Chapter 10
Active Integrated Antenna

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ABSTRACT

This chapter discusses the active integrated antenna (AIA), which is the integration of an antenna with an active circuitry that acts as a radiating element as well as to perform additional functions simultaneously. The designs of AIA can be generalized into three different classifications, the amplifier type, the oscillator type, and the frequency conversion type. An AIA is classified as the amplifier type when its active device functions as an amplifier. Correspondingly, an AIA is classified as the oscillator type when its active device offers the function of an oscillator while the frequency conversion type of AIA integrates an active device with a passive antenna element for the purpose of frequency translation.

INTRODUCTION

The terminology ‘active antenna’ simply means that active devices are used in passive antenna to improve the antenna performance. ‘Active integrated antenna (AIA)’ indicates specifically that on the same substrate, the passive antenna and the active circuitry are integrated together as a single entity (Lin & Itoh, 1994), without the need of a matching circuit or interconnecting cables. This differs from the traditional design, where the antenna and the RF front-end circuits are different components, connected with standard 50-Ω transmission lines or waveguides. The AIA not only functions as a radiating element, it also renders built-in signal and wave processing capabilities, such as amplification and frequency multiplication.

The AIA provides a new paradigm for designing modern microwave systems. It consists of one or more active devices, such as diodes and/or transistors, integrated together with a passive radiating element, such as a microstrip patch, a printed dipole, a bowtie, or a slot antenna (Chang *et al.*, 2002). It offers many advantages, which include compactness, low cost, low profile, minimum power consumption, and multiple functionalities (Flynt *et al.*, 1996). Such integration also reduces the inherent losses and noise figure (NF) of the system as well as realizes the ease of machine manufacturability. Unlike conventional antennas, the addition of active devices makes an AIA system non-reciprocal. Thus, it can only function either as a transmitting or a receiving device, but not both simultaneously (Itoh *et al.*, 2001).

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The use of AIA can be traced back to as early as the 1920s (Lin & Itoh, 1994), where an electron tube was first integrated into the antenna of a radio broadcast receiver, to eliminate the lossy and bulky interconnection between the active devices and the antenna (Wheeler, 1975). At that time, the application of AIA was limited because the usage of electron tubes was expensive to build and maintain. This status quo remained until the transistor was founded in 1948 (Tranter, 1995) and the concept of AIA was resurrected in the early 1950s. Solid-state solutions soon played a dominant role in AIA research, due to their reliability, superior inherent voltage standing wave ratio (*VSWR*), lower cost, and smaller size.

Since then, several pioneering works in AIA had been reported. Copeland and Robertson (1961) demonstrated a mixer-integrated antenna, which they called an 'antennaverter'. They used a travelling wave antenna together with tunnel diodes, to operate as a travelling wave amplifier, which they called an 'antennafier' (Copeland *et al.*, 1964). Meinke and Landstorfer (1968) integrated a field effect transistor (FET) to the terminals of a dipole to serve as a Very High Frequency (VHF) amplifier, for reception at 700 MHz. Meanwhile, Ramsdale and Maclean (1971) used bipolar junction transistors (BJTs) and dipoles for transmission applications. Lindenmeier (1976) then introduced the general theory behind the optimum bandwidth of signal-to-noise ratio (SNR) for receiver systems integrated with small antennas.

The first modern AIA was developed by Thomas *et al.*, (1985). It was a Gunn diode integrated with a patch antenna, operating at the X-band. Today, the technological maturity in Monolithic Microwave Integrated Circuit (MMIC) has enabled rigorous integration between the antenna and the circuit component. AIA with various functions can now be packed into a mini footprint. Through manipulation of the appropriate configuration, an infinite potential on multiple communication and sensor applications can be realized. Despite its original role serving as a radiating element, the active antenna can now be made injection locked, frequency tunable, power amplified, or mutually coupled. For instance, the AIA had been applied as a large-scale spatial power combiner, in which the radiation of many AIAs combines coherently. Such combiners had been demonstrated at the X-band (Chew & Itoh, 1995) and at microwave frequencies (York & Popovic, 1997). In the works of Cryan *et al.* (1997) as well as Andrew and Hall (2002), AIAs had been used to achieve synchronous operation of a number of integrated antenna oscillating elements. By controlling the phase distribution of each AIA element, the array could be transformed into a beam steering system. Likewise, Lin and Itoh (1994) and Hall *et al.* (2002) explored on simultaneous transmit-receive active arrays with duplex operation. Good transmit-receive isolations were reported in their literatures.

In general, based on the different functions of the active device applied, the AIA can be classified into the amplifier type, the oscillator type, and the frequency conversion type.

AMPLIFIER TYPE

An AIA is classified as the amplifier type when its active device functions as an amplifier. The integration of the amplifier with the antenna increases the antenna gain and bandwidth as well as improves the noise performance of the overall AIA module. When the antenna is connected to the input port of the amplifier, it acts as the source impedance of the active device and the AIA functions as part of a receiver. The goal of the receiving AIA is to obtain a low NF. Correspondingly, when the antenna is connected to the output port of the amplifier, it acts as a load impedance of the active device and the AIA functions as part of a transmitter. The goal of the transmitting AIA is to achieve high linearity and efficiency.

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