Integration of Electronics and Antennas

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Abstract

The integration of electronics and antennas forming a single front-end component offers several benefits for modern microwave and millimeter-wave system designs, such as compactness, lower power consumption, and multi-functionality. This paper highlights some of the work carried out by the author's research group in the area of active integrated antennas (AIA's).

I. Introduction

In traditional wireless system design, antennas simply serve as a kind of a transducer; for transmitters, translating electrical signals generated by RF-front end circuitry into electromagnetic radiation and for receivers, re-translating from electromagnetic radiation into electrical impulses which can then be processed by the receiver front-end. The idea of circuit integrated antennas was conceived by first observing the existing co-dependence of antenna and circuit and then taking it one step further to achieve full integration of antenna and circuit to create a single entity. This merging of antenna and circuit has led to innovative RF front-end designs that possess several desirable features such as compactness, lower power consumption, and added design flexibility.

This paper will give a brief overview of some of the work that the author's group has done to further the development of active integrated antennas (AIA's) [1]. The study of both active circuits and antennas has led to some insight into the design of new antenna array architectures for retrodirective antenna arrays and smart-antennas, which will also be discussed in this paper.

II. Single-Ended Active Integrated Antenna Amplifiers

In most transmitter designs the power amplifier (PA) is the active component that precedes the antenna. It is also the most power-hungry circuit in the transmitter chain. Therefore, much effort has been spent on maximizing PA's efficiency and output power. One method of accomplishing this is to incorporate output harmonic tuning in the amplifier design. In practice this is often realized by adding resonators at the amplifier output, which act as reactive terminations for the upper harmonic frequencies generated by the PA. Because such resonators always have some inherent loss, the addition of these components cannot lead to the maximum achievable amplifier efficiency.

The AIA approach to this problem is to design an antenna that intrinsically rejects all harmonic frequencies generated by the amplifier. Moreover, the antenna input impedance need not be 50Ω, which adds more flexibility in the design of the output matching circuit of the PA. This was first demonstrated in [2]. A modified circular segment microstrip antenna, which was designed to reject both second and third harmonics was combined with a 2.55 GHz, class-F GaAs FET amplifier (see Fig. 1). As opposed to a simple rectangular patch antenna the circular sector antenna resonant frequencies depends on the roots of Bessel functions rather than multiples of the fundamental frequencies allowing it to be designed to suppress both second and third harmonics. Using this approach, a power added efficiency (PAE) of 63% with maximum output power of 24.4 dBm was measured. In addition the second and third harmonic radiation was measured to by -33.8 dBc and -31.4 dBc, respectively.

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More recently, a similar approach was used to design an AlGaN/GaN HEMT PA, biased in class-AB. A maximum output power of 30 dBm and peak PAE of 55% with a high power gain of 14 dB were achieved [3].

III. Push-Pull Active Integrated Antenna Amplifiers

Conventional microwave frequency push-pull amplifiers use a pair of class-B amplifiers along with input and output baluns to split and combine the power. Push-pull amplifiers offer twice as much output power as single class-B amplifiers, high theoretical PAE (78.5%), and is able to intrinsically suppress even order harmonic generation by virtue of its balanced configuration.

Even the slightest addition of insertion loss at the amplifier output leads to significant reductions in PAE. For example, a power combining loss of 0.5 dB reduces an amplifier's efficiency from 60% to 53%.

In [4] an AIA design methodology that uses printed dual-feed antennas to do the job of the output balun, and harmonic tuner, while still serving its primary function as a radiator was introduced. As with the single ended amplifier AIA design, the type of printed dual-feed antenna utilized is crucial. Because the antenna is used to replace the output balun, it must perform the same function of accepting only odd excitations and rejecting even excitations. [4] demonstrates this concept using a λ-long slot antenna with two microstrip feedlines oriented in opposite directions and placed $\lambda/2$ apart on the slot (see Fig. 2). This design architecture yields a maximum PAE of 63% at an output power of 26 dBm. This AIA concept has also been used to design amplifiers integrated with patch antennas, leaky-wave antennas, and a dipole-like quasi-Yagi antenna.

IV. Low-Noise Active Integrated Antenna Amplifier

The application of the AIA design approach is not limited to transmitting amplifier designs. In low-noise amplifier (LNA) design the factor that sets the noise performance of the device is the input impedance match. [5] introduces a method for designing a LNA receiver integrated with circularly polarized antenna. In this work the antenna impedance was designed according to the optimum noise impedance, rather than 50Ω. This eliminates the need for additional matching circuits, which reduces circuit loss and size. A photograph of the circuit is shown in Fig. 3. The AIA receiver was measured to have an 11 dB gain and a 0.4 dB noise figure at 5.74 GHz.

V. Reconfigurable Retrodirective Array

Retrodirective arrays are able to re-direct a signal back to its source direction without previous knowledge. Beam pointing is performed automatically, without the use of phase-shifters or digital circuitry. The capability to perform high gain antenna pointing automatically, makes the retrodirective array an attractive candidate for advanced digital mobile communication systems.

RF front-end multi-functionality and reconfigurablity presents significant advantages in wireless system design. Such circuits would have the ability to accommodate multiple wireless standards, operate in multiple frequency bands, and potentially have the innate ability to adapt to its local environment to improve signal reception, reject interference, and compensate for multipath effects.

This design ideology was applied to develop a reconfigurable retrodirective/direct down conversion receiver array [6]. Both types of arrays generally rely on front-end mixers to perform phase-conjugation and down conversion, respectively. The two functions have been combined into a single mixer which is dynamically reconfigured by simply changing the LO frequency.

A proposed wireless sensor system using a reconfigurable active retrodirective/direct conversion receiver array is shown in Fig. 4. In the receiving mode (a), the array system functions as a direct conversion receiver and stores data received from remote sensors. Next, upon receiving an instruction signal from an interrogator, the system operates as a retrodirective transponder (b), and sends the stored data to the interrogator. This switching can be initiated by the header code contained in the signal from the interrogator. Then after a prescribed time limit the retrodirective array reverts back to receiver mode.

The retrodirective function of the array enhances the link gain between interrogator and array without requiring the interrogator to identify its exact location.

VI. Multiplexed Single RF Channel Smart-Antenna

The front-end hardware needed to implement a traditional adaptive digital beamforming (DBF) arrays usually includes LNA's and downconversion mixers at each antenna element. The downconverted baseband signal is then digitally processed to form radiation beams. The digital approach eliminates the need for costly phase-shifters and attenuators which needs to be placed following each antenna element in the analog beamforming approach. The smart antenna system introduced in [7] proposes a new receiving smart antenna array utilizing a novel Spatial MultIplexing of Local Elements (SMILE) technique in conjunction with a digital beamformer. The SMILE technique even further reduces the amount of hardware components needed in an array. A single receiver chain is time shared by the antenna elements in the implemented four-element array. Fig. 5 shows the block diagram of the proposed system. N antenna elements are multiplexed into one single channel output using a PIN switching network. The switching rate is determined by the Nyquist sampling theory, which is proportional to the number of elements and the baseband bandwidth. The single RF channel output is digitized and then digitally demultiplexed and the resulting waveforms are used for beamforming. This technique was proven experimentally at 5.8 GHz.

VII. Conclusion

This AIA design examples presented in this paper show the potential capability of this new design methodology. It allows the front-end designer an additional degree of freedom to achieve the optimum circuit performance. Moreover, the multi-disciplinary nature of this research topic provides antenna designers and circuit designers a new perspective on RF front-end components, leading to new and inventive designs. This knowledge can then be carried over to the system level, allowing hardware designers to implement circuits and antennas that are specialized for a particular system.

VIII. References

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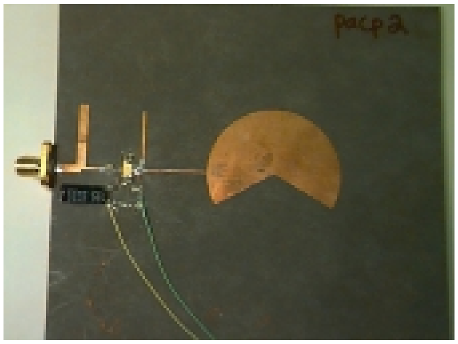

Fig. 1. Class –F power amplifier AIA.

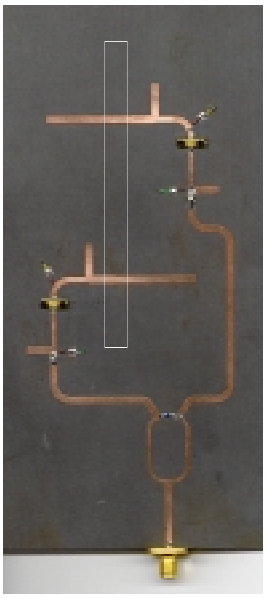

Fig. 2. Push-pull amplifier AIA with slot antenna.

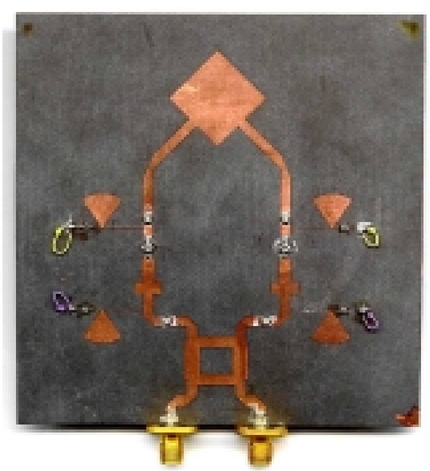

Fig. 3. AIA low noise receiver.

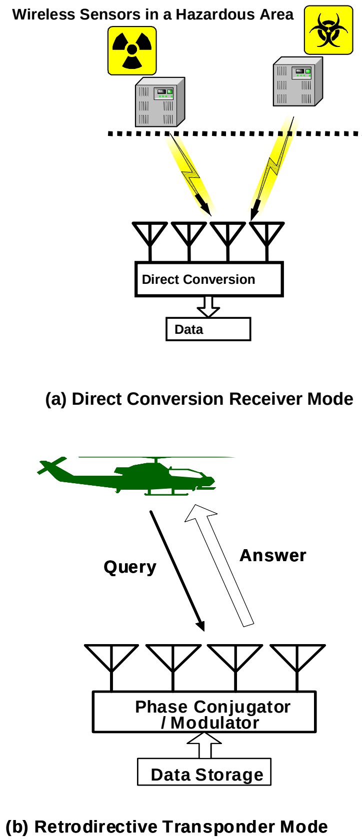

Fig. 4. Wireless sensor system using a reconfigurable array.

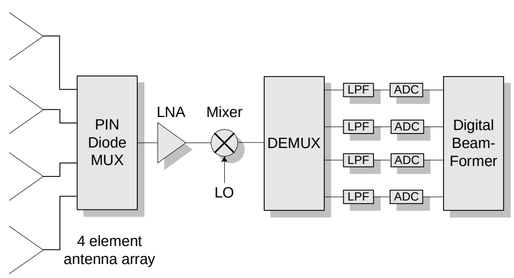

Fig. 5. SMILE smart antenna system schematic.