Reduction of Intermodulation Distortion in Active Phased Array Antenna Systems using a Distortion Controller

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Abstract **— This paper describes a novel technique to compensate the intermodulation distortion (IM) of high power amplifiers in an active phased array antenna system. This technique uses IM phase control to break the strong association between carrier and IM. This technique can make the radiation patterns of carriers and IMs different on the active phased array antenna system. As a result, carrier power to intermodulation distortion power ratio (C/IM) is increased at the carrier beam direction. This paper shows the experimental result to confirm this technique using 6-element linear array.**

I. INTRODUCTION

If mobile satellite communication systems are to support smaller earth stations, such as handy phones, the satellites must have high levels of effective isotropic radiated power (EIRP). The active phased array antenna system (APAAS) is a very interesting approach [1]. Such system demands high-power amplifiers (HPAs) that can offer kW-class RF power. Since mobile satellite communication systems use multi-carrier transmission, high carrier power to intermodulation power ratios (C/IM) are required. However, amplifiers must trade-off power efficiency against intermodulation distortion (IM). This is a serious problem because satellites have poor heat dissipation. Many linearizers have been developed that try to compensate the non-linear distortion of an HPA [2,3]. However, they operate poorly in the near-saturated region, which offers high power efficiency. It is important to realize distortion compensation techniques that allow HPAs to operate in the near-saturated region.

To address this problem, we proposed an IM control technique [4, 5]. This paper proposes a novel IM reduction technique in APAAS. It describes the principle of the technique, and introduces a recently developed IM controller. It shows experimental results obtained by applying IM control to a 6-element linear array antenna.

II. IM CONTROL TECHNIQUE

We call our proposed technique the IM control technique. It controls IM phase in the APAAS. Fig. 1 shows the concept of the IM control technique. In a conventional APAAS, when carriers are combined in phase, the IM components are also combined in phase because of the strong association between carriers and IM components. Accordingly, carrier beam direction and IM beam direction are almost the same, as shown in Fig. 1(a). On the other hand, in the proposed APAAS, when carriers are combined in phase, the IM components are not combined in phase due to the IM controllers. Then the carrier radiation pattern and IM radiation pattern can be different, as shown in Fig. 1(b). As a result, C/IM is increased along the carrier beam direction.

III. IM CONTROLLER

To improve C/IM, each IM component in an HPA must be controlled. The required functions for the IM controller are IM phase control and amplitude control.

We proposed an even-order distortion implemented intermodulation distortion controller (EODIC). It has been evaluated as a linearizer [6], and shown to offer high IM control performance [7].

A block diagram and function of EODIC for 2-tone carrier input are shown in Fig. 2. The EODIC consists of a two-way power divider, a variable-phase shifter (VPS in Fig.2), a frequency doubler, two variable-gain amplifiers (VGA1 and VGA2 in Fig. 2), an amplitude modulator, and an output-buffer amplifier. Since the spectra are converted to the second harmonic frequency band ($2\omega_0$) in the nonlinear path, the residual carriers in the fundamental frequency band are removed. The EODIC controls the phase of IM in $2\omega_0$ by VPS, which minimizes the effect on the carriers in the linear path. This makes EODIC a suitable tool for implementing the IM control technique. We developed an EODIC on a GaAs chip. The EODIC is able to control the phase of IM through 360 degrees by using the VPS.

IV. LINEAR ARRAY

The proposed IM control technique was demonstrated experimentally using a 6-element linear array comprising 10 W class SSPAs in the S-band. An experimental block diagram is shown in Fig. 3, and Fig. 4 shows the developed 6-element linear array. In this linear array, one EODIC was placed in front of each SSPA. The phase shifter, buffer amplifier and attenuator were used to equalize electrical length and loss. A 20-dB directional coupler was located behind each SSPA to monitor the output spectra. Helical antennas were used as the transmitting antennas. The antennas were regularly spaced at intervals of 0.8 lambda (2.5 GHz). The same type of antenna was used as the receiving antenna.

Fig. 5 shows the experimental setup of the 6-element linear array. The linear array was set on a turntable in a radio anechoic chamber. The distance from the front of 6-element linear antennas to the receiving antenna was about 6 m for far-field measurement. Radiation patterns were measured from –90 degrees to 90 degrees in azimuth by driving the turntable.

V. Experimental Results

In this experiment, 2-tone carriers were used to measure the radiation pattern of the carriers and IM3s. The carrier frequencies were 2.517 GHz and 2.518 GHz, and IM3 components were 2.516 GHz and 2.519 GHz.

Fig. 6 shows the measured receiving power versus azimuth. The values with EODIC are shown in Fig. 6(a). Those without EODIC are shown in Fig. 6(b). These figures show the measured data of the lower side band; the carrier is 2.517 GHz and the IM3 is 2.516 GHz.

In both cases (with and without EODIC), carrier amplitude and phase were adjusted to be uniform in front of the transmitting antennas. With EODIC, IM3 phase was randomized by VPS and VGA1 control voltages of EODIC. EODIC was controlled so that C/IM3 was 26 dB. Without EODIC, the input power level was adjusted so that the receiving power of carrier was the same value as that with EODIC.

With EODIC, carrier beam direction was 0 degrees, but the IM3 components were scattered. There are three beams at –37 degrees, 3 degrees, and +33 degrees. The radiation patterns of the carrier and IM3 are different, as shown in Fig. 6(a). On the other hand, without EODIC, carrier beam direction and IM3 beam direction were 0 degrees, as shown in Fig. 6(b). Their radiation patterns showed a remarkable degree of correspondence.

Fig. 7 shows the C/IM3 ratio calculated from the data of Fig. 6. Fig. 7(a) and (b) show the case of with EODIC and without EODIC, respectively. By comparing these figures, the within 3-dB beam width of the carrier beam was –4.3 ~ 4.3 degrees, C/IM3 ratio with EODIC was 5 ~ 15 dB higher than that of without EODIC. C/IM3 was improved by 5 dB from 21 dB to 26 dB along the carrier beam direction. To achieve a C/IM3 ratio of 26 dB, normal HPAs can achieve a power added efficiency of about 14 percent in the S-band. By using EODIC, this is increased to about 30 percent.

VI. Conclusion

A novel C/IM improvement technique by using IM controllers in an APAAS was tested. Its effectiveness was demonstrated by an experiment on a 6-element linear array with EODICs. The results showed that C/IM was improved by 5 dB along the carrier beam direction. By using this technique, at the C/IM3 ratio of 26 dB, the power added efficiency is increased from 14 percent to about 30 percent. This technique makes it possible to achieve an APAAS that offers high C/IM and high power efficiency, which will ease the heat dissipation problem anticipated for future communication satellites.

Acknowledgement

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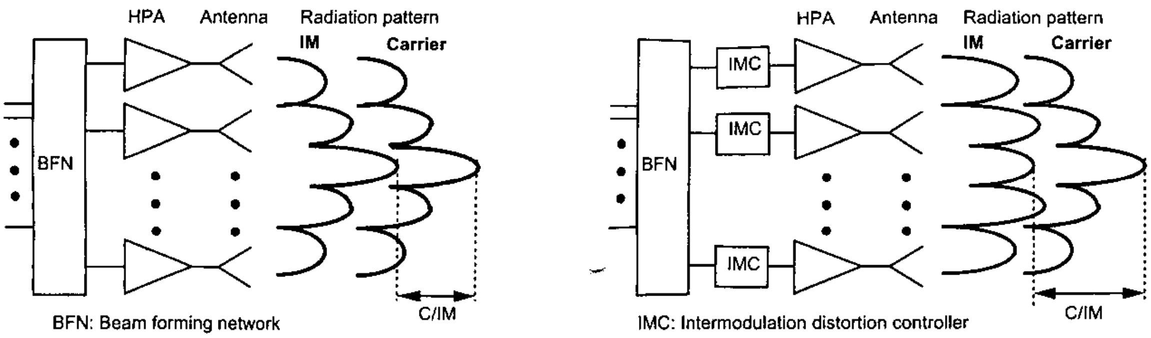


(a) Conventional active phased array antenna system.

(b) Proposed active phased array antenna system.

Fig. 1. The concept of the IM control technique in active phased array antenna system.

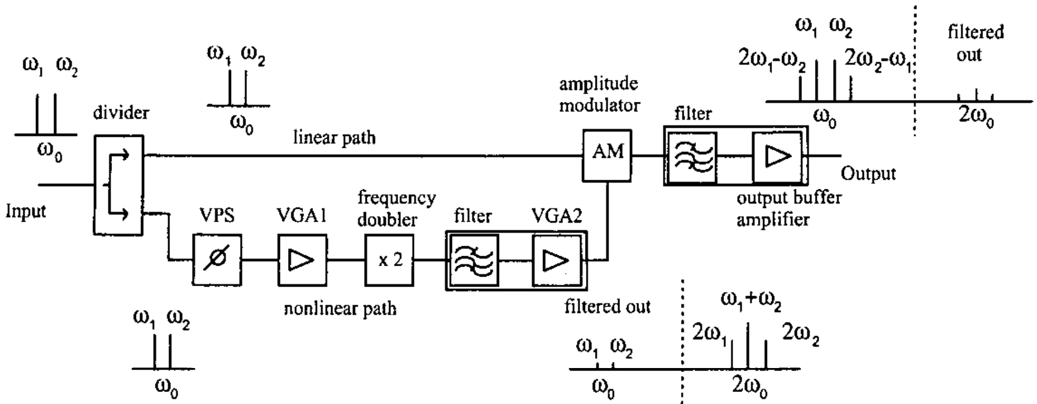


Fig. 2. Block diagram of developed IM controller, EODIC.

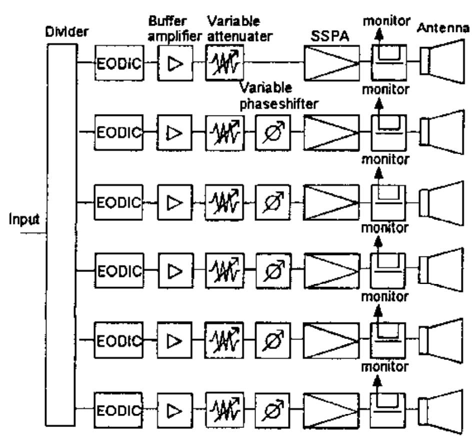


Fig. 3. Block diagram of 6-element linear array.

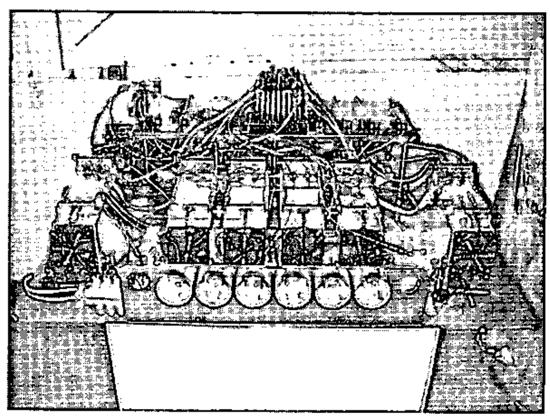
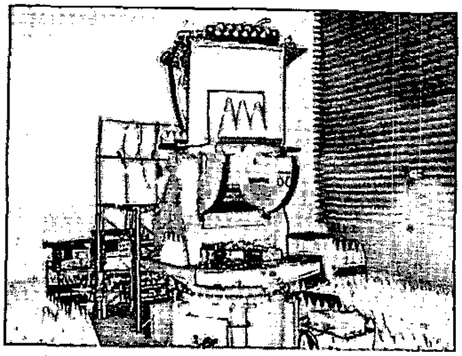
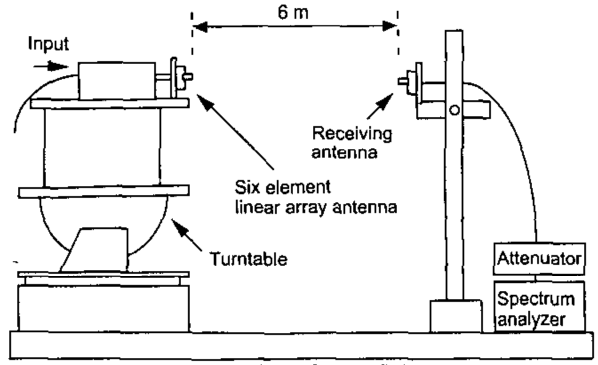


Fig. 4. Photograph of the 6-element linear array.

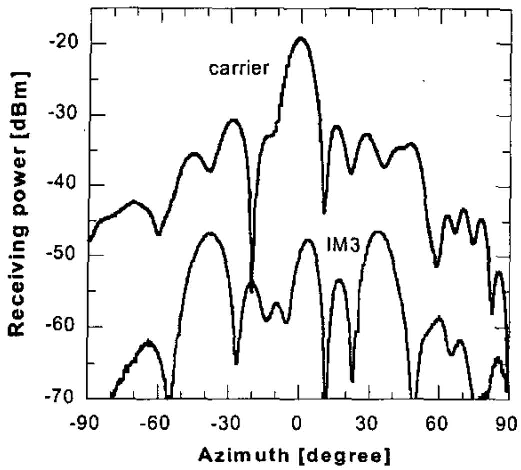


(a) The active phased array on the turntable.

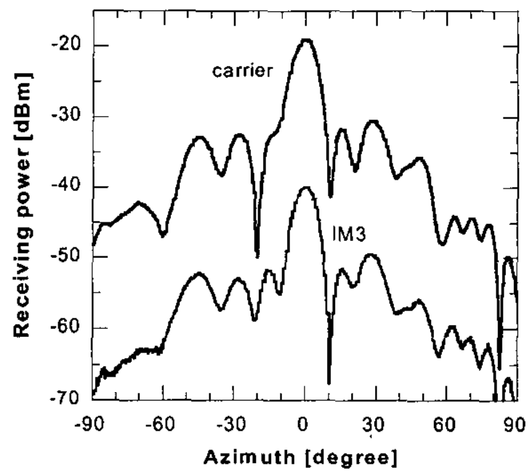


(b) Experimental condition for far-field measurement.

Fig. 5. Far-field experiment in a radio anechoic chamber.

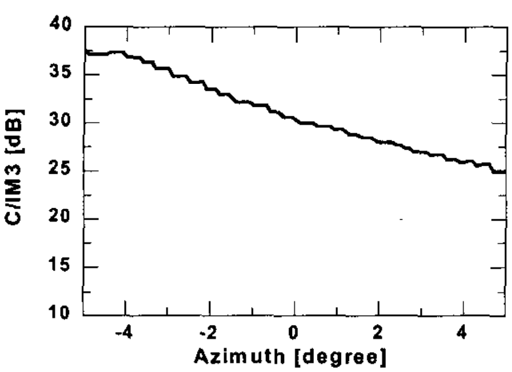


(a) With EODIC

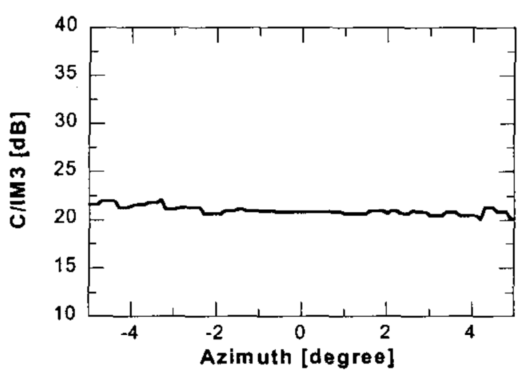


(b) Without EODIC

Fig. 6. Measured radiation pattern of carrier and IM3.



(a) With EODIC



(b) Without EODIC

Fig. 7. Measured C/IM3.