PBG Structures for Microstrip Circuits

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Introduction

Photonic band-gap (PBG) structures are periodic structures in which propagation of certain bands of frequencies is prohibited [1]. Original PBG research was done in the optical region [2], but PBG properties are scalable and applicable to a wide range of frequencies. Recently, there has been an increasing interest in microwave and millimeter wave applications of PBG structures. In the microwave region, PBG structures have been used to improve radiation pattern of antennas [3], and to design reflectors [4], broadband absorbers, and frequency selective surfaces.

In this paper, two PBG structures that are compatible with microstrip circuits are investigated. First is a dielectric PBG structure based on drilling of a periodic pattern through the substrate [5]. Second is a new PBG structure that requires only partial etching of the ground plane, which is compatible with monolithic circuit technology [6]. The experimental results of this newly proposed structure show wider and deeper stopbands than the PBG with the holes in the dielectric.

Also, the dielectric PBG is incorporated in a microstrip power amplifier in order to increase its output power and power added efficiency (PAE) [7]. Load impedances for the fundamental and harmonics are typically optimized to maximize the PAE and/or output power. Conventionally several techniques exist for harmonic termination. The tuning of the second harmonic is usually done by adding a short circuited stub approximately one quarter wavelength long at the fundamental frequency at the output [8]-[9]. A similar stub is used for tuning the third harmonic. In the active antenna approach, harmonics can be tuned using the input impedance of the antenna [10]-[11]. Unfortunately, all of these techniques are narrowband. In this work, PBG is used to tune second harmonic and to design the broadband power amplifier.

PBG Based on Drilling Holes

The first PBG structure selected is a 2-D honeycomb lattice with circular holes around 50 Ω microstrip line [5], as shown in Fig. 1. The substrate used is RT/Duroid 6010 with dielectric constant of 10.5 and 50 mil thick. The period is 250 mil and hole radius is 50 mil. This is a 2-D PBG structure, but because the fields in the microstrip line are concentrated near the line only one row of cells is necessary. It was fabricated by drilling the holes through the substrate and then adding copper tape onto the ground plane.

This structure is compared to 50 Ω microstrip line without PBG holes. Both structures were fabricated and measured using HP 8510 Network Analyzer. Fig. 2 shows (a) FDTD simulated and (b) measured results for reflection S_{11} and transmission S_{21} coefficients for PBG microstrip line. A relatively broad stopband is observed in both FDTD simulation and measurement. The peak of the stopband is at 9.07 GHz for FDTD and at 8.91 GHz for measurement.

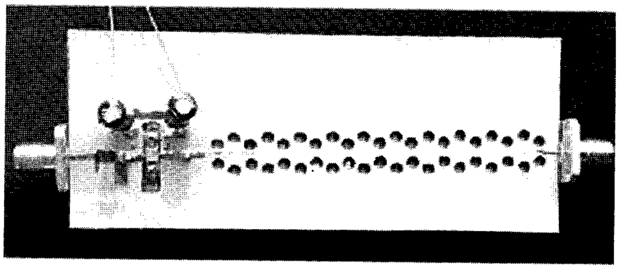
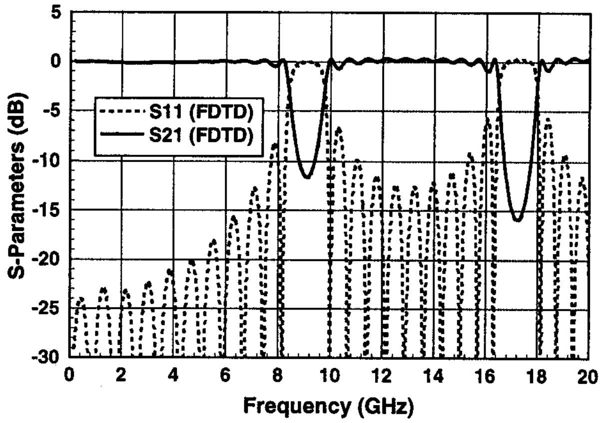
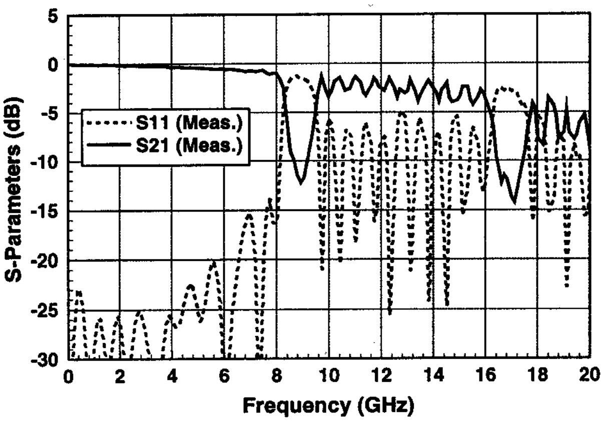


Fig. 1: Photograph of power amplifier showing the PBG structure incorporated at the output.



(a)



(b)

Fig. 2: (a) FDTD simulated and (b) measured S-parameters for the PBG line shown in Fig. 1.

Power Amplifier Design and measurement

Two class AB amplifiers were designed using Hewlett Packard's Microwave Design System(MDS) [12]. The device used was the MicroWave Technology MWT-8HP power GaAs FET. The large signal model of this device (which was in the MDS's nonlinear library) and harmonic balance simulation including the first three harmonics were used in the design. The drain voltage is 5 V, while the gate is biased so that the quiescent drain current is 10% of I_{DSS}. The microstrip line with and without the PBG were incorporated into MDS simulation as two port devices containing the measured S-parameter data from 0.13-26GHz. The input matching consists of double stub tuner and chip capacitor. The output match has a transmission line, chip capacitor and either PBG or 50 Ω transmission line.

Fig. 1 shows the amplifier with PBG structure. A comparison amplifier was also fabricated, and a simple 50 Ω microstrip line of the same length as the PBG line was connected at the output. Fig. 3 shows the measured and simulated (MDS) PAE for both amplifiers. The measured PAE is above 40 % from 4.4 to 4.8 GHz (9 % bandwidth) for the PBG amplifier, and 4.5 to 4.8 GHz (6 % bandwidth) for the reference amplifier. The maximum measured PAE is 51 % for output power of 23.7 dBm at 4.6 GHz for the PBG amplifier. Fig. 4 shows the measured output power for both amplifiers. An increase of at least 0.3 dB in the measured output power throughout the frequency band of interest is demonstrated.

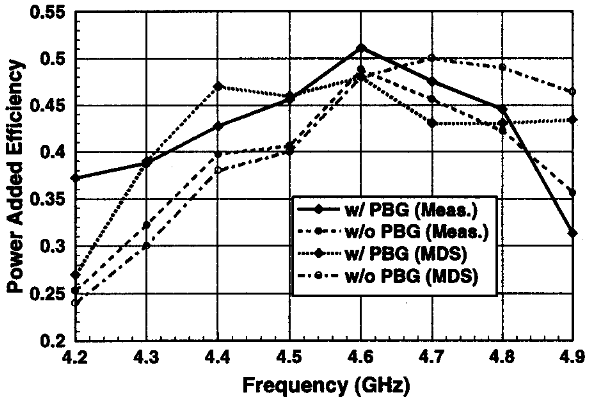


Fig. 3: Measured and theoretical (MDS) power added efficiency versus frequency for both amplifiers. "w/ PBG" means that the second harmonic is tuned using the PBG structure shown in Fig. 1.

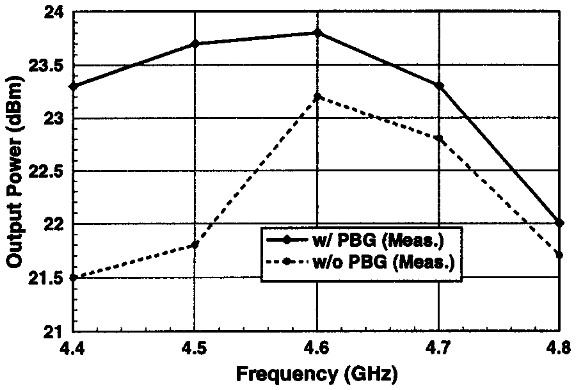


Fig. 4: Measured output power versus frequency for both amplifiers. "w/ PBG" means that the second harmonic is tuned using the PBG structure shown in Fig. 1.

PBG Based on Etching

The next investigated PBG structure has a 2-D square lattice with circles etched in the ground plane of a 50 Ω microstrip line [6], as shown in Fig. 5. The substrate used is RT/Duroid 6010 with dielectric constant of 10.5 and 25 mil thick. The period, *a*, was kept constant to 200 mil and the circle radius was varied. Only three rows of cells are necessary because the fields in the microstrip line are concentrated near the line. A conductor width of 27 mil was used, corresponding to 50 Ω line for conventional microstrip.

In order to investigate the stopband effect of the newly proposed PBG structure, three circuits were fabricated with circles of different radii. Measured results for reflection S_{11} and transmission S_{21} for all three circuits are shown in Fig. 6 (a)-(c). In all three cases the stopband is about 11 GHz. In general, the stopband center frequency f_0 is a function of the period of the structure [1]. Particularly, the guided wavelength at f_0 is twice the period *a*. Unfortunately, the propagation constant is not easily determined for the structure shown in Fig. 5, and full wave analysis is necessary to accurately characterize PBG structure. However, for small values of r/a the stopband center frequency can be assessed by using the propagation constant of the unperturbed microstrip. Based on previous research, depth and bandwidth of the stopband depend on the circle radius and number of periods [13]. The number of periods is kept constant for all circuits.

For smaller circle radii the stopband is very small, as shown in Fig. 6(a). In the limiting case $r \to 0$ (or $r/a \to 0$) there is no stopband, and the structure is a standard microstrip line. As the circle radius is increased the stopband becomes more distinctive. A trade-off is that for very large r/a factor the ripple in the passband is also increased, as shown in Fig. 6(c). Fig. 6(b) shows the S-parameters for an optimized PBG structure ($r/a=0.25$), with significant stopband depth and small passband ripple in S_{11}. Addition of the reflected and transmitted power with the metal and dielectric losses shows a low radiation level from the ground plane.

Another important design issue is the ability to bend the microstrip line to increase circuit design flexibility. A compensated right-angle microstrip bend with circle radius of 50 mil and period $a=200$ mil was fabricated. The etched circles on the ground plane follow the right-angle bend. The S-parameters for the PBG bend are shown in Fig. 7. The stopband is slightly reduced compared to that of the straight line with PBG, but shows almost identical PBG properties, as seen in Fig. 6(b). As demonstrated in Fig. 2 FDTD can be expected to analyze this periodic structure quite accurately.

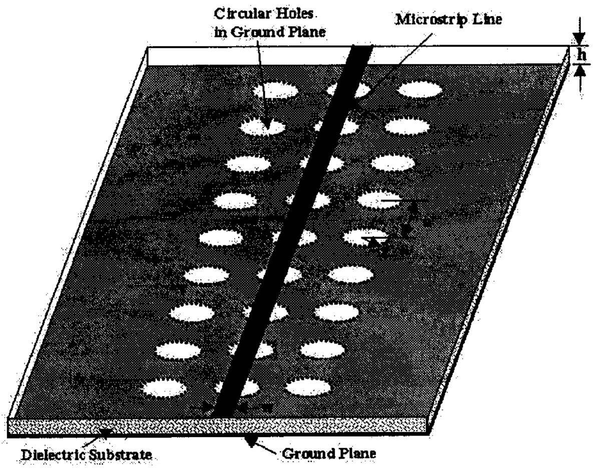
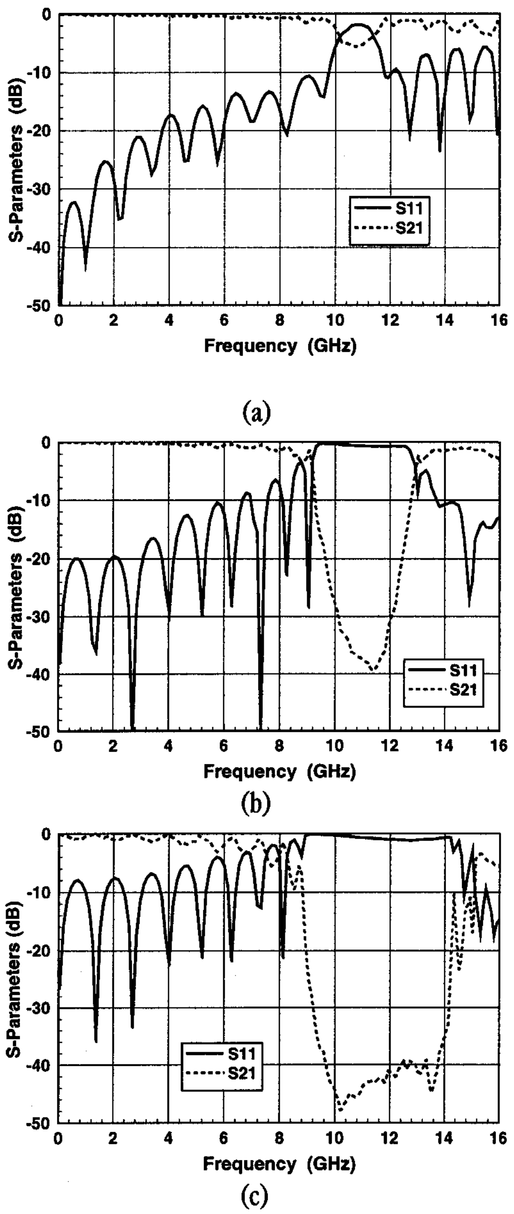


Fig. 5: Three dimensional view of the new PBG structure. The square lattice circles are etched in the ground plane of a microstrip line.



(a)

(b)

(c)

Fig. 6: Measured S-parameters for the PBG microstrip transmission line. The ground plane has a square lattice with 3×9 etched circles. The hole radius is (a) $r = 25$ mil, (b) $r = 50$ mil, and (c) $r = 90$ mil. The period is 200 mil for all cases.

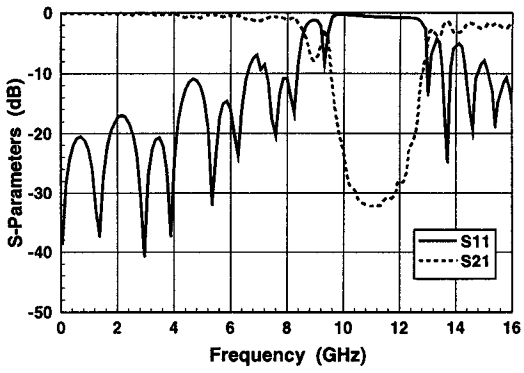


Fig. 7: Measured S-parameters for the compensated right-angle microstrip bend on the PBG structure with circle radius $r = 50$ mil and period $a = 200$ mil.

Conclusion

We investigated two 2-D PBG structures which are compatible with microstrip circuits. The first PBG structure is based on drilling hole in the microstrip substrate, and the second is based on etching a 2-D periodic pattern on microstrip ground plane. The second PBG structure is simpler to fabricate and has larger stopbands than the method based on drilling holes through the dielectric substrate.

We have also demonstrated a novel class AB GaAs FET power amplifier which incorporates the dielectric PBG structure to terminate the second harmonic. A 5 % improvement in PAE was measured at the center frequency of 4.5 GHz compared to the reference amplifier. Increase of over 0.3 dB in output power was measured over 9 % frequency bandwidth.

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