4B3-3

The R&D of Active Phased Array Antennas with Significant Cost Reduction and Usage Convenience

Tadashi Takano[1, 2], Shigeo Kawasaki[3], Hiroshi Toshiyoshi [2], Hirokazu Ikeda[1], Yasuhiro Kazama [4]

1 The Institute of Space and Astronautical Science / JAXA,
3-1-1 Yoshino-dai, Sagamihara 229-8510 Japan, ttakano@radionet.isas.ac.jp
2 University of Tokyo
4-6-1 Komaba, Meguro -ku, Tokyo 153-8505 Japan
3 Kyoto University
Gokasho, Uji, Kyoto 611-0011 Japan
4 Japan Radio Co.,Ltd
5-1-1 Simorenjyaku, Mitaka, Tokyo 181-8510 Japan

1. Introduction

Microwave frequencies have been widely used in many fields of applications. Terrestrial repeating systems, satellite communications and radars are rather old ones, and cellular phones, Intelligent Traffic System(ITS) and Electronic Toll System(ETS) are new comers. As a result, it is becoming more and more difficult to obtain a microwave frequency for a new service or system.

Recently, the Ministry of Internal Affairs and Communications (MIC) in Japan proposed to positively use so-called high microwave band from 6 GHz to 30GHz for many applications [1]. If the operating frequency of exiting services moves to those frequency bands, the resultant vacant frequency could be re-allocated to the other services which are more suitable to that frequency. For the purpose of positive utilization of high microwave band, several key technologies should be developed: antennas, amplifiers, modulation and demodulation, codes, protocols or even network architectures [2]. An active phased array antenna (APAA) is one of promising technologies due to the agility of advanced beam control.

Phased array antennas (PAA) which are wider definition than APAA are used in radars to realize quick beam scan. In communications, there were also many proposals to effectively use PAA[3]. But the attempt mostly ended in vain because of high cost and inconvenience in usage. In order to solve the above-motioned problems of PAA, a new project for the research and development (R&D) of APAA has been started in Japan. This paper describes the overview of the organization, the basic technologies to be pursued, the systems and services to be applied for, and the transition strategy from research to development.

2. Objectives and Structure of the Project

An example of APAA in conventional radar is, as shown in Fig.1, composed of radiators, transmitters and receivers (TR), a centralizer to be interfaced with a modulator and demodulator, and transmission lines to connect TR models and a centralizer. A radiator is attached with a TR. The type and number of radiators are determined to give the antenna gain, radiation pattern, weight and size, power consumption which are required by an application system. Beam scan is accomplished by phase shifters which are imbedded in the transmission- and reception-paths. The phase shifters are controlled according to the desired direction of the antenna beam. The phase shift value is different for each TR in general. If the frequency is different between transmission and reception, the phase shifters should be driven with different voltages, or should be of different types. For example, the PAA in SPY-1 radar for Aegis is said to have 4,350 radiators in an aperture of 3.7m diameter. The longest transmission line is about 2m in this case.

For practical application of APAP, the cost should be drastically reduced by one-tenth. In order to accomplish the cost reduction, we chose the following objectives:

(1) The number of driven radiators is reduced without serious degradation of principal characteristics.

ISBN: 978-4-88552-223-9 C3055©IEICE

(2) The driven radiator is integrated with a TR.
(3) The TR is installed in a small package with Monolithic Microwave Integrated Circuit (MMIC) technology.
(4) As the phase shifter operates at frequency higher than 10GHz, Micro Electro- Mechanical System (MEMS) at radio frequency (RF) is required for a switching device instead of a PIN diode or a HEMT device.

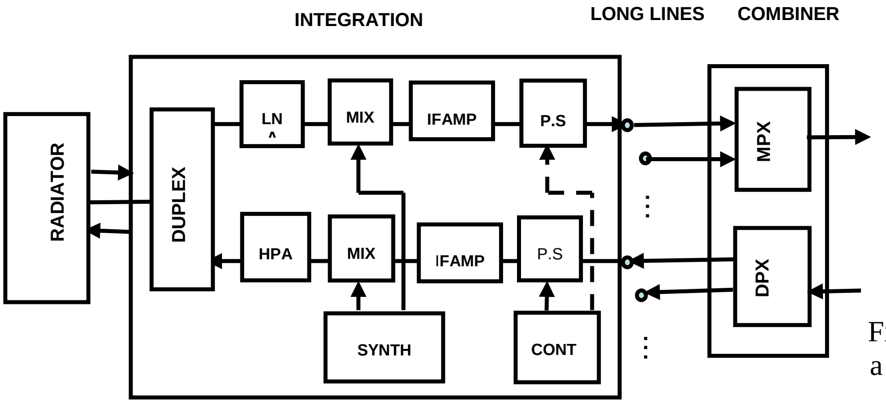

Figure1: Configuration of a Conventional APAA

As many difficulties may exist for realizing the objectives, we expect to have situations of compromise between the realizable levels of technology and the required levels by a system. Without this kind of compromise, really practical systems can not be synthesized. In this sense, the study of applications or systems is indispensable. The system with APAA will be verified at RF level at least in this project.

According to the above-mentioned objective terms, the R&D project is organized with correspondent groups as shown in Table1. The R&D activity is planned to be carried out for 4 years. The former 2 years are dedicated for rather fundamental research with a look at practical applications. The latter 2 years are used for realization of practical systems which could be utilized for services or businesses.

The objective goal is held up for each year as follows:
2006 Trial manufacturing of APAA around 6GHz.
2007 Trial manufacturing of APAA around K-band .
2008 Realization of practical APAA for car uses.
2009 Realization of practical APAA for maritime uses, and application study for airplane and space.

Table 1: Structure of the Project and Responsibilities

Group	Responsibility
Japan Aerospace Exploration Agency	Radiator, array structure
Kyoto University	Amplifier , MMIC, phase shifter
University of Tokyo	Switch in RF-MEMS technology
Japan Radio Co., Ltd	System, application

3. Basic Technologies

3.1 Antenna

In a conventional APAA, almost all radiators are fed by an amplifier and a phase shifter. One of technical issues is the coupling between radiator elements: the malignant effect to input impedance and pattern. However, It was shown that driven elements can be replaced by undriven or parasitic elements without serious degradation of antenna characteristics according to appropriate design [4]. This situation which may be called partial driving is accomplished due to positive utilization of element coupling.

An APAA with partial driving technique is shown in Fig. 2. On a reflector plane, two driven elements and two undriven elements are installed. The radiated field from the driven elements (#1, #2) propagates to the undriven elements (#3, #4), and is scattered by them. If the height h and the separations s and d are chosen properly, the directly radiated field from #1 and #2 and the scattered field from #3 and #4 are added in phase in the far field.

The ratio of the undriven element number to the total element number is defined as the cutback ratio, and is 0.5 in the case shown in Fig. 3. The later study revealed the possibility of the cutback ratio of 0.6 or even more [5], [6].

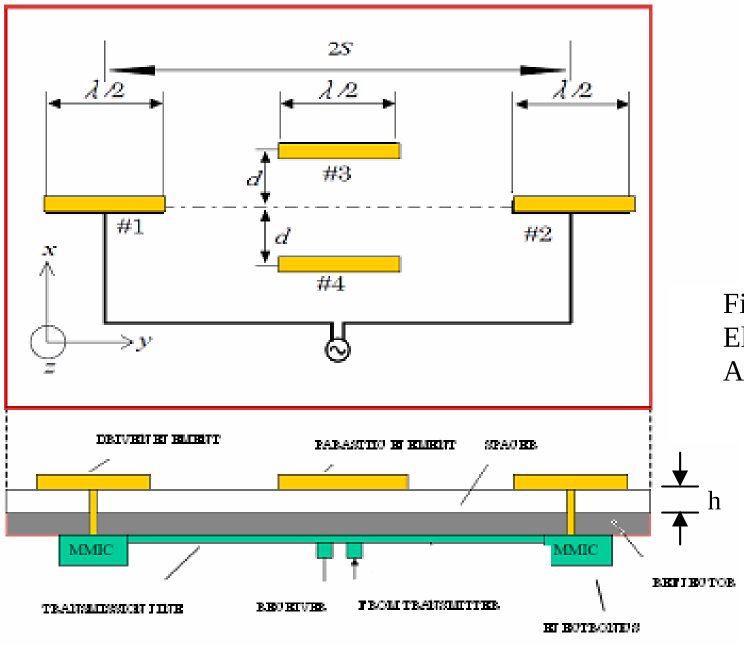

Figure 2: Layout of Radiating Elements and Electronics in APAA

3.2 MMIC

The TRs are attached to the backside of the reflector in correspondence to the radiator elements. Components in a TR such as a low noise amplifier (LNA) and a high power amplifier (HPA) are first made on each chip, then are both integrated on a single chip. The LNA and HPA are in a race to achieve the best characteristics in the world [7]. Currently, NF of 0.69dB and gain of 10.9dB have been achieved. At the final stage, mixers and phase shifters are also put in a package to realize small space, low power and mass production. Packaging is a difficult task which requires much experience.

3.3 Phase Shifter

A phase shifter is a key device to realize PAA. At high microwave band, small insertion loss and high isolation are both difficult to archive. Especially in K-band of 10GHz to 30GHz, a transmission line should be switched to realize a digital phase shift with better performances than the other phase shifters such as a loaded type and hybrid type so that a switching device is a key.

An RF-MEMS device is superior to conventional switching devices of a PIN diode or a HEMT due to small loss and high isolation. But it was difficult for an RF-MEMS device to realize a secure ON state and to avoid adhesion with an excellent impedance matching. A new configuration to solve these difficulties has been proposed where two poles are placed on the both sides of a movable arm. Simulation result suggests excellent performance.

4. Systems and Missions

The parameters relevant to a particular system are, for example, the gain, beam scan coverage, side lobe levels, polar characteristics and input impedance concerning an antenna, the gain, output level and NF concerning amplifiers, or the loss and reliability concerning a switching device, and are determined as an optimal solution for a system. And a system is studied on the bases of a particular mission or service. Therefore, the most important parameters are selected within relevant parameters in relation to a service. Technology level for each technical field such as device fabrication or integration grade is decided to optimize system objectives, and may not always be the most advanced one.

The application of APAA can be conceived in mobile communications for a car, a train, an airplane or spacecraft, traffic controls, radars, and microwave power transmission. Taking account of surrounding conditions, the actual system or service will be decided in the third year of the program. This phase will be led by business side or industries.

If the requirement to the most important parameters is satisfied, the system will be encouraged, as shown in Fig.3. The abscissa is a technical factor such as cost, power consumption or reliability. The ordinate is the attention or effort to be paid. For example, at the worse stage of cost, most R&D resource is fed to the seeds. If the cost is improved (drastically reduced), needs gather more attention, and seeds may lose a principal role or turn their effort to the other technologies. We hope to have several innovation boundaries in the future of APAA.

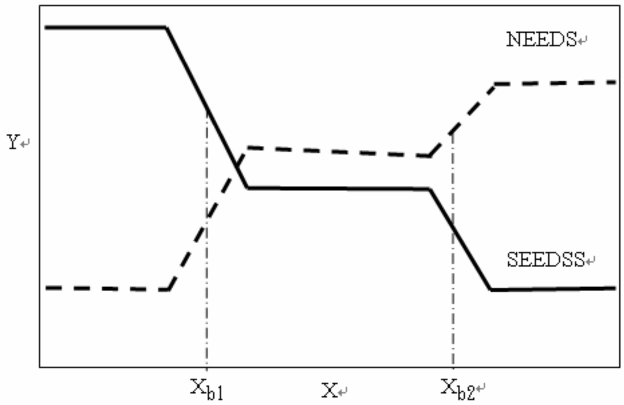

Figure 3: Change of Seeds and Needs across an Innovation Boundary

5. Conclusion

In order to put an ideal antenna of APAA into practical use, the study from both sides of seeds and needs are necessary. Academic institutions are good at basic research or seeds study while industries at applications or needs study. Both communities are expected to have close and supplementary collaboration.

Acknowledgments This work is partly supported by the research contract of the MIC.

References

[1] Ministry of Internal Affairs and Communication, “Prospect of Radio Wave Usage in the Medium and Long Term, and the Function to be Borne by Administration”, Publicity Material, July 30, 2003.
[2] Ministry of Internal Affairs and Communication, “RFP on Research and development for the Extension of Radio Wave Resources”, October, 2005.
[3] J.J Schuss et al., ”The IRIDIUM Main Mission Antenna Concept”, IEEE Trans. AP, vol. 47, no.3, pp. 416-424, 1999.
[4] T. Takano, N. Kamo and A. Sugawara, “Simplification of an Array Antenna by Reducing the Fed Elements”, IEICE Trans. Commun , vol.E88-B, No.9, pp.421-424, 2005.
[5] M. Okumura, T. Imura, Y. Kamata and T. Takano, “Experimental Study of the Driven Element Reduction in an Array Antenna using Element Coupling”.IEICE National Convention, B-1-178, Nagoya, March 2007.
[6] T. Imura, M. Okumura and T. Takano, “A Consideration of Arrangement of a Partially Driven Dipole Array Antenna”. IEICE National Convention, B-1-185, Nagoya, March 2007.
[7] S. Kawasaki, “A High Power Active Integrated Antenna Incorporated with Heat Sink Mechanism”, 384838, EuCAP06, France, November 2006.