Ferrite Phased Array Antennas: Toward a More Affordable Design Approach†

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I. Introduction

Ferrite phased–array antennas of significant size have been built and studied for more than twenty–five years. Systems in wide variety have been developed for both one–axis and two–axis scanning. A quick listing of systems known to the author yielded more than forty different antennas that have been produced over the twenty–five year period, and this list is by no means comprehensive. About forty percent of these designs were two–axis scanning types, the remainder single–axis; approximately twenty–five percent of each classification were carried into some degree of serial production. Ferrite–type phased arrays have clearly made a significant contribution to the art of electronically scanning antennas.

In parallel with the design and fabrication of the antennas, very great improvements have been realized in the design and manufacture of the ferrite phase control elements, resulting in a continuing advance in the performance–quality–cost relationship. Nevertheless, end users continue to point to the “high cost” of ferrite phase control elements as a barrier to more widespread use of this type of electronically scanning antenna. The following material presents a design approach that may reduce significantly the cost per element for a two–axis scanning ferrite phased array.

II. Ferrite phase control element cost history

One of the factors influencing cost is the desire to incorporate features into the phase control element beyond its basic phase shifting function. Examples are adding polarization switching or diversity, and building the radiating element directly into the phase control element. Those may be worthy features that can be achieved at nominal cost, but their effect is to make cost comparisons more difficult. An approach adopted here for comparison purposes is to reduce the effective cost of each model to a “baseline” low–power design in which all extra features are removed. The baseline cost is derived from the actual unit cost by reducing the materials cost, fabrication labor, and assembly/test labor in proportion to the weight change, length change, and parts count change, respectively.

The same cost comparison adjustments can be used to account for differences in operating frequency of baseline designs, at least up to Ku–Band. Applying these admittedly crude principles yields the following cost vs. frequency normalization factors, applicable to moderately large production runs:

Frequency Band	Cost Normalization Factor
Ku	0.91
X	1.00
C	1.65
S	3.27

The final consideration required to generate a meaningful cost history is the removal of inflationary factors, e.g. using the Consumer Price Index annual average figures.

Based on the above considerations, a comparison of average constant–dollar costs can be made for the USAF/ Westinghouse Electronically Agile Radar (EAR) antenna and its descendant, the antenna for the USAF/Westinghouse B–1B APQ–164 radar. The comparison yields the following results:

PROGRAM	EAR	APQ–164
ACTIVITY TIME PERIOD	1975–6	1983–7
QUANTITY OF PHASE CONTROL ELEMENTS	4,400	120,000
NORMALIZED COST PER ELEMENT FOR:		
BASELINE PHASE SHIFTER	0.70	0.54
DRIVER	3.59	0.46
BASELINE TOTAL	4.29	1.00
ACTUAL PHASE SHIFTER	0.91	0.73
ACTUAL TOTAL	4.50	1.19

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The figures given for phase shifter cost and quantities apply only to items supplied by the author's organization.

The most striking feature of this comparison is the fact that driver cost reduction provided a large part of the total cost per element reduction from EAR to APQ–164. From a historical perspective, this situation makes sense because of the differences in maturity of the phase shifter and driver designs. Basic phase shifter configuration analysis and optimization work was completed and published by 1974, prior to the start of the EAR program production. On the other hand, the EAR driver represented a new learning experience of developing and producing a microelectronic circuit for integration with the phase shifter. For the APQ–164 antenna, radical changes were made to the driver based on EAR experience, while the phase shifter design was enhanced in evolutionary (but important) fashion. Hence, the phase shifter cost improved at a relatively mature 95% learning rate, while the driver cost dropped by almost a factor of eight.

III. Future directions

If the phase shifter is a mature design and the driver cost has already dropped by a factor of eight, is there any hope for further cost reduction? If so, how might it be achieved? The answer to the first question is unhesitatingly affirmative, and for the second it is necessary to carry out a re–thinking of the antenna architecture to permit more optimum packaging, assembly, and testing.

As a reference point, consider the antenna configuration concept shown in Figure 1. In this arrangement, phase shifters, drivers, and the power and command circuitry are contained within a space between the aperture plate and an adapter connecting to the feed manifold. As shown in Figure 2, each phase shifter is fitted with a driver prior to installation into the antenna. The drivers may be arranged to plug into a circuit board which carries power and command signals to each phase control element. This approach has the advantage that each phase shifter and driver assembly can be tested prior to installation into the antenna.

In practice, it turns out that the packaging, mounting, and handling costs for the driver far exceed the cost of the semiconductor parts. Also, the power and command distribution board must provide a large number of independent circuits and might consequently need to be built up of many shielded layers. Serial data transfer is virtually necessary, which tends to complicate the driver and antenna steering controller interfaces. Furthermore, no alignment/collimation of the dynamic elements is possible until the entire antenna is assembled. Note also that replacement of a phase shifter–driver element requires complete removal of the aperture plate. If a phase control element fails for any reason during final test without causing the system to fall outside specification limits, the manufacturer is faced with the difficult choice between the unpalatable option of shipping an antenna with a known failed element, or the costly option of teardown, replacement, and retest.

An alternative modular concept is offered in Figure 3 for use in next–generation ferrite phased array antennas. In this approach, multi–channel drivers and alignment memory components are mounted on a circuit board, which is integrated with secondary feed and phase shifters into a module which accommodates two rows or two columns of the antenna. The advantages of this scheme relative to the Figure 2 approach are:

(a) All of the electronic parts are built into standard packages with conventional circuit–board mounting, compatible with automated assembly methods.

(b) A multi–channel driver is used for lower cost, estimated to be 15–20% of the single channel driver approach cost.

(c) Memory can be incorporated on the module circuit board to permit alignment/collimation at the module level.

(d) Modules can be connected to a parallel data bus, greatly simplifying the wiring and controller interface.

(e) Modules are easily replaced, and the pre–alignment feature allows replacement without re–collimation of the antenna.

IV. Conclusions

In summary, it appears that greater cost reductions in two–axis scanning ferrite phased arrays are likely to come from closer integration of the phase shifters into the antenna structure, and better optimization of the electronic circuitry, rather than from improvements in phase shifter configuration and manufacturing methods. Using some variant of the modular approach of Figure 3, it is probable that the total phase shifter–driver cost in very large production quantities will fall below the level of one hundred (1987) dollars per element, for X–Band or Ku–Band designs.

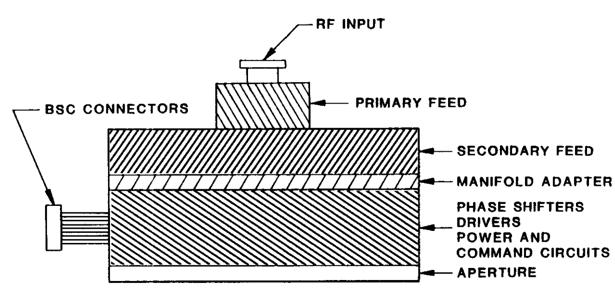

Fig. 1. Typical ferrite phased array configuration.

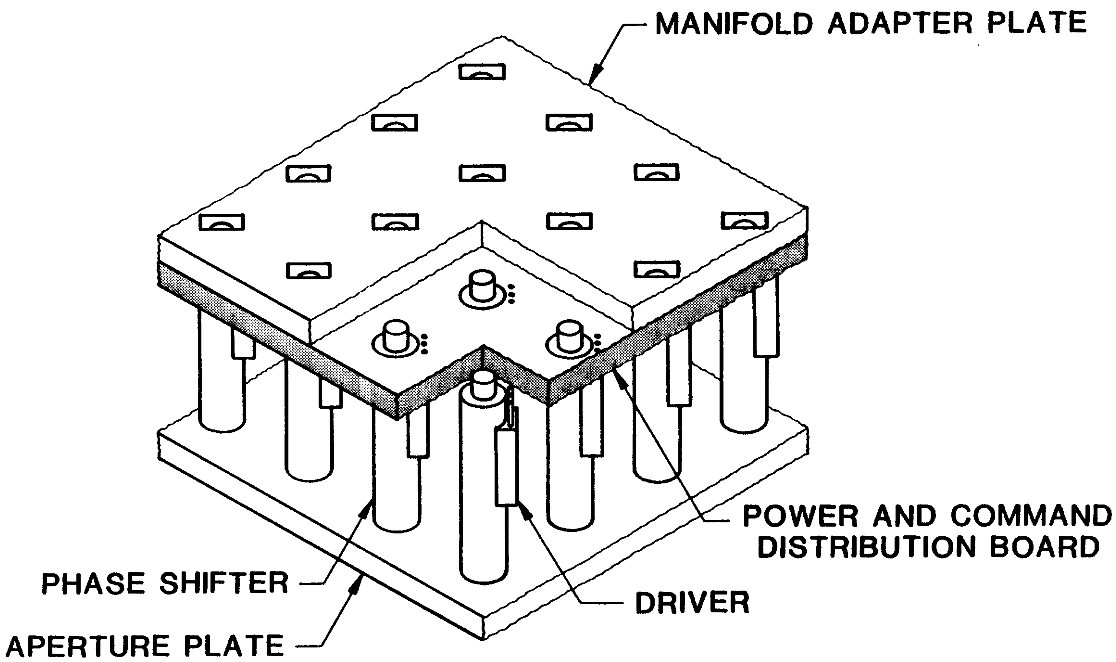

Fig. 2. Integration of discrete phase shifter/ driver units into antenna

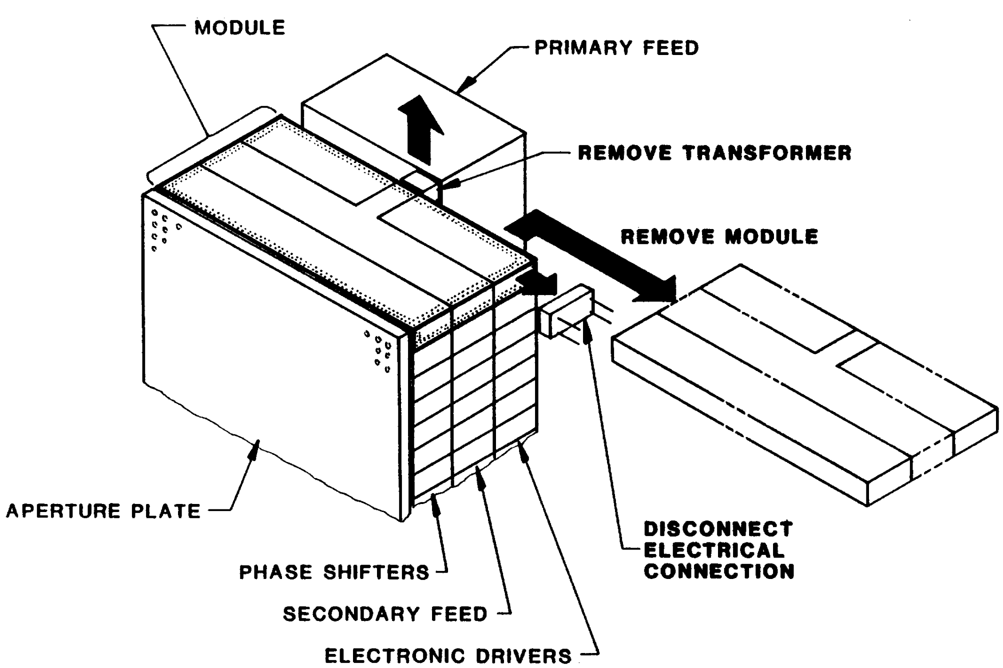

Fig. 3. Conceptual design of modular array