Study of a New 4x3 Beam Forming Network for Triangular Arrays of Three Radiating Elements

Javier García-Gasco Trujillo, Álvaro Noval Sánchez de Toca, Ignacio Montesinos-Ortego, Andrés García Aguilar, Manuel Sierra Perez
Radiation Group, Systems and Radiocommunications Department
Technical University of Madrid
Ciudad Universitaria, Madrid, Spain
{jtrujillo, anoval, nacho, andresg, m.sierra.perez}@gr.ssr.upm.es

Abstract—**An innovative dissipative multi-beam network for triangular arrays of three radiating elements is proposed. This novel network provides three orthogonal beams in θ_0 elevation angle and a fourth one in the broadside steering direction. The network is composed of 90º hybrid couplers and fixed phase shifters. In this paper, a relation between network components, radiating element distance and beam steering directions will be shown. Application of the proposed dissipative network to the triangular cells of three radiating elements that integrate the intelligent antenna GEODA will be exhibited. This system works at 1.7 GHz, it has a 60º single radiating element beamwidth and a distance between array elements of 0.57 λ. Both beam patterns, theoretical and simulated, obtained with the network will be depicted. Moreover, the whole system, dissipative network built with GEODA cell array, has been measured in the anechoic chamber of the Radiation Group of Technical University of Madrid, demonstrating expected performance.**

Butler matrix; phased arrays; adaptive arrays; nonlinear network analysis; multi-beam forming networks (key words)

I. Introduction

From the beginning of telemetry, tracking and command (TT&C) systems, mechanical scanning antennas have been employed at ground stations. As it is well-known, this technique is not only sensitive to gravity and mechanical failure but also slow, making simultaneous satellite communications infeasible. The use of electronically scanned antenna arrays overcomes these limitations, allowing much faster multi-beam scans without physical antenna rotation, [1,2]. These types of systems that use information from the link environment to set the beam shape are called intelligent architectures [3]. In order to improve the ground station performance, many studies have been carried out in the field of electronic scanning systems, in which large arrays composed of thousand of radiating elements have been considered. Generally, these array structures are divided into subarrays based on cells of at least three radiating elements [4-6]. Electronic steering technique is based on the control of the relative phase associated to each antenna that composes the whole array. The relative phase can be modified by using signal processing algorithms, e.g. MUSIC [7] or ESPRIT [8], or placing phase shifter circuits inside the hardware antenna. Nowadays, software/hardware hybrid architectures are gaining special interest because its versatility. Therefore, the study of structures that provides multiple beams in different spatial range associated to each cell is needed.

In this paper, a new multibeam network configuration that provides three orthogonal beams and an additional one with broadside steering direction by feeding a triangular array of three radiating elements will be introduced.

II. 4x3 Beam Forming Networks

After studying the state of art of classical multi-beam networks [9, 10], two original lossless networks were analyzed [11]. Intrinsic features of these networks limit the number of beams provided at the number of radiating elements and impose the orthogonally between those beams. This analysis shows the need for a beam in the broadside direction. Therefore, this research leads to consider the possibility of using dissipative networks, which are capable of providing a higher number of beams than the radiating elements compounding the cell. Because of these networks have losses, there is no need to accomplish beams orthogonal condition, which gives a greater degree of freedom that could be used to obtain desired beam steering directions. It is worth noting the orthogonally condition ensures maximum array gain. However, when radiating elements are related to radiofrequency circuits in which amplifiers are found, the relevant parameter is the factor G/T that shows the quality of the antenna. As a result, there is no problem on using dissipative network whenever there is an amplifier stage.

The scattering matrix associated to the dissipative network under study, which has three orthogonal beams and an additional beam in the broadside direction, is as shown in (1) where columns 2 to 4 generate θ_0 orthogonal beams and column 1 generate a broadside steering beam.

$$[S_T]=\begin{bmatrix} a & be^{-j\alpha} & c & c \\ a & c & be^{-j\alpha} & c \\ a & c & c & be^{-j\alpha} \\ d_1e^{j\beta_1} & d_2e^{j\beta_2} & d_3e^{j\beta_3} & d_4e^{j\beta_4} \end{bmatrix}. \quad (1)$$

The steering direction of the three orthogonal beams depends on the feeding factors, (b,c), and on the distance between elements of the array, (d), and it is giving by,

$$\sin(\theta_0) = \frac{\lambda}{\sqrt{3}\pi d}\cos^{-1}\left(\frac{b^2+c^2-1}{2bc}\right). \tag{2}$$

Losses associated with the network are related to the broadside beam power as,

$$d_1 = 1-3a^2 \tag{3}$$

$$d_i = a^2. \tag{4}$$

Several dissipative networks for triangular arrays have been studied. The most common difficult, is to avoid the appearance of side lobes and the diffraction, as shown in [11] where a truncated Butler network for three radiating elements was presented. Finally, a network of couplers and phase shifters, as shown in Fig. 1 (a), is proposed. The analysis of the scattering parameters of the network shows the relation between components. The behavior of the network is governed by the value of the central coupler, which determines the phase shifters needed. The steering direction of the orthogonal beams as well as losses associated with each of the beams depends on the coupler c as,

$$\sin(\theta_0) = \tan^{-1}\left(\frac{-2\sqrt{1-c}}{-\sqrt{c}}\right)\frac{1}{\sqrt{3}\pi}\frac{\lambda}{d} \tag{5}$$

$$L_{\theta_0} = -10\log\left(1-\frac{c}{4}\right) \tag{6}$$

$$L_{0^\circ} = -10\log\left(\frac{3}{4}c\right) \tag{7}$$

Application of the proposed dissipative network to the triangular cells of three radiating elements that compose the intelligent antenna GEODA, which is composed of 2.700 radiating elements working at 1.7 GHz with a 60º beamwidth and a distance between array elements of 0.57 λ [6, 12, 13], is exhibited in Fig. 1 (b). Moreover, the whole system, dissipative network built with GEODA cell array, has been measured in the anechoic chamber of the Radiation Group of Technical University of Madrid, demonstrating expected performance, Fig. 2.

III. Conclusions

MBFN for triangular subarrays of three radiating elements has been studied. Intrinsic features of lossless network limit the number of beams generated. A novel non-orthogonal network providing three ortogonal θ_0 beams and an extra broadside one has being proposed. Practical implementation of the network integrated to GEODA triangular subarray has been built and measured obtaining expected results.

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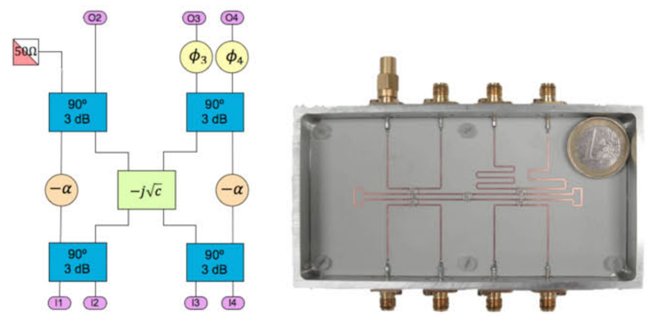

Fig. 1: 4x3 dissipative network. (a) General case. (b) Particular GEODA cell case

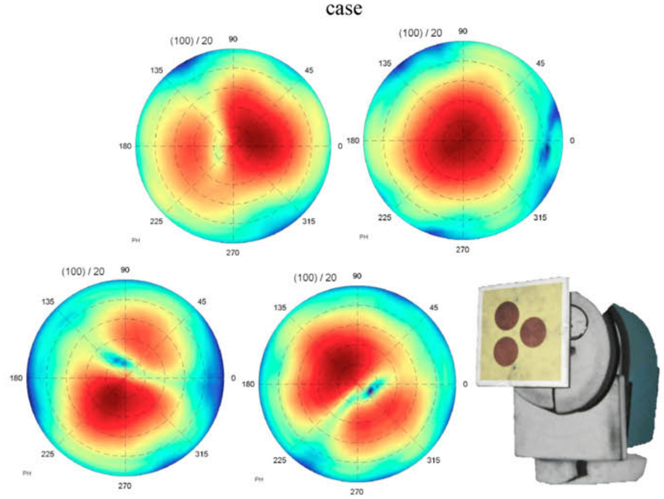

Fig. 2: Measured radiation patterns of the beam forming network and cell subarray GEODA.