Developments in Active Integrated Antennas

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Abstract

Active Integrated Antennas (AIA's) represent a new class of microwave and millimeter wave front-end circuitry, offering several attractive features such as compact circuit implementation, light weight, better efficiency, and multi functionality. This paper presents several developments in the research area of active integrated antennas for microwave and millimeter-wave front end applications.

I. Introduction

The active integrated antenna (AIA) design approach is a new way of envisioning and designing transmitter/receiver front-ends. In this design methodology, the radiating antenna is used as a functional part of the microwave circuit. Thus, it results in a highly compact, power efficient design.

This paper reviews some of recent developments in the author's group in the area of active integrated antennas [1]. The design examples included in this paper are, AlGaN/GaN HEMT amplifier and frequency doubler and millimeter-wave down converters, and finally retrodirective antenna arrays.

II. High-Efficiency AlGaN/GaN HEMT AIA Power Amplifier

Since power amplifiers consume the majority of power in transmitting RF front-ends, much attention has to be paid to maximizing the efficiency of this crucial component. One technique for improving efficiency of power amplifiers which allows for smaller and light weight power sources, reduced cooling requirements, and enhanced reliability is to properly tune output harmonics of the amplifiers.

The AIA AlGaN/GaN HEMT power amplifier is shown in Fig. 1.This design example utilizes a circular sector antenna, which is capable of reactively terminating both the second and third harmonics of the amplifier [2].

A 55 % power added efficiency (PAE), 30 dBm output power, and 14 dB power gain at 2.45 GHz was measured as shown in Fig. 2. No major degradation in the antenna radiation patterns was

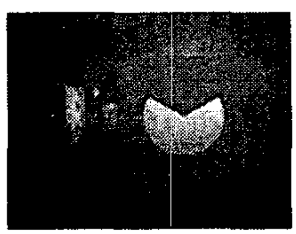

Fig. 1. AlGaN/GaN HEMT AIA power amplifier.

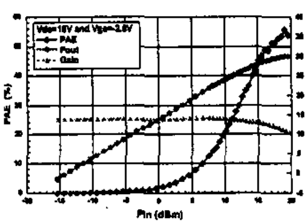

Fig. 2. Amplifier output power, PAE, and gain performance versus input power.

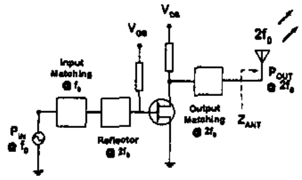

Fig. 3. Frequency doubler using AIA design approach.

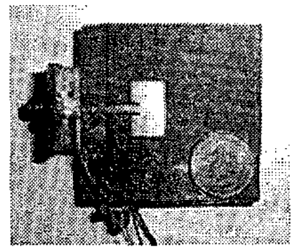

Fig. 4. AIA AlGaN/GaN HEMT frequency doubler.

observed, with harmonic suppressions of -30 dB and -20 dB for 2nd and 3rd harmonic frequencies, respectively.

III. AlGaN/GaN HEMT AIA Frequency Doubler

The application of the AIA design approach is not limited to amplifiers. In a design of a frequency doubler, the design approach is implemented by designing an antenna at a resonant frequency corresponding to the desired second harmonic frequency and integrating an active device with the antenna, as illustrated in Fig. 3 [3]. The antenna operates as a fundamental frequency reflector as in a conventional frequency doubler, thus eliminating the need of an additional fundamental frequency reflector. Because the antenna plays a double role in this design scheme, both size and transmission line loss can be reduced.

A photograph of the AlGaN/GaN HEMT AIA frequency doubler based upon AIA design concept is shown in Fig. 4. For the 4 to 8 GHz AIA frequency doubler, a 5 dB conversion gain and 25 dBm saturated output power was achieved as shown in Fig. 5. Note that those data include antenna gain.

IV. Millimeter-Wave Direct Conversion Receiver

The AIA design approach is especially attractive at millimeter wave frequencies, where feedline loss can be significant. A single integrated I/Q direct down converter is realized and shown in Fig. 6. A 40 GHz patch antenna is designed to have 10 dB bandwidth of 1.64 GHz for broad-band communication. The quadrature mixer provides a direct conversion capability for digitally modulated signals. More importantly, the existence of I/Q output channels can greatly reduce the post-stage signal processing load and increase the system throughput when an advanced system such as an adaptive beamforming array is taken into account.

The mixer uses a pair of anti-parallel diodes and is LO pumped sub-harmonically at half of the RF carrier frequency to achieve direct down conversion. Overall phase and amplitude imbalance between I and Q output channels are less than 1.2 degree and 1 dB, respectively. Fig 7 shows the measured conversion loss performance. A 14.6 dB average conversion loss of mixer is achieved over frequency range from 39.75 to 40.25 GHz.

V. Integrated 60 GHz Planar Phased Array with I/Q Mixers

As an extension to the work discussed in the previous section, an entire integrated 60 GHz receiver array has been implemented. In [5], a 60 GHz-band integrated four-element planar phased array with even-harmonic I/Q mixers based on anti-parallel diode pairs has been proposed for adaptive beam forming system applications. It is shown schematically in Fig. 8. In Fig. 9 measured conversion loss performance of each of the four channels is shown. The average conversion loss of the overall circuit is less than 10.6 dB and power imbalance and phase deviation of each I and Q outputs are less than 2.5 dB and 7 degrees.

The 60 GHz band has been utilized for short-range and indoor broadband wireless communications because of high atmospheric attenuation. In such complex communication

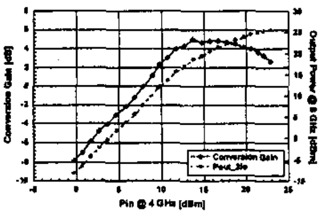

Fig. 5. Output power and conversion gain versus input power.

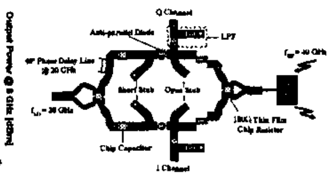

Fig. 6. Modulator/demodulator integrated with a planar antenna.

environments, adaptive beamformers provide a solution for effective use in the frequency band because the antenna arrays generate desirable radiation patterns as well as improve capacity of systems with multi-channels including high-speed data rates.

VI. Frequency Autonomous Retrodirective Array

Retrodirective arrays are antenna arrays that are able to perform automatic beam pointing and tracking Beam pointing is performed automatically, without the use of phase-shifters of digital circuitry [6]. Uses of such arrays include enhanced gain transponders and beacons. More recently, a new architecture that enables the retrodirective array to respond to an interrogator at the same transmitted frequency with no previous knowledge of the transmission frequency is reported [7]. This enhances the covert nature of the retrodirective array and also eliminates the possibility of beam pointing error due to Doppler shifts.

In this array shown in Fig. 10, phase conjugation is accomplished by first doubling the RF signal and using this doubled frequency to mix with the incoming RF. The result is the generation of a phase conjugated form of the incoming RF. The phase conjugated signal is always exactly the same as the incoming RF frequency.

Bi-static radar cross section (RCS) pattern measurements of the array were done at 5.2 and 5.8 GHz in Fig. 11 and 12, respectively. The frequency agile prototype array shows excellent retrodirectivity at various frequencies.

VII. Conclusion

From the examples given in this paper, the AIA design approach has been demonstrated as an effective and useful concept in modern microwave and millimeter-wave front-end applications.

VIII. References

[1] Y. Qian and T. Itoh, "Progress in active integrated antennas and their applications," *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 1891-1900, 1998.

[2] Y. Chung, C. Y. Hang, S. Cai, Y. Qian, C. P. Wen, K. L. Wang, and T. Itoh, "Output harmonic termination techniques for AlGaN/GaN HEMT power amplifiers using active integrated antenna approach," *IEEE MTT-S Int. Microwave Symp. Dig.* vol 1. pp. 33-436, 2002.

[3] Y. Chung and T. Itoh, "A new architecture for AlGaN/GaN HEMT frequency doubler using active integrated antenna design approach," *Asian Pacific Microwave Conf. Dig.*, 2002.

[4] J- Y. Park, S.-S. Jeon, Y. Wang, and T. Itoh, "Integrated antenna with direct conversion circuitry for broadband millimeter-wave communications," to be published in *IEEE Trans. Microwave Theory Tech.*.

[5] J- Y. Park, Y. Wang, and T. Itoh, "A 60 GHz planar phased array integrated with even-harmonic I/Q mixters," to be submitted to *the 5th Topical Symp. On Millimeter Waves*, 2003.

[6] R. Y. Miyamoto, Y. Qian, and T. Itoh, "Active retrodirective array for remote tagging and wireless sensor applications," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1431-1434, 2000.

[7] K. M. K. H. Leong, R. Y. Miyamoto, S.-S. Jeon, Y. Wang, and T. Itoh, "A frequency

autonomous retrodirective array transponder," *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 2, pp. 1349-1352, 2002.

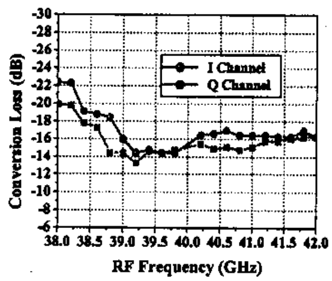

Fig. 7. Conversion loss with respect to RF frequency for each I and Q channel (LO : 11.8 dBm).

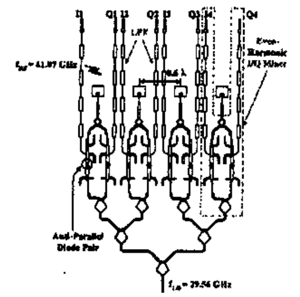

Fig. 8. 60 GHz four-element integrated phased array with I/Q mixers (Circuit size : 13.3 x 20 mm).

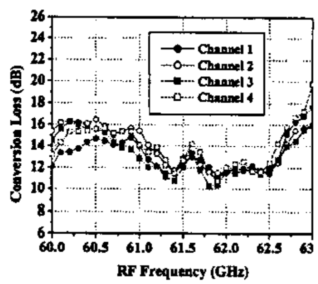

Fig. 9. Conversion losses of each 4 channel versus RF frequency (LO : 21.5 dBm).

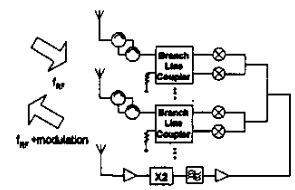

Fig. 10. Schematic of frequency autonomous retrodirective array.

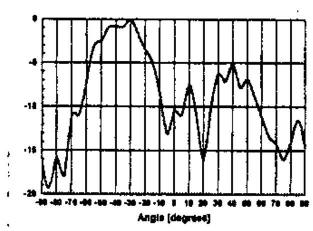

Fig. 11. Measured bistatic RCS (frequency : 5.2 GHz ,-30°).

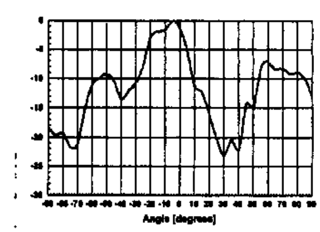

Fig. 12. Measured bistatic RCS (frequency : 5.8 GHz, 0°).