X-BAND RF TRANSMITTER AND RECEIVER DESIGN OF APAA SYSTEM FOR MOBILE SATELLITE COMMUNICATIONS

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A X-band active phased array antenna(APAA) system for mobile satellite communications was developed by ETRI. This system electrically and mechanically tracks to Korean satellite, Mugunghwa, in vehicles. Its electrical tracking range is ±35° in elevation direction and ±4° in azimuth with 360° mechanical infinite-rotation. In this system, TX-channel was primarily composed of active channel blocks (ACB) for transmitting 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 receiving beam control and low noise amplification, power combiners and beam forming blocks(BFB) for tracking beam control. Beside component and channel test in laboratory, system performances were verified by communication test in the open air and the results of the test are presented.

1. 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.

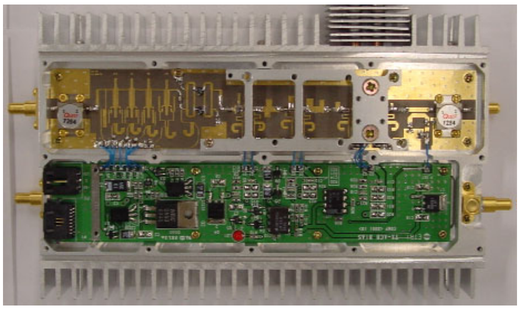
2. Design and Fabrication of APAA

As above-mentioned, this system is operated by electrical tracking mechanism in elevation and azimuth direction. In order to accomplish electrical tracking, 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 included in RX-channel. All phase shifters are controlled by the tracking algorithm of control & monitor part. In addition to beam forming, other many performances are needed to this system for normal operation. In Table1, several specifications are summarized, and they were evaluated by link budget for Korean satellite, Mugunghwa. In this chapter, main components in this system, such as T/RX ACBs, power dividers/combiners, SSPA and BFB, are described.

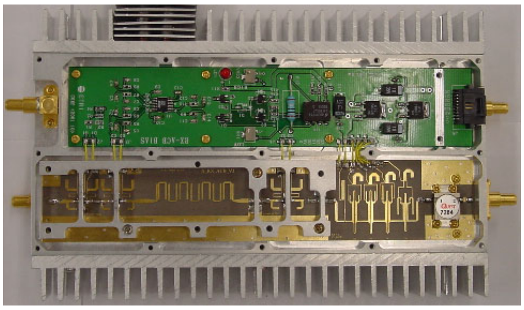
Item description	Electrical Performances
Operation frequency	TX : 7.90~8.40GHz RX : 7.25~7.75GHz
Antenna Gain	35dBi(min)
Polarization	Circular
G/T	10dB/K
Phase Control Step	22.5°(16-steps)
Allowed phase error	±11.25°(max)
Electrical Scanning Range	EL : ±35° AZ : ±4°
TX channel gain	54dB(typ)
RX channel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

Table 1. Electrical main specifications of X-band APAA svstem

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 technologies are 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 and thermal compensation circuit. And, the RX-ACB includes LNAs 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 frequency band[2]. Fig.1 shows the assembled T/R module. Its front-side includes RF and DC board for TX, and the backside contains them for RX.[3]



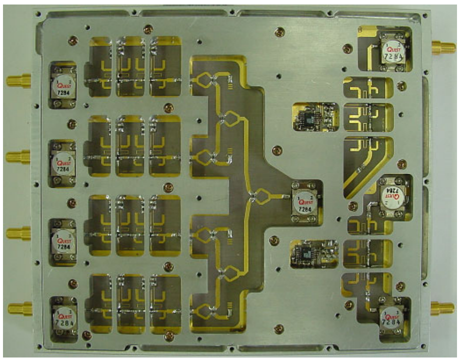
(a) Front-side(for TX)



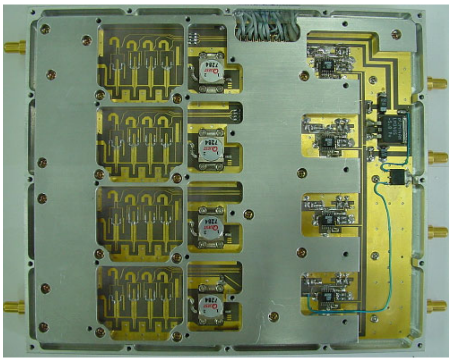
(b) Backside(for RX)

Fig.1. Photographs of assembled T/RX-ACB

SSPA has the role of high power amplification of TX signal in front of TX-ACB. For the stable performance in severe climate, it must have enhanced gain-stability and measured result of it was ±1.1dB over –20 to +75°C. Besides gain stability, it has 47dBm output power, 24.5dBc 3rd-order intermodulation and about 74dB linear gain that is adjustable from 0 to 16dB. In the RX-channel, BFB is a key unit for satellite tracking function. As shown in Fig.2, this block includes two functional circuits for main signal and tracking signal, and they are placed on both sides of BFB[4]. Circuit for main signal has the role of transmitting input signal from RX-ACB to circuit for tracking signal. And, circuit for tracking signal executes electrical beam control with beam forming for tracking signal.



(a) Front-side of BFB for main signal



(b) Backside of BFB for tracking signal

Fig 2. Photographs of manufactured BFB

Including main components above-mentioned, there are many considerations in this system design, 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 50dB. This problem is mainly generated by T/RX combined type array antenna for low profile. To solve it, many band pass filters(BPF) were used in this system. First, Waveguide (W/G) BPF was connected with sub-array antenna, and it has 40dB band rejection characteristic. 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 environment is RF-muting. It means TX signal cannot be radiated to satellite from the system in the situation that transmitting is unnecessary. For this function, high isolation RF-switch was designed and placed on duplexers. This switch was design 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.

3. System test and measured results

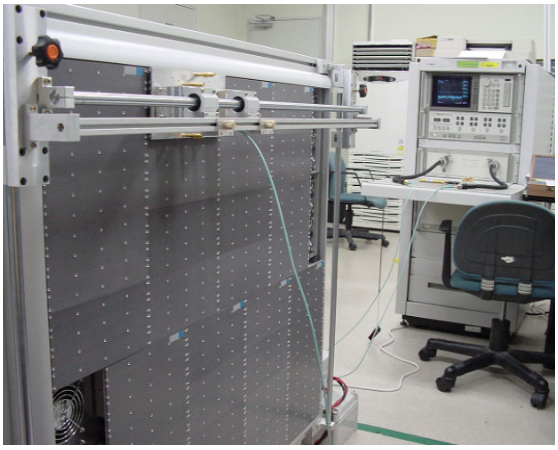


Fig 3. T/RX-channel test

Fig 3 shows the scene of T/RX channel test for APAA system. In this test, many channel performances to be verified, such as channel gain, gain variation, channel gain difference, gain variation by phase control, and so on, were accomplished by test equipments in laboratory. In this test, Gain related performances were measured by HP8510B and test antenna set, and other performances were measured by NSI near-field measurement set. As shown in Fig 4, measured result of RX-channel gain is 56.5dB with ±1.8dB gain flatness in the condition that phase shifter has 0°-state. However, 30dB input attenuation and 10dB spatial loss between test antenna and sub-array are not included in this figure. And, gain variation of RX-channel by phase control is ±1.7 dB with maximum phase error, 10°. For TX-channel, channel gain is 55.0dB with gain variation by phase control, ±1.8dB. Fig 5 is the measured result of the phase response for TX-channel by phase control. In this result, phase control is operated by 16-steps(22.5°) and maximum phase error is about 11° which meets the allowed maximum phase error, 11.25°. In this paper, all results of T/RX-channel test are not reported on account of space consideration.

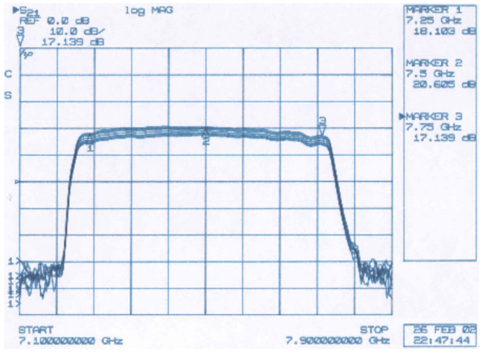


Fig 4. RX channel gain variation by phase control

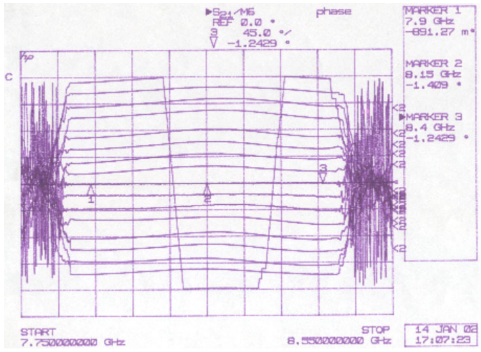


Fig 5. Phase responses of TX channel

After all components above mentioned were assembled, satellite communication test of X-band APAA was accomplished in the open air.

Fig 6. Satellite communication test of X-band APAA

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.6. In this figure, left one of two TV screens shows the picture received from Koreasat Ⅳ directly by parabola antenna, and the other shows the picture of satellite TV signal received from RF simulator. In this test, RF simulator had the role of satellite as a substitute. At the condition that the motion simulator operated, G/T of the system was minimum 11.5dB/K and it is confirmed that the normal operations of the system at satellite communication environment.

4. Conclusions

A X-band mobile 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 main beam forming together with tracking beam. And, to satisfy the specifications, several active and passive components were designed and manufactured. By measurement in laboratory, it was confirmed that, with maximum phase error, 10°, TX and RX-channel have minimum gain, 55dB and 56.5dB each. Lastly, entire system performances were verified by outdoor communication test with motion simulator.

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

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