A LOW-PROFILE ACTIVE PHASED ARRAY ANTENNA SYSTEM FOR MOBILE DIRECT BROADCASTING SATELLITE RECEPTION

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1. Introduction

A direct broadcasting satellite(DBS) service via Koreasat 3 is currently provided and there are many subscribes for a residential house. In addition, many people want to watch the DBS TV even at vehicles because it has advantages over terrestrial TV broadcasting with high quality, simultaneity, wide coverage, and so on. Several antenna systems for mobile DBS reception have been developed on the basis of various flat antennas mounted on vehicle's roofs[1,2,3]. The most attractive of these is an active phased array antenna technology. However, the conventional technology is very expensive, restricting its use in commercial products. To solve this, a modification in the phased array antenna is introduced using twelve active array elements for cost-effectiveness[4,5]. The system shows a high performance for receiving DBS, but is still expensive, large and tall to be installed on a car due to low element gain and the connection loss between the radiator subarray and the active channel block (ACB). Therefore, we have made a great effort to develop high efficiency radiator subarray[6], and have realized a small and low-profile active phased array antenna system mountable on a small car[7].

This paper describes the design of the active array antenna system and also presents experimental results. Section 2 describes the design of the 3x4 circularly polarized subarray with the corner-truncated square patch fed by a microstrip line and the stacked patch. Section 3 describes the design of the ACB using the low cost-packaged monolithic microwave integrated circuit (MMIC) phase shifter and presents the performance of the active array module, in which the antenna elements and the active circuitry are integrated on the same substrate. Section 4 describes satellite tracking algorithm for mobile DBS reception and presents test results.

2. Radiator Subarray

The patch fed by a microstrip line and stacked patch are truncated to obtain circular polarization. Lower patch and microstrip line are on the substrate with ε_r=2.5 and thickness=20mil, the stacked patch on the thin film is supported by lower foam, and this patch is covered by upper foam (thickness=2mm). Being very thin (0.04mm) with respect to wavelength, the film hardly affects radiation pattern. A 10dB return loss bandwidth is 11% (11.2 − 12.5GHz), a 3dB axial ratio bandwidth is 6% (11.4 − 12.1GHz)[6]. The designed array structure is shown in Fig. 1. The distance between each patch is 0.85 λ_0 and the array is designed using sequential rotation feed. By using these sequential rotation feed, an antenna performance is better than that of single patch. The measured result compared with simulation is shown in

Fig. 2. The maximum gain is 19.5 dBi and 3dB axial ratio bandwidth is 25% (9.8 GHz - 12.6 GHz). The simulated and experimental impedance bandwidths for VSWR < 2 are 15% (10.8 GHz - 12.55 GHz) and 15.2% (10.9 GHz - 12.7 GHz), respectively.

3. Active Phased Array Antenna

The active phased array antenna consists of two active array modules arranged on the plane of the frame. The active array module is composed of two active subarrays containing the microstrip patch subarray and the ACB, in which the active devices for amplifiers and phase shifters are integrated directly with the feeding network and radiating elements to improve the array performance on the same substrate (TLX-9, 20mil-thick, ε_r=2.5), and the subarrays are inclined at 46 ^{o} to horizon. The developed active array module is shown in Fig. 3. The ACB performs the roles to amplify RF signal with low noise coming from the radiator and to form the beam for electronic beam scanning. The ACB is composed of the FETs, microstrip band pass filter (BPF), MMIC phase shifter, stabilized DC bias circuit, and the phase control interface part. By the design specification, the typical linear gain of the ACB is about 25 dB at initial phase state and its gain variation by phase control states is less than ±2 dB, and the minimum phase control step is 22.5^o. The phase response of the active channel block by each phase states was measured using a vector network analyzer and control program. The phase variation of it by phase control state was lower than ± 5^o within operating band[7]. The integrated active phased array antenna system is shown in Fig. 5 and consists of two active array modules, a low noise block down converter, a beam steering controller, a tracking signal detector, a satellite tracking processor and a mechanical positioner. Its size is 320(D) x 85(H) mm. The radiation patterns measured at 11.85 GHz are shown in Fig.5. The side lobe level is lower than -10dB and cross-pol level is lower than -23dB for broadside direction. The carrier to noise power ratio (C/N) of the system was measured directly from Koreasat 3 DBS signal whose effective isotropic radiated power (EIRP) is 61 dBW at Daejon and bandwidth is 21.3 MHz. It exhibits the C/N of about 13.8 dB as shown in Fig. 6.

4. Satellite Tracking Method and Field Test Results

The antenna system tracks the satellite using a signal from the satellite and the signal detection is made by the signal from 4 squint beams in azimuth and elevation[8]. It has two-dimensional electronic beam tracking function with the accurate and rapid response as vehicle' movement and vibration. The azimuth antenna beam is steered electrically within ±3^o and mechnically over 360^o wide tracking range on the mechanical positioner. The antenna beam is scanned electrically within 46^o±6^o in elevation. The main functions of tracking algorithm are management of individual algorithms interaction at the organization of satellite initial search, automatic tracking and repeat search of the satellite, management of information exchange between satellite tracking processor unit and antenna assembly. A flow chart of tracking algorithm is shown in Fig. 7. The performance test of tracking algorithm was carried out by receiving directly DBS signals from Koreasat 3 by the system installed on a vehicle as shown in Fig. 8. We performed the moving test from Daejeon to Goseong in Korea on the road condition such as urban road, national road and expressway to acquire the experimental field test data. Fig. 9 shows that the system maintains constant signal strength on the highway.

5. CONCLUSION

In this paper, a small and low-profile active phased array antenna system mountable on a small car is developed for DBS reception at moving vehicles using active array modules containing the microstrip patch subarray and the MMIC phase shifters. Its design and performance were presented and described. It exhibits the C/N of 13.8 dB from Koreasat 3 DBS signal whose effective isotropic radiated power (EIRP) is 61 dBW and bandwidth is 21.3 MHz. It provides $46^{o} \pm 6^{o}$ electronic beam scanning in elevation. The azimuth antenna beam is steered electrically within $\pm 3^{o}$ and mechnically over 360^{o} wide tracking range. The performance of satellite tracking algorithm was verified by the moving vehicle test under various kinds of road conditions. The size and number of the active array module can be easily modified for various mobile multimedia service applications.

REFERENCES

[1] K. Fujimoto, J.R. James, "Mobile Antenna Systems Handbook", Artech House, Inc., 1994.

[2] Jiro Hirokawa, et al., "A Single-Layer Slotted Leaky Waveguide Array Antenna for Mobile Reception of Direct Broadcast from Satellite," IEEE Trans. On Vehicular Technology, Vol.44, No.4, pp.749-754, Nov. 1995.

[3] S.I Jeon, et al., "Vehicular Active Antenna System with Combined Electronical and Mechanical Beam steering for Reception from DBS in Ku-band", XXVII Moscow ICATT, Sept. 1998, pp. 72-77.

[4] S.I Jeon and D.G. Oh, "Active phased array antenna for mobile multimedia services via satellite", 2000 Aerospace Conference, Vol.5, pp. 165-170, 2000.

[5] S.Y. Eom, Y.C. Moon, C.S. Pyo, C.G. Park, S.I. Jeon, D.C. Oh, "Design and Test of RACM in Ku-band Vehicular APAA System for DBS Reception", INTERNATIONAL CONFERENCE ON ELECTROMAGNETICS IN ADVANCED APPLICATIONS (ICEAA99), Torino, Italy, Sept. 1999, pp. 215-218.

[6] Wonkyu Choi, Cheolsig Pyo, and Jaeick Choi, "Broadband Circularly Polarized Corner-truncated Square Patch Array Antenna", 2002 AP-S International Symposium, San Antonio, June 2002, pp.220~223.

[7] C. S. Pyo, J. M. Lee, W.K. Choi, Y. G. Yoon, and J.I. Choi, "Ku-Band Active Phased Array Antenna for Mobile DBS Reception", to be published in the 2002 Antenna Applications Symposium, Monticello, Illinois, Sept. 2002, pp.

[8] C. S. Pyo, Y. C, Moon, S.I. Jeon, D.C. Oh, and H. J. Lee, "A Tracking Method of Active Phased Array Antenna for Mobile Satellite Reception", 2000 Topical Symposium on Milliimeter Waves(TSMMW2000), Yokosuka, Kanagawa, March 2000, pp.87-90.

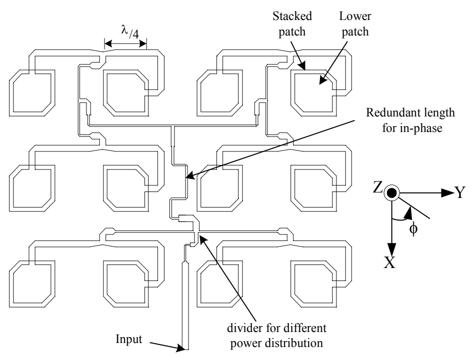

Fig. 1 Photograph of 3x4 subarray

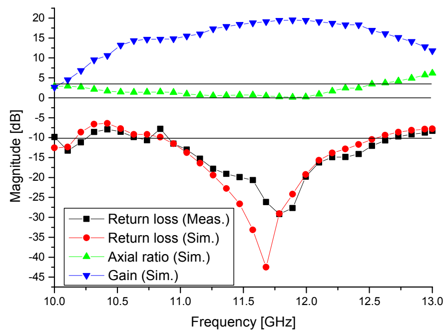

Fig. 2 Simulated and measured results of 3x4 subarray

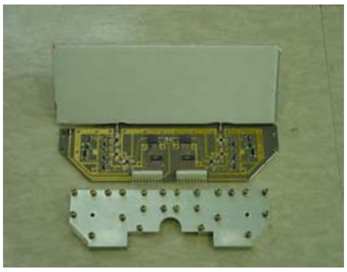

Fig. 3 Active array module

Fig. 4 Active phased array antenna system

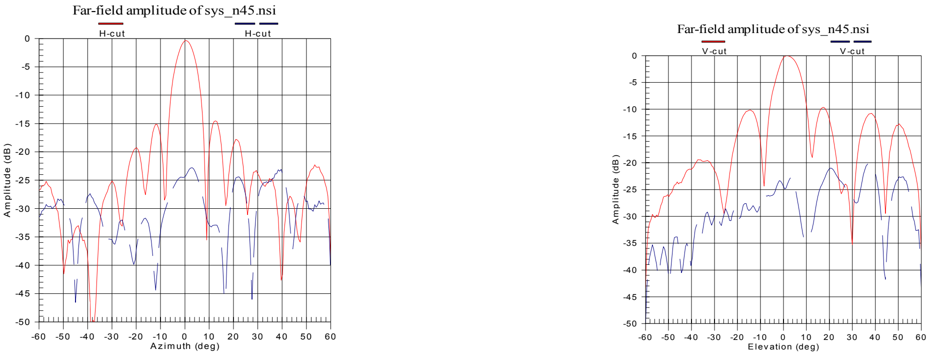

Fig. 5 Radiation patterns (meas.) of the antenna system (at 11.85 GHz)

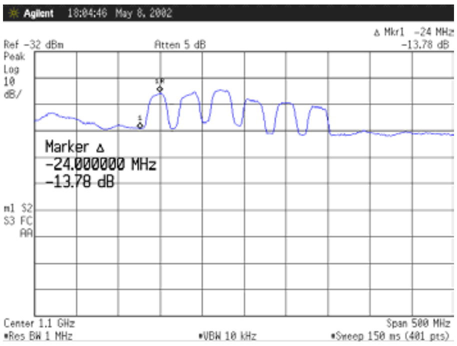

Fig. 6 Measured C/N of the system

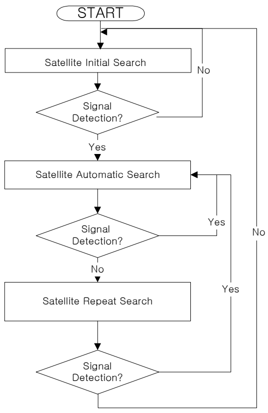

Fig. 7 Flow chart of tracking algorithm

Fig. 8 Test antenna system installed on a car

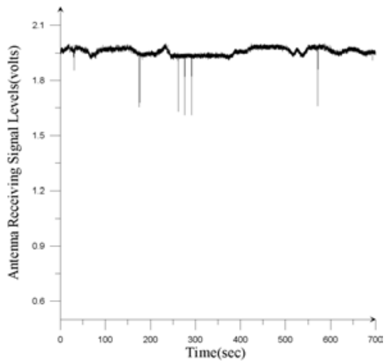

Fig. 9 Result of highway test