A General Beam-Forming Network Made with CORPS

D. Betancourt, C. del Río Bocio. Public Univesity of Navarra, Spain

e-mail: carlos@unavarra.es

Abstract- A new beam-forming Network concept is introduced. This Network is based in the design principles of CORPS. The new proposed structure presents an improvement in design over the traditional beam-forming Network since, with this kind of feed networks, is feasible to reduce the number of the Phase Shifters of N:1. Two implementations, based on Gysel Power Dividers, are also showed to corroborate the theoretical concepts.

I. INTRODUCTION

Last-Generation communication systems such as Mobile phone networks and Satellite devices, requires the ability of re-shaping its services, i.e., to change its cover areas. This kind of modification, in most of actual systems, implies to redesign the beam-forming network associated to the RF devices.

Up to now, exist few ways to re-shaping in-place of the radiation patterns of an array of antennas. More widely used method is the incorporation of Phase Shifters to the corporate feed Network [1], [2]. This solution arises with several disadvantages such as the increasing of complexity of the network, since additional electronic is necessary to controls the Phase Shifters. On the same way, the application of these active devices implies, in most of cases, fabrication difficulties, among others. Additionally, with this solution, since there is a phase shifter associated with a radiator element (antenna), is prohibitively to manage an array from medium to high dimensions.

Other alternatives to the use of phase shifters are to incorporate more complexity to the beam-forming network. This is the case of Blass matrices, Rotman lenses and Butler Matrix [1], [2]. For instance, in the last case, the Butler Matrices can produce a large number of high-quality orthogonal beams with the use of few components. The main disadvantage of this beam-forming network is that it requires many cross-over for its implementation.

In this paper we introduce a new beam-forming network based in the theory concepts of CORPS [3], which are: a). To work with a periodic structure, so the network can be characterized by an unit-cell. b). To define a filter in the horizontal plane, that prohibits signal transmission, and c). To define a band-pass structure in the Vertical plane, that allows the signal transmission. A schematic of this configuration is shown in fig 1. The use of CORPS concepts to design a beam-forming network enables the use of multi-beams and the control of the phasing by means of one phase shifter for all structure instead of use of one phase shifter by each radiator. This is, a ratio reduction on Phase Shifters of N:1.

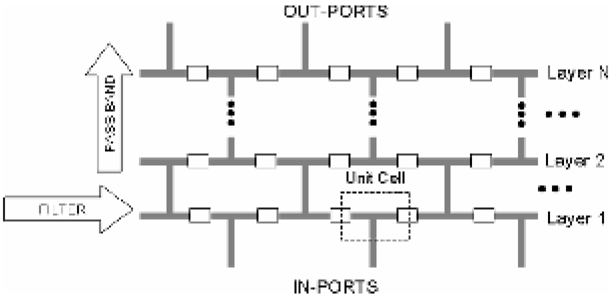

Fig. 1 Schematic of Phased Array Feed Network proposed.

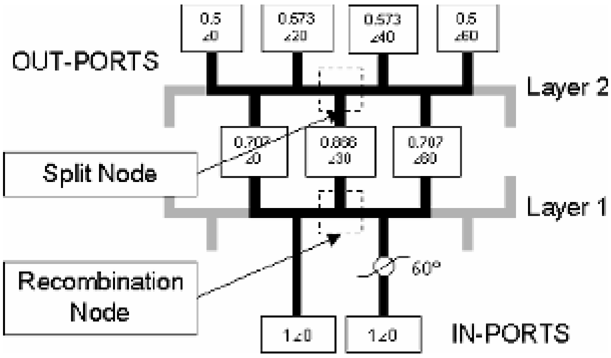

Fig. 2 Power flux throughout the structure. 2 in-ports with a phase shift of 60 deg Phases at out-ports are a lineal representation of phase at in-ports.

II. BEAM-FORMING NETWORKS BASED ON CORPS

Now, consider the characteristics related to a beam-forming network made with CORPS and the schematic representation in fig. 1. Using, the conservation of energy and taking into count that the network consists only on lossless passive components. The behavior of the beam-forming network can be only related to the named Split and Recombination Nodes (see Fig. 2).

Split Nodes are such that have one input port and N output ports. At each output port is delivered a Nth part of the power introduced at input port, as can be corroborated using the following expression [4]:

$$W_s = \sum_{k=1}^{N} \left[E_k e^{(j\theta_k)}\right]^2 G_s \, , (1)$$

Here, Ws is the power delivered at the N output ports of Split node, and Gs is the real part of the admittance seen at output ports.

In the same way, the Recombination nodes are such that have one output port (N equal to 1) and more than one input port. The power at output port can be calculated, using:

$$W_R = \sum_{k=1}^{N}\left[E_{k,1}e^{(j\theta_{k,1})} + E_{k,2}e^{(j\theta_{k,2})}\right]^2 G_k \text{ , (2)}$$

After doing some simplifications on (2), the power at output ports of a Recombination Node, can be expressed as.

$$\begin{aligned} W_R = G_R\Bigg[& \sum_{k=1}^{N}\left(E_{k,1}\right)^2 + \sum_{k=1}^{N}\left(E_{k,2}\right)^2 \\ & + 2\sum_{k=1}^{N} E_{k,1}E_{k,2}Cos\left(\theta_{k,1}-\theta_{k,2}\right)\Bigg] \end{aligned} \text{ , (3)}$$

With, G_R one half of G_s .

In Fig 2 is considered a beam-forming network of two layers, in which we set up initially two in-ports of unitary amplitude, but with different phase, this is:

In-Port 1: $Ae^{(j\theta)}$, and In-Port 2: $Ae^{(j(\theta+\Delta\theta))}$

Where A is 1 and $\Delta\theta$ is the phase shifting between ports (in this case 60 deg). The power delivered at out-port on layer 1 and 2 is calculated using (1) and (3). From this figure we can see the lineal behavior of the phase and its direct relation with Δθ. In general, the phase difference, between in-port 1 and in-port 2, is translated to a lineal combination at out-ports with initial phase equal to in-port 1 an final phase equal to in-port 2.

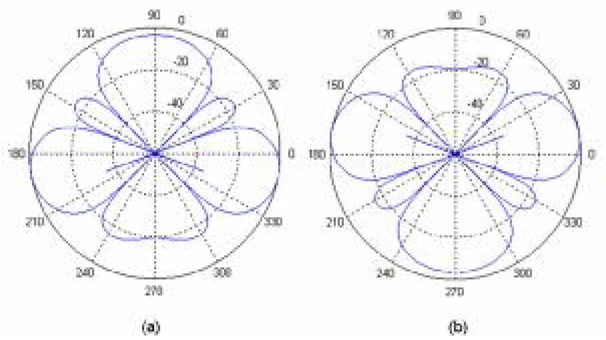

Fig. 3 Array Factor for a 1 layer Beam Forming Network (ideal) with d=0.7λo. a) Δθ=-90 deg, b) Δθ=+90 deg. Scanning angle of about 20 deg.

In order to draw the Array Pattern corresponding for a set of complex amplitudes present at the out-port of a beam-forming network, we must have into account the Electric field radiated by an Antenna Array [5], that is:

$$\vec{E}(\hat{r}) = \vec{E}_0(\hat{r})\sum_{n=0}^{N-1} a_n e^{jn(kd\cos\theta+\alpha)} \text{ , (4)}$$

Where $\vec{E}_0(\hat{r})$ the radiation pattern of the basic antenna and the Array Factor is defined by:

$$AF(\Psi) = \sum_{n=0}^{N-1} a_n e^{jn\Psi} \text{ , (5)}$$

With $\Psi = kd\cos\theta + \alpha$, and d the physical separation between out-ports. Thus, AF corresponds to the Fourier Transform of the discrete sequential coefficients at the out-ports, a_n .

Finally, we have to define the Visibly Margin of $AF(\Psi)$, as $\Psi \in [-kd+\alpha\ ,\ kd+\alpha]$ and draw.

In fig. 3 is shown the Array Factor for a physical separation at out-ports of 0.7λo, and a phase shifting at in-ports of $\Delta\theta$ -90 and 90 deg., which represent a scanning of about 20 deg .

III. FEED NETWORK IMPLEMENTATION

A beam-forming network of one layer, with the characteristics exposed before is shown in fig. 4. This network is made based on Gysel Power dividers [6]. A Gysel cell is a 3λ/2 ring impedance transformer that delivers equal in-phase power ratio in ports 2 and 3, and isolate ports 4 and 5. Thus, a Gysel Power divider, such as show in fig 5, will be used as unit cell of our structure.

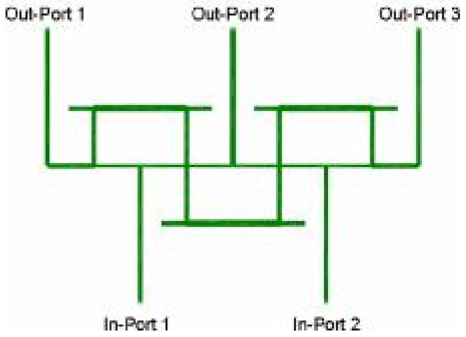

Fig. 4 Implementation of a 1 layer Beam Forming Network using Gysel power Dividers.

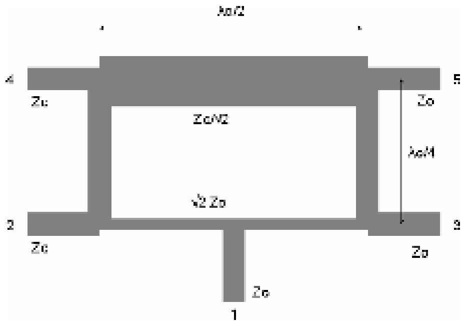

Fig. 5 Gysel Power Divider.

The fig. 7 shows the calculate results for a beam-forming Network of 1 layer (2 in-ports and 3 out-ports). The phase shifter is at in-port 2, instead at each out-port, reducing the necessity of phase shifters in a ratio of 3:1. fig. 6a, b, shows the scanning angle of the array factor calculated for the complex amplitudes at out-ports of the beam forming network. The separation between radiant elements is set to 0.7λo to reject the apparition of grating lobes in the array pattern.

Δθ (deg)	Ideal BFN out-ports [Mag / Phase(deg)]			Implemented BFN out-ports [Mag / Phase(deg)]			Phase out-port 1 to 3 (deg)	Ideal power delivered	Implemented power delivered	Power difference (%)
	1	2	3	1	2	3				
0	0,71	1,00	0,71	0,68	0,94	0,68	0,03	2,00	1,81	9,40
	0,00	0,00	0,00	55,02	54,19	54,99				
30	0,71	0,97	0,71	0,68	0,91	0,68	30,08	1,93	1,75	9,33
	0,00	15,00	30,00	55,10	39,20	25,02				
45	0,71	0,92	0,71	0,68	0,87	0,68	45,09	1,85	1,68	9,26
	0,00	22,50	45,00	55,18	31,70	10,08				
60	0,71	0,87	0,71	0,67	0,82	0,68	60,09	1,75	1,59	9,14
	0,00	30,00	60,00	55,26	24,20	-4,83				
90	0,71	0,71	0,71	0,67	0,67	0,68	90,12	1,50	1,37	8,81
	0,00	45,00	90,00	55,48	9,20	-34,64				
120	0,71	0,50	0,71	0,68	0,47	0,68	120,11	1,25	1,15	8,34
	0,00	60,00	120,00	55,68	-5,79	-64,43				
150	0,71	0,25	0,71	0,68	0,24	0,68	150,08	1,06	0,98	7,46
	0,00	75,00	150,00	55,82	-20,78	-94,26				
180	0,71	0,00	0,71	0,68	0,00	0,68	180,03	1,00	0,92	7,64
	0,00	90,00	180,00	55,85	44,00	-124,18				

Table 1 Comparison of Ideal and Implemented Complex Amplitudes at Out-ports of the Beam Forming Network of 1 layer.

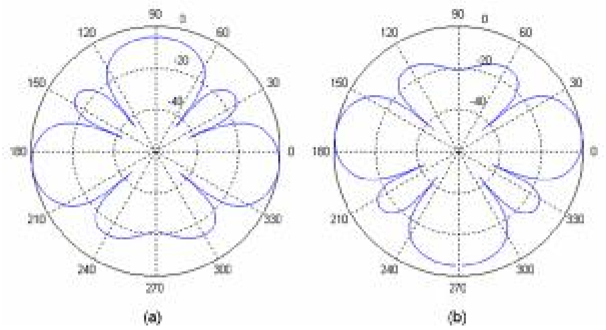

Fig. 6 Array Factor for a 1 layer Beam Forming Network (Implemented) with d=0.7λo. a) Δθ=-90 deg, b) Δθ=+90 deg. Scanning angle of about 20 deg.

Table 1 compares ideal and implemented complex amplitudes for a structure of 1 layer. The results show that the phasing made by the implemented network is almost equal to the ideal beam-forming network for a given Δθ. Also, table shows that the power delivered by the beam-forming network is proportional to ideal one. The power difference is due to the power dissipated by isolated ports on the Gysel power dividers and the power losses by radiation of structure.

Finally, it is easy to build more complex structures. For Instance, a 2 layer beam-forming network, as show in fig 7, is made aggregating a second layer to initial structure. This new beam-forming network has 2 in-ports and 4 out-ports. The ratio reduction of phase shifters is 4:1 in this case.

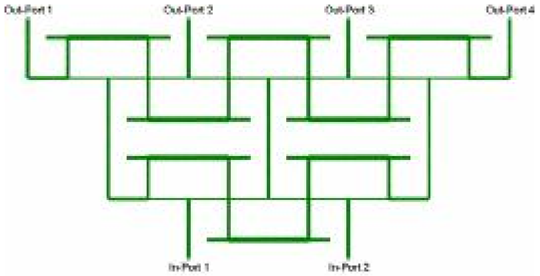

Fig. 7 Implementation of a 2 layers Beam Forming Network using Gysel power Dividers.

IV. CONCLUSION

A new beam-forming network based on CORPS concepts is introduced. This new feed Networks allows the reduction of complexity of actual Beam Forming Network, since it introduce a ratio reduction of Phase Shifters of N:1.

REFERENCES

[1] R. J. Mailloux, Phased Array Antenna Hand Book, Artech House, 1994.

[2] R. Garg, P. Bhartia, I. Bahl, A. Ittipiboon, Microstrip Antenna Design HandBook, Artech House, 2001.

[3] D. Betancourt, A. Ibañez and C. del Rio, ",Coherently Periodic Radiation Structures (CORPS): A Step Towards High Resolution Radiations Systems", IEEE AP-S 2005,Washington, USA, July of 2005

[4] R.C. Hansen, Microwave Scanning Antennas, Vol III: Array Systems, Academic Press, pag. 241-242, 1966.

[5] A. Cardama, L. Jofre, J, Rius, J. Romeo, S. Blanch and M. Ferrando , Antenas, Second Edition, Ediciones UPC, 2002.

[6] B. Ooi, "Compact EBG In Phase Hybrid-Ring Equal Power Divider," IEEE Trans. Microw. Theo. and Tech., Vol 53, No. 7, July 2005.