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OPERATIONAL USE OF PULSE COMPRESSION IN WEATHER RADAR

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1. INTRODUCTION

Two weather radar systems operationally using pulse compression have been recently deployed. This fact represents the operational exploitation of a technology that has been used only in weather radar research systems in the past.

This paper presents data examples from the radars and contrasts the use of pulse compression waveforms with more traditional non-modulated pulsed waveforms. In particular, when operating in pulse compression mode, sub-100 meter range resolution can be achieved with pulses of 40 microseconds duration while the radar benefits of the great sensitivity of long pulses. It will also be seen that traditional problems associated with pulse compression such as high range-time side lobes can be suppressed with advanced techniques of waveform amplitude and frequency modulation.

This technology represents an operational advantage when the use of coherent transmitters is becoming more popular than magnetron based transmitters due to frequency assignment concerns and increased interference from stationary and mobile emitters.

Pulse compression also offers more affordable access to coherent transmitter technology because pulse compression transmitters are low peak power and thus less expensive than their more traditional klystron counterparts. The data presented in this paper demonstrates the high resolution and high sensitivity that can be achieved with pulse compression technology with low peak power transmitters.

2. BACKGROUND

Pulse compression is a signal processing technique, which allows for the advantages of sensitivity gains of long pulses to be combined with the fine range resolution of short pulses.

The technique is especially valuable when deployed with radars of relatively low peak power. Such radars suffer from low sensitivity when compared to radars of higher peak power.

However, in the following sections it will be shown that these limitations can be overcome with pulse compression.

It is also important to note that radars of low peak power have some advantages over their higher power counterparts. These advantages include lower initial price, lower operating costs, easier maintenance, and perhaps most importantly, being very "spectrum friendly" they will more easily be able to obtain operating licenses as such licenses are already becoming more difficult to obtain as broadcast frequency spectrum becomes increasingly valuable due to various emerging communications technologies.

With the use of pulse compression, the goal of having weather radar systems using low peak power transmitters, but having the same sensitivity and range resolution of radars with high peak power transmitters has been realized.

Specifically, it will be shown that meteorological radar with 8 kW of peak power offers the same or better range resolution as a more traditional radar of 250 kW peak power.

3. PULSE COMPRESSION

The basis behind pulse compression is that if a pulsed waveform is transmitted that contains excess bandwidth given the length of the pulse, a receive filter can be constructed such that targets within the pulse volume can be resolved.

This is in contrast to a pulsed radar of no excess bandwidth in which the resolution of such targets would not be possible.

In other words as stated above, the combination of the sensitivity gain of the long pulse and the fine range resolution of the short pulse can be realized.

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There are various ways to increase the bandwidth of a pulse to achieve the above mentioned gains. One method is to employ phase coding within a pulse using coding techniques such as Barker Codes (Mudukotore *et al.*, 1988). Although workable and relatively easily realized, serious limitations apply and will be discussed in the next section.

However this same research has also helped to point more practical methods of increasing the bandwidth such as frequency modulation (FM). It will be shown in this paper that FM is a good choice for use in meteorological radar.

The amount of excess bandwidth with a pulse can be expressed by the Bandwidth Time (BT) product. A conventional pulse with no excess bandwidth (and thus can not be used to resolve multiple targets within the pulse volume) is said to have a BT=1.

Through the research presented here, it has been found that pulses with a BT between 100 and 200 are practical for meteorological radar.

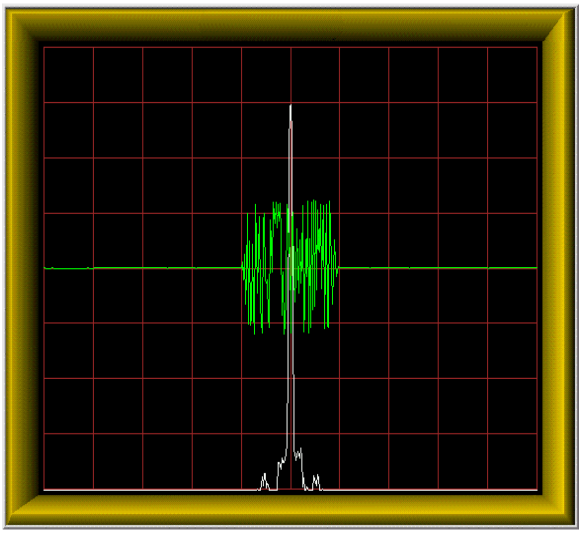

Figure 1. Transmitted FM and received compressed pulse.

Figure 1 shows a pulse of Bandwidth = 3 MHz and Length (Time) = 40 microseconds, thus having a BT=120. The vertical scale is 20 microseconds per division.

Thus the original pulse can be seen centered top to bottom (40 microseconds) and the compressed pulse 40 / 120 = 0.33 microseconds can be seen centered left to right.

The range time side lobes can be seen at the bottom of the screen, in this case with a peak about 64 dB below the primary echo.

4. PULSE COMPRESSION AND WEATHER RADAR SYSTEMS

The technology of pulse compression has been understood and used operationally in military and air traffic control (ATC) radar systems for many years. Until recently there have been barriers to practical use of such technology in meteorological radar.

The first of such barriers included the lack of understanding of how to suppress Integrated Range Time Side Lobes (ISL values) sufficiently for use with meteorological radar.

Meteorological targets differ from targets being detected and processed by military and ATC radars in that these systems are mostly interested in point targets while meteorological radars are interested in targets covering large areas such as weather systems. With such large targets, the suppression of ISL values is imperative.

Suppression of ISL values has always been a vexing problem of pulse compression systems. However the advent of technology such as digital waveform generators has allowed for this problem to be studied and solutions proposed for.

Furthermore, it is realized the high side lobe values is a problem that is more pronounced for fast moving targets (again, such as targets of interest for military and ATC radars). But as targets of interest to meteorological radar are limited in velocity to a range somewhat less than 100 m/s, some of the side lobe suppression problems can be avoided altogether when combined with technology such as digital waveform generation and careful pulse shaping.

A second major barrier to using pulse compression on meteorological radar that no longer applies is the fact that in the past, the processing systems to do such algorithms were not cost effective. But with recent advances in computer technology, this is no longer true.

5. OPERATIONAL EXAMPLES

During 2004 and 2005, two radars were installed with pulse compression processing as part of operational meteorological radar networks. Some examples of observations obtained with them are presented in this section. The first being the Creu Del Vent radar, one of the units of the radar network of the Catalan Meteorological Service in Spain (Bech et al., 2004). The second radar is the Queretaro radar installed recently in the Queretaro province, Mexico.

Both of these radars operate with Traveling Wave Tube (TWT) based transmitters capable of 8 kW peak power and making pulses up to 40 microseconds duration at a 1000 Hz PRF. A Sigmet RVP8 processor (Passarelli and O'Hora, 2002) does the pulse compression waveform generation and digital receiving and processing.

Figures 2 and 3 present data from the Creu del Vent radar. The first figure shows the results of using a 40 microsecond compressed pulse FM and the second image shows a 1 microsecond traditional pulse. The data of the two cases was collected one minute apart. It is clear that the range resolution in each case is nearly the same, but the sensitivity gain with the 40 microsecond FM pulse is about 15 dB. This would be the same as increasing the peak power by 15 dB, making the radar have similar sensitivity and range resolution to a meteorological radar with 250 kW peak power.

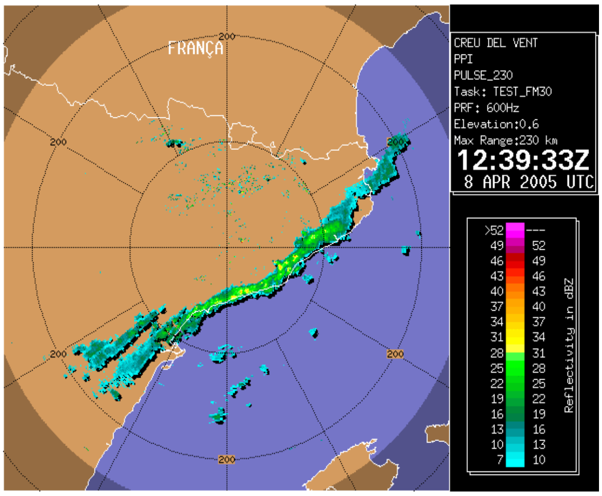

Figure 2. 40 microsecond FM pulse – Creu Del Vent radar.

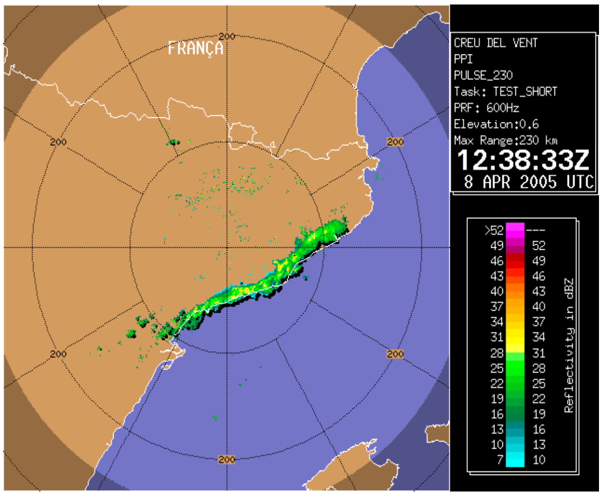

Figure 3. 1 microsecond traditional pulse – Creu Del Vent radar.

Figures 4 through 8 present data from the Queretaro Mexico radar. As before, all data from these images was collected within about one minute time so changes in the precipitation field are minimum.

Figures 4 and 5 are another example of a sensitivity comparison. With the 40 microsecond FM pulse, data down to about 10 dBZ can be seen at the final range of 230 KM, where as in figure 5 with the 1 microsecond traditional pulse, only 25 dBZ or above is detectable at this range.

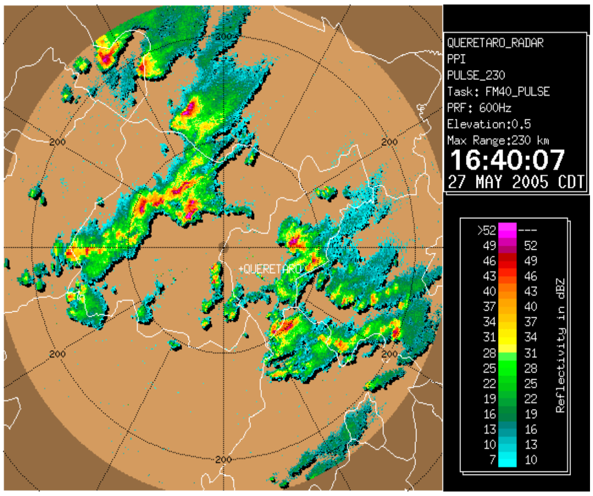

Figure 4. 40 microsecond FM pulse – Queretaro radar.

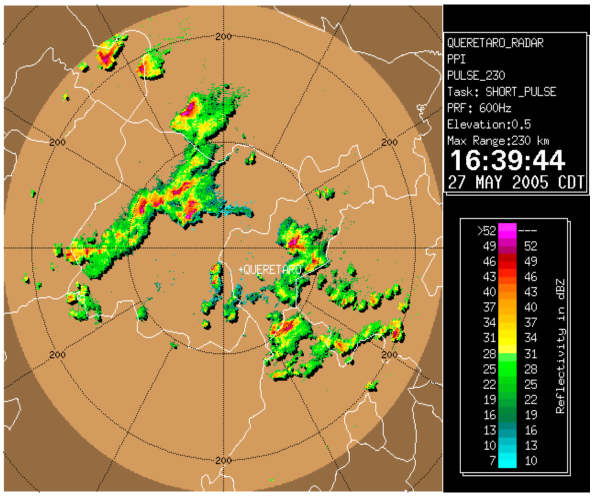

Figure 5. 1 microsecond traditional pulse – Queretaro radar.

Figures 6 and 7 are 50-km views that demonstrate the fine range resolution of the pulse compression data. Both images are processed at 75 meter binning by the RVP8 signal processor. It is clear that the resolution of the 40 microsecond data is as fine as the 1 microsecond data.

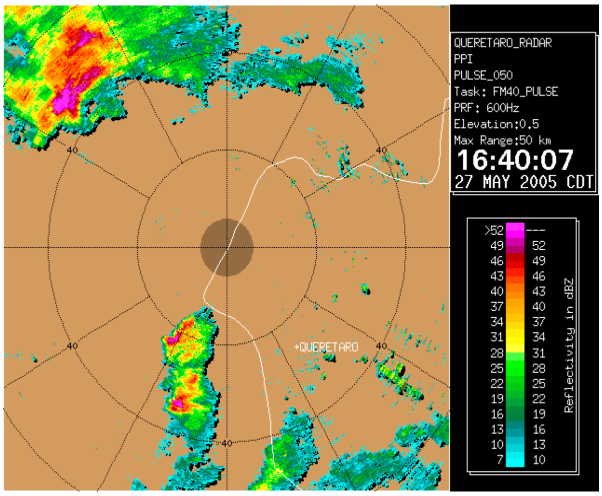

Figure 6. Range resolution – 40 microsecond FM pulse.

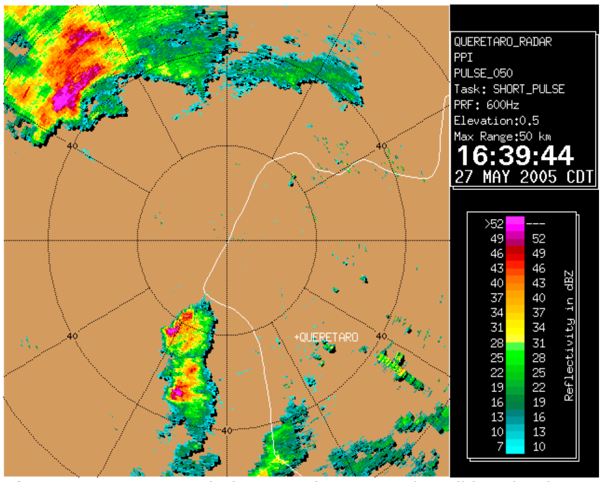

Figure 7. Range resolution - 1 microsecond traditional pulse.

6. CONCLUSIONS

It has been demonstrated that despite issues that prevented its use in the past, pulse compression technology is nowadays practical for meteorological radars.

It is not only an economical approach to modern meteorological radar, it is easy to maintain and it is very "spectrum friendly". The later is a result of using precisely shaped digitally formed pulses.

The finely tailored amplitude edge shaping and the frequency modulation result in a spectrum that is cut off sharply at the edge of the frequency channel, as opposed to more traditional meteorological radars that spill side lobe energy out at high levels many megahertz away from the center frequency of the radar. This, in combination with the low peak power, makes such modern systems very practical in a world of increasingly difficult frequency allocations.

Pulse compression technology is available today for operational systems as demonstrated by the above data sets.

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