Proposed Functional Description for Phased Arrays

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Generally speaking many photonic engineers, while working in a systems development mode, still focus on presenting the unique physical details of the optical elements, instead of using functional representation to describe the system. The purpose of this presentation is to introduce symbols that can be used to represent the functional intent of most of the phased array architectures described in

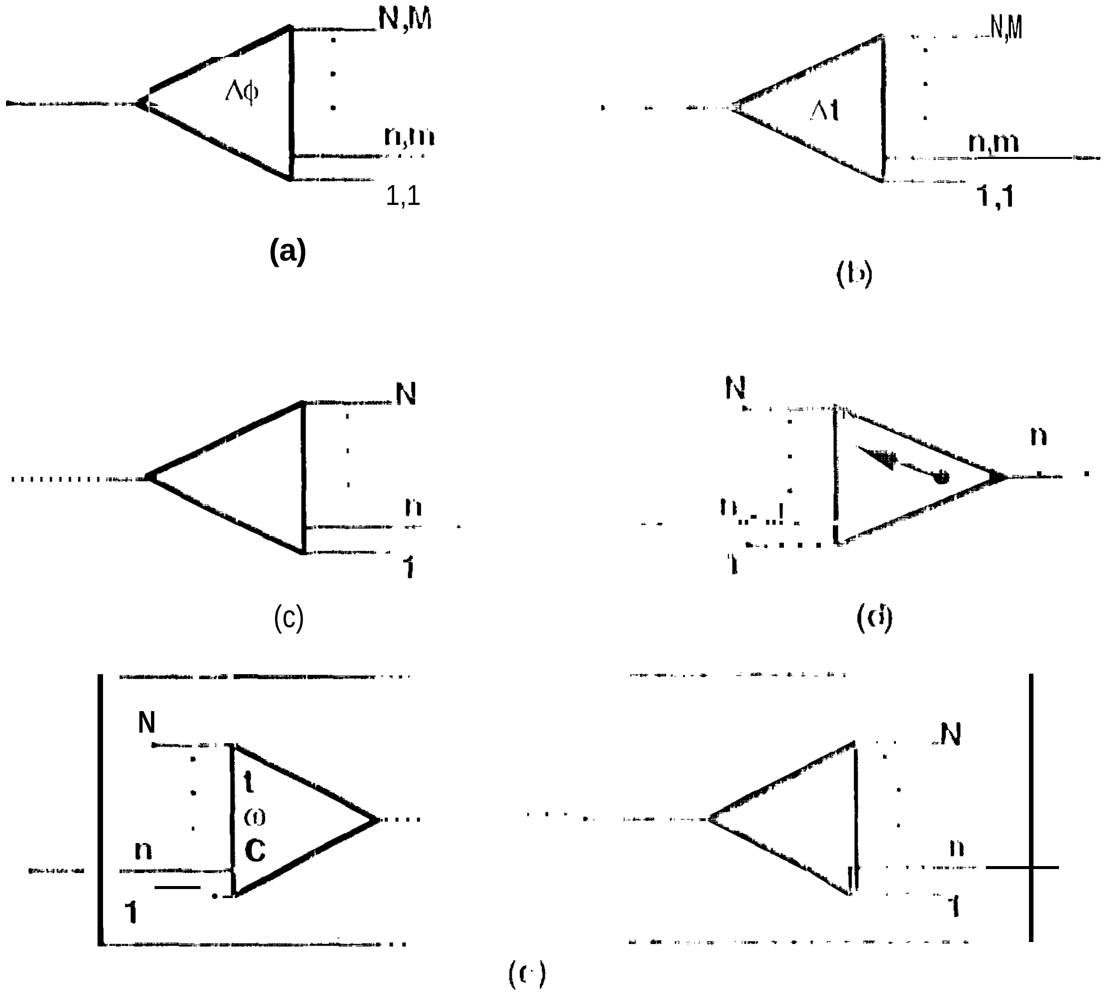

Figure 1. Proposed functional representations for Phased Array Antenna architecture concepts: (a) Modulo 2π Phase Shifting, (b) True-Time Delay Phase Shifting, (c) Passive fanning, (d) Folding, and (e) MUX and DEMUX representations, respectively.

the literature. It is anticipated that this will (1) simplify comparisons among different designs and (2) aid analysts in optimizing system performance. The examples used in this paper are taken from Parent's review paper "A Survey of Optical Beamforming Techniques" [1].

The basic function of a phased array antenna is to take a signal input, s(t), fan it out to an NxM array of radiating elements, and introduce a spatially dependent phase variation at each element of the array. A single symbol can be used to represent the fanning action as shown in Figure 1. There are two basic methods employed to introduce the spatially dependent phase variation that causes the far field steering of the radiated beam:

- Modulo 2π phase shifts
- True Time delay

The method of introducing the phase variance is represented inside of the fanning symbol by either $\Delta\phi$ or Δt, respectively, as depicted in Figure 1 (a) and (b). In addition, some architectures call for passively fanning the signal to N distribution points with the same phase. In this case, nothing is denoted inside of the fanning symbol (Figure 1 (c)) .

Using these symbols, the classical RF phased array distribution system would be represented as shown in Figure 2

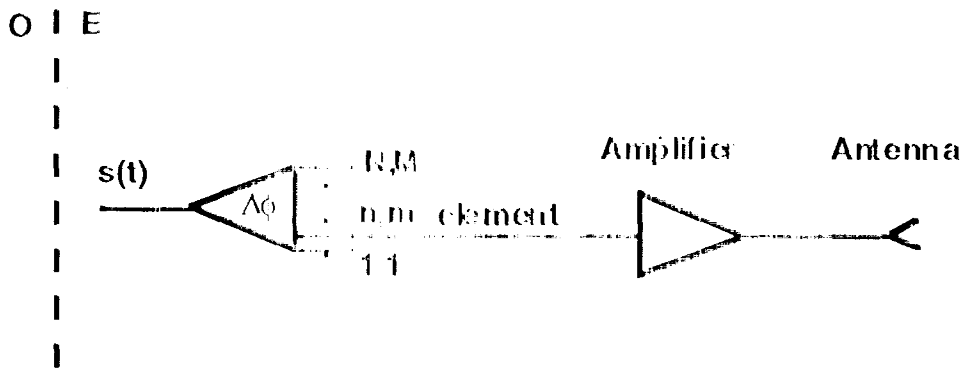

Figure 2. All RF Phased Array Antenna

In another example, the classical Mach Zehnder Beam former represented in Figure 3(a) can be expressed in functional terms as shown in Figure 3(b).

To distinguish between the optical and the electronic portions of the architecture, an O-E interface is denoted by a vertical dashed line with optical symbols on the left and the RF or electronic symbols on the right. The flow of the input signal goes from left to right, except when crossing from the electronic to the optical side of the interface, in which case the order of flow is top to bottom. In addition, when the functional implementation is optical rather than electronic, it is always enclosed in a box.

It should be noted that the vertical dashed line implies the presence of laser sources, modulators, and detectors at the interface without explicitly depicting them in the figure. Rather, since it is conventional to speak of the RF-optical-RF loss of a single optical link in terms of the net gain, G, we introduce a gain per element term, $G_{n,m}$, for the loop from the distributed RF signal input, $\frac{s(t)}{N \bullet M}$, to the output at each radiating element. Because these gain terms are determined by the efficiency of the laser sources, modulators, and photo receivers at the interface, some of the important physical properties of the interface hardware will be embodied by this gain term.

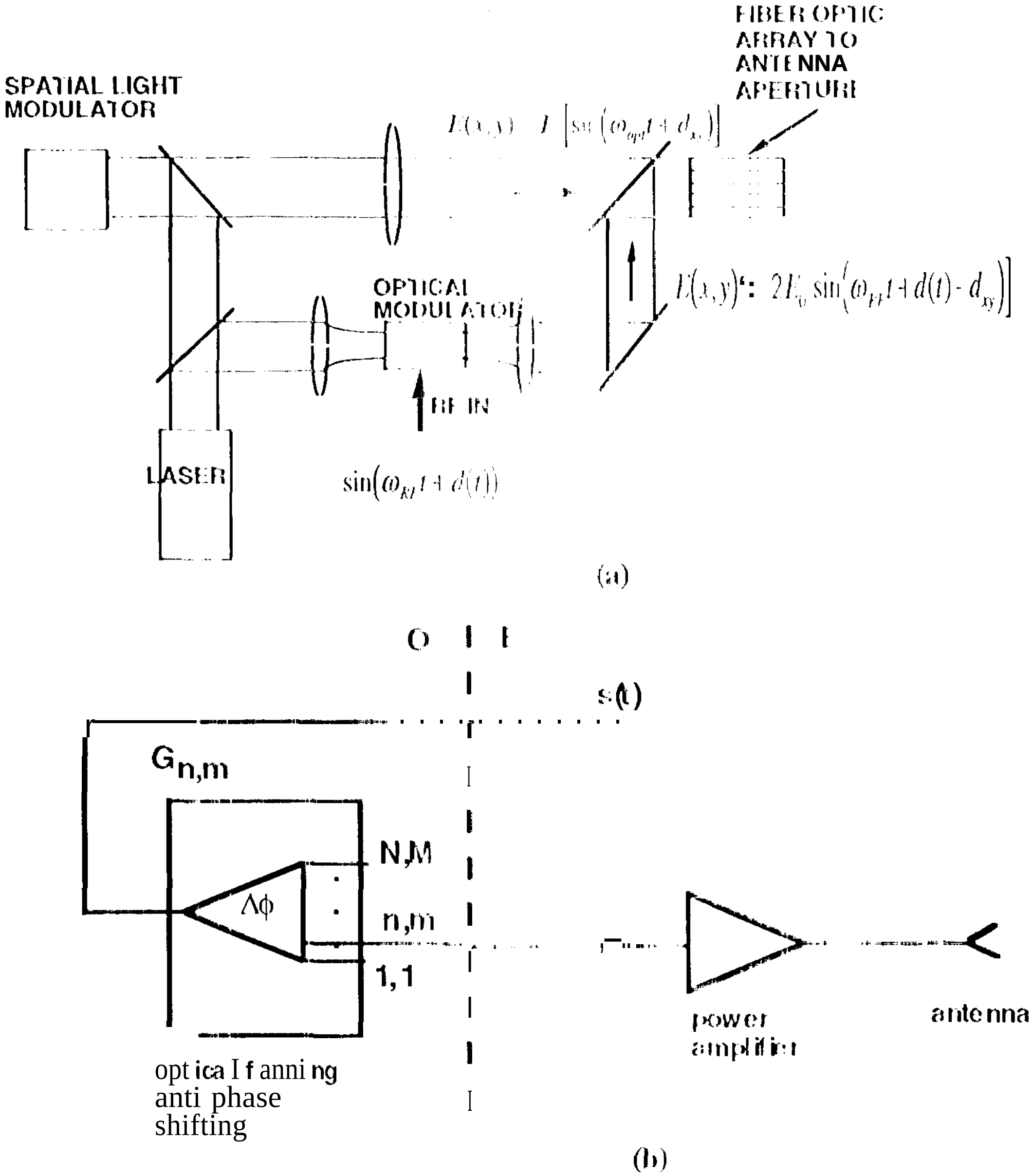

Figure 3. **(a)** Schematic of Mach Zehnder Beam former and (b) a functional representation of the Mach Zehnder beam former.

Other important design parameters such as the bandwidth, the noise figure, the RF-optical-RF link dynamic range, the uniformity of performance across the array, the mass and power consumption per fanning string, and the fanning string-to-fanning string isolation, might be included in the diagram as needed. Note that the fanning string is defined as the sequence of operations or functions that occur after the fanning function. If one implements a 1xN fanning operation, any hardware that is needed to perform any successive operations must be replicated N times in order to build the full array

In some of the true time delay approaches, only one of N fanned pathways are selected to define a given time delay. This is simply represented by the mirror image of the fanning symbol (see Figure 1 (d)). Clearly when a folding operation occurs, in the hardware string, hardware replication only occurs between the fanning and folding symbols.

For example, the Hughes design is a hybrid optical/electronic time delay steering approach. As depicted in Figure 4, the RF input signal is passively fanned to 32 outputs before crossing the E-O interface. The signals are then optically fanned over a 32-bit time delay variation. At each of the 32 outputs, a single delay path is selected. This is represented by folding the optical fan down to one selected time delay bit. The fact that the selected output appears on the electronic side of the interface implies that the conversion process at the O to E interface is used in selecting the signal path that is fed to the output. Then the output is further fanned via microwave time delays to yield either a 96x1 or a 32x3 element hybrid beam former.

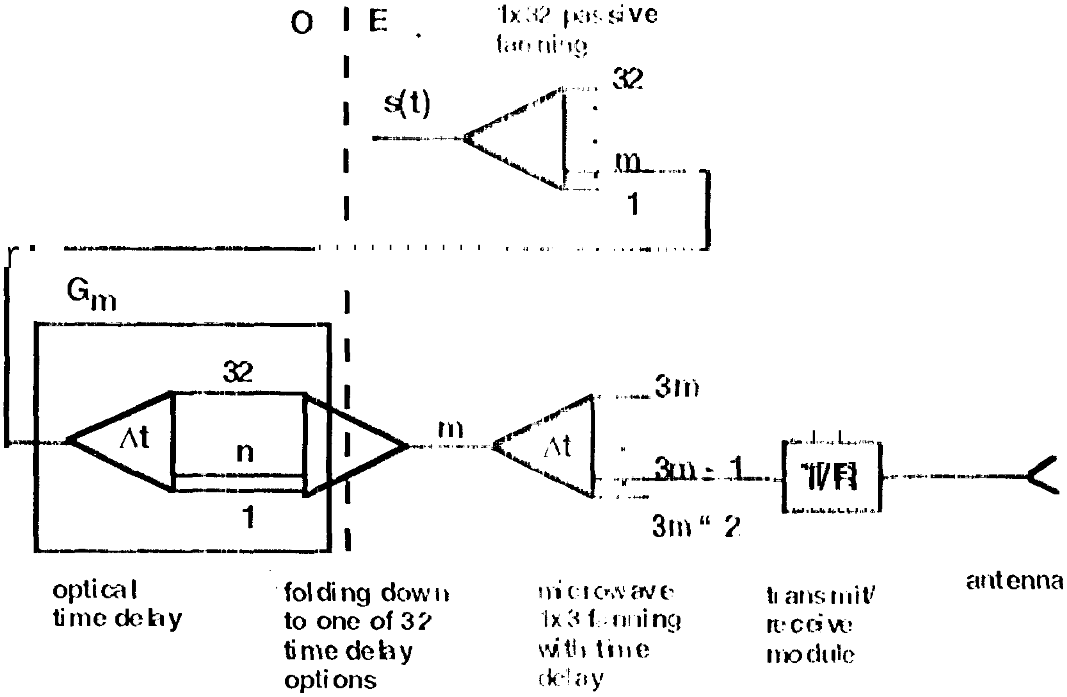

Figure 4. Functional Representation of the Hughes Hybrid Optical-Electronic Phased Array Concept (Reference 2).

When the outputs of all optical pathways are folded together, this is commonly known as MUXing and is denoted in Figure 1 (c) by the absence of a selected output signal path, n. If needed, one can denote the method used to achieve the MUXing by introducing a t, ω, or C to represent time-division, frequency-division, and code-division MUXing, respectively. When the passive fanning symbol appears after the MUX symbol, it is interpreted as a DEMUX operation. The Westinghouse compressed hybrid phased array antenna concept depicted in Figure 5 nicely illustrates this. Here the optical MUXing is used to reduce the number of time delay subcomponent modules required to construct the full antenna array. It works by taking advantage of the fact that the relative amount of time delay among adjacent apertures is repeated throughout the antenna. By identifying a subset of apertures (1 through N) that define the repeating relative time delays, and electronically fanning to set the basic pattern. Then optical time delays are introduced to set the proper absolute time delays across the full array.

Because of the large number of individual antenna apertures required in some phased array applications, design concepts such as this that reduce the number of time delay modules and other subcomponents relative to the number of radiating aperatures will be heavily explored. It is felt that symbolic functional representations will be a very useful aid in these types of investigations.

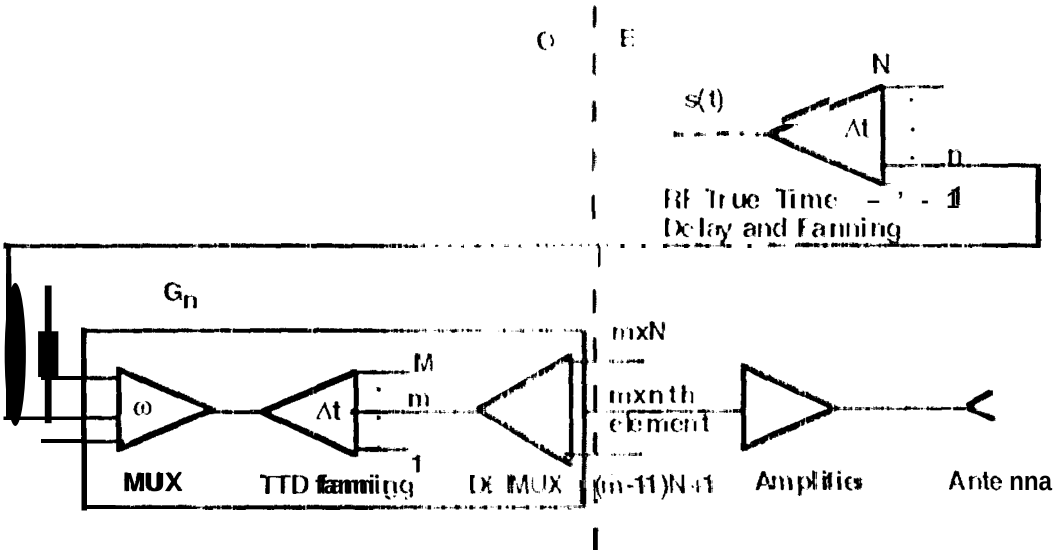

Figure 5. Westinghouse Compressed Hybrid Phased Array Antenna concept (Reference 3).

In conclusion, a symbolic formalism has been introduced that can be used to provide a functional description of many of the phased array architectures in the literature. This descriptive nomenclature facilitates the comparison of different phased array antenna designs by quickly identifying the basic functional subcomponents used in building the phased array, separating out the optical versus RF portions of the array signal distribution system, yielding an immediate indication of the size of the antenna, indicating the method of phase shifting, and giving an indication of how many times each fanning string must be repeated to construct the fill antenna.

1. Parent, Mark G., "A Survey of Optical Beamforming Techniques", *Proceedings of The 1995 Allerton Antenna Applications Symposium*, 20-22 Sept. 1995.

2. A. Goutzoulis, K. Davies, J. Zomps, D. Hryzak, and A. Johnson, " A Hardware-Compressive Fiber Optic True-Time Delay Steering for Phased-Array Antennas", *Microwave Journal*, Sept. 1994, pp. 126-140.

3. W. Ng, A. Walston, G. Tangonan, J.J. Lee, I.L. Newberg, and N. Bernstein, "The First Demonstration of an Optically Steered Microwave Phased Array Antenna using True-Time-Delay", *Journal of Lightwave Technology, Vol. 9*, Sept. 1991, pp. 1124-1131.