7.9 BEAM MULTIPLEXING ON THE NWRT: LOOKING AHEAD

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1. INTRODUCTION

Beam multiplexing (BMX) is a scanning strategy that takes advantage of the electronic steering capabilities of phased array radars. When contiguous pulses are collected with a traditional weather radar using a parabolic dish, the data from the pulses may be highly correlated especially at narrower spectrum widths. A phased array radar can collect a smaller number of pulses or even a single pulse at a particular beam position and then return to that same beam position at a later time. If there is sufficient time between these short data collection periods, the data is nearly independent and the errors after averaging will be reduced significantly. If the time between data collection periods is used to collect data at other beam positions, the radar can be utilized continuously resulting in significant time savings.

The following figure shows a simple example of how this works. In the case of contiguous pulses, a stream of pulses is transmitted at a single beam position, and the associated data is collected. In the beam multiplexing case, two pulses are transmitted at four different beam positions. This cycle is repeated so that several pairs of pulses are transmitted at each of the four beam positions. Because of the time between pairs at a particular beam position, the data should be nearly independent. Also note that the radar is being used continuously so that the time between pulses at a particular beam position is being used to collect data at other beam positions.

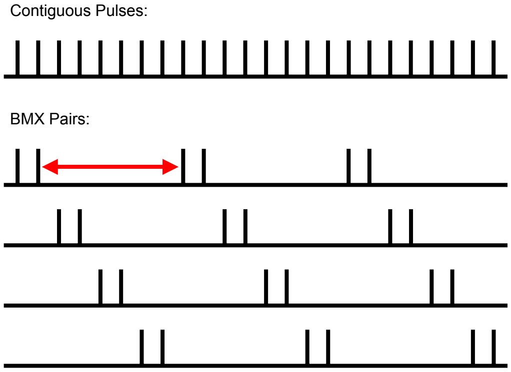

Figure 1. A comparison between contiguous pulse data collection and BMX pairs.

This particular strategy of sending pairs of pulses at each beam position is called BMX pairs.

The basic idea behind beam multiplexing should now be clear, but there are additional issues that need to be addressed before we can implement an actual scanning strategy. The first is how long we need to wait between data collection periods so that the data is nearly independent. The data is more correlated at narrower spectrum widths so a reasonable spectrum width to look at is 1 m s^{-1}. Figure 2 shows the correlation between samples at a spectrum width of 1 m s^{-1}:

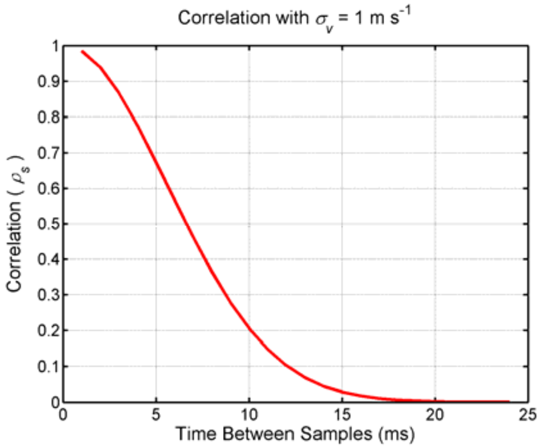

Figure 2. Correlation in time for a spectrum width of 1 m s^{-1} assuming a Gaussian spectrum

We can see from the figure that the data will be nearly independent if the time between samples is 20 ms or more. This gives us a lower bound for time between samples when collecting beam multiplexed data.

Another concern is the return from second trip echoes if the beam multiplexing beam positions are too close together. For example, if we refer to the beam multiplexing strategy from Figure 1, the return from the second trip from the second pulse in the first pair could show up in the first pulse of the first pair at the second beam position. In order to mitigate this contamination, it seems reasonable to try to avoid the main lobe and first sidelobe of the antenna pattern. For an antenna pattern with a 3 dB two-way pattern of less than 2.5° or so, keeping 6° or 7° between beam positions should be enough to avoid nearly all of these second-trip effects. Unusually strong third or fourth trip echoes could still cause problems.

Our final concern at this stage is the advection of the weather while the data is being collected. If the total

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Corresponding author address: Christopher D. Curtis, CIMMS/NSSL, 120 David L. Boren Blvd., Norman, OK 73072, USA; email: Chris.Curtis@noaa.gov collection time is less than about 700 ms, the worst of the advection effects will be avoided (Curtis 2002). By taking all of these conditions into account, we can recommend a practical beam multiplexing scanning strategy.

There are certainly many different ways to meet the previously described conditions, but a straightforward one is shown below:

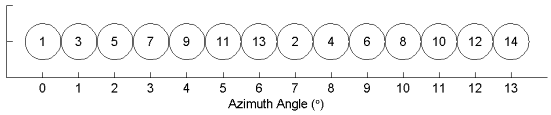

Figure 3. A simple azimuth-only beam multiplexing pattern.

The above pattern starts with position one at 0° followed by the position 2 at 7°. The third beam position follows at 1° which gives a minimum angular distance of 6° for the pattern. This pattern could be repeated as many times as necessary to collect the data of interest as long as the total time was less than 700 ms. The amount of time between collections at a particular beam position is determined by the data collection strategy at each beam position. The pattern could then be shifted and repeated to cover the entire area of interest.

An example of a collection strategy that nicely fits this pattern is collecting two pulses during each visit to a beam position and repeating the pattern 16 times for a total of 32 pulses at each beam position. Using a pulse repetition time (PRT) of 1 ms, the total time for the pattern is 28 ms. This meets the condition of 20 ms before returning to the same beam position. The total time for 16 patterns is 448 ms which meets the 700 ms condition. This is a simple pattern which meets the conditions stated above. An additional condition for measuring radial velocity (or spectrum width) is to collect at least two pulses during each visit to a beam position. The above strategy, BMX pairs, also satisfies this additional condition.

An approach very similar to the one above was implemented on the National Weather Radar Testbed (NWRT) in order to show that beam multiplexing is feasible and that the predicted theoretical performance is realizable (Orescanin, et al. 2005). This conference paper and another follow-up paper (Yu, et al. 2006) showed the feasibility of beam multiplexing on a phased array radar and confirmed the theoretical predictions. Now that this initial work has been completed, it is important to look ahead to operationally viable strategies. In the next section, we will look at some of the issues with using BMX pairs that keep it from being practical as the sole collection strategy for operational collections. After that, we will suggest some alternatives that need to be studied further. Although beam multiplexing has shown promise, there are several hurdles that still need to be overcome for it to be used in place of other proven strategies.

2. ISSUES WITH BMX PAIRS

The drawbacks to BMX pairs fall into two main categories: drawbacks to beam multiplexing in general and drawbacks specific to BMX pairs. Two of the drawbacks to beam multiplexing in general include difficulty in clutter filtering and difficulty in spectral processing. These difficulties are caused by the fact that beam multiplexing samples are not uniformly spaced. Most clutter filters rely on uniformly spaced samples, and spectral processing approaches using standard Fourier transforms also assume uniformly spaced samples. These drawbacks are significant since clutter filtering is important for accurate measurement of reflectivity. Additionally, spectral processing has a lot of promise for improving the estimation of spectral moments and for providing additional information based on the shape of the spectrum.

Another drawback to beam multiplexing is that most of the gains come at high signal-to-noise ratios (SNRs). Figure 4 shows simulation results of velocity errors for contiguous sampling with the number of pulses, M = 44, and BMX pairs with M = 26:

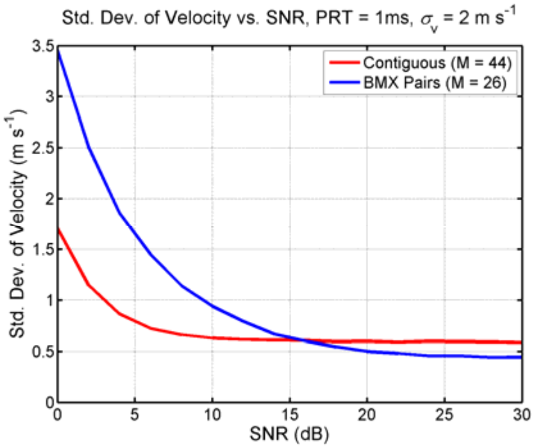

Figure 4. A comparison of standard deviation of velocity for contiguous pulses and BMX pairs.

The beam multiplexing collection takes less than 60% of the time for contiguous pairs, but the improvement only occurs above about 16 dB SNR. At very low SNR, the errors are roughly twice as large for beam multiplexing. Also note that the spectrum width for the simulations was set to 2 m s^{-1}. At larger spectrum widths, beam multiplexing may only outperform contiguous pulses if more pairs are collected or maybe not at all when using comparable collection times.

The main drawback specific to BMX pairs is that it is impossible to recover second trip echoes. Since only one pair of pulses are transmitted at each beam position, there are no second trip echoes in the data collected after the first pulse is sent. Figure 5 depicts a simplified example corresponding to a single pair of pulses:

Figure 5. A simplified example showing first and second trip echoes.

Second trip echoes do show up after the second pulse is sent (i.e. the red rectangle), but the velocity and spectrum width for the second trip echoes cannot be computed. If second trip echoes are present, the lag-1 autocorrelation of first trip echoes will not be biased since the second trip echoes are not correlated with the first trip echoes. This means that the second trip echoes will show up as noise when computing the lag-1 autocorrelation.

This inability to compute velocity or spectrum width for second trip echoes is a significant drawback. The range unfolding that is used on the WSR-88D for split cuts and batch cuts is useless for data collected with BMX pairs. In the next section, we will look at a collection strategy that addresses this problem.

3. LOOKING AHEAD

One way to recover second trip echoes would be to collect three pulses at each beam position instead of two. Single beam multiplexed pulses could be collected separately with a longer PRT to compute reflectivity. This strategy would be similar to batch mode except that the data would be collected using beam multiplexing instead of contiguous pulses. The problem with this strategy is that second trip echoes could only be computed from the second pair of pulses. This would mean that the same number of three-pulse collections would be needed as pairs. The time for this would be 1.5 times as long as collecting pairs which for the example used earlier in the paper would result in beam multiplexing taking 90% of the time compared to contiguous pulses. The 10% time savings is not very significant compared to the fact that clutter filtering and spectral processing are much more difficult. However, the previous example showed error results only for velocity. At narrow spectrum widths, significant gains can be made when measuring reflectivity. There may also be high SNR situations where beam multiplexing could be useful.

Instead of considering strategies that use second trip echoes, it makes sense to look at strategies that depend on first trip echoes only. Staggered PRT is one such strategy (Torres, et al. 2004). With staggered PRT, longer PRTs are utilized instead of the short PRTs used for batch-type strategies, and velocities are dealiased rather than being range unfolded. It may be possible to collect a few pulses using a staggered strategy but also use beam multiplexing so that the data are nearly independent.

Here is one possible scanning strategy that implements beam-multiplexed groups of short staggered PRT collections:

Figure 6. A scanning strategy that uses both staggered PRTs and beam multiplexing.

The vertical lines show when the pulses are transmitted, and the longer lines correspond to longer PRTs. This helps visualize the long PRTs compared to the shorter ones without trying to measure small changes in distances between the pulses. In this strategy, one pulse is transmitted using a long PRT followed by two shorter ones. Beam multiplexing is used so that the data from different collections are nearly independent.

A velocity can be computed from the first pair of pulses corresponding to the long PRT, and another velocity can be computed from the second pair of pulses corresponding to the shorter PRT. These two velocities can then be dealiased which results in a larger unambiguous velocity than the unambiguous velocities corresponding to each of the individual PRTs. For example, the unambiguous velocity after velocity dealiasing when the shorter PRT is 2/3 the length of the longer PRT is the same unambiguous velocity that would result from a contiguous pulse collection using a PRT that is 1/3 the length of the longer PRT.

One advantage of staggered PRT beam multiplexing (SBMX) over standard staggered PRT is that the data from the first pulse does not have any overlaid echoes. This allows for the computing of uncontaminated reflectivity from the first pulse alone. Otherwise, the processing is nearly the same. The data collected from the third pulse could be contaminated with second trip echoes from the second pulse, but in this case we are only interested in the first trip echoes. The second trip echoes will act as noise when computing the velocity from the second pair, but the estimate will not be biased. In this case, the lack of second trip echoes in both pulses is an advantage.

4. CONCLUSIONS

Staggered PRT beam multiplexing addresses one of the major shortcomings of BMX pairs, but it still has all of the other drawbacks of beam multiplexing. Staggered PRT beam multiplexing needs to be compared to both batch-type strategies and standard staggered PRT strategies. Simulations could show how much improvement if any SBMX gives compared to other collection strategies. Unless significant time savings are found when using SBMX, standard strategies will be more applicable for general weather data collection because of the ease of clutter filtering and better performance at low SNRs. Oversampling and whitening could also be combined with standard scanning strategies enabling collection times shorter than using beam multiplexing alone.

Beam multiplexing is an intriguing way to try to reduce collection times when using a phased array radar. Unfortunately, there are several significant drawbacks that limit its utility as a comprehensive strategy for collecting weather data. The difficulty in clutter filtering alone lessens its usefulness. Because of the electronic beam steering capabilities of a phased array, beam multiplexing could be used in certain situations where it might have advantages over standard collection strategies. One of the most significant strengths of a phased array is the ability to do adaptive scanning. Beam multiplexing is just one of several tools that could be used as part of a comprehensive adaptive scanning strategy. For example, beam multiplexing using single pulses at each beam position could be used to provide fast surveillance scans to check for newly developing features in the scanning volume. Another use could be fast scans to produce high quality reflectivity data for hydrological applications. The drawbacks need to be considered as with any other strategy, but we need to keep beam multiplexing in mind as we look ahead to the myriad possibilities provided by the future deployment of adaptive scanning.

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