Performance of wide band connected arrays in scanning : the equivalent circuit and its validation through a dual-band prototype demonstrator

Citation for published version (APA):
Neto, A., Cavallo, D., & Gerini, G. (2010). Performance of wide band connected arrays in scanning : the equivalent circuit and its validation through a dual-band prototype demonstrator. In *Proceedings of the 2010 IEEE Antennas and Propagation Society International Symposium (APSURSI), 11-17 July 2010, Toronto, Canada* (pp. 1-4). Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/APS.2010.5561101

DOI:
10.1109/APS.2010.5561101

Document status and date:
Published: 01/01/2010

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Performance of Wide Band Connected Arrays in Scanning: the Equivalent Circuit and its Validation through a Dual-Band Prototype Demonstrator

A. Neto* (1), D. Cavallo (1,2), and G. Gerini(1,2)
(1) TNO, Defense, Security and Safety, The Hague, Netherlands
(2) Eindhoven University of Technology, Eindhoven, Netherlands
E-mail: andrea.neto@tno.nl

Introduction

Connected array antennas are planar radiators in which the mutual coupling between the neighboring elements is so high that the antenna elements are effectively touching each other. Physically touching connected arrays have been formally introduced by R. Hansen [1] and were then developed for wideband through the foliage observations by J.J. Lee [2]. Similarly, wideband antenna concepts were also developed by B. Munk [3], who did not refer to the name connected arrays, but essentially realized the connection by means of capacitive loading at the edges of the dipoles.

Since the wideband performance of connected arrays is associated with large dimensions in terms of the wavelength, realistic demonstrators should include many elements. In order to evaluate the matching properties of the array, one is typically obliged to build a feeding network that will be lossy and expensive. Even by doing so, it is difficult to isolate the effect of the feeding lines from the properties of the radiating part of the antenna.

In this paper, the properties of the arrays in transmission are evaluated by interpreting the properties measured in reception using a prototype where all elements are closed in matched loads. The properties of the array in transmission are obtained by applying the reciprocity principle. In order to achieve this goal, the Green's Function of connected arrays in reception is developed and exploited by generalizing the procedure introduced in [4] and [5]. The extension to reception cases allows the derivation of a rigorous equivalent circuit in which each component is associated with a specific design parameter, represents a well identified physical phenomenon and is evaluated analytically. The equivalent network is then used to interpret the results of a prototype demonstrator that was manufactured to validate the design procedures presented in [5] and [6]. The excellent agreement of the measurements with the results of the equivalent network and full wave simulations indicates that a good comprehension of the dominant connected array phenomena is obtained.

Problems with Standard Equivalent Circuits in Reception

Standard equivalent circuits for antennas (see for instance [7], pp.80-85), present an evident asymmetry when they are used in transmission and in reception. In fact, while in transmission the generator only depends on the characteristics of the

978-1-4244-4968-2/10/$25.00 ©2010 IEEE

source, in reception the voltage generator contains in itself the information about the antenna shape, and not only the characteristics of the source alone (i.e. the incident field). In fact, with reference to the equivalent circuit of a receiving antenna in [7], $V_g = -E_i \cdot h$, that is the scalar product of the incident field and the effective height of the antenna. This choice imposes a value for the impedance of an equivalent Thevenin generator: $Z_{Thevenin}=Z_{antenna}$. However, as in all Thevenin equivalent circuits one cannot associate a physical meaning to this equivalent impedance (see in [8], p. 354, to this regard). In our view, a more useful equivalent circuit should be derived, that sees the antenna as a transition between two guiding structures, the dominant Floquet waves on one side and the guided waves on the other. This representation should not resort to Thevenin equivalence to represent the antenna but to Green's functions. In the following, such a circuit is derived for connected arrays in reception.

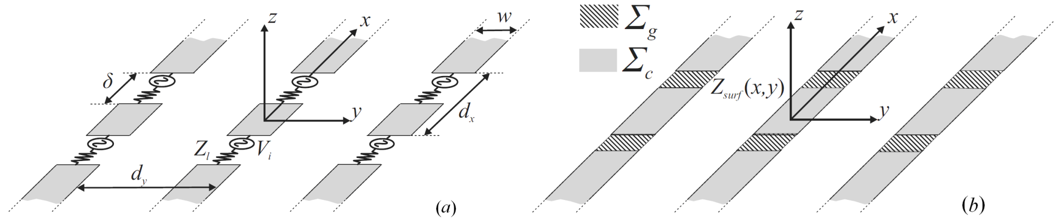


Fig. 1: 2-D connected array of dipoles (*a*) and equivalent distributed surface impedance (*b*).

Equivalent Circuits for Connected Arrays of Loaded Dipoles

The connected array of dipoles in Fig. 1(*a*) is investigated. The array is composed of an infinite number of *x*-oriented dipoles, periodically spaced by d_y along y. Each dipole is fed at locations displaced by d_x, by a voltage generator V_i with load impedance Z_l. The loads are represented by assuming equivalent distributed surface impedance over the gaps region, as depicted in Fig. 1(*b*). Accordingly, we can impose boundary conditions as $\boldsymbol{e}^{tot} = Z_{surf}\boldsymbol{i}_z \times (\boldsymbol{h}_1^{tot} - \boldsymbol{h}_2^{tot})$, where $\boldsymbol{h}_1^{tot}, \boldsymbol{h}_2^{tot}$ represent the total magnetic fields for z>0,<0, respectively. This equation is valid on the entire array surface $\Sigma_c \cup \Sigma_g$, if we assume that the surface impedance $Z_{surf}(x, y)$ is a discontinuous function which is equal to zero on the conductive part of the dipoles, and different from zero on the gaps. The total electric field can be expressed as the superposition of the incident and the scattered field. Focusing only on the longitudinal (x) component of the electric field, eq. (1) can be solved with a procedure similar to the one presented in [5], leading to the following expression for the current distribution on the zero-th dipole $i(x)$:

$$i(x) = \frac{1}{d_x} \sum_{m_x=-\infty}^{\infty} \frac{-E_x^i(k_{xm}) + Z_l i_{n_x=0}^{av} \operatorname{sinc}\left(k_{xm}\delta/2\right)}{D_l(k_{xm})}, \qquad (1)$$

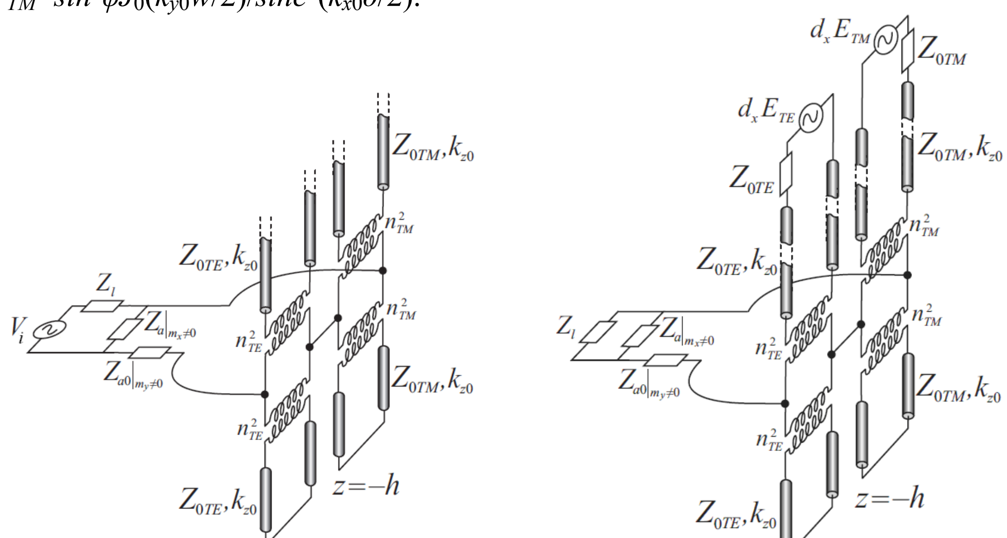
where $D_l(k_x) = (1/d_y)\sum_{m_y=-\infty}^{\infty} J_0(k_{ym}w/2) G_{xx}(k_x, k_{ym})$, $i_{n_x=0}^{av}$ is the average current flowing into the gap, J_0 is the Bessel function of zero-th order, $k_{xm}=k_0 \sin\theta \cos\varphi + 2\pi m_x/d_x$, $k_{ym}=k_0 \sin\theta \sin\varphi + 2\pi m_y/d_y$, and k_0 is the free-space propagation constant. The spectral domain Green's function $G_{xx}(k_x, k_y)$ accounts for any general stratification along z and/or for the presence of a backing reflector. The steps of the procedure are omitted for brevity, but eventually lead to the equivalent networks in Fig. 2(a) and (b) for transmit and receive. In deriving these equivalent circuits use has been made of the input admittance (impedance) of a connected array of dipoles that was derived in [6] and is equal to:

$$Y_a = \frac{1}{Z_a} = \frac{1}{d_x}\sum_{m_x=-\infty}^{\infty} \frac{-sinc^2(k_{xm}\delta/2)}{D_l(k_x)} \quad (2)$$

It is useful to isolate the following contributions in eq. (2):

1) one associated with the fundamental mode m_x=0, m_y=0, which is the only propagating mode representing the plane wave transmitted by the infinite array (Y_{a00});
2) a series term accounting for the higher order transverse modes, (m_x=0, m_y≠0), mainly depending on the dipole width ($Y_{a0,\, my\neq 0}$);
3) a parallel term accounting for the higher order longitudinal modes, (m_x≠0, m_y≠0), which models the capacitance associated with the feeding gap ($Y_{a,mx\neq 0}$).

With reference to this circuit in Fig. 2, one can represent the fundamental Floquet mode as a series of two transmission line associated with transverse electric (TE) and transverse magnetic (TM) components of the radiated plane wave, respectively. The characteristic impedances of the two TE and TM transmission lines are equal to $Z_{0TE} = \zeta_0 cos\theta$, $Z_{0TM} = \zeta_0/cos\theta$ and we introduced two transformers with transformation ratios $n^2_{TE}=cos^2\varphi J_0(k_{y0}w/2)/sinc^2(k_{x0}\delta/2)$, $n^2_{TM}=sin^2\varphi J_0(k_{y0}w/2)/sinc^2(k_{x0}\delta/2)$.



(a) (b)

Fig. 2: Green's Function based equivalent circuit in transmit (a) and receive (b) mode.

Prototype Demonstrator

A prototype demonstrator has been manufactured, based on the design presented in [7]. It represents a receiving 32×32 connected array operating on two separate frequency bands (8.5-10.5 GHz and 14.4-15.4 GHz), for simultaneous radar and

Tactical Common Data Link (TCDL) applications. Fig. 3 shows a picture of the array and the comparison between HFSS simulations, equivalent circuit and measurements, for broadside and 45^{o} scan on the E-plane. The measured reflection coefficient has been evaluated as the array Radar Cross Section (RCS) normalized to the RCS of a metal plate with the same physical dimension of the array.

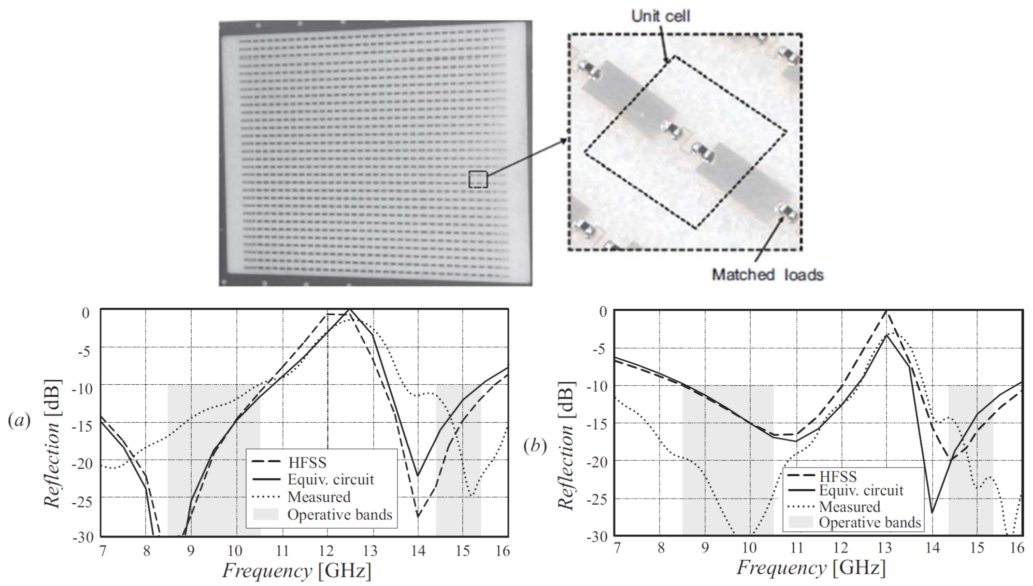


Fig. 3: Picture of the array and reflection coefficient for broadside (*a*) and 45^{o} on the E-plane (*b*).

References

[1] R. C. Hansen, “Linear Connected Arrays,” *IEEE AWPL*, Vol. 3, pp.154-156, 2004.

[2] J. J. Lee, S. Livingston, R. Koenig, D. Nagata, and L. L. Lai, “Compact Light Weight UHF Arrays Using Long Slot Apertures,” *IEEE Trans. on Antennas and Propag.*, Vol. 54, No. 7, July 2006.

[3] B. A. Munk, Finite Antenna Arrays and FSS, John Wiley & Sons, Inc., 2003.

[4] A. Neto and J.J. Lee, “Ultrawide-Band Properties of Long Slot Arrays,” *IEEE Trans. on Antennas and Propag.*, Vol. 54, no. 2, pp. 534-543, Feb. 2006.

[5] A. Neto, D. Cavallo, G. Gerini and G. Toso, “Scanning Performances of Wide Band Connected Arrays in the Presence of a Backing Reflector”, *IEEE Trans. on Antennas and Propag.*, Vol. 57, No. 10, Oct. 2009.

[6] M. Pasian, S. Monni, A. Neto, M. Ettorre, G. Gerini, “Frequency Selective Surfaces for Extended Bandwidth Backing Reflector Functions,” *IEEE Trans. on Antennas and Propag.*, in press.

[7] C. A. Balanis, *Antenna Theory, Analysis and Design, Third Ed.,* John Wiley & Sons, Inc., Hoboken, 2005.

[8] S. Ramo, J. R. Whinnery, *Fields and Waves in Modern Radio, Second Ed.*, John Wiley & Sons, Inc., New York, 1953.