Bandwidth of a Circularly Polarized Patch Antenna with a Shallow Pit

Takao MURATA and Kenji OHMARU
NHK Science and Technical Research Laboratories
1-10-11, Kinuta, Setagaya-ku, Tokyo 157, Japan

1. Introduction

A flat panel antenna consisting of microstrip antenna arrays has gradually been introduced for the reception of satellite broadcasting.

At present, however, flat panel antennas have a lower antenna efficiency caused by feeder loss than that of parabolic reflector antennas. Moreover, flat panel antennas, when used in a circularly polarized antenna system, do not have a sufficient axial ratio over the bandwidth of satellite broadcasting.

To solve these problems, we have proposed a two-layer structured patch antenna with a shallow pit, to minimize the feeder loss in flat panel antennas.[1]

This paper, following up our previous proposal, will present the impedance characteristics and axial ratio of a dual-feed circularly polarized patch antenna. Also, it will prove that impedance characteristics can be improved by adding a shallow pit under the patch.

2. Impedance Characteristics of the Patch Antenna with a Shallow Pit

The impedance characteristics of patch antennas have a wider bandwidth as the substrate thickness increases, as many reports have pointed out. However, as the substrate becomes thicker, spurious radiation increases at discontinuites in the feeder line such as T-junction, bends and impedance transformers, resulting in low antenna efficiency. Concerning this problem, our previous paper stated that the optimum substrate thickness for the highest antenna efficiency was somewhere between 0.4 mm and 0.6 mm.

On the other hand, a patch antenna made of such a thin substrate will have a narrow impedance bandwidth. According to the modal-expansion cavity analysis, the input impedance of the edge-fed patch which is viewed as a TM_{10} mode cavity with magnetic walls is given by [2]

$$Z_{in} = jX_L - \frac{j\,(\omega / C_{10})}{\omega^2 - (\omega_r + j\,\omega_i)^2} \qquad (1)$$

where

$$(\omega_r + j\,\omega_i)^2 = \omega_{10}^2\,(1 + j/Q) \qquad C_{10} = C_{dc}/2 \qquad (2)$$

In this expression, Cdc is the dc patch cepacitance (=ε·a·b/h, ε : dielectric constant, a:patch width, b:patch length, h:substrate thickness), Q is the quality factor for the TM_{10} mode, and ω_{10} is the radian frequency at resonance. X_L is the series reactance which is caused by discontinuity of the substrate thickness in the two-layer structured patch. Fig. 1 shows the impedance characteristics of rectangular patches configured on an 0.787 mm thick substrate. In order to widen the bandwidth, we have added a pit under the patch, as shown in Fig. 2. In this structure, the substrate has a thickness which causes minimum loss at the feeder section and, has a thickness that equivalently increases with the pit depth to achieve a wide bandwidth at the patched portion.

Fig. 3 shows the input impedance characteristics of the patch with the Fig. 2 structure, calculated and measured. As seen in Fig. 3, the added shallow pit improves the voltage standing wave ratio (VSWR) from 1.8 to 1.4 over a 300MHz bandwidth of the 12 GHz satellite broadcasting band. In the impedance mesurements, the effect of the feed connector is removed by using the time domain capability of the network analyzer (HP 8510).

3. Axial Ratio of the Circularly Polarized Patch Antenna with a Shallow Pit

Circularly polarized patches are used as the elements for a flat panel antenna, since satellite broadcasts are transmitted on circularly polarized waves.

There are two types of feeding method on circularly polarized patch antennas, single feed and dual feed; the latter having a wider bandwidth on axial ratio. However ,in the case of single feed ,the microstrip pairs-element composed of a pair single-feed circularly polarized patches can widen the axial ratio bandwidth .[3] Dual-feed antennas are of two types: branching and hybrid. The hybrid type requires a large space for the feeder and a wider array interval, resulting in poor aperture efficiency. Therefore, we investigated the branching-type dual-feed patch antenna to widen its bandwidth.

Fig. 4 illustrates the configuration of the branching feed type circularly polarized patch antenna. A 90° phase difference is produced in a one-quarter wavelength phase-shifting line. However, when the patch input impedance diverts from the feeder's characteristic impedance, the one-quarter wavelength line works as a one-quarter wavelength impedance transformer and changes the ratio of the power separated at the branching point. The deterioration of axial ratio bandwidth caused by this is smaller as the patch antenna input impedance is of a wider bandwidth.[4] To improve the input impedance bandwidth of the patch antenna, we added a shallow pit under the patch.

In Fig.4, I_2 / I_1 of the branching-type dual-feed patch is given by

$$\frac{I_2}{I_1} = \cos\left(\kappa \cdot \frac{\lambda g}{4}\right) + j\,\frac{Z_s}{Z_{in}} \cdot \sin\left(\kappa \cdot \frac{\lambda g}{4}\right) \equiv a \angle \delta \qquad (3)$$

Where Zin is the input impedance of the patch, $k = 2\pi / \lambda g$, and Zs is the characteristic impedance of the 90° phase-shift line. The angle of inclination from a horizontal axis, τ of the elliptical polarization radiated from the patch is given by [5]

$$\tau = \frac{1}{2} \tan^{-1} \frac{2a\cos\delta}{1-a^2} \qquad (4)$$

and the axial ratio is given by

$$AR = \left\{ \frac{(a\sin\tau - \cos\tau)^2 + 2a\sin\tau\cos\tau\,(1+\cos\delta)}{(a\cos\tau - \sin\tau)^2 + 2a\sin\tau\cos\tau\,(1-\cos\delta)} \right\}^{1/2} \qquad (5)$$

Fig. 5 shows the calculated and measured axial ratios of an ordinary patch antenna and Fig. 6 those of a patch antenna with a shallow pit. The measured axial ratio over a 300 MHz bandwidth of an ordinary patch antenna is 3.5 dB, whereas that of the shallow-pit added patch antenna is improved to 2 dB.

Fig. 7 shows the caluculated and measured radiation pattern of the circularly polarized microstrip patch antenna with a shallow pit.

4. Conclusion

The patch antenna used in flat panel antennas for satellite broadcasting reception inevitably has narrow impedance and axial ratio bandwidth when feeder loss is minimized. To solve this, we have added a shallow pit under the patch so the impedance bandwidth becomes wider and the axial ratio characteristics are improved over a wide band.

References

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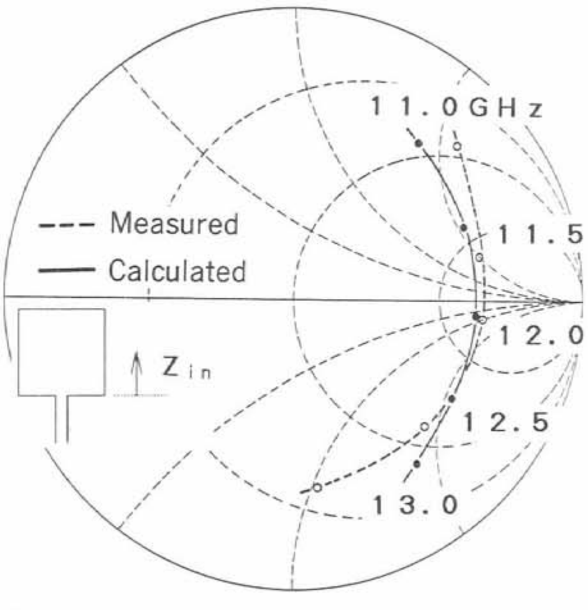


Fig. 1 Calculated and measured input impedance of ordinary microstrip patch.(h=0.787, εr=2.2)

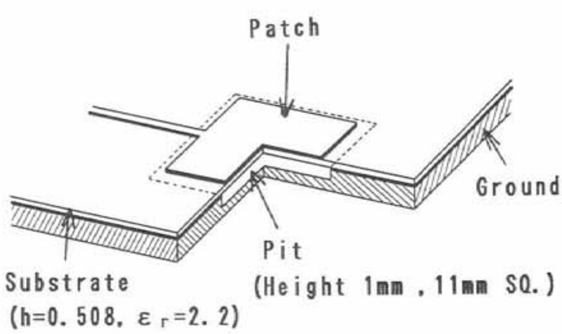
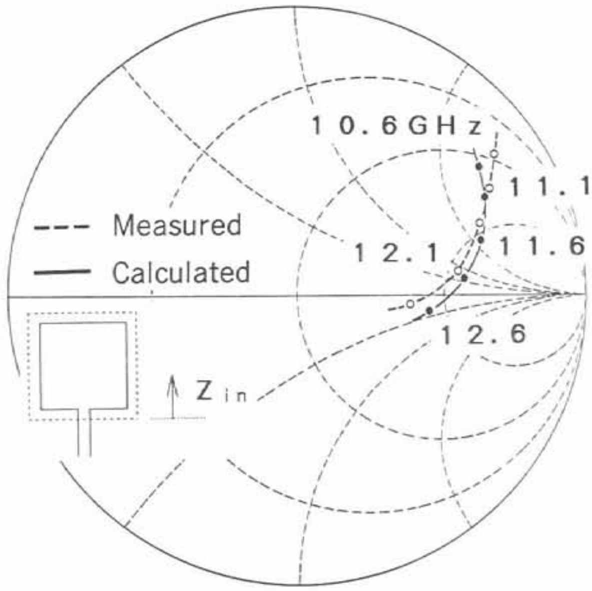


Fig. 2 Microstrip patch antenna with a shallow pit



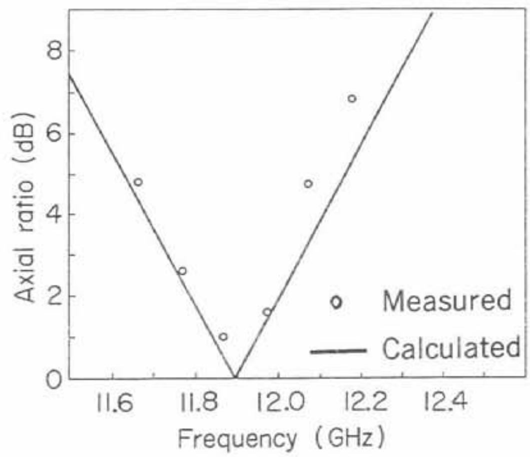
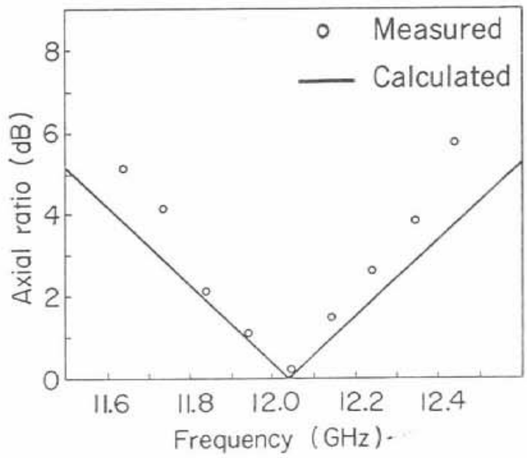


Fig. 5 Calculated and measured axial ratio of ordinary dual-feed microstrip patch antenna. (h=0.787, εr=2.2)

Fig. 3 Calculated and measured input impedance of microstrip patch with a shallow pit. (Substrate: h=0.508, εr=2.2, Pit: Height=1mm, 11mm SQ.)



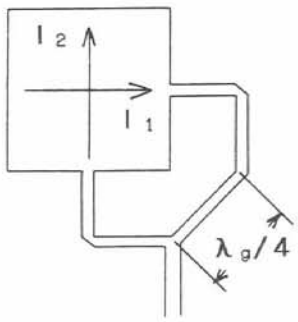


Fig. 4 Circularly polarized pach antenna with dual-feed.

Fig. 6 Calculated and measured axial ratio of microstrip patch antenna with a shallow pit.

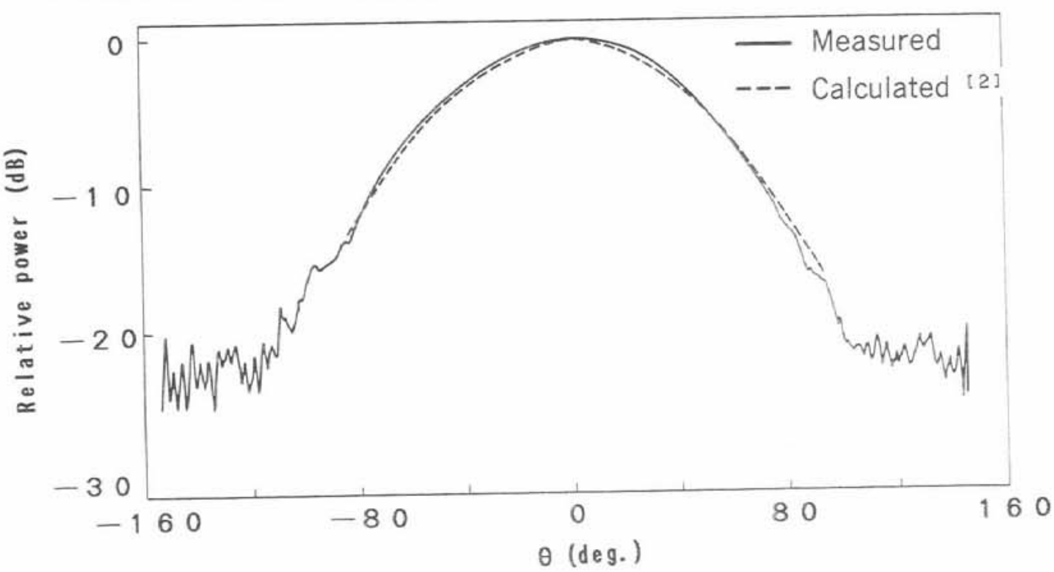


Fig. 7 Calculated and measured radiation pattern of circularly polarized patch antenna with a shallow pit.