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TITLE A PORTABLE CW/FR-CW DOPPLER RADAR FOR LOCAL INVESTIGATION OF SEVERE STORMS

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A PORTABLE CW/FM-CW DOPPLER RADAR
FOR LOCAL INVESTIGATION OF SEVERE STORMS

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1. INTRODUCTION

During the 1987 spring storm season we used a portable 1-W X-band CW Doppler radar to probe a tornado, a funnel cloud, and a wall cloud in Oklahoma and Texas (Bluestein and Unruh, 1988). This same device was used during the spring storm season in 1988 to probe a wall cloud in Texas. The radar was battery powered and highly portable, and thus convenient to deploy from our chase vehicle. The device separated the receding and approaching Doppler velocities in real time and, while the radar was being used, it allowed convenient stereo data recording for later spectral analysis and operator monitoring of the Doppler signals in stereo headphones. This aural monitoring, coupled with the ease with which an operator can be trained to recognize the nature of the signals heard, made the radar very easy to operate reliably and significantly enhanced the quality of the data being recorded.

At the end of the 1988 spring season, the radar was modified to include FM-CW ranging and processing. These modifications were based on a unique combination of video recording and FM chirp generation, which incorporated a video camera and recorder as an integral part of the radar. After modification, the radar retains its convenient portability and the operational advantage of being able to listen to the Doppler signals directly. The original mechanical design was unaffected by these additions. During the summer of 1988, this modified device was used at the Langmuir Laboratory at Socorro, New Mexico in an attempt to measure vertical convective flow in a thunderstorm.

We can now collect data that include, as a sequential time shared video record, a boresight video picture of the radar field of view, FM-CW data taken at the horizontal sweep rate of the video system, and conventional CW Doppler high resolution spectra. In the FM-CW mode the unambiguous Doppler velocity is 115 ms^{-1} with an unambiguous range of 5 km. These wideband signals are recorded in VHS format for later analysis, along with the interspersed boresight pictures.

2. DESIGN CONSIDERATIONS

2.1 General Features. The modifications were added without altering the original configuration of our earlier CW instrument. Two 50 cm parabolic reflectors (f/0.5), having 30 dBi gain and a 3 dB beam width of 5°, are mounted on a sturdy aluminum enclosure of dimensions 0.87 X 0.4 X 0.13 m. This box contains all the electronics and the various fixtures for attaching the video camera, the output cables, etc. A septum mounted on the box separates the two antennas. The linearly polarized antenna feeds are tapered for sidelobe suppression. The direction of polarization may be individually adjusted for each feed, although this modification cannot be made rapidly in the field. This package can be mounted on a conventional heavy duty tripod by means of the standard 3/4-20 thread. For situations in which it is desirable to point the radar vertically, a fork mount on a special tripod is available.

All of the electronics, including the associated video camera and recording devices, are battery powered. The radar itself is powered by a 12-V battery pack which allows continuous operation for 3 to 4 hours and can be recharged completely in a comparable time.

Documentation of the recorded data is particularly convenient with this system. The FM-CW data are documented directly on the video tape by the associated boresight video images, which can include a date and time stamp. During the time when FM-CW data are being recorded, the stereo audio channels of the portable VHS recorder may be used to record spoken commentary describing the scene, special circumstances, etc. Conventional CW Doppler audio signals may be recorded on the stereo audio channels of the portable VHS recorder when the radar FM ramp is disabled, while the video boresight view and date/time stamp can be simultaneously recorded for continuing documentation. The way in which these modes are used in the field remains under the control of the operator who must select either the CW or FM-CW modes manually. It would be easy to make this function automatic, choosing fixed time intervals for FM-CW, video boresight pictures, and CW/boresight pictures. Until we have more experience obtaining measurements in the field, it seems wise to allow the operator to choose which type of data to take on the basis of what is being observed visually.

2.2 Electronic Design. The linear FM modulation and Fourier transform data analysis scheme used in our design have been described by Chadwick and Strauch (1979), who have shown very clearly how to process FM-CW signals from distributed targets. Radar returns from a continuous series of FM ramps are Fourier transformed to provide spectral information in which each of a series of range bins contains the complete speed spectrum (both + and −) of that part of the distributed target within a range bin. Each spectrum is centered on the so called zero velocity point (ZVP) at the center of its range bin. These ZVPs occur in the Fourier transform at harmonics of the FM ramp repetition frequency. The relationships between the rf parameters (ramp period, tuning rate, etc.) and the analysis parameters (number of ramps processed, the Nyquist frequency, number of channels and number of successive ramps processed, etc.) are clearly set out in the discussion of Chadwick and Strauch (1979). As they mention, these simple relationships make it very easy to design an instrument whose characteristics can be tailored to the specific target application.

Because of our interest in severe storms, specifically wall clouds and tornado vortices, we wanted to obtain a high unambiguous Doppler velocity. This objective requires a high repetition frequency for the FM tuning ramp. Obtaining good range and speed resolution then requires a large detection bandwidth and a large number of spectral channels in the analyzed data. The time series input to the Fourier transform must include the received data from a large number of successive ramps. The required bandwidth is essentially twice the unambiguous Doppler frequency times the number of range bins desired. In our case, these considerations required a bandwidth of about 1 MHz, which is difficult to record in the field with portable instrumentation. Video recording technology appeared to be the appropriate choice, and this prompted a consideration of recording the radar data in VHS format.

For an X-band radar, an FM ramp frequency of 15 kHz is required to provide an unambiguous Doppler frequency of approximately 100 ms^{-1}. By coincidence, the horizontal sweep frequency of standard video is 15.750 kHz. Thus, one can use 15.750 kHz as the radar ramp frequency, record the radar return signal from a single FM ramp as one horizontal line of the video field, and obtain more than 256 successive data records in a single field. These fortuitous circumstances have led to the design described below. Given this fixed ramp frequency, the other parameter choices to be made involve the maximum unambiguous range and the number of digitized data points during each ramp.

We have chosen an unambiguous range of 5 km, well within the effective range of the radar for typical meteorological targets, and 128 digitized points for each ramp. The radar characteristics resulting from these choices are: 1) The 5 km range is divided into 64 bins, each 78 m deep; 2) The unambiguous Doppler velocity spectrum spans from -115 to +115 ms^{-1} in each range bin; 3) The effective duty cycle for targets at 5 km is 0.49; 4) A time series of 128 X 128 = 16k data points (with a Nyquist sampling of 2) in an FFT returns an 8k channel spectrum in which there are 128 channels per range bin, giving a Doppler resolution of 1.8 $ms^{-1}channel^{-1}$.

3. CIRCUIT DESCRIPTION

A simplified block diagram of the radar is shown in Fig. 1. The 10-GHz oscillator is a cavity-mounted Gunn diode, chosen for low sideband noise. It is driven by a ramp generator that includes the compensation required to linearize the frequency sweep. This microwave signal is amplified to 1 W and applied to the transmit antenna feed through a microwave attenuator. The operator can reduce the radiated power level for targets with high reflectivity. Received signals are amplified by a low noise, solid state microwave amplifier (30 dB gain, 4 dB N.F.) and detected directly by homodyne quadrature mixers. The audio and video signals from the I and Q mixers are amplified by very low noise operational amplifiers with exceptional gain bandwidth performance (Plessy SL561C). The overall receiver noise figure is essentially determined by the input microwave amplifier.

In the FM-CW mode, the I and Q mixer signals are summed in a low noise wideband amplifier to provide the required input level for the video recording system. The amplifier includes a high pass filter that provides the increased gain at high frequencies required as range compensation. These signals are converted into standard VHS format using horizontal and vertical sync signals derived from the boresight camera. Each horizontal line consists of the received signal from an individual FM ramp. A frame switch allows the operator to record either the radar data or a boresight picture on the VHS tape.

The signal being recorded can also be viewed on a small battery powered video monitor, providing the operator with a means of verifying the quality of the data and of qualitatively identifying the characteristics of the target. In fact, the visual appearance of radar data in video format is quite distinctive. One can easily recognize the essential features of the target by looking at this visual display of the radar data.

In the CW mode the ramp generator is disabled and the I and Q mixer outputs are amplified through a wideband 90° analog phase shifter. Adding and subtracting the two channels produces direct separation of the sense of the Doppler signal for monitoring in stereo headphones and for direct audio recording. The operator can choose whether to record video data or the boresight picture and audio data.

Listening to the audio data in the headphones provides the operator with a unique method of "seeing" what the radar is detecting. It allows one to carefully center the radar beam on features being measured and to search through the field of view for regions of interest.

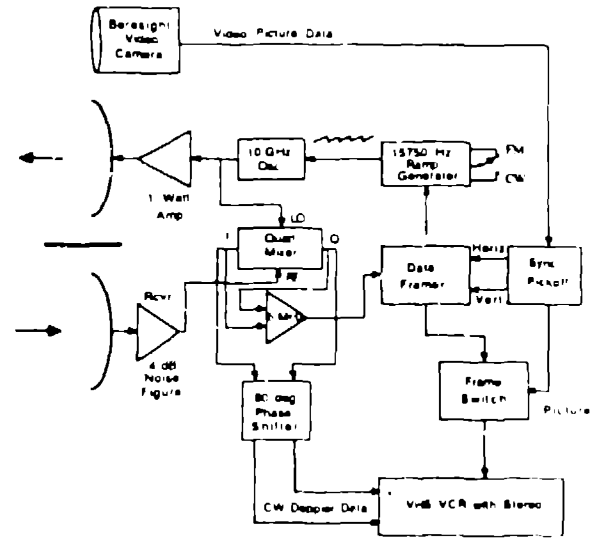

Fig. 1. Simplified block diagram of the FM-CW/CW portable radar system.

4. PERFORMANCE OF THE SYSTEM

The dynamic range of this device is over 70 dB, much better than can be recovered from the data recordings. In typical deployment situations, ground clutter and direct leakage effects between transmitter and receiver are low enough that receiver noise performance is not appreciably degraded. Leakage effects can easily be determined in the field by reducing the transmitted power in the CW mode while observing the detected noise floor of the radar.

Because of the limitations of the recording devices, it is especially important to set the recorder gains carefully so that the radar noise floor is properly reproduced. In the CW mode, a recorded dynamic range of over 50 dB is possible with a high quality tape recorder, provided the recorder does not have an automatic gain control (AGC). In the FM-CW mode, the data recordings are more limited. There are several deleterious effects resulting from the characteristics of video recorders. Video recorders incorporate a form of AGC. While this feature tends to maximize dynamic range and has the beneficial effect of reducing overload distortion in the recorded data, the effective gain of the radar system can change as signal levels and near field clutter effects change, making it impossible to calibrate the radar. Thus, only relative spectral intensities can be recovered from such recordings. Under the best of circumstances, the maximum dynamic range available seems to be 35-40 dB. Finally, video recording systems add significant intermodulation and harmonic distortion to the data in some frequency ranges, further reducing the dynamic range of the recording in these spectral regions and complicating interpretation of the data. The portable recorder used in our design (a Panasonic AG-6400) was chosen to minimize these limitations.

Tape recordings of CW radar data are analyzed in the laboratory by means of an HP [illegible] spectrum analyzer. [illegible]

Fourier transform data together (adding 16 or 32 transforms) in order to improve the signal/noise of the Doppler spectrum. Both channels (+ and - Doppler shifts) are captured and analyzed together.

The video recordings of FM-CW data are digitized by means of an 8-bit video frame grabber. The 32k numbers generated by this device are passed to a computer in a format which simply appends each horizontal line of 128 numbers to the previous line, directly producing the time series required for the Fourier transform. We actually use only 16k of this record, i.e., one half-field. Most recordings are contaminated by very low frequency signals from ground clutter close to the radar. These usually show up as nearly linear increasing or decreasing signals superimposed on the data in each horizontal line. Because of the abrupt discontinuity in these clutter signals at the end of each FM ramp, the Fourier transform often contains much higher spectral intensity at the ZVP points (at harmonics of the FM ramp repetition frequency) than is desirable. Spectral broadening from the windowing used in the time series can obscure the low-velocity part of each Doppler spectrum. We use a preprocessing program which removes these low-frequency components from the data before the Fourier transform is computed.

During the summer of 1988, this system was used briefly at the Langmuir Laboratory near Socorro, New Mexico in an attempt to measure vertical convective motion in a thunderstorm. The FM-CW results shown below were obtained at the laboratory at an elevation of over 3150 m from a storm which was beginning to dissipate. No upward convection was detected to a height of 5 km, which was beyond the height at which precipitation could be seen. Figure 2 shows an example of the results for a region above ground level in which moderate precipitation was falling.

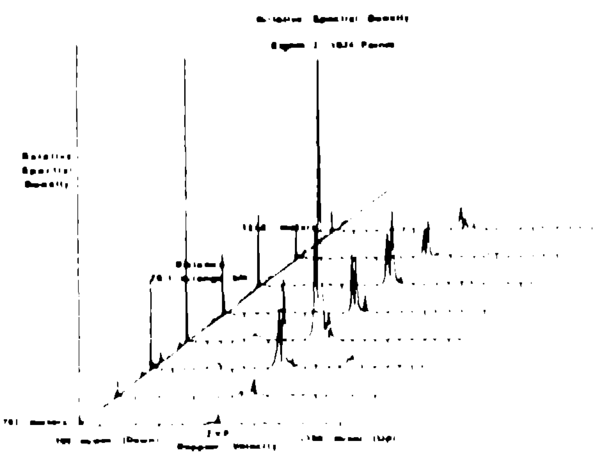

Fig. 2. A section of typical data obtained at the Langmuir Laboratory on August 18, 1988, with the portable radar pointed upward into a moderate thunderstorm. Relative spectral intensity is plotted vertically on a linear scale. A short section (1/8) of the 8k Fourier transform obtained from a single video field is plotted along the y axis (into the page) showing the variation in spectral intensity with vertical distance between the indicated ranges. The Doppler velocities (both + and -) within each range bin are plotted along the x axis at a y coordinate corresponding to the center of the range bin. The zero velocity point (ZVP) is shown for each Doppler spectrum. Velocity markers are spaced 10 msec^{-1} apart.

This graph shows the power spectral density of the falling precipitation during the last stage of the storm. It represents the situation during the [illegible] required to record the single video field. One can see that the downward velocity of the precipitation lies in the range below 10 ms^{-1}. There appear to be two distinct terminal speeds within the precipitation. A series of such graphs shows the evolution in time of the precipitation reflectivity and speed vs height. The radar generates the data for such an 8k spectral display every 1/60 s. The amount of data which could be digitized and analyzed is enormous and highly redundant. Restraint and selectivity in the analysis process are necessary.

Figure 2 also exhibits some of the difficulties resulting from the use of a video recorder. The recovered dynamic range is clearly not very great. It may be improved substantially by averaging together spectra from several successive video fields. The intermodulation distortion appears as the broad, low-level responses near 50 ms^{-1} on both sides of the spectra near the middle of the plot. These spurious effects are found adjacent to the largest components in the spectrum, so that they do not obscure basic spectral features within regions of high reflectivity. We are attempting to find ways of reducing these effects (e.g., by using frequency-modulated video signals of constant amplitude). We hope to find ways of significantly improving the performance of the video recording before the 1989 storm season.

5. ACKNOWLEDGMENTS

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