C-FMCW - COMPACT SOLID-STATE 95 GHZ FMCW RADAR SYSTEM

1. SYSTEM DESCIPTION

ProSensing, Inc. has developed 1-Watt solid state W-band radar, coined C-FMCW, primarily used for observation of non-precipitation clouds. The C-FMCW hardware can be set up in two configurations. The first uses two 12-inch antennas and is suitable for airborne measurements. The second uses 24-inch antennas and is suitable for ground-based operation.

For airborne measurements, the C-FMCW radar can be installed on the CIRPAS Twin Otter in two specially-designed pods. **Figure 1** shows the fiberglass wing pod manufactured by Zivko Aeronautics. This aircraft installation can accommodate both downward- (**Figure 1**) and side-looking (**Figure 2**) configurations. For upward-looking measurements, a different pod mounted on the top of the Twin Otter's fuselage is used as seen in **Figure 3**. The pod with the radar unit weighs 36 kg.

Figure 1. 95 GHz cloud radar C-FMCW mounted on the wing of the CIRPAS Twin Otter in downward-looking configuration.

Figure 2. Wing pod with the CFMCW radar mounted in a side-looking configuration.

Figure 3. The CFMCW in overhead pod in the aircraft's fuselage. The small insert picture shows the radar hardware on the top fuselage before the pod is installed.

ProSensing has also manufactured a frame capable of holding the complete CFMCW system, including the larger antennas for the ground-based operation. **Figure 4** shows C-FMCW in the new mechanical layout. The requisite connections to the CFMCW hardware are an AC power line and a LAN (Internet) connection. ProSensing will complete the manufacturing of the ground-based CFMCW by the end of February, 2011, with Zivko Aeronautics providing a lightweight environment-proof fiberglass enclosure at a later date.

Figure 4. Mechanical layout of the CFMCW system with two 24-inch antennas.

2. HARDWARE DESCRIPTION

A block diagram of the pod-mounted compact C-FMCW radar system is shown in **Figure 5**, with key system parameters summarized in **Table 1**. The system employs a simple homodyne receiver design in a palm-sized package that minimized the number of components and system power consumption.

Table 1. Key system parameters of the C-FMCW.

Parameter	Value
Center frequency	94.8 GHz
System power consumption	28V at 8.5 A
RF output frequency	94.8 GHz
Peak transmit power	30 dBm (1 W)
Transmitter duty cycle	6.25%
PRF	20 KHz
Integration time	20 ms typical
Chirp pulse bandwidth	variable; up to 20 MHz
Minimum range	20 m
Maximum range	20 km
Raw Range Resolution	5 m to 150 m
Receiver noise figure	7.0 dB typical
Airborne Configuration	
Antenna Diameter	12 inches [30 cm]
Antenna Gain	46 dBi
Antenna Beamwidth	0.7 degrees
First sidelobe level	-18 dBi typical
Ground Configuration	
Antenna Diameter	24 inches [60 cm]
Antenna Gain	52 dBi
Antenna Beamwidth	0.3 degrees
First sidelobe level	-18 dBi typical

The radar hardware is shown in **Figure 6**. The transmitter IF waveform is multiplied from 15.8 GHz to 94.8, where it is amplified by a 1 W IMPATT diode amplifier. To minimize the number of components, a single down conversion stage is used to translate the received signal to an IF offset frequency of 24 MHz before digitization. A millimeter-wave I/Q detector is used instead of a simple mixer to reject noise from the unused upper sideband. The IF offset of 24 MHz is achieved by generating separate linear FM waveforms for the transmitter and receiver local oscillator, which are offset by 4 MHz. The millimeter-wave receiver, including LNA, homodyne I/Q detector, x6 LO generation, and IF amplification, is packaged in a microwave integrated circuit weighing 120 grams.
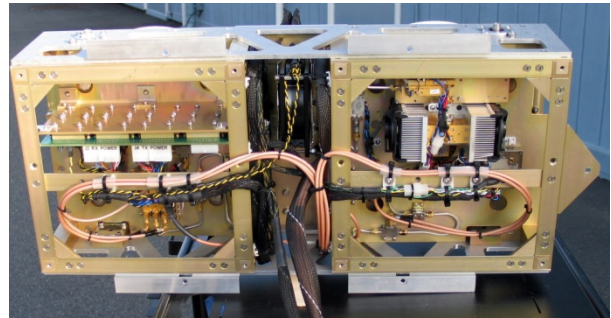

Figure 6. The CFMCW radar hardware. On the right is the transmitter, the receiver and power condition circuit on the left.

The data acquisition and processing subsystem is comprised of PMC-based digital receiver and a high performance Intel based rack-mounting computer running Linux-OS. The digital receiver and signal processor software and hardware are capable of computing in real-time, with no gaps, range profiles of reflectivity and FFT-derived velocity products at PRF's up to 20 kHz. A graphical user interface, shown in **Figure 7**, is used for operator's system control and real time display of data products. The developed software is capable of unattended operation of the CFMCW radar by executing prepared radar configurations based on the desired experiment parameters.
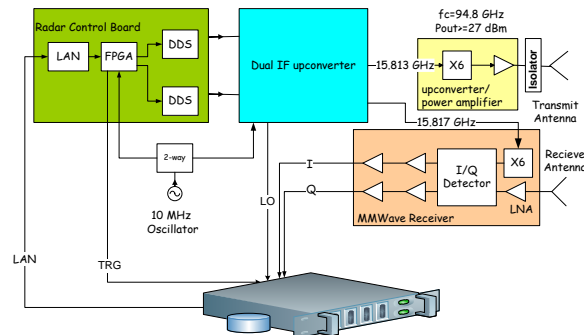

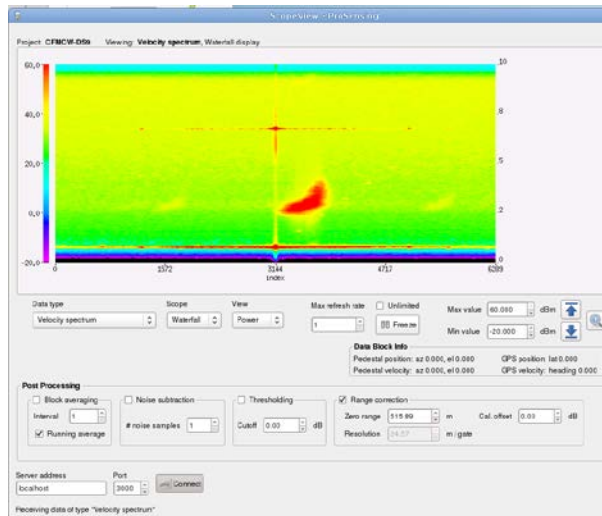**Figure 5.** CFMCW system block diagram

Figure 7. Graphical user interface for radar control and display of data products. The image in the GUI shows the Doppler spectra (x-axis is velocity, y-axis is range and pseudo-color code represents uncalibrated reflectivity) for 5 m height resolution, 15 kHz PRF, and 0.05 s integration time.

The radar's minimum detectable sensitivity, predicted from the radar range equation [1], is plotted in **Figure 8** for 30 m range resolution. The range resolution is continuously variable from 5-300 m, which is governed by the bandwidth of the digitally-synthesized chirp waveform. The radar has a minimum range of approximately 20 m, where it achieves better than –45 dBZ sensitivity at 5 m range resolution.
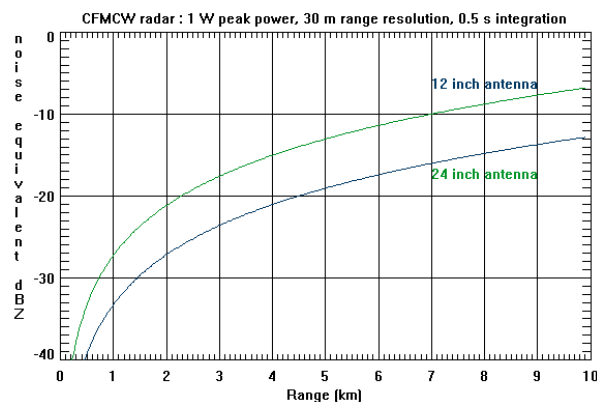

Figure 8. Minimum detectable reflectivity assuming 30 m range resolution, .25 second averaging, 5 kHz PRF, and 2 percent false detection rate.

An example reflectivity image for an ice cloud passing over Amherst, MA on December 25, 2002 measured from the roof of ProSensing's facility is shown in **Figure 9**.
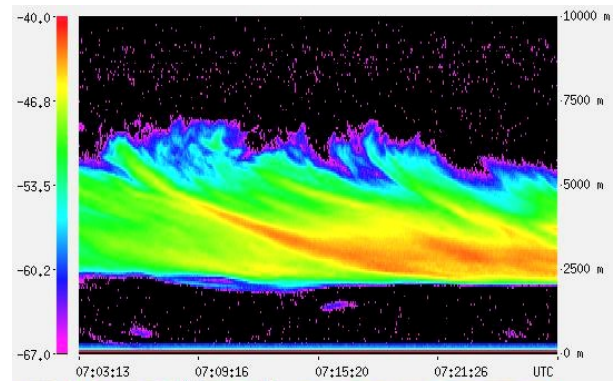

Figure 9. Height vs. time plot of backscattered power (uncalibrated reflectivity) for an ice cloud measured by C-FMCW.

In 2010, CFMCW participated in a one-month airborne experiment organized by ONR and based out the island of Barbados. During this experiment CFMCW was operated by graduate students at the Rosenstiel School of Marine and Atmospheric Science, University of Miami. **Figure 10** shows the sample of reflectivity and velocity images uncorrected for the aircraft motion.
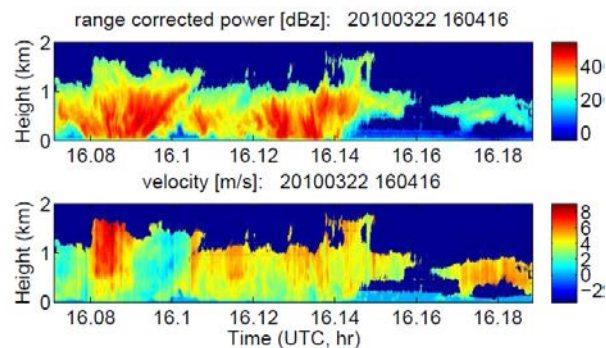

Figure 10. Height vs. time plot of backscattered power (uncalibrated reflectivity) and velocity obtained during the airborne measurements from Barbados.