DESIGN METHODOLOGY FOR HIGH EFFICIENCY ACTIVE RADIATORS

This article describes the basis and principles of high efficiency active radiators. First, the relation between power amplifiers and microstrip patch antennas is presented. Then, a high efficiency active patch (HEAP) antenna in BAR mode is shown as an example of the basis previously described.

High efficiency power amplifiers have been developed over the last few years, largely due to their use and application in mobile communications. In a similar way this fact has caused the development of active antennas and, more specifically, active radiators. Some authors have tried to unify the concept of high efficiency in power amplifiers associated with antennas.[1] However, it is only recently that a true high efficiency active patch (HEAP) antenna has been reported.[2,3] A schematic of this structure is shown in ***Figure 1***.

To understand the basic principles and basis of these antennas, it is important to note that the fact that the amplifiers are an integral part of the antenna must be taken into account, and the operation of the amplifiers should be correctly described. For this purpose, the shape of the current and voltage variations in these devices must be known. To obtain these variations, it is necessary to synthesize the optimum output impedance for each of the harmonics to ensure that the amplifier is working in the appropriate mode.

Fig. 1 Block diagram of the HEAP antenna.

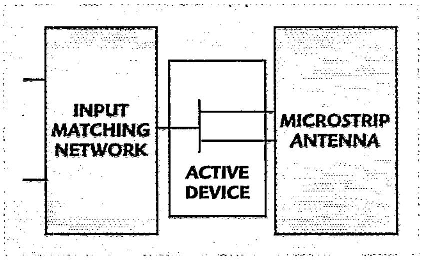

Table 1 shows the optimum impedances that should be synthesized at the output of the device to ensure proper operation. However, other necessary parameters such as the excitation or the feed of the device to obtain the desired mode of operation are not shown.

After the impedances that should be synthesized for each one of the modes are obtained and the right excitation and feeding parameters are known, the radiator type to be used should be selected.

Carrying out a detailed study, it is easily concluded that the only appropriate radiators for use as high efficiency active radiators are the patch and linear wire (dipoles) antennas. By modifying the length and the width (in the case of the dipoles) or the shape, feeding point and excitation type (for the patches), the desired impedances can be obtained. The impedance conditions make the use of other types of radiators, such as horns, for example, inappropriate.

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TABLE I

OUTPUT IMPEDANCE OF DIFFERENT AMPLIFICATION CLASSES

Amplification Class	Maximum Output η (%)	Fundamental Impedance Z_{fo}	Even Harmonic Impedance $Z_{even\ harmonic}$	Odd Harmonic Impedance $Z_{odd\ harmonic}$
A saturated	63.5	Real	Short Circuit (SC)	Open Circuit (OC)
A saturated and overexcited	80	Real	SC	Real
B	78.5	Real	SC	SC
C	100	Real	SC	SC
C saturated	100	Real	SC	SC
C_E	80	Complex	HIGH Z (OC)	HIGH Z (OC)
D	100	Real	SC	OC
E	100	Complex	HIGH Z (OC)	HIGH Z (OC)
F	88	Real	SC	Real
BAR	80	Real	HIGH Z (OC)	HIGH Z (OC)

TABLE II

AVAILABILITY OF DIFFERENT TOPOLOGIES IN PATCH ANTENNAS

Amplification Class	Rectangular Patch	Circular Patch	Open-circuit Ring Patch	Short-circuited Ring Patch
A saturated	yes	yes	yes	yes
A saturated and overexcited	yes	possible	possible	possible
B	possible	possible	possible	possible
C	hard	difficult	difficult	difficult
C saturated	hard	difficult	difficult	difficult
C-E	hard	yes	yes	yes
D	hard	difficult	difficult	difficult
E	hard	yes	yes	yes
F	possible	difficult	difficult	difficult
BAR	possible	yes	yes	yes

Moreover, although linear wire antennas, due to their inductive character, seem very adequate for systems working in C-E and E-class, this type of antenna cannot be used for systems working in other classes because it would be necessary to present other types of impedance. Therefore, their use as active antennas is not possible.

Because patches offer higher integration possibilities than linear wire antennas, the realization of HEAP antennas with patches will be discussed.

HEAP DESIGN METHODOLOGY

A possible procedure for the design methodology is described below.

Design Requirements

In this stage, the characteristics imposed as main parameters for the design include operating frequency, radiation pattern, polarization, configuration, minimum required efficiency, EIRP and linearity.

Topology Selection

The previous data is a guide to select the adequate solution to the problem with the aid of the displayed information shown in ***Table 2***. In this table the relationship between the shape of the antenna and the viability for working in the desired class for high efficiency is summarized. Although the use of more complicated shapes has been proposed, it is believed that classical geometries are preferred because of their simplicity and versatility.

If Tables 1 and 2 are analyzed in more detail, it can be concluded that the most suitable modes of operation for these types of antennas are E, C-E and BAR.

Active Device Characterization

The active element is selected according to the amplification class, the effective isotropic radiated power (EIRP) and the frequency of operation. After the active device has been chosen as a function of the first stage objectives, it is necessary to characterize its behavior with different output loads not only at the operating frequency but also at the harmonics, due to the inherent lack of this knowledge in the commercial devices that are available in the market. To carry out this process, techniques based on load pull methods are usually employed.

Passive Device Characterization

The object of this stage is to characterize the impedance of the antenna in order to find the adequate calculated load impedances and to check if the appropriate shapes of voltage and current that define the amplification mode are obtained. In addition to these simulations, a measurement of the load impedance should be made.

Construction and Simulation

After the calculations and measurements of the different elements have been carried out with the help of a computer, and linear and nonlinear simulation programs, the HEAP antenna should be adjusted for good operation. With these last simulations, the value of the components is adjusted, the good operation of the design is verified and the design of the matching input network is completed. All these simulation processes end with the construction of the initial prototype on which measurements and adjustments are made.

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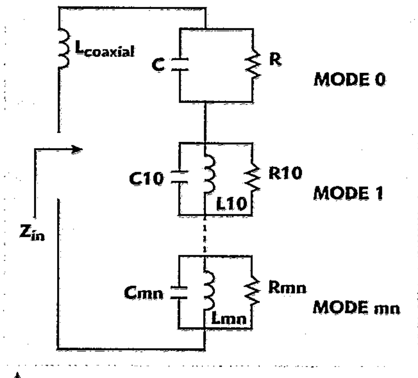
TABLE III	
HEAP ANTENNA SPECIFICATIONS	
Frequency (MHz)	1650
EIRP (W)	≈3
Efficiency (%)	60
Bias Voltage (V)	3
Antenna's shape	Short-circuited ring
Radiation pattern	Omnidirectional in azimuth, maximum at the zenith
Polarization	Circular



▲ *Fig. 2 Cavity model for the calculation of the input impedance of the antenna.*

Measurements, Adjustment and Redesign

The measurement of the main characteristic parameters of the HEAP antenna, especially the EIRP, efficiency and obtained polarization, should be performed.

After the antennas have been measured and the pertinent adjustments have been made, a simulation should be made to try to model correctly the final design for the construction of the definitive prototype.

EXAMPLE OF A LOW BIAS HEAP ANTENNA

The construction of the antenna follows the steps proposed in the previous section and in Radisic, et al.[2] The first step is the determination of the specifications, as listed in ***Table 3***.

The second step is the characterization of the radiating element impedance. The selected antenna is a short-circuited ring, fed by a coaxial line due to its good performance characteristics. The input impedance of this antenna has been obtained based on a cavity model resulting from the circuit of ***Figure 2***. It is composed of an input inductance and different resonant equivalent circuits corresponding to the radiating modes. It must be noted that $L_{coaxial}$ results from the impedance of the feeding system (remember that the drain is directly joined to the patch), which is modeled as a coaxial line with its inductive impedance. It can be seen that at high frequencies the equivalent circuit at the first resonant mode presents a high inductive impedance. Then, in accordance with Table 1, it can be concluded that the suitable impedance for even and odd harmonics can only be reached through E or BAR modes. The BAR mode has been chosen to construct the active antenna because of the low bias voltage required, although the efficiency is not very high.[4]

The third step is the selection and characterization of the active device. The selected transistor used in the HEAP antenna is the SHF-0589 from Stanford Microdevices, which is an AlGaAs/GaAs heterojunction FET, housed in a low cost, surface-mount plastic package. HFET is an ideal choice for high dynamic range requirements because of its low output capacitance resulting in low transient time.

The design of the amplifier starts with an input matching network at the center frequency. This network is based on a high pass filter consisting of a series capacitor and shunt inductor to reduce noise effects. The selection of the device must be done according to the efficiency and output power contours as previously suggested.[5] As a result, it can be concluded that there is a wide set of loads that satisfy the requirements.

After the active device has been characterized, the full integration of the antenna and device is completed. It should be noted that, because a short-circuited ring is used, a small coupling capacitor has been placed over the patch to enable the feed for the active device. The gate voltage, depending on the device pinch-off voltage, V_p and the saturated drain current, I_{dss}, is then adjusted for the desired value of drain current. I_d is calculated from

$$V_{gs} = V_p\left(1 - \sqrt{I_d / I_{dss}}\right) \quad (1)$$

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The fourth step consists of the computer-aided design of the complete HEAP antenna using commercial software such as Touchstone® or Spice.® The use of Spice requires the knowledge of the active device model, while the microstrip antenna can be simulated according to the model previously described. The use of Touchstone requires the scattering parameters of both the transistor and microstrip antenna. Then the prototype can be mounted to prove the design.

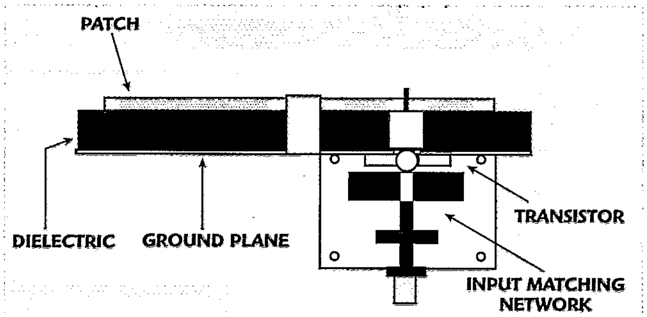

Fig. 3 The amplifier and microstrip antenna.

The fifth step is the prototype construction to conclude all the previous tasks. Both the amplifier and microstrip antenna are mounted in a single structure, as shown in ***Figures 3*** and ***4***. Different measurements are made to show the results obtained. The radiation pattern, S_{21}, S_{11} and efficiency as a function of input power are shown in ***Figures 5***, ***6***, ***7*** and ***8***, respectively (S_{21} has been measured using an auxiliary test antenna that receives the radiated signal from the HEAP antenna and from a conventional short-circuited ring antenna). The radiation pattern is nearly the same for both antennas. The main differences between the two antennas are the gain (S_{21} parameter) and efficiency. From the displayed data, it can be seen that the S_{21} of the HEAP antenna is 10 dB higher than the S_{21} of the conventional one at the operating frequency. Also, the efficiency is not as high as the one presented previously.[2] This is a logical result due to the fact that BAR mode amplifiers have lower efficiency than mode E amplifiers. However, there is a great advantage of using BAR mode amplifiers because of the lower input power required.

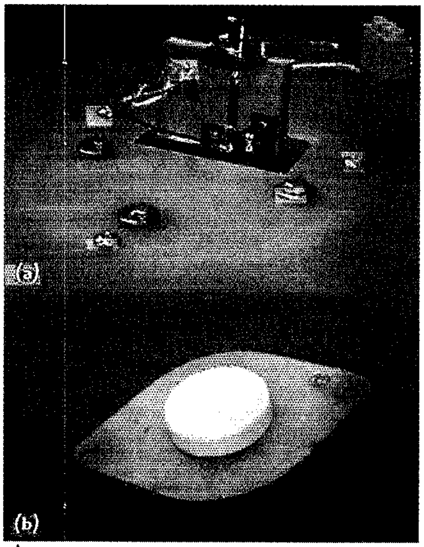

Fig. 4 The final HEAP prototype at 1650 MHz; (a) amplifier side and (b) radiator side.

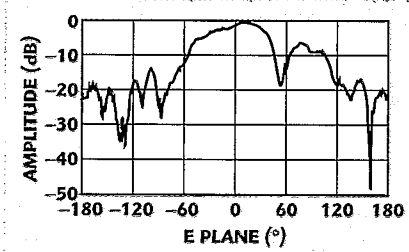

Fig. 5 Radiation pattern in E plane of the HEAP antenna working at 1650 MHz.

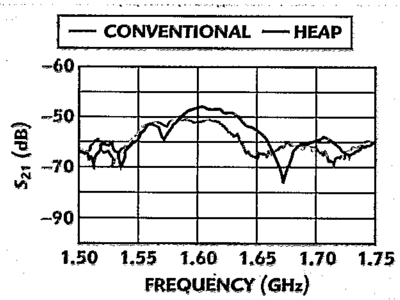

Fig. 6 Comparison of S_{21} between the conventional and the HEAP antenna.

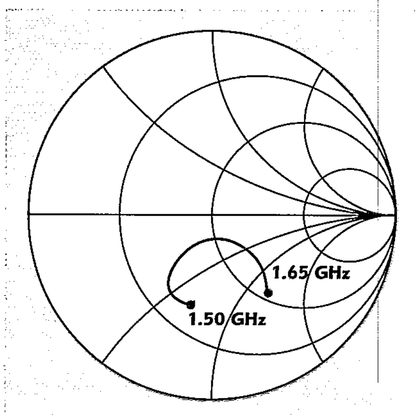

Fig. 7 HEAP antenna's S_{11} parameter.

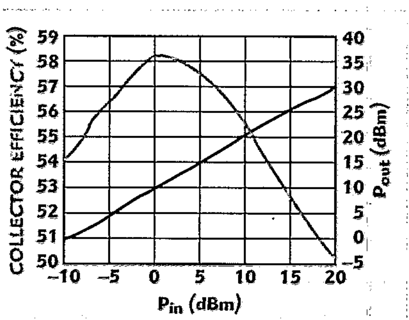

Fig. 8 Added efficiency in HEAP antenna.

TABLE IV

BAR MODE HEAP ANTENNA PERFORMANCE

Maximum EIRP (W)	2.5
Maximum added efficiency (%)	58
Gain (dB)	14

Finally, ***Table 4*** shows the main results of the BAR mode HEAP antenna.

CONCLUSION

In this article the principles of design of HEAP antennas have been presented. Two main results have been shown that are displayed in Tables 1 and 2 — the optimal impedance that an antenna should present to become a part of a high efficiency active device, and the relation between possible realizations and the topology of the patches, respectively.

The HEAP antenna concept is first intended for communication applications and is primarily based on the integration of high efficiency amplifiers and a patch antenna. Its principle of operation is intended for the use of both BAR and E modes, but the initial requirement of low supply power restricts its use to the BAR mode at the cost of reduced efficiency. The supplied power of the BAR mode HEAP antenna is very low according to the initial requirements. ■

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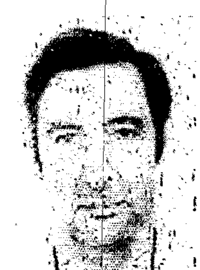

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