Phased Array Active Loop Antenna for Digital Television Receiver

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Introduction

Microwave antennas integrated with active devices have attracted much interest in the world of microwave and millimeter-wave communications, because of their low profile, light weight, easy fabrication and suitability to mass production [1]. The authors have analyzed the actual gains of active dipole and loop antennas for television receiver and reported their broadband operations [2], [3]. The actual gain of a receiving active antenna is expressed in terms of the transducer power gain of the amplifier circuit and the effective length of the passive antenna. Actual gains of active loop antenna are more than 3.5 dBd (relative gain to a half-wave dipole) for channels 1 -12, from 90 to 222 MHz, and more than 6.5 dBd for channels 13 - 62, from 470 to 770 MHz. The active loop antenna is comparable to the conventional 10-element Yagi-Uda antenna for channels 1 - 12 and the 16-element Yagi-Uda antenna for channels 13 - 62. However, in order to use it as the outdoor television reception antenna, its front-to-back ratio has to be improved.

In this paper, a phased array active antenna composed of two active loop antennas is proposed for the reception antenna of the digital television in Japan, will be planned to start at the frequencies from 470 MHz to 590 MHz in 2003. The high actual gain and front-to back ratio are reported.

Structure of active array antenna

Figure 1 shows the structure of phased array active antenna and DC equivalent biasing circuit. The feed point region of antenna element and CPW are printed on a polyimide film of thickness 45 μm. The relative permittivity of film is 3.5. The antenna element and CPW are covered by a film 50 μm thick for protection. The silicon transistor 2SC3604 is integrated at the feed point of the loop antenna. The characteristic impedance of CPW is chosen as 75 Ω for impedance matching to the coaxial feeder of the television receiver [2]. The CPW also serves as a bias supply line to the amplifier circuit. The available power gain of 2SC3604 is 24 to 18 dB at frequencies from 90 to 770 MHz. The self-bias circuit is adopted to suppress the undesired oscillation and to increase the stability. The output signals of two active antennas are added with different phase shifts $\phi 1$ and $\phi 2$.

Actual gain of active array antenna

The receiving antenna #i is expressed by series connection of the open-circuit voltage V_{oci} and the input impedance Z_{ini}. The amplifier circuit is represented by the scattering parameters.

The open-circuit voltage Voci is defined by the inner product of the effective length L_{ei} of the loop antenna and the incoming electric field E_o [4]:

$$V_{oci} = L_{ei} \cdot E_o, \qquad i=1, 2 \qquad (1)$$

The effective length of the receiving antenna is the same as that of the transmitting antenna [4]. The effective length L_{ei} of the transmitting antenna is expressed using the radiation field $E_i(r)$ at the distance r from the feed point as [5]

$$E_i(r) = \frac{jk\eta}{4\pi} \frac{\exp(-jkr)}{r} I_i(0) L_{ei} \qquad (2)$$

$$L_{ei} = \frac{1}{I_i(0)} \int_{\text{antenna \#i}} \left[[R \times i_r I_i(s')] \times R \right] \exp\left(iki_\rho \cdot R \right) ds' \qquad (3)$$

where $I_i(s')$ is the current distribution of antenna element #i. $I_i(0)$ is the feed point current of the antenna. In the numerical calculation, the mutual coupling between antenna elements are considered. η is the intrinsic impedance of free space, and R and i_ρ are the position vectors of the observation point and the source point, respectively. i_r is the unit vector along the antenna axis. The input impedance and radiation field of antenna element are calculated using the computer program WIPL developed by Kolundzija et al. [6]. In this program, Pocklington's integral equation is solved using Galerkin's method. The current expansion function and testing function are polynomials. In the calculation, antenna elements are approximated by wire antennas whose radii are $W_i/4$ (i=1, 2). Since the dielectric film is very thin, its existence is not considered.

In the measurement of the actual gain of active antenna, we used a standard half-wave dipole antenna as the reference of gain. Therefore the actual gain of the active antenna is defined as the ratio between the average power received by the active antenna and that received by the half-wave dipole antenna. The actual gain of antenna element #i is expressed as follows [3].

$$G_{ai} = \frac{|L_{ei} \cdot E_o|^2}{|L_{ei}^s \cdot E_o|^2} \frac{|S_{21i}|^2 |1 - \Gamma_{si}|^2}{|S_{21}^s|^2 |1 - \Gamma_{si} S_{11}|^2} \qquad (4)$$

where the superscript s denotes quantities related to the half-wave dipole antenna. Γ_{si} is the reflection coefficient at the input port of the amplifier toward the antenna #i.

Numerical and experimental results

Figure 2 show the calculated electric field receiving patterns in the horizontal plane. Figure 3 show the comparison between the calculated and measured receiving patterns in the horizontal plane. The phase shifts ϕ_1 and ϕ_2 in Fig. 3 are opposite phase to those in Fig. 2. The calculated patterns agree well with the measured data. Figure 4 shows the calculated actual gains of phased array active antenna. The actual gains are expressed in values relative to the half-wave dipole. Figure 5 shows the calculated front-to-back ratio of active array antenna. When the distance between two loop antennas is 30 cm, the actual gains of more than 13 dBd and the front-to-back ratio more than 8 dB are obtained for the digital television frequencies from 470 to 590 MHz.

Conclusion

The phased array active antenna composed of two active loop antennas has been proposed for
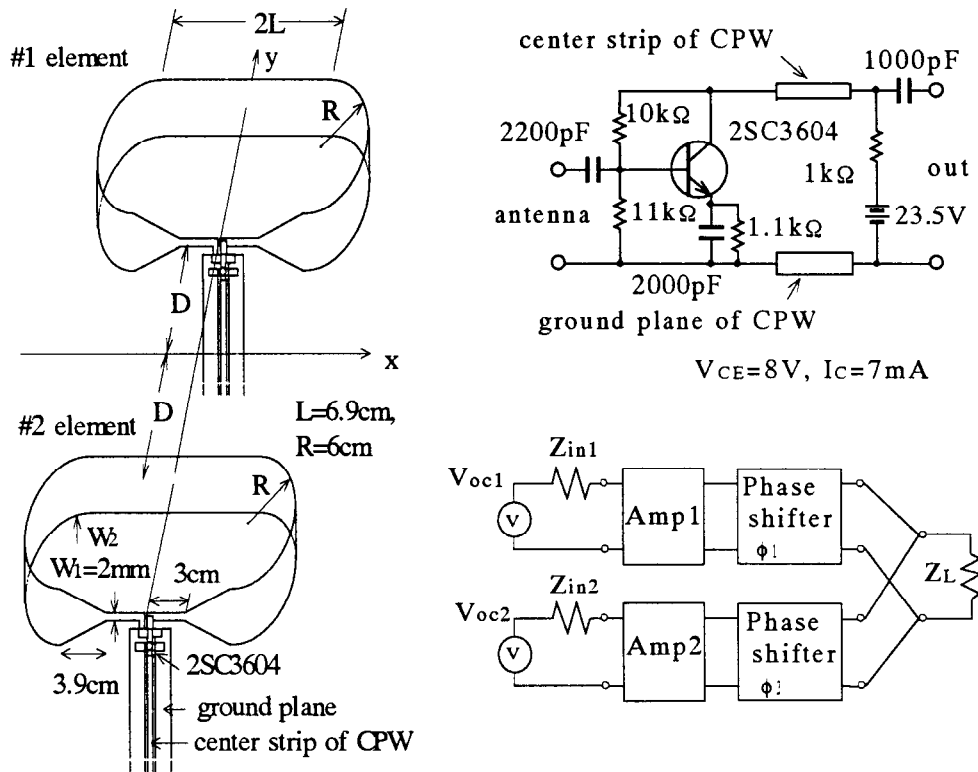
Fig. 1 Structure and equivalent circuit of phased array active antenna.

the reception antennas of the future digital television in Japan and its actual gain and front-to- back ratio have been analyzed.

Acknowledgment

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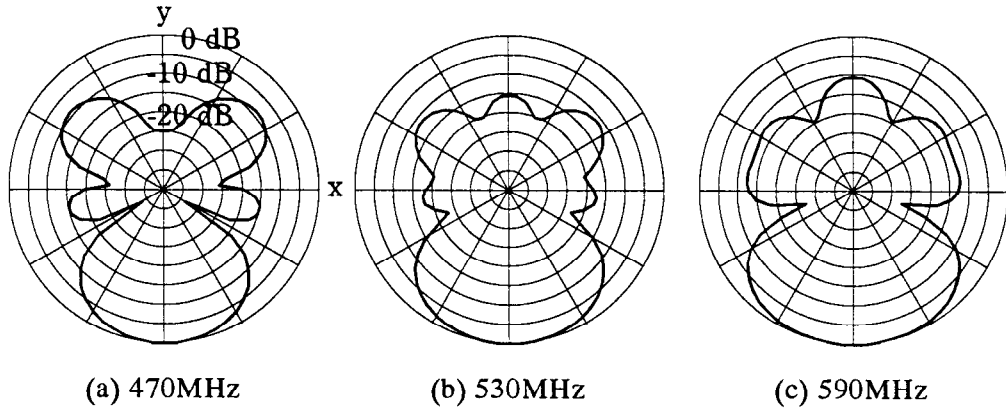
(a) 470MHz   (b) 530MHz   (c) 590MHz

Fig. 2 Calculated electric field receiving patterns in horizontal planes.

D=15cm, $\phi 1=-\pi/2$, $\phi 2=0$

(a) 470MHz   (b) 530MHz   (c) 590MHz
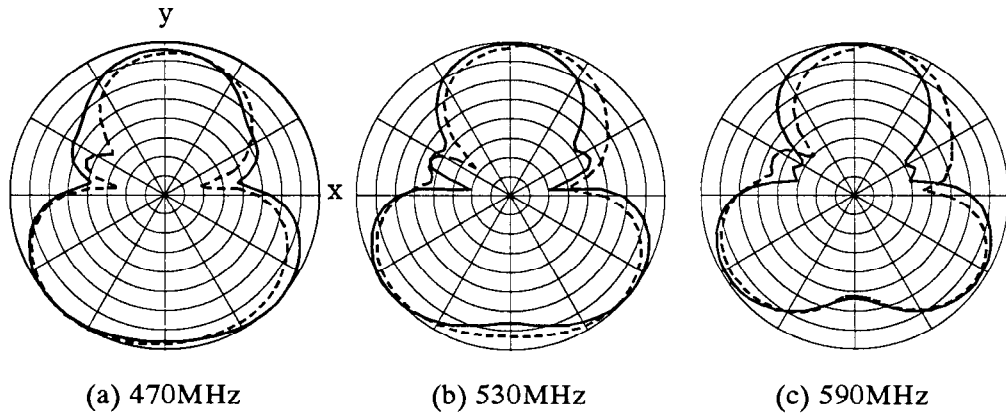
Fig. 3 Electric field receiving patterns in horizontal planes.

D=11cm, $\phi 1=0$, $\phi 2=-\pi/2$ —— calculated   - - - measured

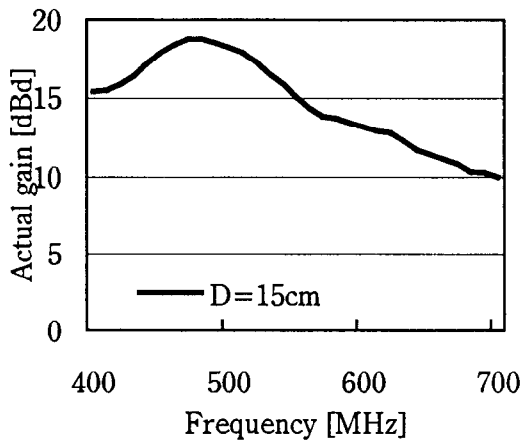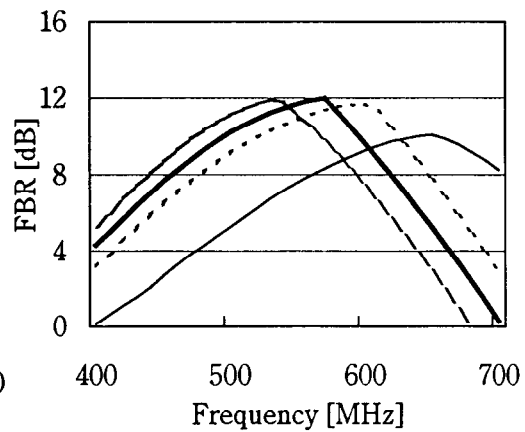Fig. 4 Actual gains of phased array active antenna.

Fig. 5 Front-to-back ratio of phased array active antenna.

—— D=11cm   ······ D=14cm

—— D=15cm   - - - D=16cm