A Novel Vector Control Active Patch for Beamsteering with Linearity Enhancement Capability

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Abstract — **In this paper, a novel integrated vector control active patch is investigated for its introduction in compact arrays with beamsteering capabilities. A dual-feed aperture coupled microstrip patch is simultaneously used as transmitting antenna and output power combiner of two quadrature-phase PHEMT amplifying branches. Gain and/or phase control can be achieved by properly biasing both devices either on the saturated region or in an attractive low voltage highly linear zone.**

I. Introduction

Modern communication systems are demanding for electronic beamsteering and beamforming capabilities of their radiating structures. Satellite links, third generation mobile services, etc, can be distinguished among these systems, centering the attention of a lot of recent studies in array aperture distribution design [1].

An efficient electronic beamcontrolling array relays on the possibility of accurately adjusting the amplitude and phase of each element excitation in the desired range. Both signal characteristics may be varied in a polar way, through the cascade connection of a phase shifter (PS) and a variable gain amplifier (VGA), or in a rectangular form through a vector summing unit. The undesired phase and gain variations that usually appear in a VGA and a PS, have converted the vector solution in the preferable architecture for narrowband applications.

The need for introducing these traditionally complex techniques in commercial applications has determined a tremendous interest for compact and low cost solutions, reason why active antennas are being increasingly employed in this field. In this sense, most of the proposed works have tried to substitute the use of phase shifters by injection and phase-locking techniques [2], while just a few authors have taken advantage of printed antenna structures for simplifying the classical control schemes [3].

In this paper, a simple and novel architecture is investigated for designing a vector signal control as an active integrated antenna. The in-phase output combiner, typical of a rectangular amplitude/phase controller, has been replaced by a dual feed aperture coupled patch, in an analogous way as dual feed printed structures have been recently proposed for push-pull amplifying or direct quadrature demodulators [4, 5]. Low cost and high performance PHEMT transistors have been used for efficiently implementing the variable gain amplifiers in the in-phase and quadrature-phase branches.

A linearity enhancement capability, significant when using digital modulation formats or signal multiplexing, has been also added. An adequate selection of the device biasing points, near the border between the linear and saturated operating regions [6], has assured low intermodulation distortion levels along each amplifier gain control range, something impossible to guarantee when only the gate-to-source voltage is adjusted in the voltage-controlled current source operating condition.

II. Gain and Phase Control

In Fig. 1, a scheme of a one quadrant gain/phase control unit, based on the vector sum method, is shown. Two variable gain amplifiers are excited with the same magnitude and in quadrature-phase through a *90°* hybrid coupler. The outputs of these VGAs are combined through an in-phase power combiner.

The signal vector sum is also represented in Fig. 1. Depending on the chosen gain for each branch, the magnitude and phase of the resultant vector may be controlled. Although limited to one quadrant, this topology may be easily extended to cover the complete *360°* phase range by different ways [7], as for example, introducing the possibility of adding an extra *180°* phase shift fixed element in each branch through a simple switching architecture.

Based on this idea, a new architecture is proposed in Fig. 2. A printed antenna with dual feed is used to combine its radiating properties with its opposite-phase power combining feature. In this way, the signal losses, usually associated to a printed circuit combiner are avoided.

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As it can be observed in Fig. 2, changing from a circuital sum to a spatial subtraction does not affect the phase control range, but only produces a quadrant shift.

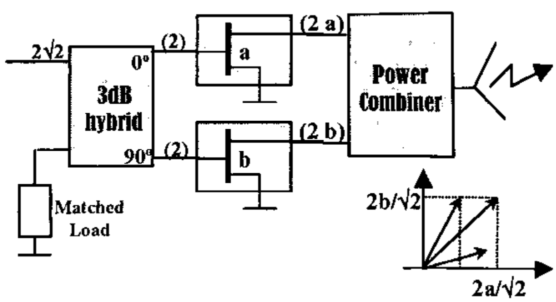

Fig. 1. Schematic and vector diagrams for a gain/phase control unit using the vector sum method

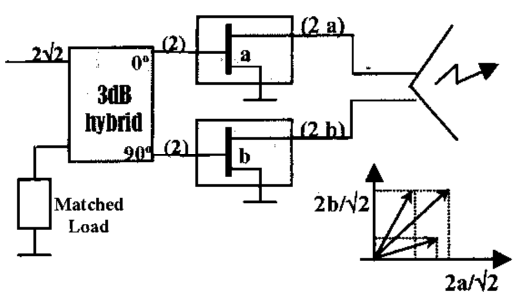

Fig. 2 Schematic and vector diagrams for the proposed active antenna

III. ANTENNA DESIGN

For most applications that require small size and wide bandwidth, the aperture coupled patch is the preferable antenna class. This printed structure also allows to separate the feed layer from the radiating patch, resulting adequate for their integration with active circuit elements.

In Fig. 3, the designed antenna is shown. The dimensions are determined by the frequency band, *5.8 GHz*, in our particular case. In the lower layer, the patch antenna has two microstrip feeds placed in opposite sides. With this type of feeding the same mode is excited with each microstrip line, resulting in a sort of spatial power combining and also in a poor isolation between ports.

Both, the patch and feed microstrip lines, have been implemented in substrate ARLON 25N with $\varepsilon_r = 3.38$ and thickness of *0.762mm* (*30mils*). They are separated *5 mm* (*196.85mils*) by air.

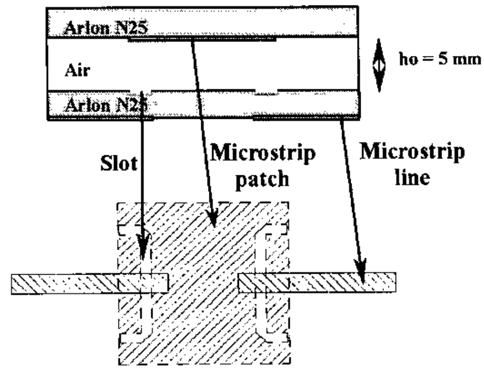

Fig. 3. Aperture patch antenna (side and top view).

An EM simulator, Ansoft Ensemble, has been employed to analyze the structure. In Fig. 4, the simulated and measured input matching as well as the isolation between the input ports are shown.

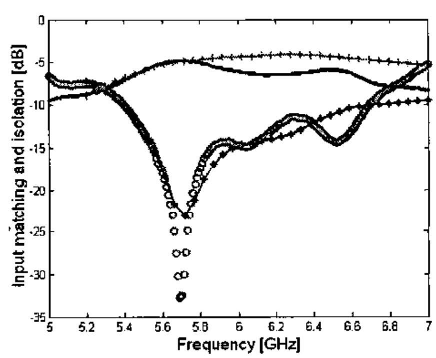

Fig. 4. Measured (o) and simulated (*) input matching, as well as measured (+) and simulated (.) isolation.

IV. ACTIVE ELEMENT DESIGN

Two NE3210s01 PHEMT amplifiers were inserted in the feed side. Simple input and output networks were used to assure an acceptable matching value along the whole control range. Variable gain in the amplifiers was achieved, in a first experiment, by adjusting the gate bias (from $-1V$ to $-0.4V$) in the saturated region ($V_{DS} = 2V$).

The radiation patterns for the active antenna element, achieved when the gain of each amplifier is conveniently modified, have been measured in an anechoic chamber.

As a way of illustrating the gain and phase control in the active patch over a quadrant, the measured phase values in the main beam direction for three gain points are shown in Fig. 5. The minimum gain point was selected equal to the gain of the passive patch, and as it can be observed in the figure, a *10 dB* range over this value is possible thanks to the amplifiers. The lowest phase variation was of *72°*, and appeared for the minimum gain value, when both devices are near pinch-off.

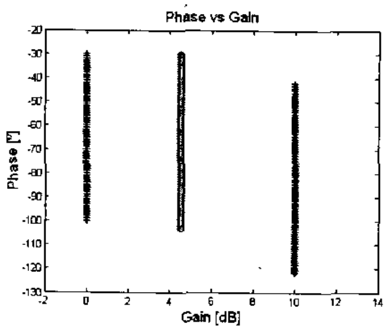

Fig. 5. Measured phase values for three different gain points (normalized to the passive patch gain).

V. BEAMSTEERING TWO-ELEMENT ARRAY DEMONSTRATOR

Based on previous section results, a two-element array was constructed to demonstrate the beamsteering potentiality of the active structure. A photograph of the constructed lab model appears in Fig. 6. The elements were spaced at $0.5\lambda_0$ for a *5.8 GHz* frequency.

The phase values, obtained for a same gain, were used to scan the main lobe following a uniform amplitude distribution. The required phase shift between elements ϕ, was obtained based on the widely used eq. 1:

$$\phi = k_o \cdot d \cdot \sin(\theta) \qquad (1)$$

where θ is the desired main lobe pointing angle and d is the distance between the elements.

The required phase shift for three different and illustrative beam positions is shown below:

$\theta=0° \rightarrow \phi=0°$

$\theta=10° \rightarrow \phi=30.98°$

$\theta=20° \rightarrow \phi=61.03°$

With these values, and based on the results presented in Fig. 5, the biasing transistor points were selected.

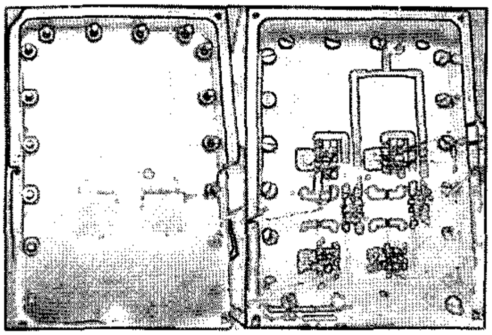

Fig. 6. Photograph of the constructed two-element active array demonstrator

In Fig. 7, the measured radiation patterns for different active antenna gains (*13.7*, *9* and *2.9dB*) and for the three previously mentioned pointing values are shown. As it can be observed, the desired beam control was approximately achieved, although with the typical deterioration that could be expected from such a simple demonstration array.

VI. LINEARITY ENHANCEMENT CAPABILITY

In a recent work [6], the authors proposed the use of a set of points near the border between the linear and saturated PHEMT operating regions, where gain variation can be obtained assuring low intermodulation distortion and improved efficiency along the control interval. This selective biasing technique was here applied to increase the linearity/efficiency tradeoff capability of our designed active antenna, something of interest when handling strongly varying envelope signals (the case of some digital modulation formats) and when worried about the power consumption.

A two-tone (f_1=*5.8 GHz* and f_2=*5.81 GHz*) linearity test experiment was carried out for the array, when controlling gain in the previously used saturated region and the proposed biasing points. The phase values were adjusted to assure a fixed *0°* (broadside) pointing.

In Fig. 8, the extracted output third order intercept point (OIP3) evolution versus gain is presented. It can be noticed that a better linearity (around *11 dB*) is assured over the control range for the newly proposed operating points, at the expense of a *6 dB* gain reduction. The DC power consumption was also reduced from *300 mW* to *92 mW*.

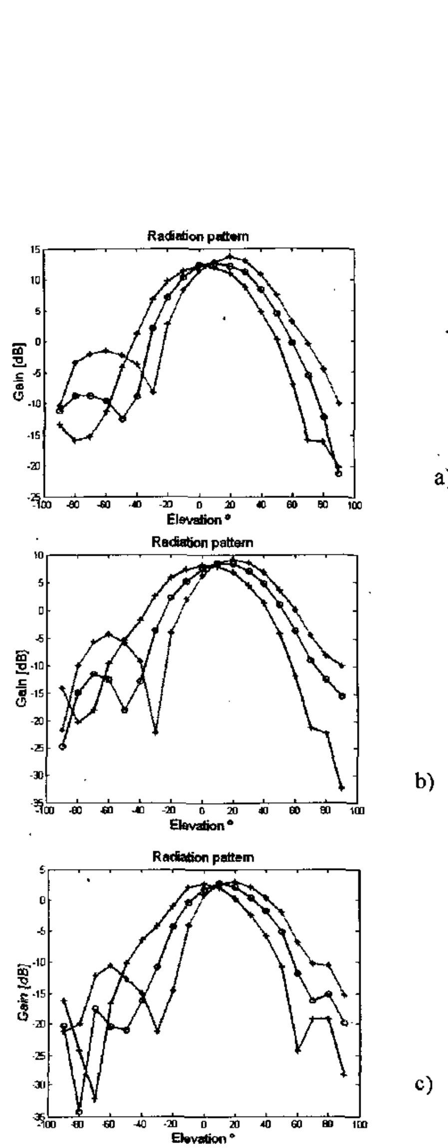

Fig. 7. Different radiation patterns with beamscanning for a) *13.7 dB*, b) *9 dB*, and c) *2.9 dB* gain values.

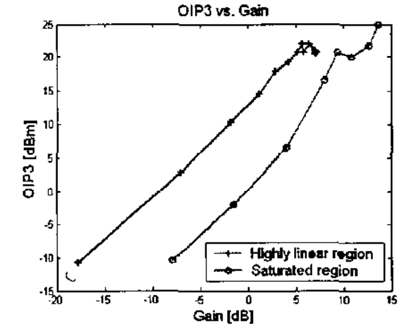

Fig. 8. OIP3 vs gain evolution for the operation in the saturated and proposed regions.

VII. CONCLUSIONS

A novel integrated vector control active patch has been presented, for its introduction in simple and compact arrays with beamsteering capabilities. A *10 dB* control over the passive patch gain was obtained, and a quadrant was covered (although its extension to a *360°* phase range is easy to implement). The beamscanning capability of this element was proved through the characterization of a two-element array. The possibility of improving the linearity performance by means of a correct biasing point selection has also been shown with success.

ACKNOWLEDGEMENT

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