In addition, a connection metal line of 1 mm width was printed between the two side-feeds. This connection metal line mainly serves as a delay line in the proposed antenna to provide a 90° phase difference between the two side-feeds. This desired phase difference can be obtained by adjusting the distance (1.5 mm in this study) between the connection metal line and the ground conducting patch in the proposed design. Also notice that two small notches were cut near points A and B in the ground conducting patch to avoid the short-circuiting of the two side-feeds to the ground.

To excite the proposed antenna with right-hand CP operation for GPS operation, a 50 Ω microstrip feed line printed on the test circuit board is connected to the side-feed at point A. In this case, the side-feed at point A will have a 90° phase lead, as compared to the side-feed at point B. This condition can lead to successful excitation of two orthogonal resonant modes of equal amplitudes and 90° phase difference for right-hand CP operation. Also note that, if left-hand CP operation is desired for some other applications, the microstrip feed line can be connected to the side-feed at point B. In this case, the side-feed at point A will have a 90° phase lag, as compared to the side-feed at point B, thereby making possible the generation of a left-hand circularly polarized wave.

3. EXPERIMENTAL RESULTS AND DISCUSSION

A prototype with the design dimensions shown in Figure 1 was constructed and studied. Figure 2 shows the measured return loss of the constructed prototype. An impedance bandwidth, determined by 10 dB return loss, of 12 MHz (1570–1582 MHz) centered at about 1575 MHz is obtained. In addition, there are two resonances excited at very close frequencies, which are contributed from the excitation of the two side-feeds in the proposed design. Figure 3 shows the measured axial ratio in the broadside direction of the constructed prototype. A 3 dB axial-ratio CP bandwidth of about 3.5 MHz is obtained, which covers the required bandwidths for GPS operation at 1575 MHz. The measured radiation patterns in two principal planes at 1575 MHz are also plotted in Figure 4, and the measured antenna gain is shown in Figure 5. From the obtained results, good right-hand circularly polarized (RHCP) radiation is seen, and the measured antenna gain is about 3.0–3.4 dBi for operating frequencies across the 3 dB axial-ratio CP bandwidth.

4. CONCLUSIONS

A novel surface-mountable ceramic chip antenna for CP operation has been proposed, and a prototype for GPS operation at 1575 MHz has been implemented and studied. With the use of a square-disk ceramic chip having a relative permittivity of 45, the constructed prototype occupies a compact volume of 4 × 17.5 × 17.5 mm³ and demonstrates good CP radiation characteristics.

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AN ARRAY OF STAGGER-TUNED PRINTED DIPOLES AS A BROADBAND FREQUENCY SELECTIVE SURFACE

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Received 18 June 2002

ABSTRACT: In this paper, the frequency selective property of an array of rectangular dipole microstrip patches resonant at three different
frequencies (within the same frequency band) is investigated. Experimental data indicate a prominent band separation between transmission and reflection bands of the FSS in the normalized transmitted electric field vs. frequency plot. Investigation of the FSS of an array of rectangular dipole microstrip patches resonant at a single frequency shows that the bandwidth of the reflection band is very narrow. In our present investigation resonance at triple frequencies within the same frequency band is used to broaden the bandwidth of the reflection band.

**DESIGN OF THE FSS**

The dipoles resonant at 8.7 GHz, 10 GHz, and 11.3 GHz are spaced alternately in a row and these rows are repeated to form the two-dimensional array. Area of the dielectric slab was 120 mm × 120 mm. Its dielectric constant was 2.4. The FSS was designed in such a way that it may resonate at the frequencies of 8.7 GHz, 10 GHz, and 11.3 GHz. At these frequencies the corresponding free space wavelengths are 34.48 mm, 30 mm, and 26.55 mm. Hence the lengths of the rectangular dipoles were made equal to 17.24 mm, 15 mm, and 13.27 mm (half wavelength). The breadth of each dipole was always made to be one-tenth of its length. Three types of dipoles were placed one after another in a row, and five rows were similarly fabricated. The spacing between any two dipole patches was so chosen that the rule governing a conventional array antenna be maintained. Grating lobes appear when spacing between two adjacent patches becomes electrically large. A general rule is that the spacing between adjacent patches should be less than one wavelength for the broadside-incident case (0° incident angle) [11]. Here the spacing between three adjacent patches in a row was 6.63 mm and the spacing between adjacent patches in a column was 6.63 mm. All the dimensions are shown in Figure 1.

**MEASUREMENT**

Transmission tests for the FSS (Figure 1) were performed at X-band. Measurements have been made in the frequency range of 8 GHz to 13 GHz with an interval of 0.2 GHz. From these measured data, normalized transmitted electric field vs. frequency was plotted as shown in Figure 2.

**CONCLUSION**

The experimental results show that the maximum transmission through the FSS occurs at the frequencies of less than 8.0 GHz and above 13 GHz 10 dB reflection from the FSS occurs at the frequency range of 9.3 GHz to 12.6 GHz, i.e., reflection bandwidth is 3.3 GHz considering 10 dB reflection. If we consider frequencies at 15 dB and 20 dB reflection, the reflection bandwidth will be 2.3 GHz and 1.7 GHz, respectively.

**REFERENCES**

APPLICATION OF AN OPTICAL BIREFRINGENCE INTERFEROMETER TO PHOTOTHERMAL DETECTION

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Received 2 April 2002

ABSTRACT: In this paper a birefringence interferometer is used for detecting both change in reflectivity and surface deformation caused by photothermal effect or thermal waves excited by any other pump source. The instrument is very simple, with high immunity against noise and sensitivity. © 2002 Wiley Periodicals, Inc. Microwave Opt Technol Lett 35: 140–143, 2002; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.10540

Key words: birefringence; interferometer; photothermal detection

1. INTRODUCTION

Analyzing and detecting thermal waves are often used to characterize important optical, thermal, and elastic properties of materials. A number of methods for the detection of the thermal waves have been established. Rosenzcwaig et al. [1] developed a method for detecting thermal waves by monitoring the change in the surface reflectivity of a sample caused by the change in the temperature of the sample. Royer et al. [2] and Cho et al. [3] presented an optical heterodyne technique utilizing Bragg effect for photoacoustic and photothermal detection. Chen et al. [4] introduced an improved Jamin interferometer which is more suitable for detecting strongly light-scattering samples. Using a Twyman–Green interferometer and videography, Power [5] developed an advanced video thermal wave imager to obtain the transmission thermal wave image. Each method has its intrinsic characteristics and inadequacies, some of them are complicated and difficult to build and apply. In order to synthesize and improve the interferometric systems, Kuo et al. [6] presented an optical birefringence interferometer for transmit medium, which used a natural birefringence as the beam splitting and recombining elements. Based on this novel system, a modified theoretical model for reflective detection of samples with opaque surfaces is described in this paper. According to this model, both the change of the reflectivity and the displacement of the sample surface can be detected and evaluated.

2. THEORY

To excite thermal and elastic waves in a material, a heating beam from Ar ion laser is modulated by an acousto-optic modulator at frequency \( \omega \) and initial phase angle \( \phi \). The displacement \( \varepsilon \) in the surface of the sample induced by the heating beam can be expressed as:

\[
\varepsilon = \varepsilon_0 e^{-i(\omega t + \phi)},
\]

where \( \varepsilon_0 \) is the amplitude of the displacement at the sample's surface.

When a material is illuminated by the heating beam, the optical properties such as the reflective index of the material will be changed. According to studies of Rosenzcwaig et al. [1], the change of the reflectivity can be used to detect thermal waves, and then to characterize the properties of materials. Therefore, in addition to the displacement, the change of the reflectivity should be considered in the interferometer measurements when the reflective mode is used.

The optical birefringence interferometer using natural birefringence crystals (calcites) as the beam splitting and recombining elements is shown in Figure 1, in which the \( Y \) axis is parallel to the surface of the first calcite and horizontal line, the \( Z \) axis is along with the central light of incident beam. A linearly polarized convergent laser beam is used to pass through a natural calcite plate with thickness \( d \) and fast axis at \(-3\pi/4\) against the \( X \) axis. The birefringence causes the e-ray and o-ray to be covered into two separate but nearby focal points. When the two reflect beams pass through another identical calcite plate, which has the same thickness and the fast axis at \( \pi/4 \), the e-ray and the o-ray recombined as one beam. If the e-ray is used to detect a change of optical length \( \delta \) which is induced by a thermal or elastic wave, the o-ray is used as a reference beam, then the \( \delta \) is:

\[
\delta = 2 \sin(\beta) \varepsilon_0 e^{i(\omega t + \phi)},
\]  

\( \beta \) is the tilted angle of the incident beam against the surface of the sample. Set \( \delta_0 = 2 \sin(\beta) \varepsilon_0 \), the optical distribution \( b(\delta) \) in the interferometer will be:

\[
b(\delta) = m(-3\pi/4, d) g(\pi/4, \delta) m(\pi/4, d)
\]

\[
= \frac{1}{2} e^{-ik_x \delta} \left( 1 + C e^{-ik_0 \delta}, \quad 1 - C e^{-ik_0 \delta} \right),
\]

where \( k_x \) and \( k_0 \) are wave numbers of e-ray and o-ray, respectively. In \( C = 1 + (\Delta R/R_m) e^{i(\omega + \phi)}, \Delta R \) is the change of the reflectivity and \( R_m \) is the sample reflectivity at the initial temperature. \( m(-3\pi/4, d) \) and \( m(\pi/4, d) \) are the matrix expressions of e-ray and o-ray distributions in two nature calcites, respectively; \( g(\pi/4, \delta) \) is the phase shift in spatial distribution in the natural calcite setup.

For a linearly polarized semiconductor laser beam with the polarization angle \( \alpha \) against the fast axis of the first calcite and the field intensity \( E \), the output field intensity of the interferometer is:

\[
(E_1, E_2) = E [\cos(\alpha), \sin(\alpha)] + b(\delta),
\]