HIGH EFFICIENCY MODE "E" AMPLIFIER POWERS HIGH EFFICIENCY ACTIVE TRANSMITTING PATCH ANTENNA

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Abstract: This paper describes a high efficiency amplifier that uses the load presented by a patch antenna to work in class "E". The resulting set is a high efficiency transmitting active antenna. The dimensions, shape and location of the feeding point in the antenna are selected to obtain an input impedance to force the transistor to work in class "E" at 885 MHz with very high collector efficiency: ηc=90% @ Vcc=12.5, Pout=1.5W

INTRODUCTION

This paper shows a high efficiency mode "E" amplifier designed to power a patch antenna. The set is a high efficiency transmitting patch antenna for the 900 MHz band.

To design this "E" mode amplifier a load-pull concept [1] based on studying the load impedances needed at the fundamental and harmonic frequencies instead of the classic time-domain approach has been used. The main results of the amplifier are shown in the Fig. 1.

The load impedances needed for "E" operation are obtained in a selected feeding point of a patch antenna. The dimensions, shape and the location of the feeding point are designed to achieve the required load impedances for the transistor. A matching network is not needed.

Together the previous elements make up an active high efficiency transmitting patch antenna. This is a new concept (at least to the known of the authors).

1. AMPLIFIER DESCRIPTION

To achieve class "E" (or a good approximation) it is not necessary to use the classic "E" matching networks described in the classic bibliography [2,3]. Those networks are most times difficult to implement at R.F. and they use loads different from 50 Ω.

To achieve class "E" it is only necessary to fulfill the conditions specified in [2,3]. Basically those conditions are: active device switching, (heavily overdriven), right output voltage and current shapes.

Those conditions can be fulfilled at high frequencies with an output network that exhibits a very high reactive load at least at the second and third harmonic, the adequate load at the fundamental frequency and proper overdrive. This is enough to perform "E" operation or at least a good approximation. Therefore once the high reactive harmonic impedance is provided and the amplifier is properly overdriven the collector efficiency heavily depends on the load (R+jX) at the fundamental frequency.

Any load network with the previous high frequency behavior made of discrete components, transmissión lines, input impedance of an antenna, etc., would allow class "E". Furthermore, sometimes those conditions are easily provided by very simple matching networks [11].

The amplifier uses the internal device output capacitance and parasitic effects of the package to perform the shunt capacitance needed for "E" operation. At this frequency the internal capacitance combined with the resistive part of the load is enough to achieve class "E" with appreciable gain and at an oputput power level acceptable for the transistor. In general this internal capacitance would be smaller or greater than the capacitance needed to perform class "E".

The load at the fundamental is calculated using the method described in [1]. A very very simplified approximation (for ideal switching) of the required load at the fundamental frequency for "E" operation is given in the equation (1) derived from [3,5,6,7].

$$Z \simeq R\,(1 + 1.152\,j)\,; \qquad R = 0{,}57.\left[\left(V_{cc} - V_{CE(sat)}\right)^2 / P\right] \tag{1}$$

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Where P is the desired (and allowed) output power.
Nevertheless, the previous equation is very simplified. It is only a starting point to have a raw knowledge of the load for "E" operation. Non linear simulation and final trim of this load in a harmonic controlled load-pull bench are also performed, see Fig. 2.

Once the value of "R" is fixed for a desired and allowed level of output power, if the internal capacitance is lower than the required capacitance for class "E" this should be increased with an external capacitor. Nevertheless, depending on the working frequency, the package would be an important problem to do it.

If the internal capacitance is higher than the required and R cannot be modified (transistor limited) the amplifier still would work in "C-E" or mixed "C" mode [6,7].

The device, as most devices intended to work in this band, operates not very far away from its maximum usable frequency. Therefore, the switching behavior of the device at this frequency is far from ideal. Then the collector current fall time is not negligible but this does not preclude class "E" [5]. In this sense the mode of operation has something of C-E mode [6] or "mixed" C [7], like most so called "E" amplifiers at these frequencies. The effect of the package is included as a part of the output network.

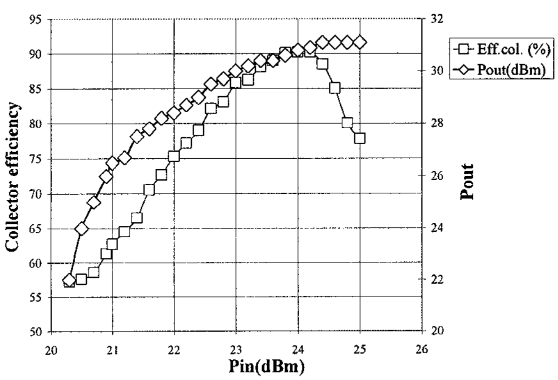

Fig.1. Power & collector efficiency versus P_{IN}

The amplifier is finally trimmed in harmonic controlled load-pull bench. The harmonic controlled load-pull bench provides a test-fixture where the reactive impedance at the second and third harmonic can be adjusted separetely. Basically it is made of open-circuited $\lambda_g/4$ lines at the second and third harmonic. These lines are located along the main 50Ω line. The effect is similar to move a short-circuit at $2f_0$ and $3f_0$ over the main line.

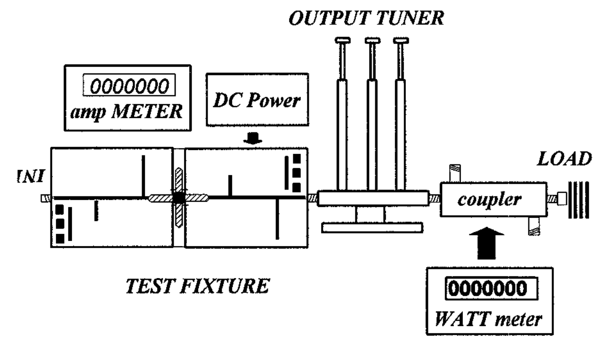

Fig.2. Hamonic controlled load-pull bench.
Output section (symplified)

The input circuit of the amplifier was designed following similar principles like those used for the output load. The low input impedance of the bipolar and the package effects rule substantially the behavior at the input.

2. ANTENNA DESCRIPTION

Once the previous steps are fulfilled and the needed load is determined, an optimum feeding point at the patch antenna is searched. A simplified electric input model of the circular patch antenna based on a cavity approximation has been used. It is shown in the Figure 3. It is basically made of several tuned tanks in cascade [8,9,10]. The input impedance in the patch antenna depends on its radius. It varies from short-circuit at its center to an ideal open circuit at its edge (In the practice this is a finite value of some hundred of ohms)

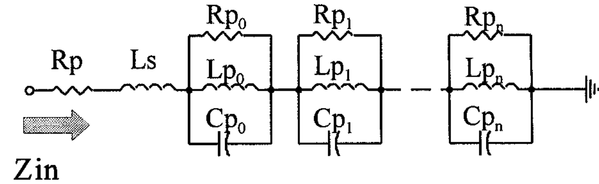

Fig.3. Input model of the patch antenna

A ground plane is used in this antenna; apart from radiation considerations it modifies the input impedance. Therefore, the distance from the patch to the ground plane has been controlled to get the desired load impedance.

It has been shown that the load impedance required for class "E" should be resistive with an inductive component at the fundamental frequency, strongly inductive for harmonics. The input impedance of the antenna is complex with inductive component for frequencies lower than its resonant frequency. For frequencies higher than its resonant frequency the impedance has a capacitive component.

The input impedance is a function of the frequency, separation of the active patch from the ground plane, board material, etc. All these factors are controlled to get the proper impedance not only at the fundamental but also at the harmonics (specially the second harmonic) of the working frequency 885 MHz.

To perform "E" operation a complex load with inductive component is needed at the fundamental frequency. So the trick consists on working at a frequency slightly lower than the resonant frequency of the antenna.

A complex load impedance with positive imaginary component at the fundamental frequency and high inductive behavior for the second harmonic is searched over a radius of the antenna.

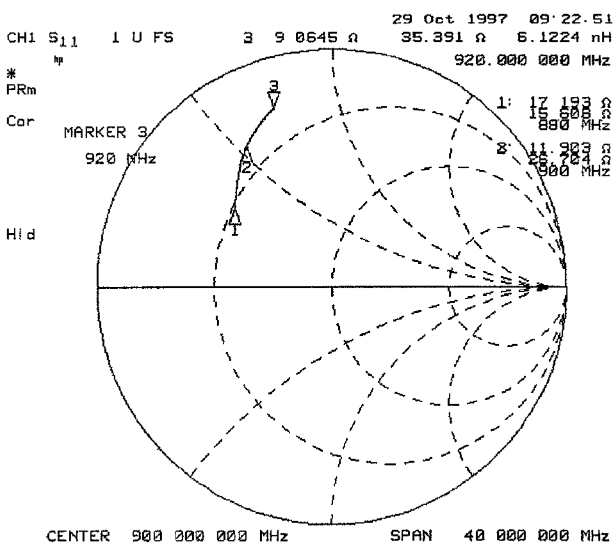

Fig.4. Antenna input impedance around fundamental.

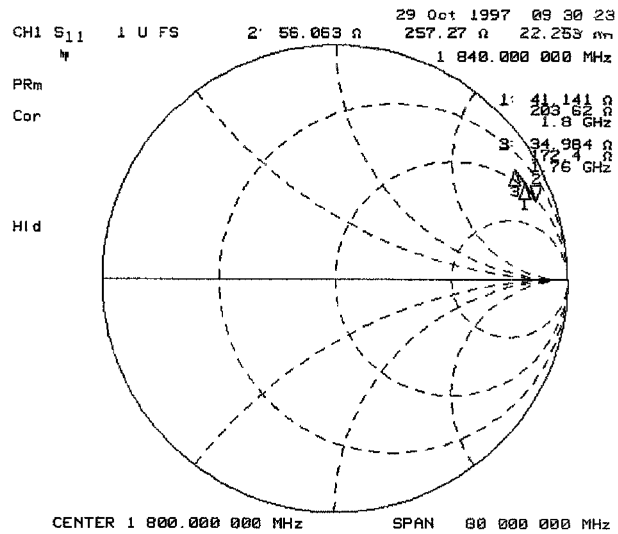

Fig. 5. Antenna input impedance around 2nd harmonic

The Fig. 4 shows the measured values at the fundamental and second harmonic of this load impedance. The Fig 5 shows the load impedance at the second harmonic.

The radiation pattern and other parameters of the antenna are almost the same for slight variations from the resonant frequency.

3. SETTING UP

Both elements, antenna and amplifier are put together in a fixture as shown in the Fig.6.

There is not any matching network at the output of the transistor. Then matching losses don't exist. The antenna is constructed over PTFE microwave substrate. At this time new prototypes are being constructed with different substrates, transistors and antenna topologies. The inductance of the wire needed to connect the active radiator to the amplifier is also considered and included as a part of the input impedance of the antenna. In this sense this stray inductance contributes to achieve the "E" mode of operation.

The D-C power is applied to the set amplifier+antenna at a selected low impedance point of the antenna (close to its center) to avoid any disturbances. The feeding wire is slightly squeezed to increase its inductance and to improve its filtering capabilities.

The transistor fixture is joined to the ground plane of the antenna. The collector is directly attached to the feeding point of the antenna without any matching network.

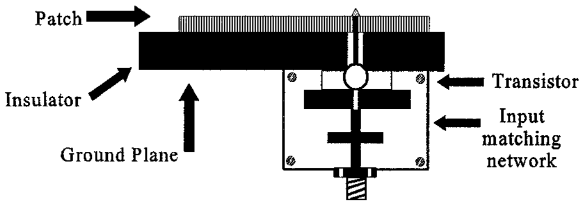

Fig. 6. Diagram of the set: amplifier+antenna

4. CONCLUSIONS

A high efficiency mode "E"amplifier is designed at the 900 MHz band to power a circular patch antenna. Once the right impedance and drive level are determined to perform "E" operation this load impedance is searched over a patch antenna. Then the collector of the transistor is directly attached to the selected feeding point. This avoids any loss at the matching network improving the efficiency and saving space.

The system, new for the knowledge of the authors, combines an original approach to class "E" based on the study of load impedances at fundamental and harmonics (with proper overdrive) and a patch antenna to provide the required load impedance.

The system is primarily intended for communication applications but this principle of operation can be easily adapted for different applications at different frequencies.

5. ACKNOWLEDGMENT

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