T/RX Channel Design of X-band Shipboard APAA System for Mobile Communications via Satellite

Young-Bae Jung[1], Soon-Young Eom[1], Soon-Ik Jeon[1], Chang-Joo Kim[1] and Seong-Ook Park[2]

[1]Electronics and Telecommunications Research Institute(ETRI)
161 Gajeong-dong, Yuseong-gu, Daejeon, 305-350, R.O.KOREA, +82-42-860-1684
[2]Information and Communications University(ICU)
119 Munji-dong, Yuseong-gu, Daejeon, 305-350, R.O.KOREA, +82-42-866-6132

***Abstract* —A X-band active phased array antenna(APAA) system for satellite applications was developed and manufactured for commercial and military use. This system tracks satellite by using electronic beam-forming technology in elevation and azimuth direction. And mechanical operation was adopted in azimuth. This paper describes the architecture of this system, especially T/RX channel design, and details measured results of channel performances. In this system, TX-channel is primarily composed of active channel blocks(ACB) for transmit beam control and power amplification, multi-way power dividers and solid-state power amplifier(SSPA) having 50-Watt output power. And, RX-channel is composed of ACBs for receive beam control and low noise amplification, power combiners and beam forming blocks(BFB) for tracking beam control. Lastly, to confirm the system performances of APAA including the T/RX channel, communication test accomplished in the open air, and the result of it is presented.**

I. INTRODUCTION

After 1990s, because the various demands of many people for mobile multimedia service, terrestrial mobile communications via satellite has been widespread till now and vehicle antenna system via satellite will be more populated before long[1]. By this reason, vehicle antenna system technologies to access various multimedia service regardless where one is has been rapidly developed with people's high attention. In this situation, ETRI launched the development of X-band mobile shipboard APAA system for satellite communications.

This system can be divided by 3-parts according to its function such as radiator, T/RX active channel and system power/control. As written above, this paper mainly describes T/RX active channel part including component design, its test and outdoor system test.

II. DESIGN AND FABRICATION OF APAA

Developed APAA is operated by electrical tracking method in elevation and azimuth direction by phase shifters. And, mechanical tracking by motor revolution is applied in azimuth direction. Figure1 illustrates a block diagram of the X-band shipboard APAA system. As shown in this diagram, main beam is formed by 1'st level phase shifters of T/RX-ACBs and tracking beam forming is carried by 2'nd level phase shifters of BFB. All phase shifters accomplishing beam forming are controlled by the tracking algorithm of control & monitor part.

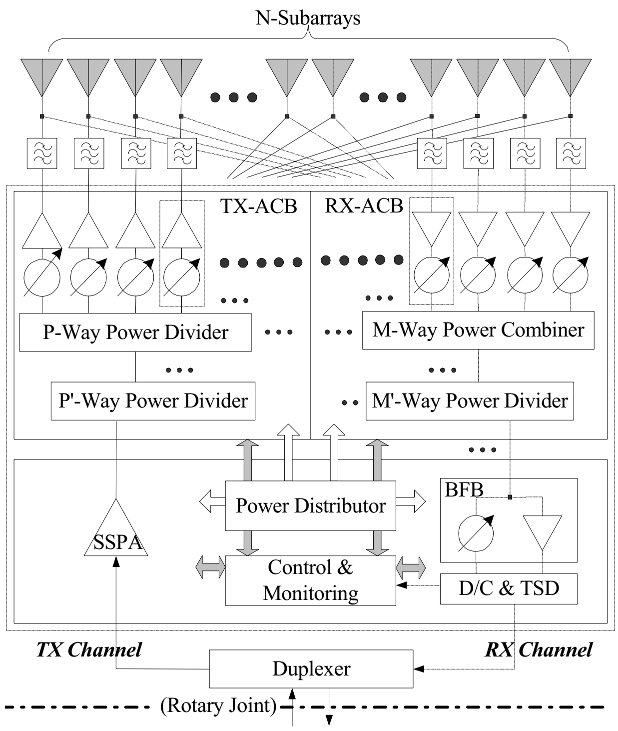


Fig 1. Block diagram of X-band APAA system

In addition to the beam forming, T/RX-channel is composed of several active and passive components, such as T/RX ACBs, BFB, filters, duplexer and SSPA, in order to accomplish several electrical specifications. This specifications needed for APAA are evaluated by link budget for KoreasatⅤ, and they are summarized in Table 1.

Item description	Electrical Performances
Operation frequency	TX : 7.90~8.40GHz RX : 7.25~7.75GHz
Antenna Gain	35dBi(min)
Polarization	Circular
G/T	10dB/K
Phase Control Step	22.5°(16-steps)
Allowed phase error	±11.25°(max)
Electrical Scanning Range	AZ : ±35° EL : ±4°
TX channel gain	54dB(typ)
RX channel gain	56dB(typ)

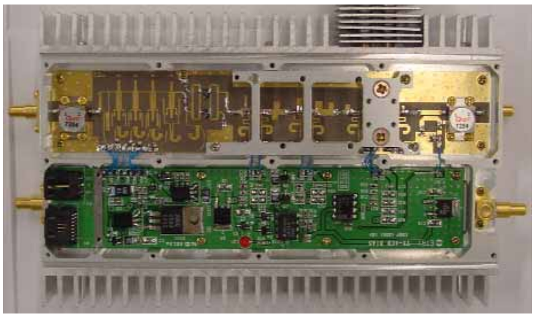
TABLE I. ELECTRICAL SPECIFICATIONS OF X-BAND APAA

T/RX ACB. For low profile and weight reduction, TX and RX ACB are combined in one mechanic box. So, isolation capacity of this block is very important. For this problem, electrical and mechanical methods were adapted in the fabrication of it, and high isolation more than 80dB was achieved in normal operation conditions. In this block, TX-ACB is primarily composed of 3-stage power amplifier having 4-Watt output power, microstrip 4-bit phase shifter(MICPS) controlling 16 phase states, thermal compensation and power detection circuit. And, the RX-ACB includes 3-stage LNA using hetero junction FETs for optimum G/T performance, MICPS and microstrip hairpin type BPF for TX power rejection. The MICPS used in this antenna system was designed for low cost and low profile concept in hybrid circuit. And, its basic element is modified branch-line coupler that makes use of the form of quarter-wavelength coupler for 22.5° in the operational band[2].

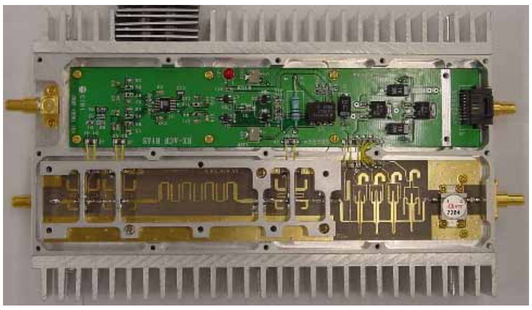
Item description	Electrical Performances	
Classification	TX	RX
In/Out Return Loss	14dB(min)	14dB(min)
Linear Gain	20dB(min)	24dB(min)
Gain Flatness	±2.0dB(max)	±2.0dB(max)
Gain Variation by Phase Control	±2.0dB(max)	±2.0dB(max)
P_1dB	35dBm(min)	-
IM3	24dBc(min)	-
Noise Figure	-	1.2dB(max)

TABLE 2. ELECTRICAL SPECIFICATIONS OF T/RX ACB

In Table 2, measured results of this block are described and Fig.2 shows the assembled T/R module. Its front-side includes RF and DC board for TX, and the backside contains them for RX.[3]



(a) Front-side(TX-ACB)



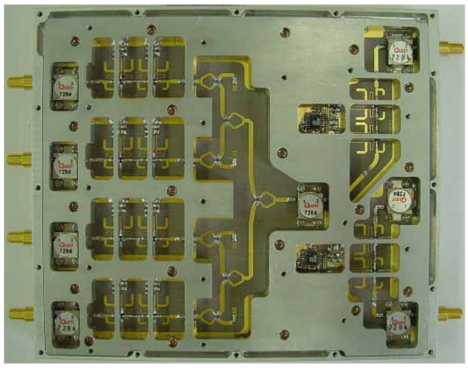
(b) Backside(RX-ACB)

Fig.2. Photographs of fabricated T/RX ACB

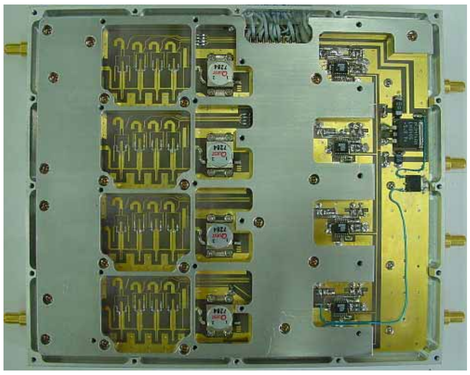
SSPA/BFB. SSPA has the role of high power amplification of TX signal in front of TX ACB. For the stable performance in the marine climate, it was designed to have enhanced gain-stability and high power capability. So, it has 47dBm output power, 24.5dBc 3rd-order intermodulation and about 74dB linear gain performance with ±1.1dB gain variation over –20 to +75°C that is adjustable from 0 to 16dB by gain control voltage.

In the RX-channel, BFB is a key unit for satellite tracking. This block includes two functional circuits for main signal and tracking signal, and they are placed on both sides of BFB. The Circuit for main signal has the role of combining the signal power entered from RX-ACBs, and the combined signal is equally divided into two channels. The one of them is connected to the port of main terminal for the data demodulation, and the other is connected to the circuit for tracking signal placed on the backside of BFB. In the circuit for traking signal, 4 MICPSs same as the phase shifter in ACB were included, and they have the role of beam forming of satellite tracking and electrical beam control by using external tracking algorithm. In Fig 3, the photo of fabricated BFB, (a) is the front-side of BFB which was designed for main signal with 2-stage LNA having 25dB linear gain and 4 Wilkinson dividers. (b) is composed of 4 MICPSs for tracking beam forming and control as stated above. And, all the circuits were designed by using RF and microwave simulator, ADS of Agilent Technology Inc. and Ensemble of Ansoft Inc., and fabricated on the soft substrate, TLY5A, of Taconic Inc.

The measured results for BFB are arranged in TABLE 3, and CMS and CTS in this table mean the circuit for main signal and tracking signal each.



(a) Front-side of BFB for main signal



(b) Backside of BFB for tracking signal

Fig 3. Photographs of fabricated BFB

Item description	Electrical Performances	
Classification	CMS	CTS
In/Out Return Loss	14dB(min)	14dB(min)
Linear Gain	42dB(min)	38dB(min)
Gain Flatness	±0.5dB(max)	±1.0dB(max)
Gain Difference among channels	±1.0dB(max)	±1.0dB(max)
Gain Variation by Phase Control	-	±1.5dB(max)
Initial Phase Difference among channels	-	±20°(max)

TABLE 3. ELECTRICAL SPECIFICATIONS OF BFB

Others. In this system design, there are many considerations, and one of them is channel isolation between TX- and RX-channel. In front-end of this system, T/RX isolation needed for preventing LNA saturation and other problems is about 60dB. This problem is mainly generated by T/RX combined type array antenna for low profile, and, to solve this problem, many band pass filters (BPF) were used. First, Waveguide(W/G) BPF was inserted between sub-array antenna and T/RX-ACB. It has the performances of 40dB band rejection, 0.5dB insertion loss and ±10° maximum phase difference among all BPFs. And, for more isolation, several microstrip BPFs were considered in all component designs, especially T/RX-duplexers connected with rotary joint. Together with channel isolation, another one of considerations for stable communication is RF-muting. It means that TX signal cannot be radiated to satellite from the system in the situation that transmit is unnecessary. For this function, high isolation RF-switch was designed on duplexers. This switch was designed by using silicon planar and mesa beam lead PIN diodes, and its isolation performance is about 70dB as switch ON and OFF. In addition to RF-switch, RF-muting can be achieved at SSPA and T/RX-ACB.

III. SYSTEM TEST AND MEASURED RESULTS

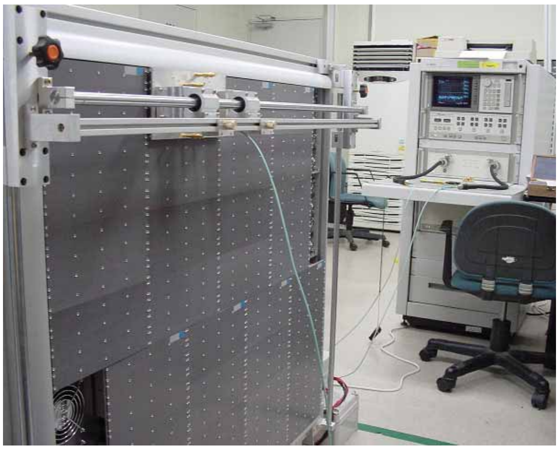


Fig 4. System channel test for X-band APAA system

Fig 4 shows the scene of T/RX-channel test for APAA system. In this test, many channel performances to be verified were accomplished by test equipments in laboratory. Gain related performances were measured by HP8510B and test antenna set as showed in Fig 4. And, spurious signal radiation and TX channel output power were measured by NSI near-field measurement set. In Fig 5, the measured result for RX- channel gain and channel gain variation by phase control is shown. However, 30dB input attenuation and 10dB spatial loss between test antenna and sub-array antenna are not included in gain curves. In this test, 0-state minimum gain for RX-channel is 56.5dB and gain flatness is ±1.8dB. And, gain variation by phase control of RX-ACB is ±1.7 dB, and maximum phase error, 10°, was confirmed. For TX-channel, minimum channel gain is 55.0dB with ±1.8dB gain variation by phase control. Fig 6 is the measured result of the phase responses of TX-channel, and this result was obtained by 16-step(22.5°) phase control of TX-ACB. In this result, maximum phase error is about 11°, and this result meets the allowed maximum phase error, 11.25°.

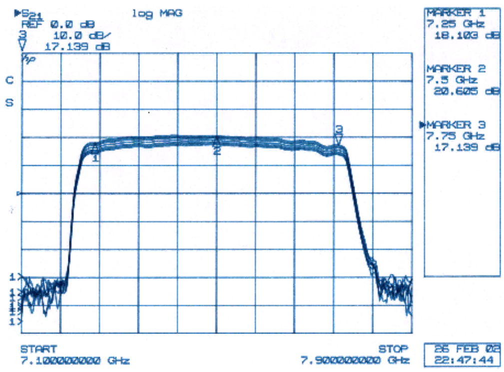


Fig 5. RX channel gain and gain variation by phase control

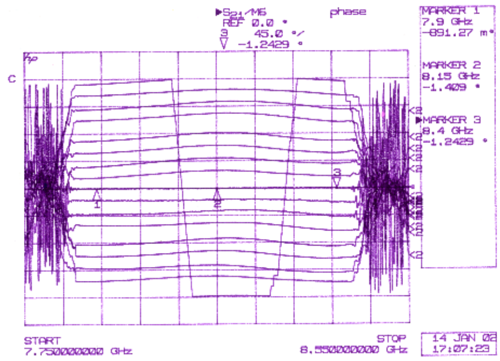


Fig 6. Phase variation for TX channel by phase control

After system assembly, satellite communication test of APAA was accomplished in the open air. To meet mobile environment, the system was loaded on motion simulator that has same capacity as system movement specifications, such as roll, pitch, yaw and heave. The outdoor test scene was shown in Fig.7. In this figure, left one of two TV-screens shows the picture received from Koreasat Ⅳ directly by parabola antenna and low noise block(LNB). And, the other shows the picture received from RF simulator. In this test, RF simulator received signal from the APAA, and radiated same signal to APAA after frequency conversion. So, it had the role of transceiver like as satellite. Outdoor test was practiced in the condition that the motion and RF simulator operated, and it was confirmed that the minimum G/T of APAA is 11.5dB/K.

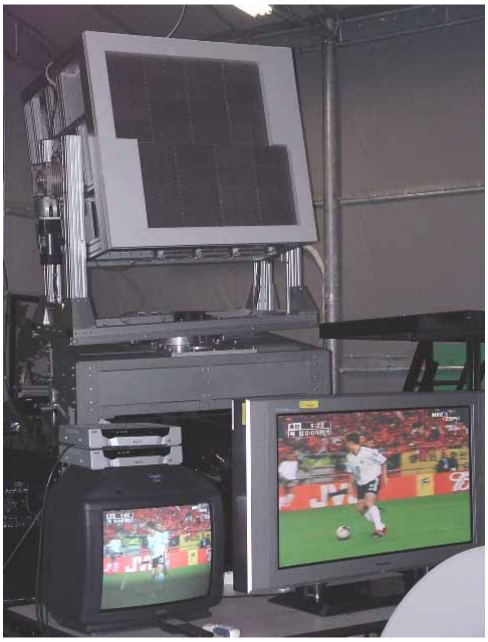


Fig 7. Satellite communication test of X-band APAA

IV. CONCLUSION

A X-band shipboard APAA system for satellite application has been demonstrated. Although the whole system performances and all components are not introduced in this paper, the outline of this system is briefly described. T/RX-channel was design to meet electrical system specifications such as EIRP, G/T, channel gain and etc. And, to satisfy the specifications, several active and passive components were designed and manufactured. By measurement in laboratory, it was confirmed that TX- and RX-channel have minimum gain of 55.0dB and 56.5dB each. Lastly, entire system performances were verified by outdoor communication test with RF and motion simulator.

In the future, ETRI will launch the development of practical model by using MMIC and LTCC technologies.

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