Review and Classification of Active Antennas

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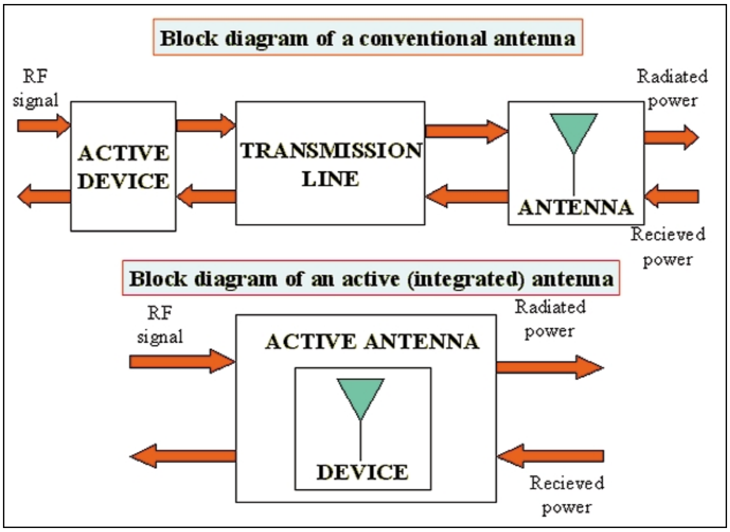
The demand for wireless communication systems is forcing frequencies used higher and higher. At higher frequencies two problems arise: increasing losses in transmission lines and solid-state devices are power limited. In addition, there are problems in the design and implementation of conventional radiation systems when high RF power is needed. Combining several RF devices to reach the required RF power level is inefficient because power combiners are lossy at microwave frequencies and a high noise figure results because of the losses in the interconnection lines.

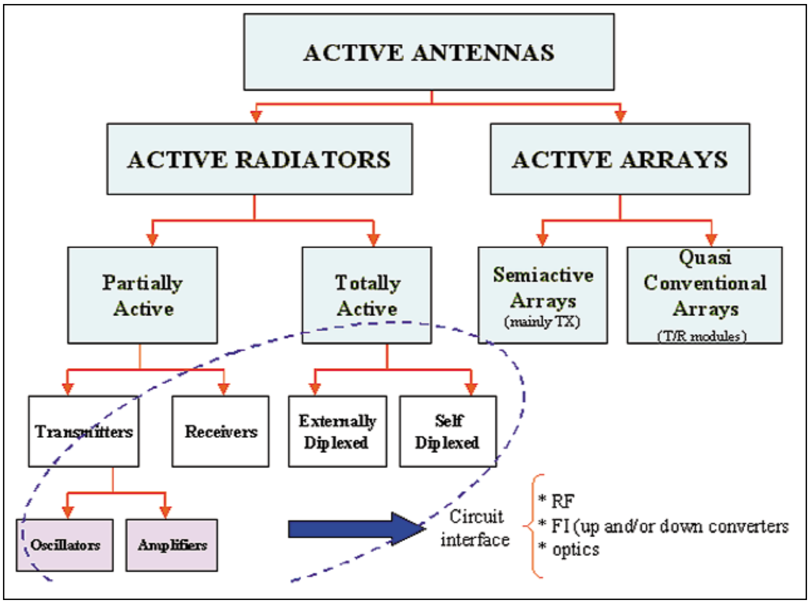


▲ **Figure 1. Block diagrams of conventional and active integrated transmitting antennas.**

Important advances have been made in the field of antennas. These advances are driven by the increasing demand for wireless systems and are resulting in improved aspects of solid state devices and new designs for small antennas.

Active antennas provide a new paradigm for designing modern microwave systems. Active antennas can be explained from either the microwave or the antenna point of view. From the microwave engineer's point of view, an active antenna integrates the active RF front-end on the antenna directly, as shown in Figure 1. The active device and the antenna are treated as a single entity. This differs from the traditional design methodology where the antenna and RF front-ends were different components connected to standard 50-watt transmission lines or waveguides. The antenna is not only used as a radiating element, but also provides circuit functions, such as filtering, diplexing, amplifying and oscillating. From the antenna designer's point of view, active antennas overcome some of the drawbacks traditionally related to conventional antennas, such as loss between the RF front-end and the antenna and they provide signal processing functions.

Active antenna concepts and types are described in several papers [1-6]. However, a complete and concise classification of active antennas has not been published. This article presents a classification of active antennas according to system function the antenna (i.e., diplexing, amplifying, oscillating) and to a single radiator or array group. Additionally, examples are given showing recent progress and future trends in active antennas according to the ones presented in [5-6].



▲ **Figure 2. Classification of active antennas.**

Classification of active antennas

Some papers [1-6] describe all active antennas according to the radiator function. These papers propose a classification method consisting on sorting the active antennas by different functions of the active devices they integrate. As the basic functions of active circuits are oscillating, amplifying and frequency converting, then the active antennas can be classified into three groups: oscillator type, amplifier type and frequency conversion type. According to this classification, only the antennas integrating an active element and arrays integrating these active radiators could be considered as active antennas. In [5-6], a second difference was whether or not the antenna and the active element shared one substrate. Two classifications were proposed: the active integrated antenna (AIA) with the antenna and active element on the same substrate and the active antenna with components on different substrates.

Although the radiator function can be a classification criterion, from our point of view, the final aim of active antennas is to manage and distribute the power. This function can be achieved with active devices or passive ones. The best criterior would be to classify active antennas into two groups: active radiators or active antennas composed by only one element and arrays, or active antennas composed of several elements (active or passive). The concept of an active array is related to the antenna system function of managing and distributing the power actively. This implies two tasks: designing passive subarrays and designing transmitting/receiving (T/R) modules. Furthermore, the concept of an active radiator is the integration of both the active device and the antenna as a whole. Figure 2 shows the classification of active antennas with corresponding subgroups.

Active radiators

Active antennas comprise a great number of antenna architectures composed of radiating elements and active devices with the final aim of minimizing the losses between the radiator and the T/R module. These losses degrade receiver noise figure and reduce transmitting power. Active radiators facilitate systems with desirable features, such as compactness, low cost, low profile, minimum power consumption and multiple functionality [6].

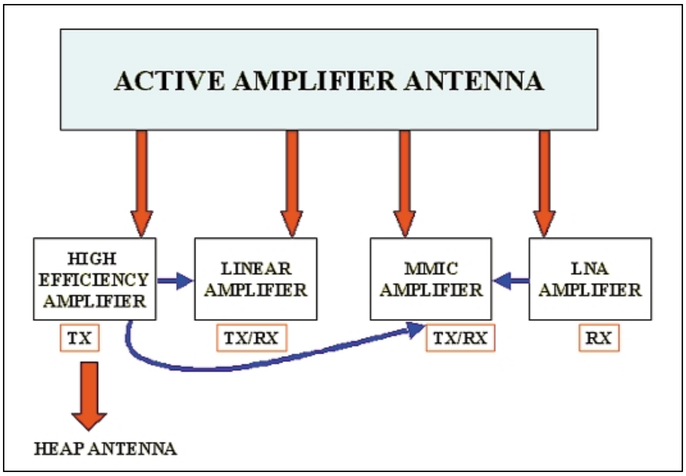
An active radiator can be considered as an active microwave circuit where one of the ports is free-space and the other interfaces to the circuit. The antenna is not only used as a radiating element but it also provides circuit functions as impedance matching, amplifying, filtering, diplexing, frequency conversion and oscillation. The active antenna is typically composed of a bipolar or FET transistor embedded in a substrate where a dipole, loop, patch or slot has been printed.

In Figure 2, one criteria for classifying the active radiator is its possibility for use as a transmitter and receiver simultaneously. That implies the integration of the diplexing function. Therefore, active radiators are classified as partially active, when there is no diplexing function integrated on the radiator, or totally active, when the diplexing function is fully integrated. The latter can be divided into two groups, depending on where the diplexing is done, inside the radiator or outside the radiator. Then we have self-diplexed radiators [7-9] or external diplexed radiators [10].

In the case of partially active radiators, the classification criteria is the function of the transmitter and receiver active radiators. These are divided into two groups depending on their main function: amplifying, oscillating or mixing. As shown in Figure 2, functions can occur at optical frequencies, RF frequency or intermediate frequency. This depends on the application developed in the system (i.e., RF front ends, millimeter wave power combining, beam steering). When the goal of the system is the implementation of an efficient radiator, the functions are amplifying or oscillating. These structures have particular features that can be summarized as follows: categorized as active amplifier radiators or active oscillator radiators.

Active amplifier radiators

Active amplifier radiators amplify the transmitted or received signal. The active and radiating elements are embedded in the same substrate. In the transmitting case, the input is fed through the input port while the output is the antenna [11]. The classification shown in Figure 3 is according to the type of the amplifier. The goal of receiving antennas is to obtain a low noise figure



▲ **Figure 3. Classification of active amplifying radiators.**

while transmitting antennas. The goal is to obtain the highest EIRP. In the case of transmitting antennas, two goals arise: linearity or high efficiency. Most active antenna designs require high linearity, which reduces the efficiency of the antenna. High-efficiency active patch (HEAP) antennas [12] have changed the roll of traditional designs prioritising the efficiency instead of the linearity.

Active oscillator radiators

Traditional designs of active oscillator radiators did not take into account the effect of the antenna in the oscillator circuit. However, active oscillating radiators must be classified according to both the oscillating structure used (i.e., Colpitts, Hartley, series or parallel type configurations) and the function of the antenna in the oscillating circuit (resonator, filter, negative feedback). For frequencies under 3 GHz bipolar technology is typically preferred while for higher frequencies FET technology is more suitable. HFET transistors based on InP show promising results at millimeter frequencies [13]. When the integration density of active devices must be increased, oscillators are often designed with two FETs in push-pull mode on the active antenna. [14-15]

Arrays

The second classification group of active antennas is array antennas. These are divided into two groups: semi-active arrays and quasi conventional transmitting and receiving arrays.

The first group is comprised of arrays that are not completely active but have a better performance than passive structures and similar features to active arrays [16]. In these, the active devices are placed at an intermediate point between conventional RF feeding networks and new active radiators. Although these arrays are only considered in transmitting mode with amplifier devices [7, 16], they can also be used as receivers with either amplifying or oscillating devices that can synchronise the phases of the receiver generators through the feeding matrices (Butler or Blass [17, 18]). These semi-active antennas provide two important advantages over conventional active arrays: the failure of one of the active devices does not imply the failure of the whole system and all amplifiers work at the same input level.

The second group is comprised of quasi-conventional transmitting and receiving arrays: arrays composed of active radiators (diplexed or not) and arrays whose main function is power combining or electronic scanning. In [6] a classification of quasi-conventional arrays according to their function in the system is given.

Table I shows a classification with references where these quasi-conventional arrays can be found depending on their function to combine power or control a beam. ■

Type of quasi-conventional array	Reference
Frequency conversion	[14, 19-22]
Optical beamforming networks (BFN)	[23-25]
Active networks	[15, 26-28]
Array combiners	[29-36]
Power combiners in two dimensions	[37]
Beam steering arrays	[38-41]
Switching beam arrays	[42-44]
Retrodirective arrays	[45-46]
Beam polarisation-agile antenna	[47]

▲ **Table 1. References for antenna classification types.**

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