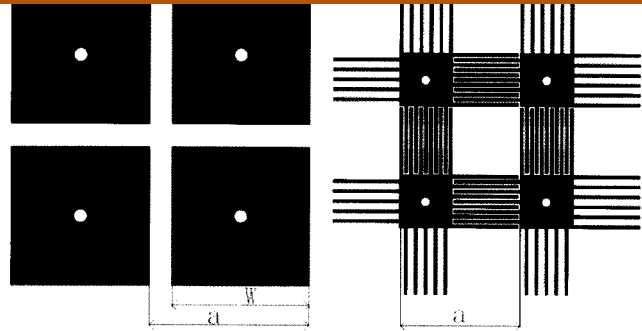


Figure 1 Geometry of the structure's layout of HIP

1. INTRODUCTION

In recent years, photonic bandgap (PBG)/electromagnetic bandgap (EBG) structures have been extensively studied in the applications of microwave circuits and antennas [1–7], and so-called high-impedance surfaces (HIPs) [1–4] have attracted even more attention. HIPs possess the two advantages of high surface impedance and in-phase reflected plane wave, whereas the reflected plane wave from a metal sheet is out of phase. Second, it shows a frequency bandgap within which the propagation of surface waves is forbidden. HIPs have been used as microwave antennas, such as the wire antenna microstrip patch antenna [3–4]. Another merit of HIP surfaces is their compact sizes. The periodic spacing can be about one-tenth of the guided wavelength for two-layer HIPs, and for three-layer HIPs, it can be one-thirtieth of guided wavelength [2]. The two-layer structures are more easily integrated into printed circuits using normal MMIC techniques than into three-layer structures. But when the layout of the components is required to be very compact, the two-layer structures will still be too massive.

In this paper, the concept of interdigital capacitors has been introduced to the design of two-layer HIPs. The connection of two adjacent elements creates an interdigital structure, which results in a larger fringe capacitor; hence, a very compact HIP can be obtained for much lower frequencies. The effective-circuit model is used in the design procedure. Several samples have been manufactured and the measured propagation parameters of the surface wave have been given. The measured results show that this new type of HIP is prospectively useful for realizing more compact size.

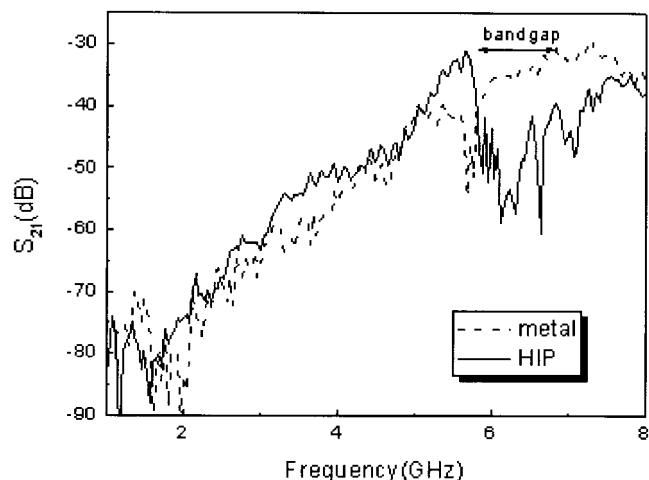


Figure 2 Measured S_{21} of the TM surface wave of C-HIP 1

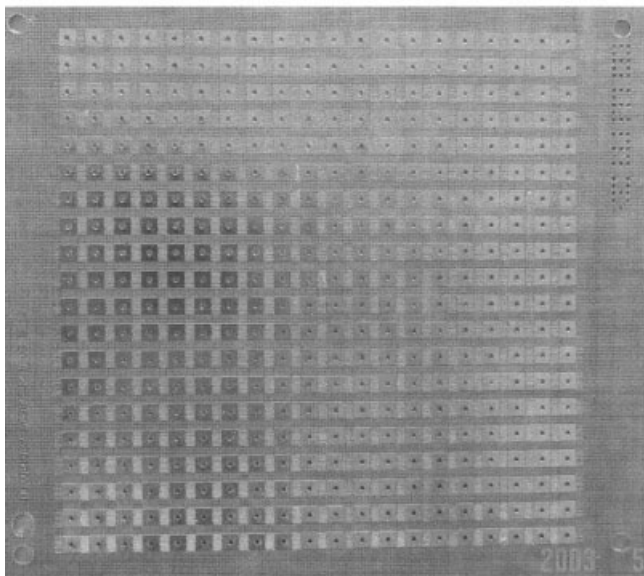
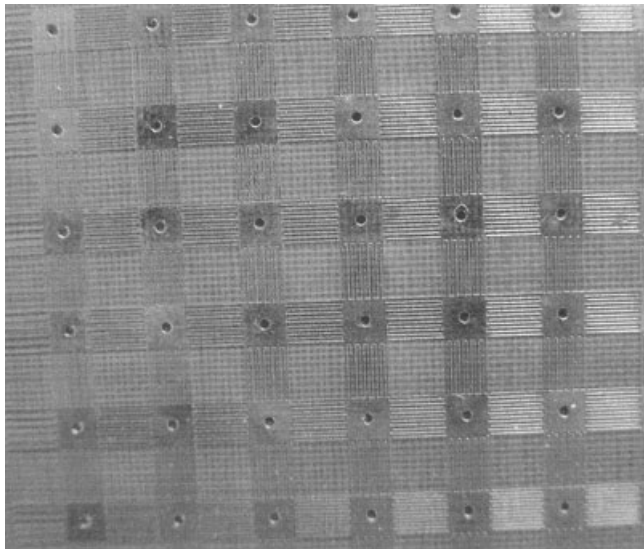


Figure 3 Photographs of two ID-HIPs: part of ID-HIP 1 (top) and the whole view of ID-HIP 2 (bottom)

2. EFFECTIVE CIRCUIT MODEL

The proposed HIP structure is given in Figure 1(b), together with the conventional HIP structure in Figure 1(a). The two-layer HIP has been successfully designed using the effective-circuit model [2]. But it will still be too massive in some applications. For example, when the HIP is used in a handset system, the system volume is very small and only two or three periods can be used. The resonant frequency is determined by $\omega_0 = 1/\sqrt{LC}$. It can be seen that a more compact HIP can be obtained by increasing the capacitor or the inductance. Once the material is chosen, the inductance is not easy to change (for $L = \mu t$, where μ is the permeability and t is the thickness of the material). However, the capacitor can be changed with the geometry of the periodic elements. For the purpose of enhancing the coupled capacitor, the concept of an interdigital capacitor is adopted.

The periodic cell is not a square patch in this structure. Its branches cross over the neighboring ones to construct an interdig-

ital capacitor [7]. We call this an interdigital HIP (ID-HIP) structure. The value of this interdigital capacitor, is obtained as in [8]. This interdigital capacitor is based on the model of two parallel metal plates with finite width, given by

$$C = \frac{(\epsilon_r + 1)\epsilon_0 K(k)}{2K(k')} (N - 1)l,$$

where w is the width of the finger, s is space, N is the number of the fingers, and l is the length of the fingers. $k = \sqrt{(a + b)^2 - a^2}/(a + b)$ with $a = s/2$, $b = (w + s)/2$, and $k' = \sqrt{1 - k^2}$.

$K(x)$ is the first-order complete elliptical integral and ϵ_r is the relative permittivity of the substrate.

3. RESULTS AND DISCUSSION

A conventional HIP is designed for comparison. The substrate is 1.5-mm thick with relative permittivity 2.65. The length of the square patch is $W = 7$ mm, and the periodic spacing is $a = 7.3$ mm. A 27×27 array is manufactured. To measure the bandgap characteristic, two probes are used to excite and receive surface waves. The probe is perpendicular to the surface; thus, TM surface waves are excited predominantly. An Advantest R3767CG vector network analyzer is used. The measured result is given in Figure 2. The transmission over a flat metal plate is measured as well. From the measured results, the bandgap is found to be 5.3–6.4 GHz.

An ID-HIP with the same periodic spacing as the above conventional HIP is designed for comparison. For a maximum capacitor, the finger width and space width should be equal. Based on this rule, an ID-HIP with 11 fingers is designed. The finger and space widths are both 0.15 mm, and the finger is 4-mm long. The square patch is then 3.15-mm long. The substrate on which the ID-HIP is printed is 1.5-mm thick with relative permittivity of 2.65. Thus, in an array layout, the periodic spacing will be 7.3 mm, which is the same as that of the conventional HIP, except for the geometry structure. A 15×15 array is fabricated and measured. A photograph of one part of the structure is shown in the top half of Figure 3. The measured result is given in Figure 4. The bandgap range is from 3.15 to 3.91 GHz, which is much lower than that of the conventional HIP with the same periodic spacing. Hence the new type of HIP structure will be very compact, thus saving more than 40% of volume.

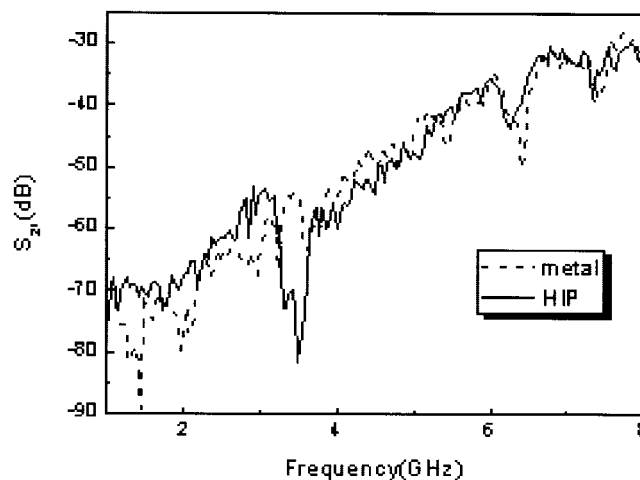


Figure 4 Surface impedance and measured S_{21} of the TM surface wave of ID-HIP 1

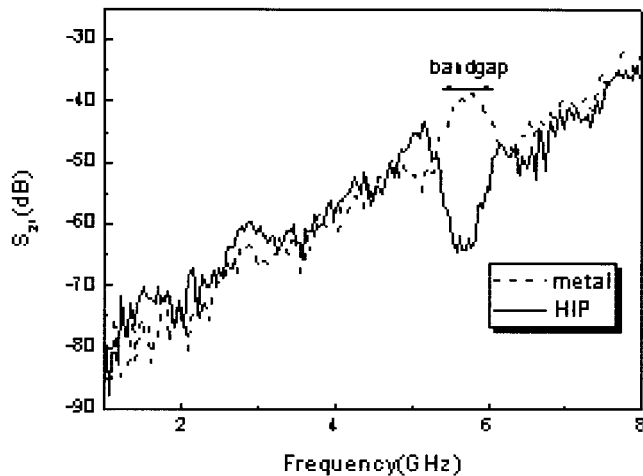


Figure 5 Surface impedance and measured S_{21} of the TM surface wave of ID-HIP 2

Another ID-HIP is also designed to verify the conclusion. The finger and space widths are 0.1 mm each, the finger length is 1.5 mm, and the finger number is 13. The substrate on which the structure is printed is 1.5-mm thick with relative permittivity of 2.65. The array spacing is 4.2 mm and the resonant frequency will be 5.82 GHz. A 20×20 array is fabricated, and a photo of the whole structure is shown in the bottom half of Figure 3. According to the measured result, the bandgap is from 5.7 to 6.8 GHz. For a conventional HIP with periodic spacing of 4.2 mm (with $w = 4$ mm and $g = 0.2$ mm), the resonant frequency will be 9.35 GHz. Thus, the ID-HIP is 30% smaller than conventional HIP.

4. CONCLUSION

A novel high-impedance structure with interdigital elements has been presented. The interdigital elements are regarded as an interdigital capacitor in order to enhance the coupling effect of the adjacent elements. The design formula for an effective-circuit model has been given and two examples have been manufactured. The measured results show that the size of the high-impedance surface has been dramatically compressed, as compared to that of the conventional structure. This novel type of high-impedance surface will be valuable in practical applications such as circuits and antennas.

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DESIGN OF DUAL-BAND ANTENNA FOR THE ISM BAND USING A BACKED MICROSTRIP LINE

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ABSTRACT: In this paper, we propose a new dual-band antenna for applications of the ISM band. The proposed antenna is designed to operate at 2.4 and 5.8 GHz. The lower-frequency band (2.4 GHz) can be obtained by using the meandering technique, and the upper-frequency band (5.8 GHz) for dual-band operation was achieved by embedding a backed microstrip line. Details of the proposed antenna design and experimental results are presented and discussed. The measured radiation patterns at 2.4 and 5.8 GHz and antenna gain across the respective frequency bands are also presented. © 2004 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 41: 457–460, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20170

Key words: dual-band antenna; ISM band; meandering technique; backed microstrip line

1. INTRODUCTION

The meandering technique has been widely used in mobile-communication applications due to its compactness, and various geometries for single and multi-band operations have been investigated [1–3]. A ceramic-chip antenna using meander lines has been designed, fabricated, and measured [1] and an adjacent conducting plane has been used to increase the impedance bandwidth. Using a triangular-shaped meander line and two coupled lines, a novel, compact, monopole antenna suitable for triple-band operation at 900, 1800, and 2450 MHz has been studied in [2]. In [3], four kinds of techniques were applied to the proposed antenna in order to minimize the antenna size while retaining high gain, thus obtaining the features of small size and high gain.

In this paper, we propose a new dual-band antenna for ISM-band applications (2.4/5.8 GHz). The proposed antenna consists of a meander line and backed microstrip line. The lower-frequency band (2.4 GHz) can be obtained by using the meandering technique [1] and the upper-frequency band (5.8 GHz) for dual-band operation was achieved by embedding a backed microstrip line (see Fig. 1). By changing the backed microstrip line's width, length, and position, the antenna can be tuned to operate at the desired operating frequencies with good impedance matching. Investigations based on experiments and simulations were conducted. The simulation was performed using the commercially available simulation software CST Microwave Studio. The proposed antenna has been successfully implemented and the simulated results agree reasonably well with the measured results. In this design, 12% and 13.3% impedance bandwidths for $VSWR <$