

Active Radiating Structures Based on Nonlinear Behavior of Active Devices

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I. SUMMARY

The main research topics of this activity are:

1- Beamsteering by IQ control.

a) Arrays with low intermodulation distortion pattern.

In this section, an 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 attractive low voltage highly linear zone.

b) Reflectarrays: Electronic control by mixers.

As electronic control by mixers we are going to describe an active reflectarray topology with the capability of steering the main beam and achieving different amplitude distributions. An aperture coupled patch with perpendicular feeds was selected as radiant element. One of its ports is employed to receive signal and the other one to retransmit it with the phase and gain selected in an IQ modulator.

c) Variable gain amplifier with phase control.

As an example of variable gain amplifier with phase control a variable gain/phase control unit to be employed in each element of a reflectarray is proposed. Following the vectorial sum method, a dual device variable gain bi-phase amplifier is implemented in each branch of the control architecture. This solution is also integrated in an aperture coupled square patch with orthogonal polarizations for receiving and retransmitting the signal.

2- IMD radiation pattern reduction by spatial power combining.

In this part, a linearity improving technique for active antennas and arrays, based on spatial power combining, is presented. In the proposed approach, the antenna serves as an in-phase power combiner of two HEMT-based amplifier branches. The auxiliary branch is added for cancelling the third order intermodulation distortion (IMD3) current of the main branch, without diminishing its gain. The potentialities

of implementing the derivative superposition technique in small- and large-signal regimes, both in an array and in an antenna element are analyzed.

3- Radiofrequency identification solutions (RFID).

As an example of RFID solutions, we are going to describe a novel frequency doubling active antenna, based on a PHEMT device, with BPSK modulation capability. A dedicated nonlinear transistor characterization reveals the existence of two biasing regions, where the second harmonic could be generated with maximum level and phase opposition. Taking advantage of this issue, a low frequency data signal applied to the gate terminal may be used to create a BPSK modulated signal, centered at twice the carrier frequency. An adequate integration of this modulator in a dual- frequency and dual-polarization slot coupled patch, results in a compact and high performance solution.

II. BEAMSTEERING BY IQ CONTROL

Nowadays, modern wireless systems demand “intelligent antennas” capable of providing more functionalities apart from their proper radiating characteristics. In this sense, a tremendous effort has been done to achieve beamforming and beamsteering properties. These capabilities require an accurate adjustment of the amplitude and phase excitation in each antenna. Traditionally, two different approaches are employed to obtain this dual control: in a polar way, through a cascade connection of a variable gain amplifier (VGA) and a phase shifter (PS) or in a rectangular form through a vector summing unit. The undesired amplitude and phase variations that usually appear in the VGA and PS have converted the vector solution in the preferable architecture for narrow band applications.

In this section, based on the commented vector sum method, different active antennas have been developed to be employed either in arrays or reflectarrays. The proposed unit to control the amplitude and phase of the output signal in each radiator can be observed in Fig. 1. Following an IQ architecture, the input signal is equally divided through a 90° hybrid coupler that excites two equal devices capable of controlling the output signals amplitude (VGAs or mixers). To complete the unit a power combiner is employed at the end of the structure.

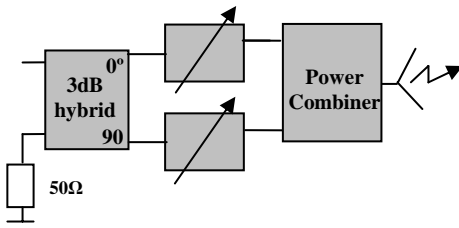


Fig. 1 - Schematic of the proposed unit to control amplitude and phase.

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

The in-phase output combiner, typical of a rectangular amplitude/phase controller (see Fig. 1), has been replaced by a dual feed aperture coupled patch, varying the radiating field. Low cost and high performance PHEMT transistors have been used for efficiently implementing the VGAs in the in-phase and quadrature-phase branches. In this way, only one quadrant control can be achieved, demanding for an additional phase switching element to obtain a 180° phase for a complete phase control.

Two different biasing techniques have been adopted to control the amplifier gain in FET transistors. In one of them, the classical approach, the control is achieved thanks to adjust the gate bias of the FET when is operated in saturated region. The other takes advantage of the control obtained when the device is biased along the transition from the linear to saturated region. The first, permits to achieve wider control range whereas the other to reduce the DC power consumption and to assure low level intermodulation distortion levels, something impossible to guarantee in the classical situation.

In order to probe the potentialities of this architecture the lab model shown in Fig. 2 was constructed and measured. The obtained radiation patterns for three different pointings can also be seen in Fig. 2.

B. Amplitude and phase electronic control by mixers in a reflectarray unit.

To employ active antennas as cell units of the reflectarray permits to add amplifying functions or to vary the phase of the scattered field, achieving beamsteering capabilities. The complete phase control range in each element permits to obtain the required phase-shift not only to convert the spherical incident wave into a plane one but also to steer the main beam.

A new active reflectarray element has been developed (see Fig. 3). As can be observed, the amplitude and phase of the reradiated field from each cell is controlled, applying a DC voltage through the IF port of two double balanced diode mixers in an IQ configuration.

A 4x2 active reflectarray lab model was constructed. Once the radiation pattern phase evolution for each unit was calibrated in its broadside, it was possible to select those biasing points per unit for obtaining the adequate phase to point at different directions. Finally, the reflectarray's far field radiation pattern was measured for three main pointings (0° , 10° , -10°) for a uniform amplitude distribution, see Fig. 4. A

comparative study between the resultant measurements and the calculated array factor of the retransmitted patterns has been done, obtaining similar results in both cases.

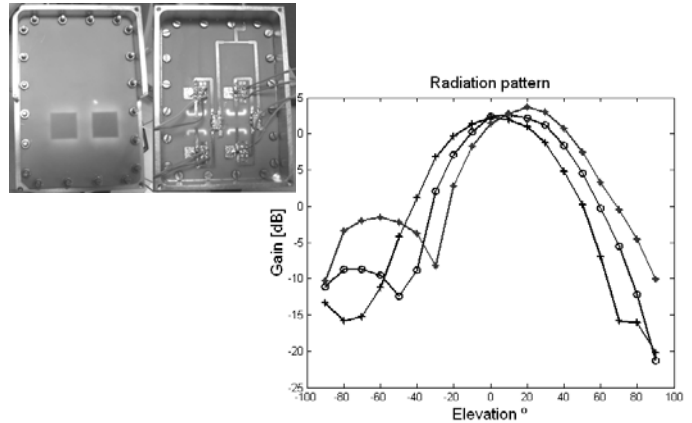


Fig. 2 - Photograph of the constructed two-element active array demonstrator and different radiation patterns with beamsteering (Gain=13.7dB).

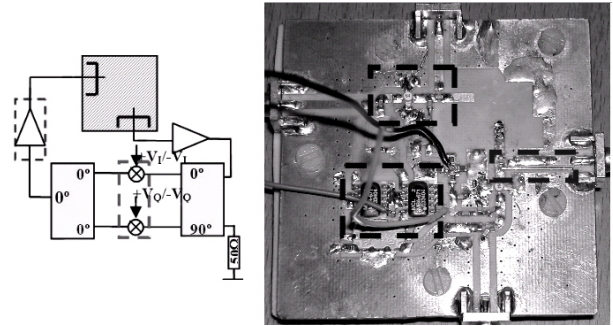


Fig. 3 - Schematic and photograph of the reflectarray unit.

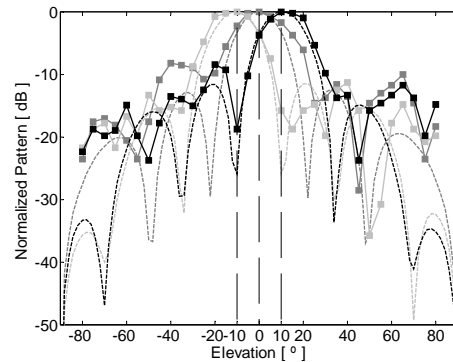


Fig. 4 - Measured ('-•-') reflectarray normalized radiation patterns and calculated array factors ('- - -') pointing to -10° , 0° and 10° .

C. New dual device variable gain bi-phase amplifier to be used in each branch of an IQ modulator

A new variable gain bi-phase amplifier is proposed to be employed in a IQ modulator for a complete phase range. The proposed amplifier is shown in Fig. 5.

Following this structure, a bi-phase amplifier VGBPA was designed and characterized for operation in the 5-6 GHz frequency band. Fig 5 illustrates the S_{21} results for such element, at the optimum V_{gs} value and as a function of V_{ds} (from -1 to 1 volts).

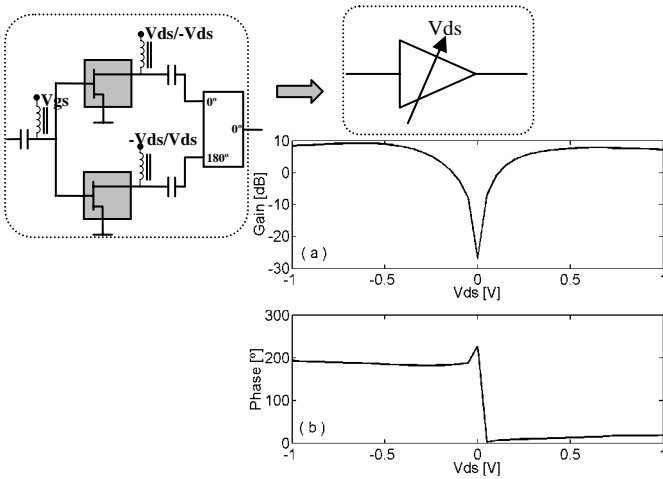


Fig. 5 - Schematic of the variable gain bi-phase amplifier and a) Gain and b) phase evolution as a function of Vds for the optimum Vgs value.

The use of these amplifiers in each branch of the vector control unit (Fig. 1), permits a full 360° phase control for a range of amplitude close to $22dB$.

This structure was inserted in an aperture coupled patch antenna with orthogonal polarizations following the AIA concepts. An specific antenna test set-up was required due to the impossibility to access to the antenna ports, being required employing the radar cross section (RCS) figure. In Fig.6 a polar representation of the radiation pattern phase evolution in its broadside direction for two calculated RCS (with a level difference of 5 dB) can be seen. Four quadrant control has been achieved.

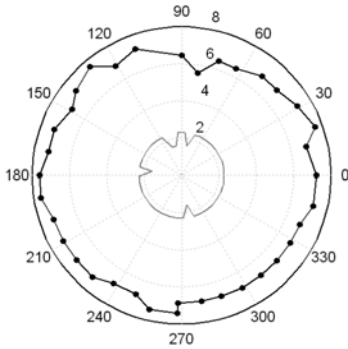


Fig. 6 - Phase evolution for two normalized RCS, 0 dB reference corresponds to a RCS value of 18.28 dB cm^2 .

III. IMD RADIATION PATTERN REDUCTION BY SPATIAL POWER COMBINING

In this section, a linearity improving technique for active antennas based on spatial power combining is presented. Fig. 7 shows the proposed amplifying antenna based on derivative superposition technique. In this structure, a second (auxiliary) branch is added for getting the same third order intermodulation distortion current of the main branch, but with a 180° phase shift. The antenna is used an in-phase power combiner to cancel the radiated power from each branch at the IMD3 products.

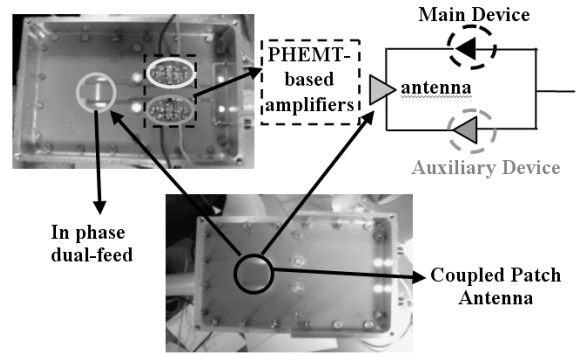


Fig. 7- Active amplifying antenna using a dual-feed aperture coupled patch.

The main non linearity in FET transistors, the drain to source current, can be expressed as a power series expansion with respect to the input voltage if operating over certain load condition,

$$I_{ds}(V_{in}) = I_{DS}(V_{IN}) + G_1 \cdot v_{in} + G_2 \cdot v_{in}^2 + G_3 \cdot v_{in}^3 + \dots \quad (1)$$

where G_1 represents the gain and G_3 is the main responsible of the IMD3.

Studying the evolution of the G_1 and G_3 coefficients as a function of V_{in} , it can be observed the existence of two main regions around the first null (corresponding to the pinch-off transition) with opposite signs and high control range over the G_3 level. In small signal condition, the main branch is biased to obtain maximum gain (G_3 negative) so it is possible to find bias point below pinch off with equal G_3 value and opposite sign. Applying the selected biasing points in each branch of the antenna of Fig. 7, the radiation patterns were measured. The radiated power at the intermodulation product has been reduced about 25 dB in the main direction whereas at the desired frequency has been improved in about 0.4 dB . In order to compare the resultant patterns at fundamental and IMD components, the third order interception point (IP3) radiation pattern was also estimated, obtaining an improvement in about 13 dB at broadside (see Fig. 8).

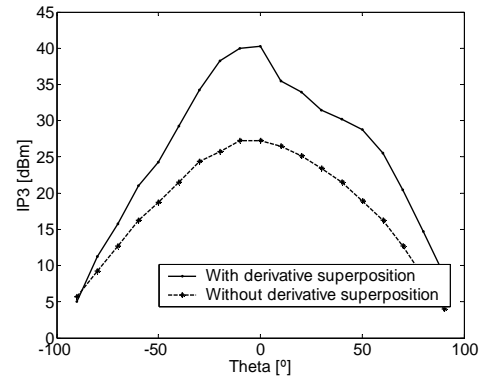


Fig. 8- IP3 radiation pattern for the active amplifying antenna of Fig. 7.

IV. RADIOFREQUENCY IDENTIFICATION SOLUTIONS

In this section, a novel frequency doubling active antenna with BPSK modulation is described. Once an approach to

accurately predict the harmonic generation in any operating regime is obtained, the conversion gain evolution at the second harmonic can be estimated. From the Chebyshev polynomial expansion properties, the phasor representing the second order harmonic current, I_{ds}^2 , can be expressed in terms of the phasor representing the fundamental component of the input voltage, V_{in}^1 , through the use of the DC, 2nd and 4th harmonic of the periodic $G_2(t)$ waveform (G_2^0 , G_2^2 and G_2^4):

$$I_{ds}^2 = \frac{1}{4} \cdot (V_{in}^1)^2 \cdot \left[G_2^0 - \frac{4}{3} \cdot G_2^2 + \frac{1}{3} \cdot G_2^4 \right] \quad (2)$$

Fig. 9a shows the evolution of the conversion gain in terms of the DC V_{GS} value and the input power. It can be observed that two regions with optimum frequency doubling operation exist, each with opposite phase.

Such doubling circuit was integrated in an orthogonal-feed double-frequency slot coupled patch (see Fig. 9b). Thus, applying a low frequency data signal at the gate terminal, a BPSK modulated signal can be reradiated at twice the frequency with respect to the interrogating signal.

A specific test set-up was employed to properly characterize the proposed antenna, obtaining an isotropic conversion gain of 13 dB once the conversion radar cross section patterns were measured.

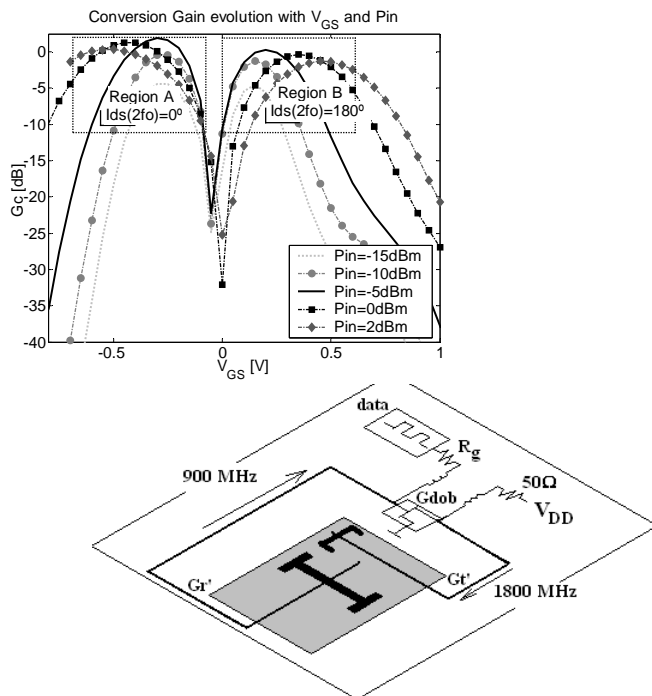


Fig. 9- a) Calculated second harmonic power evolution with V_{GS} and P_{in} and b) schematic of the frequency doubler integrated in a patch.

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