DEVELOPMENT OF A NEW ELECTRONIC PHASE SHIFTER - APPLICATION FOR PHASED ARRAY

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Abstract— **This paper gives an overview of the design of a new phase shifter for phased array application. Firstly, we present the state of art of phased array system and its components. Advantages and drawbacks of the different passive and active phased array are reviewed. Secondly, we explain the design of our new phase shifter based on digital modulation. Then, the first simulation results of the system, and its characteristics are described. Finally, we give some examples of application of this new phase shifter.**

Keywords : Phased Array, Modulation, Digital Communications

I. INTRODUCTION

The telecommunication systems of last generation are developed in the objective to optimize the flows and to improve quality of communications. New techniques as the space distribution of energy are under development. These techniques are based on the smart antenna technology.

Another high frequency electronic system uses the phased array, the radars. In order to decrease the space requirement, those use an electronic and non-mechanical system to direct their beam. This system is based on the technique of electronic phase shifting and the antennas arrays. It allows, moreover, improving the capacity of detection of the radar.

The objective of this article is to present a new electronic system making possible to create a reconfigurable electronic sweeping with a good precision. First of all, we will expose the current state of art on the phased array. Then, we will present the new technological solution we developed in the laboratory. Then, we will show the results obtained by simulations of this solution. Lastly, we will conclude on the possible applications from this solution in the detection or in the current communication systems.

II. EXISTANT PHASED ARRAY

In the current state of the art, several solutions are proposed according to the applications. Thus, some antenna networks integrate a module with fixed phase shifting making possible to direct the electromagnetic field towards a given direction. This type of module has only some determined angles, defined at the manufacture of the system.

Other systems with more recent phase shifter module, containing PIN diodes or MEMS switches making it possible to vary phase shift in a given range.

A. Passive systems

1) Butler Matrix: The Butler matrix [1][2] is a very much used feeding circuit because it produces narrow orthogonal beams with a good directivity while using a simple technology of design, the microstrip. However, it presents the disadvantage of being dependent on the frequency and requires rather complex crossings. Moreover, the component count necessary very quickly increases with the size of the network.

2) Blass Matrix: The Blass matrix [3] creates as many beams as there are feed ports. Contrary to the Butler matrix, the Blass matrix doesn't have crossing, and it has a broadband of use. On the other hand, it presents serious disadvantages such as the number of couplers and their design which is single for each element. Moreover, the interaction between the elements is difficult to apprehend with the design. All that implies an increase in the cost and in the size.

3) Nolen Matrix: This matrix [4] is a combination of the Butler matrix and Blass matrix. It generates as many beams as there are feed ports in entry, while having a number of antennas different. However, it presents the major disadvantage of the Blass matrix, the difficulty of design and cost.

B. Electronics Phase shifters

The electronic phase shifter generates a delay variable and ordered by a continuous tension. It has the advantage of controlling the delay precisely but generally does not offer a broadband for use. Moreover, their design is relatively complex to obtain a miniaturized system. In short, the major disadvantage of these systems is the difficulty of developing them at high frequencies, and their narrow bandwidth. Moreover, dimensions of these systems are often dependent of the frequency what can give place to modules of big sizes and not easily integrate in some applications.

III. THE NEW SOLUTION

The objective of the solution suggested in this article is to develop a system of phase shifter allowing to obtain a higher precision than the current systems. For that, we chose to support us on digital communications principles [5], the digital phase modulations.

A. THE PHASE SHIFT KEYING MODULATION

PSK modulation consists in varying the phase of carrying according to the modulating signal.

$$m(t) = A\cos(\omega t + \varphi_k) \quad (1)$$

Each symbol of the modulating signal is associated to a phase φ_k of the carrier. The possible phases φ_k are given by:

$$\varphi_k = \varphi_0 + \frac{(2k+1)\pi}{M} \quad (2)$$

with $0 \leq k < M$.

The value $M = 2^n$ is the number of symbols which can be distinguished. It is seen that these symbols are distributed in a uniform way on a unit radius circle. This representation, named constellation, represents the various states of the modulation [6]. For a symbol a_k transmitted in the interval $[kTs, (k+1)Ts]$ with Ts the time symbol, the signal $m(t)$ (equation 3) is generated with f_c the carrier frequency and φ_k the phase associated with the symbol a_k.

The signal $m(t)$ modulated PSK is:

$$m(t) = \sum_{k=-\infty}^{+\infty} h(t-kTs)\cos(2\pi f_c t + \varphi_k) \quad (3)$$

$$m(t) = \sum_{k=-\infty}^{+\infty} \cos(\varphi_k) h(t-kTs)\cos(2\pi f_c t) - \sum_{k=-\infty}^{+\infty} \sin(\varphi_k) h(t-kTs)\sin(2\pi f_c t) \quad (4)$$

$$m(t) = Zi(t)\cos(2\pi f_c t) - Zq(t)\sin(2\pi f_c t) \quad (5)$$

with:

$$Zi(t) = \sum_{k=-\infty}^{+\infty} \cos(\varphi_k) h(t-kTs) \quad (6)$$

the component in phase I,
and

$$Zq(t) = \sum_{k=-\infty}^{+\infty} \sin(\varphi_k) h(t-kTs) \quad (7)$$

the component in quadrature Q.

Thus, PSK modulation is obtained by linearly combining two amplitude modulations in quadrature.

We can observe in this explanation of the digital modulations of PSK type which the phase of the modulated signal is dependent of the symbol of the modulating signal. Thus, according to the modulation chosen, we can obtain a variable phase shifting of the modulated signal. The characteristics of some modulations PSK are summarized in the following table. For example, in the case of a modulation QPSK, we will have 4 different states of phase, therefore of 4 gradients of phase: -180°, -90°, 90°, 180°.

Modulation	Minimum phase difference	Number of phase gradient
QPSK	90°	4
8-PSK	45°	8
16-PSK	22.5°	16
32-PSK	11.25°	32

TABLE I
SUMMARIZE OF PSK MODULATIONS CARACTERISTICS

B. THE NEW PHASED ARRAY

According to a symbol, the numerical quadrature modulator generates a signal more or less out of phase. It is this property we used in our technological solution. Thus, according to the desired orientation, we calculate the gradient of phase and we apply phase shift corresponding to each element of the network. The figure 1 represents a model of this system of phased array comprising 4 elements or cells.

On the left of this figure, the first element represents the source generating the symbol corresponding to the computed phase. The following block separates the code in a way I and a way Q and makes the mapping corresponding to selected PSK modulation. Then, the quadrature modulator generates the signal corresponding to the carrier frequency or to an intermediate frequency. In this last case, the resulting signal is mixed at the desired carrier frequency. Lastly, the signal is amplified and filtered according to the application which is intended to it.

C. RESULTS OF SIMULATION

Several simulations were carried out in order to validate the operation of this new system. First of all, the quadrature modulator was tested in order to observe its operation in various forms of PSK modulation. Then, we observed its behavior in the presence of imperfections such as the quadrature error or amplitude imbalance, and we evaluated the phase errors we could obtain.

Figure 2 shows the possibilities of a cell of our system configured with a 8-PSK modulation. We can observe that for each symbol [0 : 7] corresponds a phase [-157.5° : 157.5°].

These simulation results are obtained without including the defects in the quadrature modulator.

Figure 3 shows the phase of each of the 4 cells of the system in the preceding figure. Codes 00, 01, 10, 11 were applied respectively to each of the 4 cells. Thanks to a QPSK modulation, we can observe on each output a different phase, corresponding to the state of phase associated with each symbol.

Figure 4 shows the application of our new phased array with a linear network of 4 patch antennas. The diagram of radiation shows us the orientation of the beam towards the selected direction.

Figure 5 shows the capacities of our system associated with a linear network of 8 patch antennas spaced with a $\frac{\lambda}{4}$ distance. The various generated beams cover an area going of -60° to +60° with an increased precision. The directivity of only one element of the array is of 5.6dB whereas in the case of the array, directivity is about 10 dB. We can also note that the amplitude of the various beams is identical in the band -45° to +45°.

All these simulations were made with linear networks of patch antennas. Of course, it is perfectly possible to put another type of antenna and thus to increase the beamwidth of the array.

D. *Evaluation of the phase errors*

Within the framework of a practical realization, all the components are not as perfect as within the framework

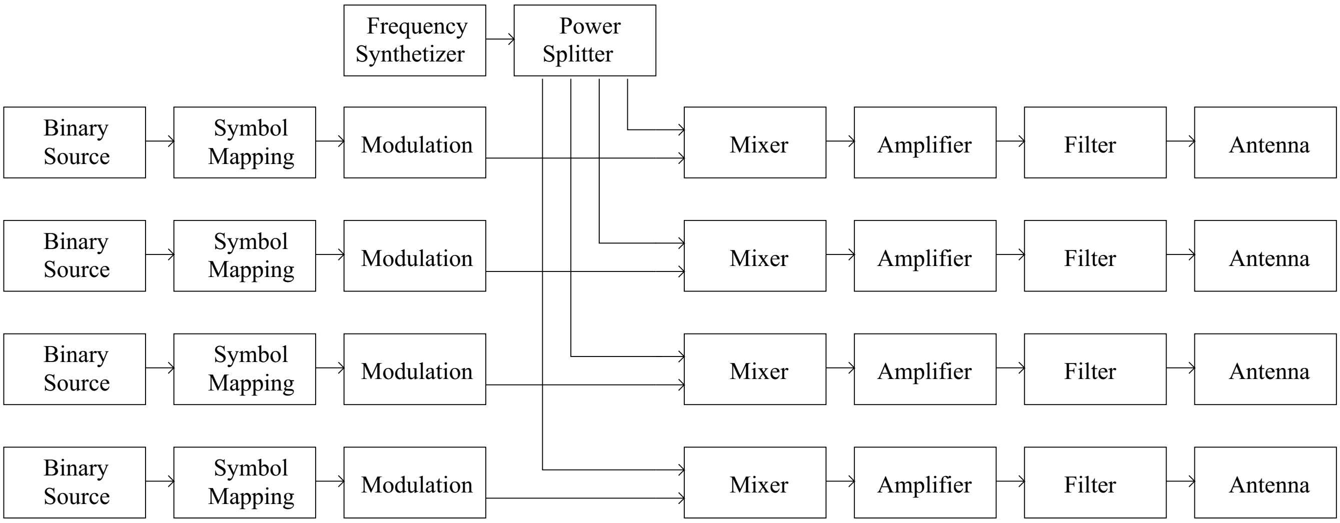

Fig. 1. Example of a new phased array with 4 cells

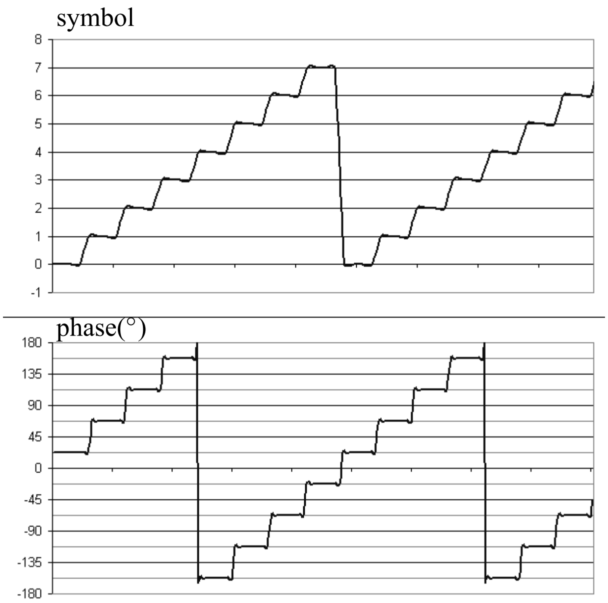

Fig. 2. Caracterization of our system with a 8-PSK modulation

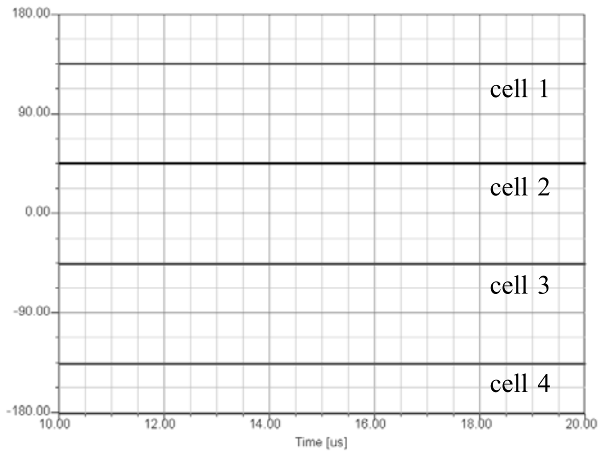

Fig. 3. Phase angle of each 4 cells

Components	Phase error
Quadrature modulator	0.3°
Power divider	6°
Filters	<0.5°
Total	<7°

TABLE II
SUMMARIZE OF PHASE ERRORS IN THE NEW SOLUTION

of this simulation. The quadrature modulators have a defect creating many problems in the digital communications: the phase imbalance. Of course, this defect will also appear within the framework of this system with phase shift. However, the last components of the market show that this defect can be less than 1°, typically 0.3° [7].

The other element which can bring defects is the power divider making it possible to distribute the carrier frequency resulting from a VCO towards the various mixers of each cell. In this case, the phase error can be about 6°.

The last point bring a defect is the filter of emission. However, the phase error of this element can be largely lower than 1°. The following table summarizes the various possible phase errors.

We can thus observe that the maximum phase error remains relatively weak compared to the gradient of phase of a 16-PSK modulation.

IV. APPLICATION OF THIS SOLUTION

The phased array are more and more used in the radars of fixed or mobile target detection [8], such as radars of continuation of planes or missiles.

They are also embarked on board of communications satellites in order to better distribute the energy transmitted towards a receiver and thus to optimize energy necessary to the transmission.

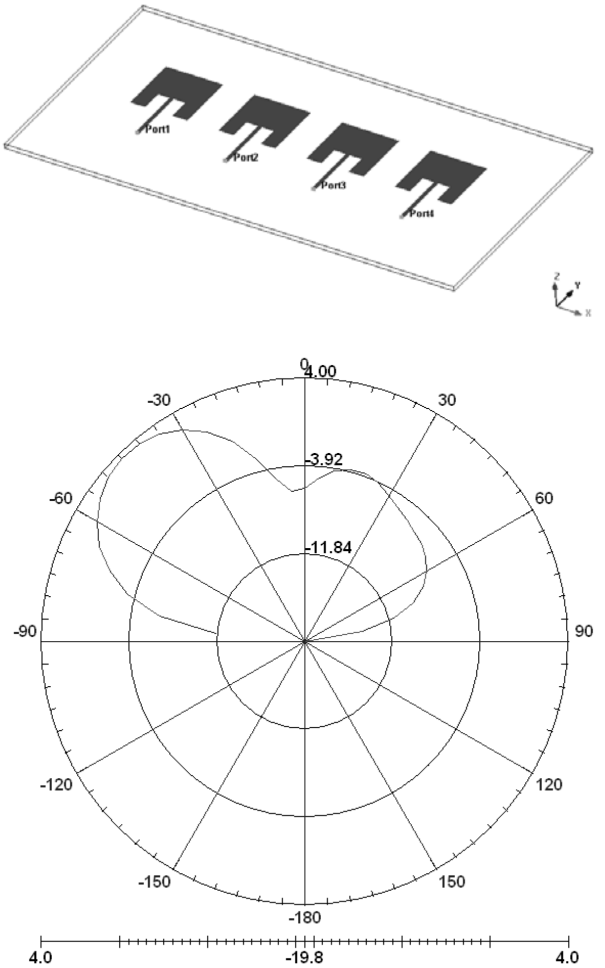

Fig. 4. Linear array of 4 patch antennas and diagram of radiation

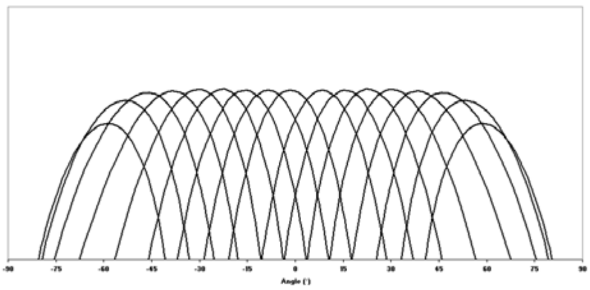

Fig. 5. Representation of the different beam generated with a 8-PSK modulation

The new solution of phased array proposed in this article will be able to perfectly adapt in systems of detection radar with electronic sweeping.

Indeed, within the framework of electronic sweeping, it is important to better control the orientation of the electromagnetic waves beam in order to improve the precision of the radar. This condition can be perfectly met using a modulation having a great number of state of phase.

Moreover, this solution could also be integrated in the systems of telecommunication in order to better control the transmissions and the interferences between the various users of the same network and thus to improve the quality of service.

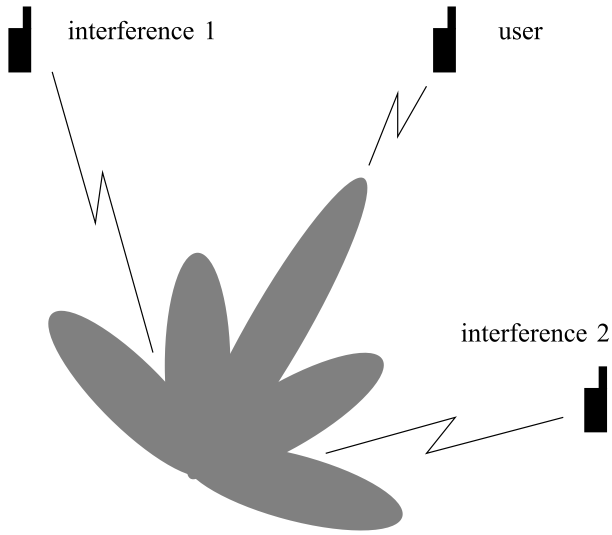

Fig. 6. Application of SDMA with interference users

V. CONCLUSION

This new solution brings many advantages compared to the present solutions. First of all, it has the advantage of offering a number of gradients of phase proportional to the type of selected modulation. Thus, the system is completely reconfigurable according to the modulation and it offers an adaptation to a large majority of the applications used today. Then, this system comprises a reduced size report to the passive phased array like the Butler matrices. Lastly, this system can perfectly adapt to broadband communications systems by choosing the adapted components.

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