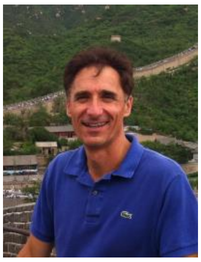
An Airborne Ka-Band PMS Probe Radar

Andrew L. Pazmany

ProSensing Inc., 107 Sunderland Rd Amherst MA 01002, USA

(Dated: 23 June 2014)



Andrew Pazmany

1 Introduction

ProSensing Inc. is developing a compact Ka-band dual-beam Precipitation Radar (KPR), designed to install and operate from a standard PMS (Particle Measurement Systems) 2-D probe canister. The key components of this compact radar, shown Figure 1 and Figure 2, are an arbitrary pulse waveform generator, a 10 W pulsed solid state power amplifier, a low-loss, latching circulator switch network, a pair of flat plate waveguide array antennas for interleaved profiling below and above the aircraft and an integrated noise source and warm reference load for radiometric measurement capability (above the aircraft). The transmit pulse consists of a linear-FM pulse compression waveform followed by an offset frequency short RF pulse. This allows the radar to measure precipitation as close as 100 m from the aircraft using the short pulse return, while achieving enhanced sensitivity at farther ranges using the chirped pulse segment. The recorded data products include profiles of radar reflectivity, Doppler velocity above and below the aircraft and radiometric brightness temperature.

Figure 1: External view of the KPR pod section. ProSensing KPR Webpage

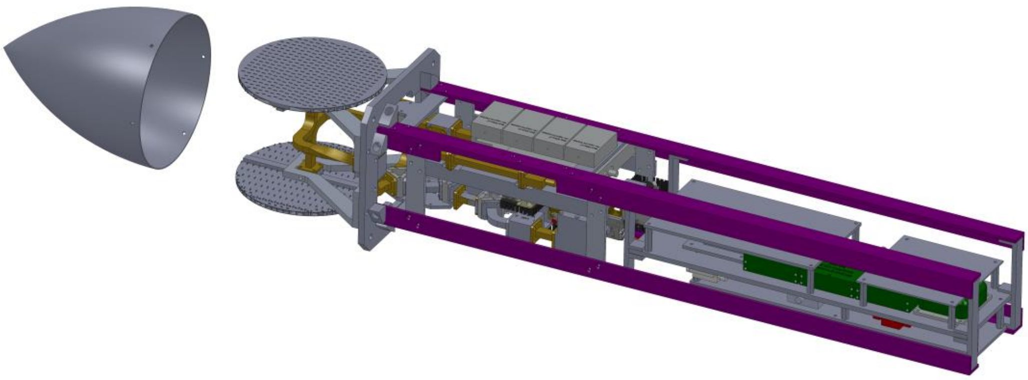


Figure 2. Internal view of the KPR pod section 3-D computer design.

2 System Description

Simplified component level and system-level block diagrams of the KPR are shown in Figure 3 and Figure 4 with the key system parameters summarized in Table 1. A 120 MHz crystal oscillator, located in the LO Signal Generator section, serves as the reference to all the phase locked oscillators and timing circuits in the radar. Transmission is initiated by the Transmit Pulse Generator circuit, which can produce an RF pulse with arbitrary frequency modulation and amplitude taper. The transmit pulse will consist of a chirped pulse with approximately 10:1 compression ratio centered at 90 MHz, immediately followed by a short RF pulse, centered at 150 MHz (Figure 5). . The TX Upconverter section mixes the transmit pulse to 35.64 GHz and a solid state power amplifier boosts the output peak power to 10 W. A fast latching circulator switch network can switch operation, to the up- or down-pointing antenna on a pulse-to-pulse basis.

The backscatter from the two pulse sub-segments are received simultaneously with a wide band receiver front-end and then separated in the IF. In addition to the frequency offset, the transmitted sub-pulse segments are also amplitude tapered for improved isolation.

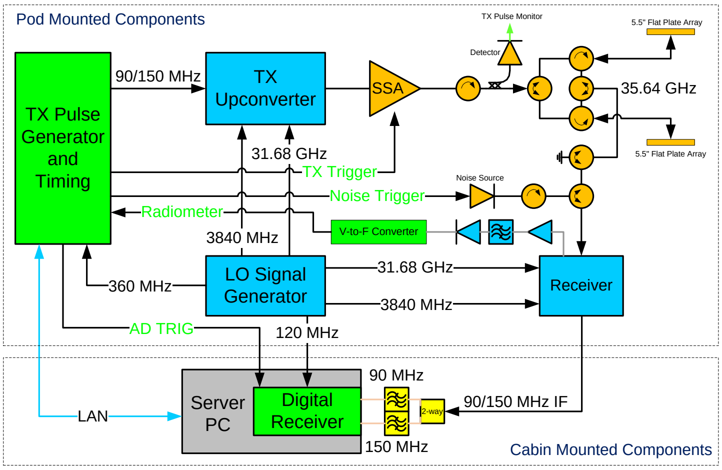


Figure 3. KPR radar simplified system block diagram.

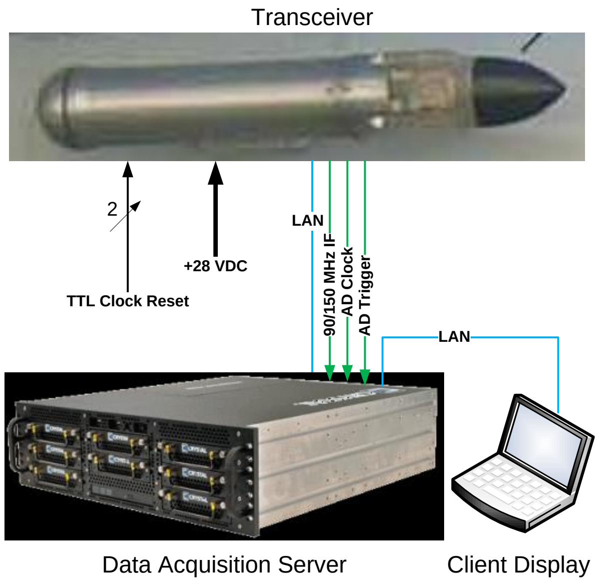


Figure 4. KPR system block diagram.

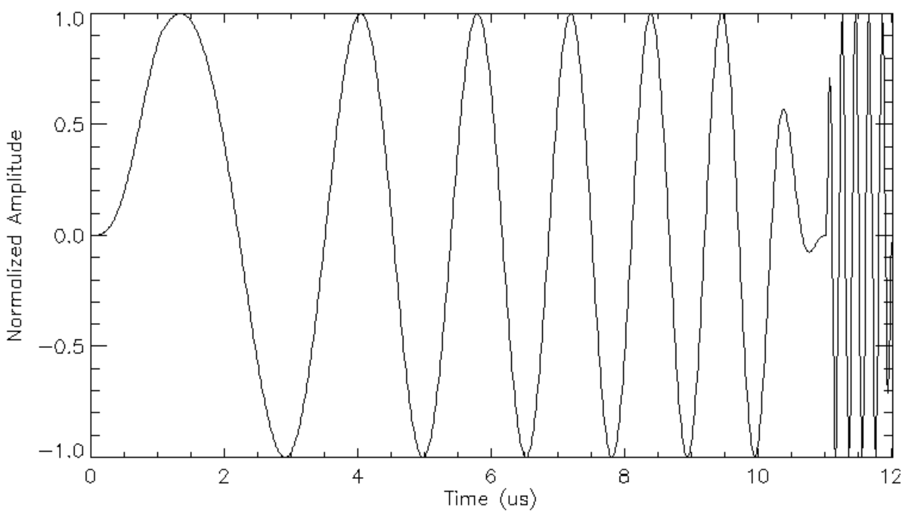


Figure 5. Combined chirped and offset-frequency RF transmitted pulse. Both pulse sub-segments are amplitude tapered for improved isolation.

Table 1. KPR key system parameters.

Parameter	Value
Radar Frequency	35.64 GHz +-30 MHz
Power Amp Output Power	10 W peak, ~5% duty
Transmitter Loss	~1 dB
Transmit Pulse Width	0.1 – 20 us
Transmit Waveform	Interleaved Chirp/RF
Transmit Polarization	Linear
PRF	Up to 20 kHz
Antenna	Up and Down Pointed, Linear Polarized Flat-Plate Arrays
Antenna Bandwidth	35.5 – 35.9 GHz
Radome	Rexolite (0.1 dB loss one way)
Antenna Diameter	5.5”
Antenna Beamwidth	4.2^o Half-power
Antenna Gain	32.5 dB
First Sidelobe Level	-23 dB
Receiver type	Single Wide-Band RF; Dual IF
Receiver Noise Figure	4 dB
Range Gate Spacing	7.5 to 75 m
Radar IF Frequency	90/150 MHz
Digital Receiver	Dual-channel, 16 bit ADC
Dynamic Range	90 dB @ 1 MHz Bandwidth
Processor	Industrial PC, Dual Quad-core 2.0 GHz (min.) Xeon
Radiometer RF Freq.	35.7 – 35.9 GHz
Radiometer IF Freq.	4020 – 4220 MHz

3 Data Acquisition System

The server computer, using dual-quad core 2.0 GHz (min.) Xeon processors performs all the remaining signal processing: pulse compression of the chirped samples, the calculation of various moments, averaging and assimilation with auxiliary data (GPS, INS, system health, etc.). The data acquisition system can transmit large blocks of processed data via a network connection to client computers for real-time display and can record the raw I/Q time series from the digital receiver, or the averaged data products. These data products include: up- and down-beam measured power (for estimating dBZ), complex autocorrelation at one or two lags (Doppler velocity mean and standard deviation), and radiometric brightness temperature.

4 Radar Sensitivity

In standard dual-beam operating mode, pairs of the hybrid chip/RF pulses are transmitted in the Up and Down antenna beams at a typical pulse repetition interval of 50 µs (20 kHz), yielding about 500 pulse-pairs and 1000 power samples per averaging interval. This pulsing sequence is illustrated in Figure 6.

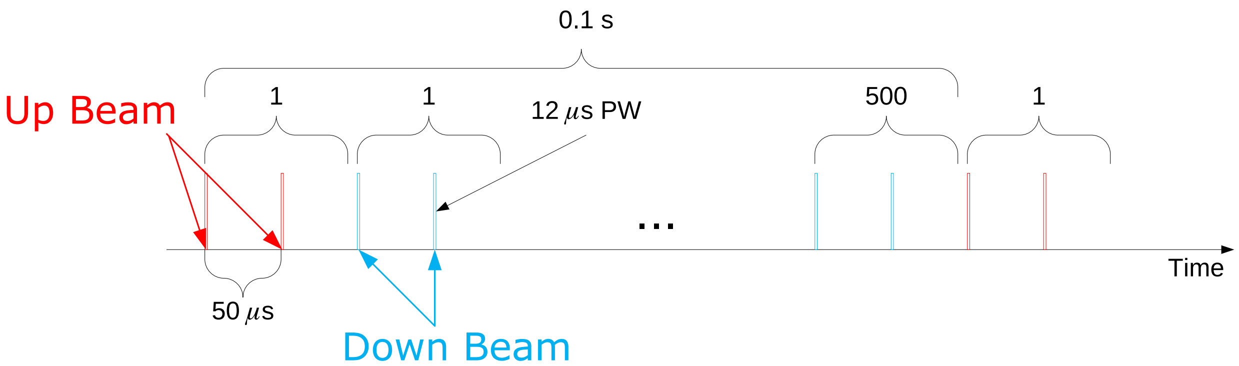


Figure 6. In standard operating mode, pulse-pairs are transmitted in the Up- and Down-beams and the standard pulse-pair data products averaged for about 0.1 sec (10 Hz record rate).

Sensitivity analysis is based on the radar range equation for volume targets[1]:

$$Z_{min} = \frac{P_n 10^{18} 2^{10} \ln(2) R^2 l^2 l_r l_{rx} l_{tx}}{P_t C_r E_c \sqrt{N} G^2 \theta^2 c\tau |K_w|^2 \pi^3}$$

Where P_n = noise equivalent signal power referenced to the antenna input =*kTBF*, where *kT*= -174 dBm, *B* is the receiver bandwidth, and *F* is the receiver noise figure. P_t = peak transmit power, C_r = compression ratio (1 at close range, 10 farther out), E_c = compression efficiency (0.80), *N* = number of samples per beam (5 kHz * 0.1 sec), *G* = antenna gain, θ = antenna beamwidth, $K_w = 0.94$ is a factor associated with the complex index of refraction of liquid water at Ka-band, *c* is the speed of light, τ=pulse length (τ=500ns for 75 m, and τ=1000 ns for 150 m range resolution), *R* is the range to the center of the pulse volume, *l* is the one-way propagation loss, l_r is the finite bandwidth loss factor (1.8 dB for perfectly matched filter; 2.0 dB for practical FIR filter used in this analysis), l_{tx} =transmit path loss to the antenna, including one-way radome loss, l_{rx} =receive before the LNA port, including one-way radome loss.

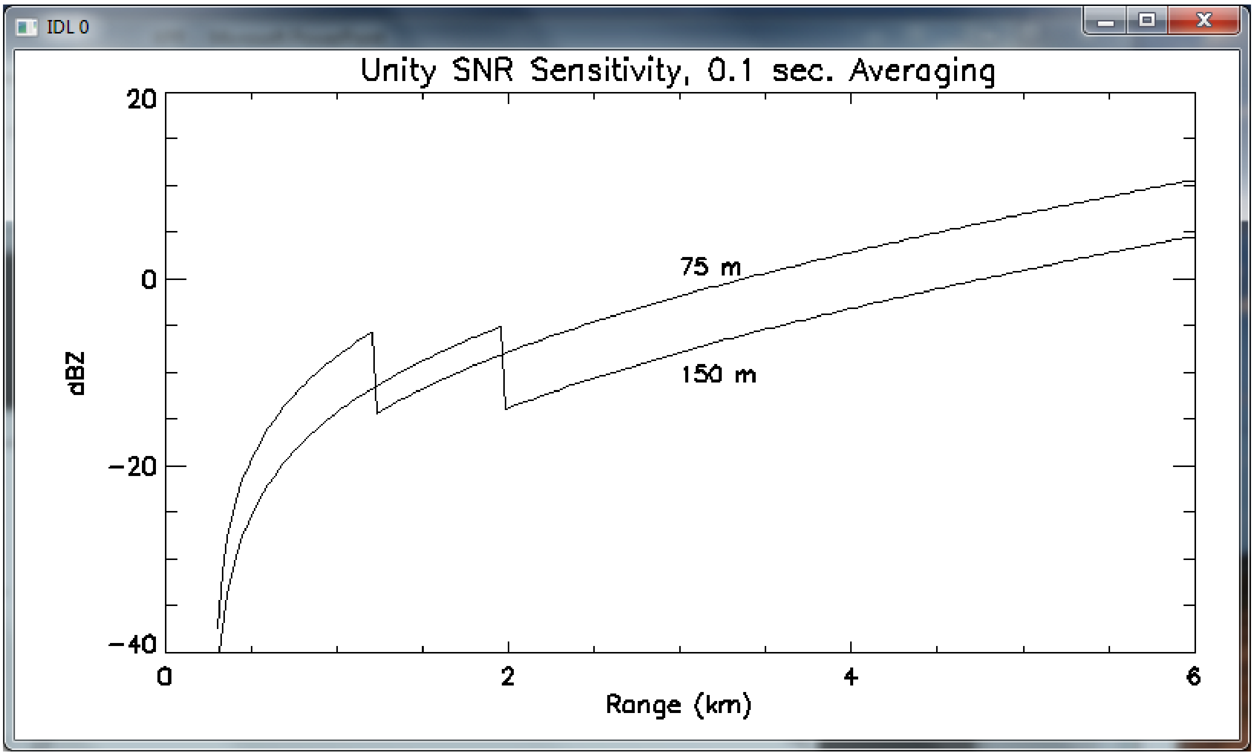


Figure 6. Unity signal-to-noise ratio (SNR) sensitivity for 75 and 150 m range resolution and 0.1 sec integration in dual-beam mode.

5 Radiometer

A radiometer receiver channel is split from the main wide-band receiver arm at the 4 GHz, first IF stage. A bandpass filter isolates the radar signal from the radiometer receiver channel and then multiple amplifiers boost the noise floor to detectable level. Another filter sets the 200 MHz radiometer bandwidth and the detector output voltage is converted to a TTL pulse train with a voltage-to-frequency converter. The radar control card counts the pulse train, during the programmable "quiet" time segment of the pulse sequence, to measure the noise power level. A temperature controlled and monitored noise source and matched load, located in the T/R switch network are used for calibration.

The expected radiometer ΔT of each noise measurement, corresponding to a 10 ms integration time, is approximately 0.5 K:

$$\Delta T = \frac{T_A + T_{REC}}{\sqrt{B\tau}} = \frac{290 + 435}{\sqrt{200e6 \times 0.01}} \approx 0.5\,\mathrm{K}\ ,$$

[1]Doviak and Zrnic, **Doppler Radar and Weather Observations, Second Ed**., Equation 4.34 solved for Z, assuming *P*(r0) is noise floor power, Z in mm^6/m^3 , and system gain g_s is 1.0.

where $T_{REC} = (F-1)T_o = (2.5-1)\times 290 = 435\,\mathrm{K}$

6 Status

The first KPR has been assembled and tested on a bench-top. The mechanical design to package the instrument into PMS canister is currently on-going. The instrument is expected to be ready for flight tests by the end of 2014.

Acknowledgement

This work is being supported by the NASA EPSCoR grant NNX13AN09A to the University of Wyoming.

References

Doviak and Zrnic, Doppler Radar and Weather Observations, 1992. Academic Press:

San Diego, California