# 6.2A PRACTICALITY OF ELECTRONIC BEAM STEERING FOR MST/ST RADARS

W. L. Clark and J. L. Green

Aeronomy Laboratory
National Oceanic and Atmospheric Administration
Boulder, Colorado 80303

## INTRODUCTION

Electronic beam steering has been prominently described as complex and expensive (SKOLNIK, 1962). In this paper we describe the Sunset implementation of electronic steering, which has been in routine use since 1981, and demonstrate that such systems are, in fact, cost effective, versatile, and no more complex than fixed beam alternatives, provided three or more beams are needed.

First, as an example of the need for multibeam systems, the problem of determining accurate meteorological wind components in the presence of spatial variation is considered. Next, a cost comparison of steerable and fixed systems allowing solution of this problem is given. Then the concepts and relations involved in phase steering are given, followed by the description of the Sunset ST radar steering system. Finally, the implications are discussed, references to the competing SAD method are provided, and a recommendation concerning the design of the future Doppler ST/MST systems is made.

## ESTIMATION OF METEOROLOGICAL WIND COMPONENTS

Beam pointing ST/MST radars measure the component of wind in the direction of probing. The wind components of meteorological interest (u, v, and w) are related to these radial velocity (vr) measurements by a set of linear vector equations. The vertical component, w, can be directly measured by a vertically pointing beam, but the u and v components must be obtained by solving these equations. Unfortunately, solution is possible only if a model of the local wind field is assumed.

The most often used model assumes that there is no horizontal change in the velocity components so that measurement of vr at only three beam positions is sufficient to determine u, v and w. This assumption is often not justified and leads to inaccuracies and bias in determinations of u and v (CLARK et al., 1983).

The next simplest model assumes that only the first spatial derivative of the velocity components is significant, requiring measurements of vr for a given height at seven beam positions to solve for u and v. There is a bonus for dealing with this added complexity. The necessary estimation of the first-order spatial derivatives allows estimation of the divergence and vorticity at each probed height above the radar. Thus, a seven-beam system provides not only more accurate, but additional meteorological information. A detailed consideration of optimum beam positions for solving this first-order model has been given by KOSCIELNY and DOVIAK, 1983.

The first-order model above may be inadequate in some cases. For example, under lee wave conditions a pseudo-sinusoidal model of the flow would be more appropriate in the direction of the wind. Under convective conditions, the flow can be too complex to model in a useful way. These cases will not be considered further except to note that the flexibility of electronic steering can allow use of more appropriate wind field models than a fixed-beam system.

COST COMPARISON

The biggest barrier to implementing a system capable of seven or more beam positions is probably cost. Fixed beam installations require seven separate arrays at $25,000 to $50,000 each. Electronic beam steering, coupled with time-multiplexing of beam positions, can reduce this cost to that of two orthogonal antenna arrays and the cost of the steering system. The steering system in the Sunset radar was added to two previously existing antenna arrays at a cost of about $15,000. Thus a seven-beam time-multiplexed system was implemented for less than the cost of a fixed three-beam system, and for less than 3/7 the cost of a fixed seven beam system. Furthermore, other configurations for other types of experiments can be, and often are, implemented in minutes at no further cost. The cost of transmitters and receivers is ignored because of the many possibilities for both types of system.

PHASE STEERING

Referring to Figure 1, it can be seen that when the constant phase surface of a plane wave just arrives at antenna element n with angle A to the zenith, it has the distance d(n) remaining before it reaches the last element. By adding compensating lengths of feedline to each element equal to this distance, the received signals are made to add in phase at the receiver. Thus, the gain of the antenna is made maximum for plane waves arriving at angle A and the antenna is said to point in this direction. A more detailed description of this process and approximations for the antenna pattern are presented in SKOLNIK (1962).

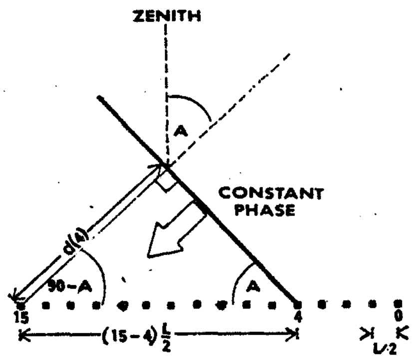


Figure 1. This is a side view of a constant-phase surface for a plane wave just reaching element 4 of a 16-element antenna array. The quantity of interest, d(4), is the distance from the surface to the last antenna element. The zenith angle of incidence is A and the freespace radar wavelength is L. The black squares represent the phaseable antenna elements spaced 1/2 L apart.

From the geometry shown in Figure 1 it is easy to develop the feedline compensating length relation

(1.1)... $d(n) = (15-n)\,(L'/2)\,\sin(A)$ [m]

Similarly, for a plane wave arriving from the other direction

(1.2)... $d(n) = n(L'/2)\sin(A)$ [m]

where

d(n) is the length of feedline to add to element n.
L' is the radar wavelength in the feedline in meters.
A is the zenith angle of the radar probing direction.
n = 0, 1, ..., 15 is the dipole number.

These relations will be used later on.

THE SUNSET ELECTRONIC PHASE STEERING SYSTEM

An electronic phase steering system, implemented in 1981, is in routine use in the Sunset radar system. The system has proven to be very reliable and yearly checks with a vector voltmeter show variability within each module to be less than a degree of phase. The system selectively steers either the north-south or east-west probing antenna to within .4 degree of any zenith angle between 0 and 45 degrees. The steering is under program control of the online computer controlling the radar and processing the return signals. Before beginning each sounding the program sets the probing direction from a sequential list of directions, input by the operator when the system is initially started. As presently implemented, up to eight positions may be in the list, which is repeatedly cycled. The operator may change this position list at any time.

The time needed to change probing directions is about a millisecond, but ground clutter removal filters have made the practicable switching rate about 30 seconds. It should be possible to remove this delay should faster cycling become important.

Power loss through the steering system is difficult to measure because it is less than 1 dB, including the harness where the element feedlines are joined. Each of the 16 phase shift modules can handle 10 kW of peak power, of 1 kW of average power at 40 MHz. This is the same capacity as that of the RG-8 cable used throughout the antenna system after the harness so that the system can handle 160 kW total peak power.

PHASE SHIFT MODULES

Each phase shift module is an aluminum box which is inserted into the feedline to a single antenna element. A mechanical relay inside the box selects connection to an element of either the north/south or east/west steering array. Eight additional mechanical relays are used to insert up to eight selected lengths of coaxial cable into the feedline as it passes through the box.

The position, 0 or 1, of each of the relays is controlled with nine TTL level control signals entering the phase module through a 25 pin D connector. When in position 1 the first phasing relay adds L'/2 meters into the feedline. The second adds L'/4, and the third L'/8, and so on geometrically till the eighth and last phasing relay adds L'/256 meters. Thus, any fraction of a wavelength that can be expressed as an eight-digit binary fraction can be inserted. The ninth relay in the box is used to select the north/south or east/west steering array.

STEERING CONTROL

The task of setting each of the 16 phase delay modules to the proper delay is handled by the main radar system computer. At the start of each sounding the desired zenith angle is converted to the appropriate 16 delays, expressed as fractions of a wavelength, Fn, using the relations

$$(3.1)\ldots \quad Fn = (n/2)\sin(a) \bmod 1, \; n=0, 1, \ldots, 15$$

$$(3.2)\ldots \quad Fn = [(15-n)/2]\sin(A) \bmod 1, \; n=0, 1, \ldots 15$$

These are, of course, equations (1.1) and (1.2) where the length information has been removed; the phase modules themselves contain the length information in the form of cut cables. The mod function is used because lengths greater than a wavelength are not necessary; the goal is to keep the elements in phase, not to sample the same phase surface. The selection of (3.1) or (3.2) is determined by the sign of the zenith angle.

The control signals for the phasing relays are obtained by converting the fraction, Fn, to an eight-bit binary integer; Fn is multiplied by 256 and truncated. An additional bit is appended to select north/south or east/west steering. This operation is performed for all 16 phase shift modules and the resulting 144 bits are sent serially over coaxial cable to shift registers located near the modules. The output of these shift registers controls the relays in the modules.

## DISCUSSION

Implementation of phase steering at the Sunset facility has proven to be simple, cost effective, versatile, and reliable. The radar has all the capabilities of fixed-beam systems except for simultaneous probing in two or more directions. This is an important lack, but the addition of a second transceiver could allow simultaneous probing in two directions. Furthermore, mutual interference makes difficult the probing of more than two directions simultaneously for any type of system. Finally, the added flexibility in experimental programs provided by a steerable system more than compensates for this limitation.

Only Doppler systems are considered here, but it should be noted that spaced antenna drifts (SAD) systems may be cost competitive and provide superior results in some instances. HOCKING (1983) argues strongly for this technique, while ROYRVIK (1983) describes an observed limitation. ROTTGER (1983) compares the two techniques from a theoretical standpoint.

## RECOMMENDATION

Beam-swinging facilities still being designed, especially as prototypes, should include expansion to electronic steering capability in the design, even if electronic steering is not originally implemented. This will place few constraints on the design because there are many ways to achieve the necessary phasing delays and will allow later expansion to steering at minimal cost.

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