A technique to increase the scanning rate of a phased array weather radar

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1. Introduction

Severe weather phenomena develop so fast that update time for radar remote sensing should be less than 1 min (e.g., Heinselman et al. 2008). The shortest update time for current network WSR-88D conventional radar is 4.5 min. The update time can be reduced with an agile-beam radar that steers its beam electronically (e.g., Zrnic et al. 2007). To reduce the update time on a prototype of a 10 cm wavelength phased array radar (PAR) located in Norman, OK, multiplexing of radar beams (Yu et al. 2007), oversampling and whitening in range (Torres and Zrnic, 2003), and adaptive scanning (Reinoso-Rondinel et al. 2010) have been tested. Multiplexing of radar beams aims at reducing correlation between weather signal (i.e., echoes) samples from different radar resolution volumes and consequent reduction of the standard deviations in estimated parameters for a given fixed number of collected samples, or at decreasing the number of samples required for spectral moment estimation and consequently to achieve a more rapid sampling of weather. Oversampling and whitening in range decorrelate return signals within the radar pulse and reduce the standard deviation of estimates (Torres and Zrnic, 2003). The adaptive scanning selects parts in the atmosphere with weather returns and scans those parts more frequently skipping areas with no radar echoes (Reinoso-Rondinel et al. 2010).

Frequency allocation at S band for weather radars is stringent. The frequency band for a network WSR-88D radar is 0.7 MHZ so no frequency agile technique is commonly implemented with the weather radars, but the frequency agile technique was used to shorten the update time for a 3 cm wavelength weather radar used for research (Pazmany and Bluestein, 2011). Given the demands on spectral usage, it is unlikely bandwidth allocation will be increased. Thus this technique is unlikely an option for the future weather PAR. So other alternatives should be explored, and one such alternative is described in this paper.

The update time can be also reduced with an imaging radar that transmits a wide beam and forms multiple receiving beams of a phased array (e.g., Palmer et al. 1998, 2005, Li and Stoica 2007, Kidder et al. 2011, Isom 2012). The major pitfall of this approach for weather applications is a reduced radiation power density of the transmit beam and consequently reduced detection capability. Detection capability attained with the WSR-88D has become a standard for operational weather radars in the US.

The update time of a PAR can be reduced by switching the beam directions of each of several pulses transmitted in rapid succession (e.g., pulse separations about a pulse width) so that multiple beams in transmit can be formed. Return signals from these beams can then be received simultaneously (Lai et al. 2004). To isolate weather signals, phase coding for every transmit pulse could be employed. This technique is a particular implementation of the MIMO radars (Multiple In Multiple Out, e.g., Li and Stoica 2007). Coding of transmitted pulses have also been considered to reduce coupling between received signals; the Walsh coding (Urkowitz 1997) or 13-bit Barker code have been studied (Lai et al. 2004). Experiments using the Barker code showed a good spatial isolation for reflectivity fields having no strong gradients (Lai et al. 2004). This technique is attractive but its implementation in the weather PAR is questionable because phase coding is used in the WSR-88D to resolve range ambiguities and most likely will be employed in the future weather PAR.

In this paper, we present a verification of a different technique for the selection returns from various directions using the multiple transmit beams approach. This technique does not use pulse coding and frequency agile technology. In the next section, the approach is applied to data collected with a WSR-88D KOUN radar to prove the technique.

2. Verification of the technique on WSR-88D radar's data

Although the radiation pattern of a future weather PAR will be different from that for the present WSR-88Ds, it is possible to assess effects of mainlobe-to-sidelobe coupling for time multiplexed transmissions using real storm data and the measured WSR-88D radiation pattern. This will be accomplished by simulating multiplexed transmissions and simultaneous reception using two beams and real storm data.

Consider time multiplexing of two pulses sequentially transmitted by a simulated PAR in the two azimuths $\varphi = 0^o$ and 6^o and having the radiation patterns of the WSR-88D radar. This certainly would be a worse case because the sidelobes are significantly higher than those expected for a PAR. Consider transmission of two radar pulses in two directions sequentially: the first pulse is transmitted at 0^o direction and the second pulse is transmitted at 6^o direction. At $\theta = 6^o$, the value of one-way antenna diagram is -27.9 dB in the WSR-88Ds.

To demonstrate effects of the sidelobes, time-series data collected with the WSR-88D KOUN were used. We take the KOUN data as "ground truth" and then emulate transmission of two beams at directions of 0^o and 6^o. This is made to show the effect of 6^o sidelobe. The time-series radar data are proportional to voltages of returned signals. Fig. 1a is assumed to represent the true reflectivity field and was obtained with KOUN on March 31, 2008 at 0334Z at elevation of 1^o. This is the field collected with a single radar beam and there is no mainlobe-to-sidelobe coupling. Figs. 1b,d present fields of reflectivity and Doppler velocities for the main lobe with signal leakage from the beams. Reflectivity field in Fig. 1a is for a tornadic thunderstorm with a hook echo located at the south-western part of the storm near the strongest reflectivity core. Despite rather coarse color gradations (6 dB) in the figure, one can see that the field in panel (b) has anomalous reflectivities in the weak reflectivity region of the hook echo to the south of the 60 dBZ reflectivity core. These anomalous reflectivities are due to the mainlobe-to-sidelobe coupling associated with product of the 6^o mainlobe gain. This exemplifies unacceptable mainlobe-to-sidelobe coupling. Despite the sidelobes of the two-beam pattern are weaker than -27.9 dB, the proposed technique is needed to get the undistorted field. After applying the technique to the data in panel (b), a data field in panel (a) was restored.

Panels (c) and (d) demonstrate mainlobe-to-sidelobe signal leakage for the Doppler velocities. One can see that the field in the hook region gets severely distorted. All other estimates of weather variables (i.e., the spectrum width and polarimetric parameters) can be severely biased due to the sidelobes if the restoration technique is not applied. Once the proposed technique is applied, all fields become undistorted; the reflectivity field in Fig. 1(b) recovers to the one shown in Fig. 1(a). Thus, despite the weakness of the two-beam sidelobes, the proposed technique retrieves correct weather variables even in locations having strong reflectivity gradients.

3. Conclusions

The proposed multiplexed beam technique increases the scanning radar rate by a factor of the number of beams. No frequency agile and phase coding technologies to separate returns from different directions are used in the technique; it has the same sensitivity as the usual single beam measurements.

The proposed technique allows separating of signal voltages. Thus all existing signal processing techniques in the WSR-88Ds to resolve range ambiguities and suppress clutter remain the same. The only limitation is the duty circle of the transmitter. The duty circle must allow transmitting few pulses with short delays (order of microseconds). In the surveillance scan, the WSR-88D utilizes PRF of 320 Hz with the 1.5 μs pulse. The duty circle of the transmitter is 0.002, so four pulses can be transmitted in the surveillance scan with such a delay. Data from distances close to the radar are lost due to transmission of RF pulses. For instance, if four 1.5 μs pulses are transmitted with time delay of 1 μs between them, then the time for transmission is 4x1.5 μs + 3x1 μs = 9 μs that equals to 2.7 km of lost distances, which is tolerable because first 5 km of distance are strongly contaminated by ground clutter and are not used in data analysis.

Practically achievable leakage in a PAR antenna is about –25 dB. At such isolation, the proposed technique restores true voltages in both transmit directions at SNR difference of 93 dB in these directions, which means that isolation of -25 dB becomes equivalent to isolation of -46.5 dB when the proposed technique is applied.

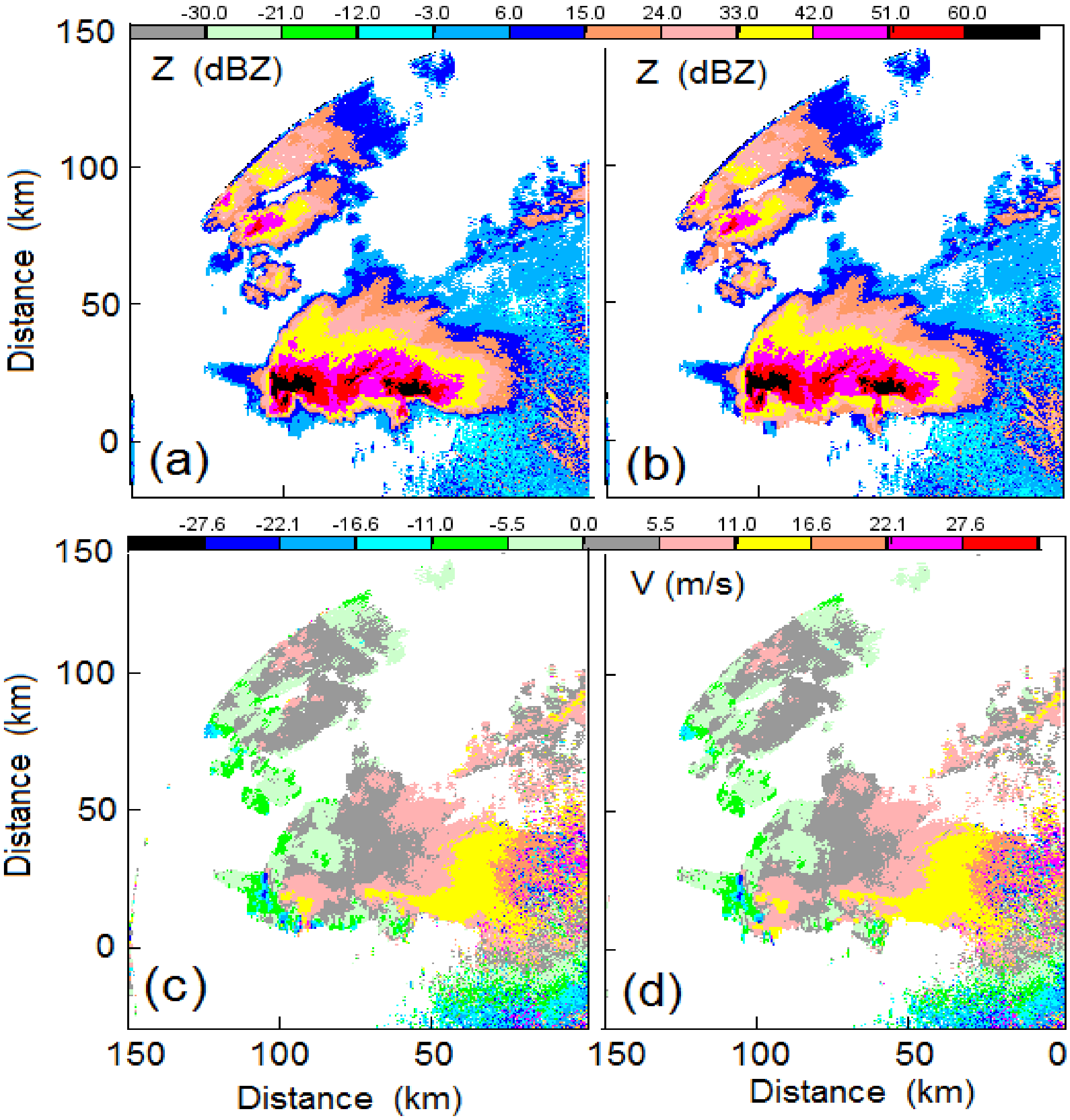

Fig. 1. (a): Reflectivity field collected with KOUN on March 31, 2008 at 0334Z at elevation of 1^{o}. (b): Reflectivity field of the 0^{o} beam showing contamination by mainlobe-to-sidelobe coupled power when using the 3-beam pattern. After applying the technique, the retrieved reflectivity field is exactly as shown in panel (a). Panels (c) and (d) are the same as (a) and (b) but present Doppler velocity.

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