GAIN IMPROVEMENT OF A MULTI-CHANNEL ARRAY ANTENNA

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1. Introduction

A multi-channel array antenna system which is composed of a variety of element antennas excited at different frequencies on the same aperture was suggested in order to improve the efficiency and reliability of the broadcasting satellite[1]. In such array antennas, the mutual coupling not only between element antennas excited at the same frequency but also between element antennas excited at different frequencies affect the antenna characteristics such as radiation pattern shape and gain. In this paper we investigate the reduction of the antenna gain caused by the latter mutual coupling and propose a means to improve the antenna gain and confirm its validity.

2. Multi-channel array antenna

Figure 1 shows the geometry of the multi-channel array antenna investigated here. This antenna consists of 4 array antennas (4 channels) excited at different frequencies on the same aperture. Each channel has 7 element antennas which are spaced with a triangular grid shown in Fig. 1. The element antenna is a circular microstrip antenna. The geometry and parameters of the element antenna are shown in Fig. 2 and Table1, respectively.

In this array antenna, when only a certain channel is excited, the field radiated from an element antenna couples not only to element antennas excited at the same frequency but also to element antennas excited at other frequencies. Since the distance between elements excited at different frequencies is closer as shown in Fig. 1, the latter mutual coupling causes a great deal of disturbance to the radiation pattern and leads to a reduction of the antenna gain.

When only a certain channel is excited, the radiation field including the mutual coupling effect can be expressed as follows:

$$\mathbf{E}(\theta,\phi) = \mathbf{e}(\theta,\phi)\sum_{m}\left\{\delta_{ml} + \sum_{n} S_{mn}\delta_{nl}\right\}e^{jk_0\mathbf{P}_m\cdot\hat{\mathbf{r}}} \tag{1}$$

where the index l denotes the excited element antenna, the indices m and n denote all element antennas, δ_{ml} is the Kronecker's delta, $\mathbf{e}$ is the radiation pattern of the isolated element antenna, k_0 is the free-space wave number, $\mathbf{P}_m$ is the position vector of the mth element, $\hat{\mathbf{r}}$ is the unit vector to the observation point and S_{mn} is the S-parameter from the nth element to the mth element. In this equation the first term is the primary field radiated from the excited channel. The second term is the coupling field radiated from the excited or non-excited channels, which can be assumed to be the same field as is transmitted to the connecting transmission lines by the mutual coupling when the element antennas are matched with them.

S-parameters in eq. (1) can be obtained from

$$[S] = \{[Z]/Z_0 + [U]\}^{-1}\{[Z]/Z_0 - [U]\} \tag{2}$$

where $[Z]$ is the impedance matrix of the above array antenna, Z_0 is the characteristic impedance of the connecting transmission line and $[U]$ is the unit matrix. Each element of the impedance matrix, self or mutual impedance, is given by[2][3]

$$Z_{ii} = \frac{2}{I_i I_i^*}\left\{\frac{-1}{2}\int_{S_i} E_z J^* dS + \text{copper loss}\right\} \tag{3}$$

$$Z_{ij} = \frac{1}{I_i I_j} \int_{S_j} \mathbf{H}_i \cdot \mathbf{M}_j dS \tag{4}$$

where S_0 and S_j are the surfaces on the feed pin and on the edge of the jth microstrip antenna, respectively. I_i and I_j are the input currents of the ith and jth element antenna. $\mathbf{M}_j$ is the equivalent magnetic current. E_z is the electric field inside the microstrip antenna and $\mathbf{H}_i$ is the magnetic field radiated from the ith element antenna.

$$E_z = \frac{j}{2} \omega \mu I \sum_{n=1}^{\infty} \frac{\cos n\phi}{A_n} \{ J_n(kr_<) J_n(kr_>) + A_n J_n(kr_<) N_n(kr_>) \} \tag{5}$$

$$\mathbf{H}_i = -\frac{j\omega\varepsilon_0}{2\pi} \int_{S_i} \left(\bar{\mathbf{I}} + \frac{\nabla\nabla}{k_0^2} \right) \frac{e^{-jk_0 R}}{R} \cdot \mathbf{M}_i dS \tag{6}$$

3. Reduction of Antenna Gain

Figures 3(a) and 3(b) show the calculated and measured radiation patterns when only the element antennas of the channel 1 in the above multi-channel array antenna are uniformly excited at 11. 85 GHz. In these figures, the dashed lines are for the case when the element antennas of other channels are removed and the solid lines are for the case when other channels exist and are terminated with matched loads. Thus the mutual coupling effect with different channels is included in the latter case. Note that the antenna gain at broadside is reduced by the mutual coupling.

4. Improvement of Antenna Gain

In this section, we propose a means to improve the above gain reduction. Figure 4 is the scheme for improving the antenna gain, and it shows that the coupling waves which are transmitted to the transmission lines connected with other channels by the mutual coupling are reflected with the phase θ and are again radiated from them. In this case, the total field radiated from this multi-channel array antenna consists of three vectors shown in Fig. 5, i.e. , 1) the primary field vector radiated from the excited channel, 2) the coupling field vector radiated from the excited and non-excited ones and 3) the reflected field vector radiated from the non-excited ones. The antenna gain can be improved by choosing the phase θ so that the reflection field vector is in phase with the composite vector of the primary field and the coupling field.

Figure 6 shows the relationship between the reflection phase θ and the relative broadside antenna gain compared with the non-improved one. The calculated result is in good agreement with the measured one. Note that about +2. 5dB gain improvement is achieved in the case of θ=240[deg.].

Figures 7(a) and 7(b) show the calculated and measured radiation patterns in the case of reflecting the coupling wave with θ=240[deg.]. For comparison the non-improved results are also plotted. Note that about +2. 5dB gain improvement at broadside has been achieved by the above improvement method.

5. Conclusion

This paper has quantitatively investigated the gain reduction caused by the mutual coupling in the multi-channel array antenna which is composed of a variety of element antennas excited at different frequencies on the same aperture. The means to improve this gain reduction was proposed by reflecting the coupling wave with the adequate phase and its validity was confirmed.

References

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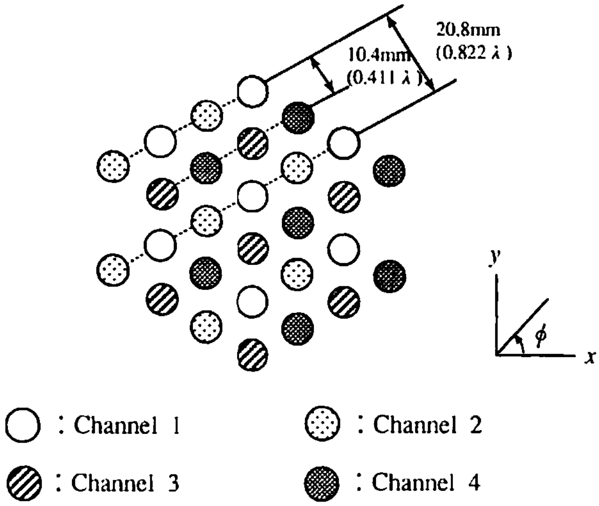


Fig.1. Geometry of the multi-channel array antenna.

Table 1
Parameters of the element antenna.

Element antenna	Circular MSA
Resonant frequency f	11.85GHz
Radius of patch a	4.3 mm
Thickness of substrate d	0.6 mm
Feed point r_0	1.85 mm
Feed point angle ϕ_0	90 deg.
Thickness of patch t	0.018 mm
Diameter of feed pin r_f	0.15 mm
Relative Permittivity of the subtrate ε_r	2.6

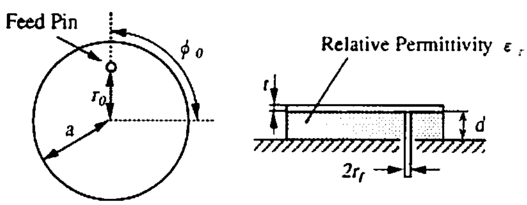
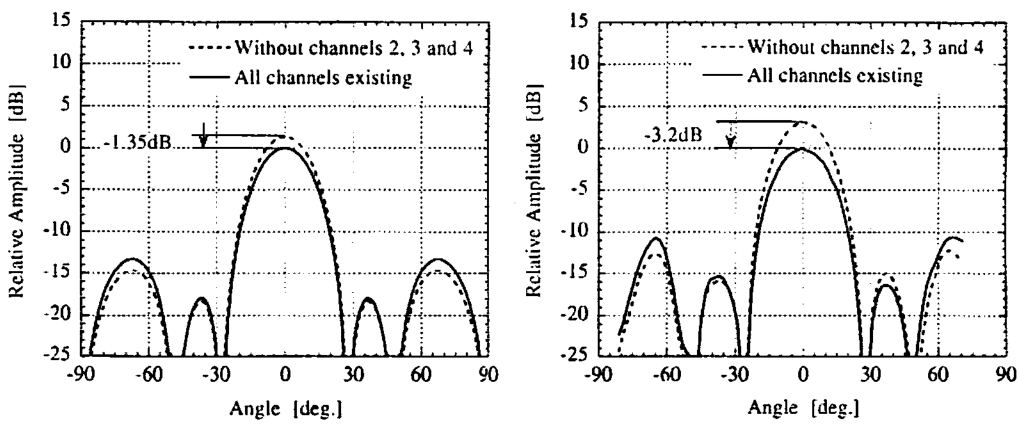


Fig.2. Geometry of the element antenna.



(a)Calculated (b)Measured

Fig.3 H-plane radiation patterns when exciting channel 1.

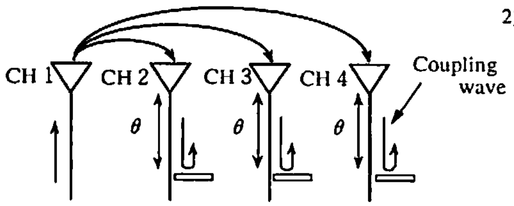


Fig.4. Scheme for improving the antenna gain.

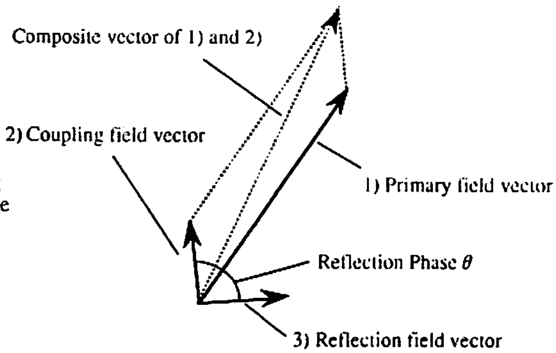


Fig.5. Radiation field vector.

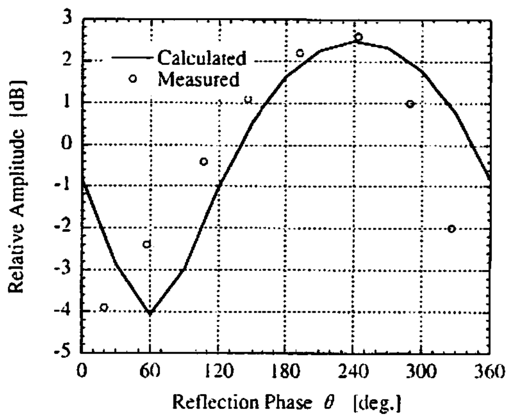
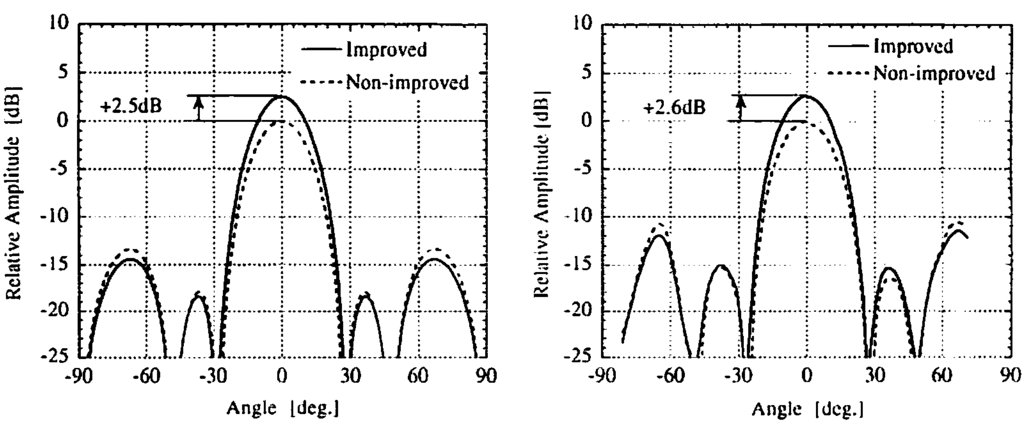


Fig.6. Relative antenna gain at broadside.



(a)Calculated (b)Measured

Fig.7. Radiation patterns after gain improvement.