EXPERIMENTAL INVESTIGATION OF A NEW SMART ANTENNA FOR PCS SYSTEMS

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Abstract--- **For future personal communication systems, smart antennas represent a powerful mean for improving the transmission quality in hostile environments. This new technology provides various potential improvements, such as reduction of multipath fading, suppression of interference, increasing of the coverage range, and boosting of the cellular capacity. In the same perspective, we propose an experimental investigation of a new smart antenna that is designed for applications at base-station on the uplink level. This system uses a fixed set of eight broadband microstrip antenna elements that arranged as a linear array. Signals from these antenna elements are combined by a RF hardware beamforming network for providing a steerable beam pattern. This allows to steer electronically the mean pattern beam for tracking the mobile units, while it helps to reduce the impact of the interferences by minimizing the antenna system gain in their directions, which can improve significantly the transmission quality. The beamforming network is based on 8X8 Butler matrix that provides eight different discrete beams. The antenna system uses also an adaptive control unit that allows to steer the beam in the desired direction. For high data rate applications, the antenna elements used into the array were designed by using multilayer microstrip structure that provide a bandwidth of 10% at operating center frequency 1.9 GHz. Theoretical, computer simulation and experimental results will be presented.**

I. INTRODUCTION

Due to the advent of multimedia communication era, the demand for high data-rate wireless transmission, allowing of diverse multimedia services of high quality, has been increased. However, the presence of multipath propagation and the co-channel interference phenomena make the data-rate transmission difficult because of the increased inter-symbol interference. Therefore, the spectrum is becoming a scare resource and its use must be optimized with respect of the cellular capacity.

To overcome these circumstances, new advanced technologies, which can improve the capacity of radio-communication systems, are investigated. One of those techniques, beamforming antenna arrays (smart antennas) has recently been chosen as an efficient alternative. This kind of antennas uses beamforming network in order to shift in phase and combine all signals from the antenna array elements, which are typically spaced less than a wavelength apart. This produces a composite antenna pattern that can be controlled by adjusting the amplitude and phase at each individual element output. In other words, this antenna system acts as a spatial filter, which can improve or throw out signals based on their arrival direction.

In this paper, we present a novel smart antenna project for the personal communication system at 1.9 GHz. This antenna system consists of an eight broadband patch antenna array and a beamforming network, which is based on the 8x8 Butler matrix. This matrix is advantageously used to feed a linear broadband microstrip antenna array at 1.9 GHz as well as to control the beam direction of the antenna array. The microstrip technique was adopted to design this matrix. This printed circuit approach allows us to implement both of the antenna array and the beamforming network at the same substrate. The electronic pattern steering of this antenna is achieved by using a unit control based on a micro-controller. This unit assures the adaptive control for scanning beam in desired direction. It is consisting on a modified version of On-Off algorithm, which has revealed the potential improvement in gain and interference suppression [1].

In the next section, an overview of the antenna array design is presented. We describe in the third section the function of the Butler matrix and how the beamforming network can be used in antenna array to take shape different beams. The fourth section, presents the control unit and the adaptive algorithm used in the antenna beams control. A summary will be presented in the last section.

II. BROADBAND ANTENNA ARRAY

The main objective is to design a broadband microstrip antenna for the personal communication systems band centered at 1.9 GHz. During the last decade, several solutions were suggested in order to improve the bandwidth of microstrip antennas, which provide significant advantages over conventional antenna: low profile, reduced weight, compact relatively low manufacturing cost, and polarization diversity. With the same approach, the wide-band microstrip antenna configuration is implemented with eight elements. The solution adopted for improving the bandwidth of the patch antenna is to use multi-layers substrate technique and aperture coupled as feeding technique. This structure allows to design a patch antenna with wide bandwidth. Ideally this configuration uses a free-air gap with constant dielectric $\varepsilon_r = 1$ between two RT/Duroïd 5880 substrates, but those have to be supported mechanicaly in someway. Therefore, a hard foam layer, with constant dielectric $\varepsilon_r = 1.07$, is placed between the two substrates. Both of the two substrates have a constant dielectric $\varepsilon_r = 2.2$ and the thickness 0.787 *mm*. The first layer supports the microstrip feed line on one side and the ground plane with coupling aperture on the other. The second RT/Duroïd layer serves to support the patch over the foam. It is also a protective dielectric cover of the antenna. We have to fine-tune the dimension of the patch to take count of the three layers together in order to keep the central frequency at 1.9 GHz. For each element, the slot dimensions are 40.4x1*mm*; the foam thickness used is 12.7 *mm* and the radiating patch is 68.2x56.9*mm* was found.

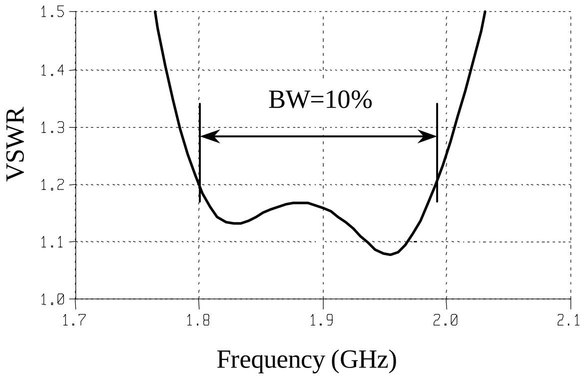

Fig. 1 Antenna Array Bandwidth

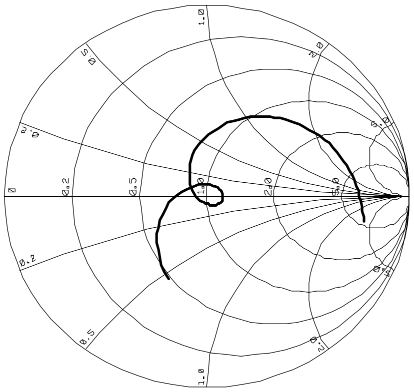

Fig. 2 Smith Chart

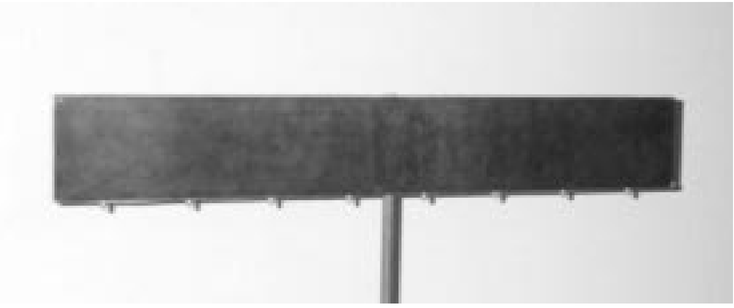

Fig.3 Photo of the broadband antenna array

The mutual coupling between the antenna elements would be minimized as well as the grating lobes. In order to accomplish this focus, all patches are spaced by 0.54 λ, where λ is the wavelength at operating center frequency of 1.9 GHz. The ENSEMBLE release 5.1 software package, which is based on the full wave method, was used, as CAD tool, to examine the performances of the proposed design. The bandwidth, defined at *VSWR* of 1.2:1 was found to keep at 10% for the best antenna design, Fig.1. The Fig.2 shows the smith chart of the antenna array, and it's clear that its input impedance is well matched with 50Ω. We can see also there are two resonant frequencies apart from 1.9 GHz. This antenna array was realized at the University of Quebec at Rimouski and the Fig.3 shows its photo.

III. BEAM-FORMING NETWORK

		Antenna Ports							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Tx/Rx ports	**4R**	0	157.5	315	112.5	270	67.5	225	22.5
	3R	0	112.5	225	337.5	90	202.5	315	67.5
	2R	0	67.5	135	202.5	270	337.5	45	112.5
	1R	0	22.5	45	67.5	90	112.5	135	157.5
	1L	0	-22.5	-45	-67.5	-90	-112.5	-135	-157.5
	2L	0	-67.5	-135	-202.5	-270	-337.5	-45	-112.5
	3L	0	-112.5	-225	-337.5	-90	-202.5	-315	-67.5
	4L	0	-157.5	-315	-112.5	-270	-67.5	-225	-22.5

Table 1. Phase Progressive for the 8x8 Butler Matrix

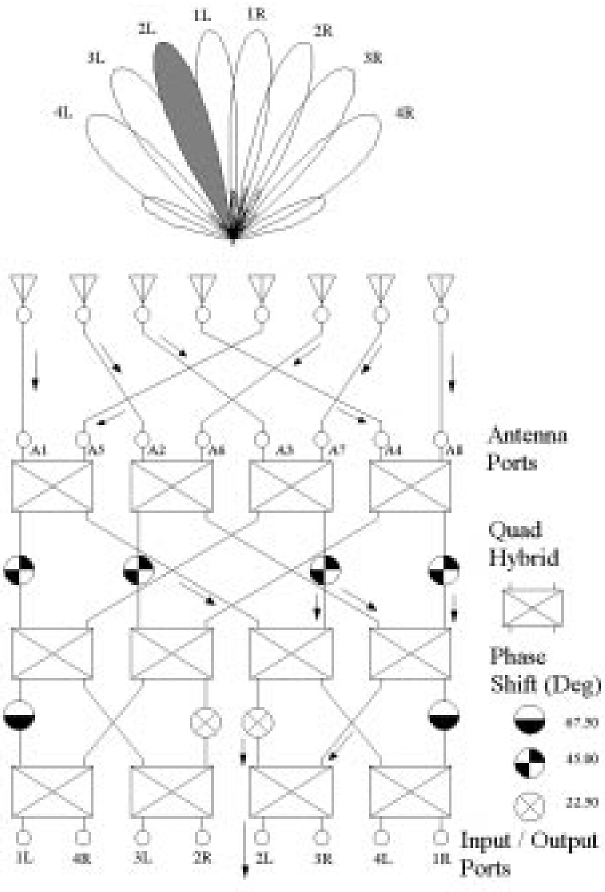

Fig. 4 A Butler Matrix Block Diagram producing multiple beams

The most popular network to form the beams in switched-beam technology is the Butler matrix. In this section we describe a new topology of the beam-forming network based on such matrix. The Butler beam-forming matrix for an eight contiguous beam system is shown in Fig.4. A Butler matrix is typically a network with *N* input ports and *N* output ports. It is used to feed the linear antenna array described in the second section for the personal communication systems at 1.9 GHz, as well as it serves to control the beam direction of this antenna array. When the signals pass trough the network, they will be combined together and shifted in phase. Therefore eight beams will be generated in different directions according their tapered phase used. In order to implement the network on one layer, the microstrip technique was used. Hence, we can employ the whole of the system in one same layer. J. Butler and R. Lowe [2] introduce the butler matrix. Fig 4 gives the block diagram of this network. In our case, where there are eight input ports and eight output ports (*N*=8). The butler matrix is array of *Q* quad hybrids 3 dB and *P* fixed phase shifters, where $Q = (N/2)\cdot\log_2 N$ and $P = (N/2)\cdot(\log_2 N - 1)$. This is a reciprocal structure, thus either end can be the RF input or RF output. Notice that all phase shifters are trough the network; therefore there are no bore-sight beam formed [3]and the beams are symmetrically deployed about the array axis. For the ports driven as indicated in the figure, we see that the phase front across the aperture elements is 0°, -67.5°, -135°, -202.5°, -270°, -337.5°, -45° and -112.5°. Therefore, the shaded beam is produced. The tapered phase depends primarily on the driven port used, as shown in the Table 1. The progressive shift phase is given by $\Psi_n = \pm(2n-1)\pi / N$ where *N* is the matrix order and *n* is an integer varies from 1 to *N*/2. The major problem in the design of this matrix in a single layer substrate is the crossover between lines, as shown in Fig 4. To overcome this problem, we designed a hybrid named crossover, which it's consists of two quad hybrids connected together at the output ports. Therefore we have a four port-circuit designed on one layer within the microstrip technique. When the signal inputs by one of the four ports, it comes out by the opposite port. More information about the crossover and the hybrid design can be found at [4]. The design of all components is accomplished by using the EEsoft HP ADS. The implementation was done using the substrate RO3006, which have a dielectric constant $\varepsilon_r = 6.15$ and the thickness is t =1.27*mm.*All antenna ports and Input/Output ports are well matched with the antenna array feed line and the RF switch respectively. Hence, all cables between the sub-systems are missed. Therefore, the insertion loss is minimized and a good compactness of the system is achieved.

IV. UNIT CONTROL

The main aim of this unit control is to optimize the antenna system output. The criteria performance adopted is the received signal power. Hence, the system output will be maximized. The unit control, based on micro-controller MC68HC812A4 from the Motorola family, drives the RF switch (Fig. 5) to select the appropriate input / output port of the beam-forming network in order to generate a beam in the desired direction. First of all, the eight beams will be scanned, and the algorithm will select the beam, which receive the highest signal power level. When this power becomes less then 12dB, the algorithm commands the RF switch to select the beam within a power level higher than the threshold (12 dB). Accordingly to the power level, the simple rule used is shown below as:

$$\begin{cases} \dfrac{dP_r(t)}{dt} > 0 & \Rightarrow Sign = 1 \\ \dfrac{dP_r(t)}{dt} < 0 & \Rightarrow Sign = -1 \end{cases}$$

The algorithm uses the time derivative of the output power to designate the right direction, which had to be taken. Where the *Sign*=1, the *P(t)* is increasing and this means that direction of the search of the next iteration is in the same direction at the previous one. And where the *Sign*= -1, this conclude that the direction of the search is in the opposite direction. The signal received on n^{th} antenna port is $x_n(t) = a\cos(\omega_0 t + \varphi_n + \rho) + \beta_n(t)$. Where *n* varies form 1 to 8, $\beta_n(t)$ represents the noise and φ_n is the phase at each antenna element. At each input/output beam-forming network port, the signal can be written as: $y_n(t) = \sum_{i=0}^{N-1} x_{i+1}(t) \cdot e^{(ji\psi_n)}$, and the power is $P_n = \left[y_n^2(t)\right]$.

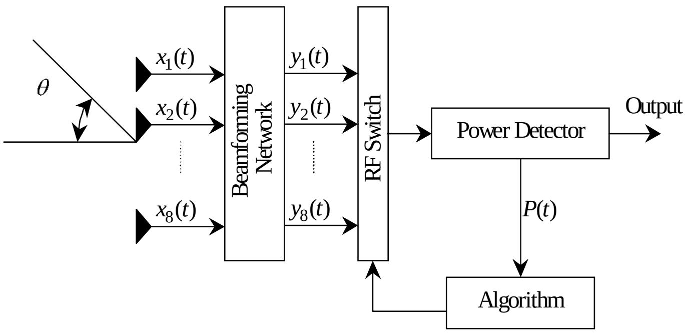

Fig.5 Antenna System Block Diagram

V. CONCLUSION

In this paper, we proposed a novel switched beam-forming antenna for the PCS application at 1.9GHz with a broadband microstrip antenna array. Although, the proposed beam-forming network requires a design of quad hybrid, crossover and fixed phase shifters on one layer. Therefore the whole antenna system can be implemented in the same layer. Also, all cables between the antenna array and the beam-forming network and the RF switch are missed. Therefore a significant compactness is done. A micro-controller from the Motorola family was used to implement a modified version of the On-Off algorithm. This control unit drives the RF switch with the power level chosen. This new beam-forming antenna will be used for the third generation of the personal communication system application. It provides a greater coverage area for the cellular cells, a higher rejection of interference and co-channel phenomena.

VI. REFERENCES

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