CANCELLATION OF SIDELOBE ECHOES IN PULSED DOPPLER RADARS

M. Sachidananda, R.J. Doviak, D.S. Zrnic'
National Severe Storms Laboratory
Norman, Oklahoma 73069

1. Introduction

Pulsed Doppler weather radars are continually plagued by the mixture of echoes received through sidelobes. Measurement criteria for weather radars impose a more severe constraint on the sidelobe level than those for radar detection of aircraft and missiles, mainly because of the distributed nature of the scatterers and because weather echoes can have powers that exceed an 80 dB range. Furthermore echo power is proportional to the integral of the reflectivity field weighted by the antenna pattern so the power received through sidelobes can be as large as that received through the main lobe, especially when the sidelobes are directed at heavy rain and the radar beam is pointed at weak reflectivity portions of the storm where, nevertheless, severe weather hazards can reside.

In antenna design it is commonly thought that, for a fixed antenna size, there is a trade off between low sidelobe levels and narrow beamwidth. This paper presents a technique that allows cancellation of sidelobes without sacrificing beamwidth. By switching the antenna pattern from pulse to pulse between two specially designed patterns, the signal spectra of targets in the sidelobes can be altered without affecting the spectra of targets in the beam. This technique of sidelobe echo spectra manipulation via pattern switching coupled with a matched signal processing systems allows cancellation of sidelobe power and eliminates its effect on observation of weather phenomena. Examples are given of spatially coherent Doppler velocity fields falsely mapped by echoes received through sidelobes of a parabolic reflector antenna used in thunderstorm observations.

2. Pattern Design Criteria

Two antenna patterns are designed so that the phase of the signal from all directions in the sidelobe region can be changed by 180 degrees without affecting the phase of the signals in the beam. Therefore the spectrum of the sidelobe signal can be altered by switching between these two patterns from pulse to pulse in a predetermined sequence without affecting the spectra of signals in the mainlobe.

To change the phase of the signal received from all directions in the sidelobe region without affecting the mainlobe pattern requires two patterns with identical mainlobes but sidelobes with 180 degree phase difference. In equation form:

$$g_1(u) = g_2(u);\ \text{for } u \text{ in the beam}$$

and (1)

$$g_1(u) = -g_2(u);\ \text{for } u \text{ in the sidelobe region}$$

where $u = \sin\theta$ is the pattern variable and g_1, g_2 are two-way complex voltage pattern functions.

It is emphasized here that g_1 and g_2 are two-way pattern functions and as such are not linear functions of excitation currents. Theoretically, it is possible to satisfy the above criteria only because of this peculiar nonlinearity (square law), thus limiting the application of this technique to radar. The technique cannot be applied to cancel sidelobes in one-way patterns.

3. An Example

Consider a linear broadside array of 2N elements with nonuniform spacing symmetric about the array center and uniform excitation phase so that all the array coefficients are real. If the array coefficients are decomposed into symmetric and anti-symmetric parts, a_n, and b_n, the first part produces a symmetric pattern and the second part produces an anti-symmetric pattern which is in phase quadrature with first. Thus, g(u) can be expressed as:

$$g(u) = \left[\sum_{n=1}^{N} a_n \cos(\psi_n u) + j \sum_{n=1}^{N} b_n \sin(\psi_n u)\right]^2 \tag{2}$$

where $\psi_n = 2\pi d_n/\lambda$ with element spacing d_n measured from the array center, and λ is wavelength. Now criteria (1) can be written as:

$$\sum_{n=1}^{N} b_n \sin(\psi_n u) = 0;\ 0<u<u_B;$$

and (3)

$$\sum_{n=1}^{N} a_n \cos(\psi_n u) = \sum_{n=1}^{N} b_n \sin(\psi_n u);\ u_B<u<1;$$

where u_B specifies the first zero crossing of the pattern. The latter criterion stipulates element excitation such that the one-way pattern has sidelobe electric fields that are phase shifted $\pi/4$ (or $3\pi/4$, $-\pi/4$, $-3\pi/4$) from those in the beam.

The two patterns $g_1(u)$ and $g_2(u)$ are obtained by changing the sign of b_n while keeping a_n the same for both patterns. Figure 1a shows an ideal one-way pattern and in Fig. 1b the combined two-way voltage pattern $g_1(u)$. Note that because $g_1(u)$ is the square of the one way pattern its sidelobes are in phase quadrature with the main lobe. By changing the sign of b_n the pattern $g_2(u)$ is obtained.

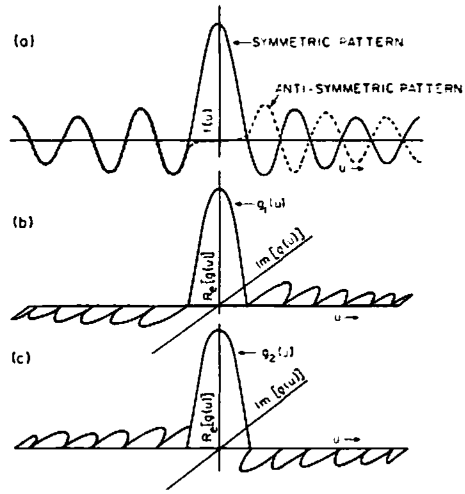

Figure 1. Symmetric and anti-symmetric design goal pattern functions and the radar two-way voltage patterns $g_1(u)$ and $g_2(u)$ for the dual pattern switched array. The symmetric (solid lines) and anti-symmetric (dotted lines) one-way patterns in (a) are in phase quadrature.

If the patterns are randomly switched then sidelobe power will be whitened and as such cannot bias velocity estimates of targets in the beam. However noise power is increased and hence there could be increased variability in the estimated velocity. On the other hand if the patterns are switched in a uniform sequence, the sidelobe signal spectrum will be shifted about the Nyquist frequency; equal to 1/2 the pattern switching frequency. Then if the sidelobe and mainlobe signal spectra are confined to spectral domains less than ±1/2 the Nyquist frequency the sidelobe power can be filtered without affecting spectra of targets in the mainlobe. In practice there is a limit to the accuracy of matching $g_1(u)$ and $g_2(u)$ and the effective sidelobe level depends on this. The difference in the two patterns produces an effective sidelobe pattern.

A numerical minimization technique is used to synthesize the coefficients a_n, b_n, and spacings d_n such that criteria (3) are satisfied in most of the sidelobe region without affecting the mainlobe. The method consists in formulating an objective function which is minimized using the Simplex method of Nelder and Mead [1], and details are explained elsewhere [2].

A 20-element linear array is synthesized using the numerical technique given in [2]. The effective pattern is given on Fig. 2. The dotted line corresponds to the total rms power pattern, (i.e. the sum of the symmetric and anti-symmetric parts) and the solid lines are the effective pattern after sidelobe power is filtered. It may be noted that the normalized excitation currents are truncated to second decimal digit in computing the pattern in Fig. 2, which shows that with reasonable accuracy in the excitation coefficients a practical antenna can be built. The patterns shown are equivalent one-way power patterns.

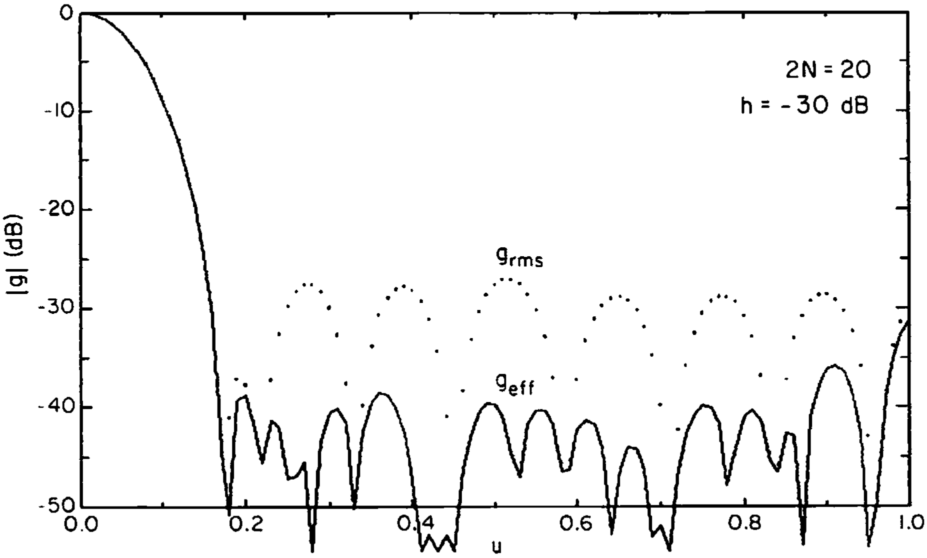

Figure 2. g_{rms} and g_{eff} for dual pattern switched array.

4. Conclusions

Pattern switching in a coherent Doppler radar can be used to cancel echoes received through sidelobes. Such filtering techniques are being investigated and a prototype linear array for demonstration is being constructed. It is important to note that the technique is applicable only to coherent radars and not to one-way communication links or passive receive patterns.

References

1. J.A. Nelder and R. Mead, "Simplex method for function minimization". Computer Journal, Vol. 7, pp 308-313, 1965.

2. M. Sachidananda, D.S. Zrnic', and R.J. Doviak, "Whitening of sidelobe power by pattern switching radar array antenna". Accepted for publication in IEEE Trans. on Antennas and Propagation.