Ka-Band Polarimetric Doppler Radar for Profiling of Low Level Clouds at Mumbai During Monsoon Season

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Abstract:
Cloud microphysical study is one of the important physical processes that impact predictability of the NWP models. Qualitative observations of these cloud microphysical properties can be obtained from Cloud radar. In this paper the technical, hardware specifications, system design & development and initial results of the prototype ka-band cloud radar developed by SAMEER Mumbai are presented.

Key words: Ka-band, Cloud radar, Doppler, Polarimetric variables

I. INTRODUCTION

Cloud is an important constituent of earth's water cycle. It is well known fact that clouds modify earth's energy budget and plays an important role in affecting Earth's climatic system [1-5]. Therefore, study of Cloud variability in time and space is very important. In tropical region like India, the observation of cloud fields and its evolution in time has not been studied due to lack of proper instrumentation. For the first time in India a ka-band System (zenith looking) has been built to study the low level clouds prevailing during monsoon period in Mumbai. This paper discusses about the overall system design, its hardware details and some key features. System has been integrated and deployed outside in the terrace of the office building. Integrated System testing is going on.

During monsoon there are heavy clouds in Mumbai region. The targeted reflectivity of the cloud for the system design has been taken as -17 dBZ @ vertical height of 5 kms (Figure 1). Scientific requirement demands long-term observations of non precipitation and weakly precipitating clouds. In view of this the developed system is coherent, Polarimetric, Doppler Radar. It would measure the following parameters at each range gate, typically from 0.5 km above ground level (AGL) to a height of 5kms;

i. Radar reflectivity profiles of co-polar component of H- and V- Polarisations,
ii. Radar reflectivity profiles of cross-polar component of H- and V- Polarisations,
iii. Radial mean velocity profiles of co-polar H- and V.
iv. Velocity variance profiles of co-polar H- and V,
v. Doppler spectrum of co-polar H- and V
vi. Linear depolarization ratio (LDR),
vii. The raw I & Q outputs of the Digital Receiver

These parameters would be accessible in real time in graphical form.

II. RADAR EQUATION

Radar equation for meteorological purposes, in its simplified form, is given by [6]

$$P_r = \frac{P_t G_0^2 c\tau\pi^3 \theta\phi |K_w|^2 Z_e}{1024\ln(2)\lambda^2 L_{tx} L_{rx} r_0^2 I_{atm}^2 10^{27}}$$

Where, Z_e is the equivalent reflectivity factor ($mm^6\ m^{-3}$).
P_r is the received power referenced to LNA input (mW), r_0 is range to centre of sampling volume (km), I_{atm} is one way integrated atmospheric loss factor,
λ = wavelength (m), c = speed of light (3×10^8 m/s), G_0 = peak antenna gain,
P_t = peak transmit power in Watts, τ = pulse width in µs, θ & Φ = antenna half power beam width in radians, L_{tx} = losses between transmitter output port and the antenna input port where antenna gain has been measured. L_{rx} = losses between input port of LNA and the antenna output port.

$$|K_w|^2 = \frac{|n_w|^2 - 1}{|n_w|^2 + 1}$$, where $\boldsymbol{n_w}$ is the complex index of refraction of water at 0º C.

In the above equation, τ = 0.250µs, G_0 = 128824.96 (corresponding to 51.1 dB gain), $\theta = \Phi = 0.31^0$, P_t = 4 Watts, K_w = 0.91, L_{tx} = 2.0 dB, L_{rx}= 3.0 dB. For clear air the reflectivity plot with height is given in Figure1 for 1 sec averaging, 37.5 meter range resolution for zero dB SNR. It can be seen that with this system, -6dBZ and -16dBz reflectivity can be obtained @ 6 kms height without and with pulse compression respectively. The detailed specifications of the system are given in the Table 1.

III. SYSTEM DESCRIPTION

Block diagram of radar is shown in figure 2. The system frequency of operation is 35.6 GHz. The RF signal for transmit, LO signals, sync signals are generated from the basic 100 MHz source feeding to various PLLs, power divider and filter chains. The transmitter is Solid-state Power Amplifier and generates 4 Watts output RF power. Provision exits for coding of transmit pulse during certain modes of operation. Antenna is Cassegrain fed parabolic reflector. Reflector diameter is 1.8m. Sub-reflector is hyperbolic. Feed is corrugated scalar horn with OMT. OMT has two separate feeds for horizontal and vertical polarization. The switching between the two polarizations is done by combinations of seven fast switching circulators. Power handlings of switching circulators are 1.5 kW peak and 50 Watts average; maximum switching time is 1.2μs, maximum switching frequency is 5 KHz, insertion loss is 0.3 and isolation is more than 20 dB. The system during transmit alternates between the two polarizations but can receive simultaneously in both polarizations. Thus we get one co-polar and one cross polar return signal. There are two receivers for the two polarizations. Both channels are similar in structure and characteristics. Noise figure of LNA is 4.0 dB. The receivers are double heterodyne type with a final IF of 70 MHz. Receiver has two paths with different IF gains for processing co- and cross-signals. The final IF signals are then processed in a pair of digital receivers. Overall gain of the receiver is around 52 dB. The measured dynamic range of the receiver is 92 dB. It is shown in figure 3. The digital receiver unit consists of ADC (80 MSPS) + DDC, FPGA (Virtex-2), two Tiger SHARC DSP, 256 MB SDRAM etc. The timing signal generation is implemented in Digital receiver unit using FPGA. The radar operation is controlled by a Local PC through Gigabit Ethernet (GbE) interface. Radar can be operated through a Graphical User Interface (GUI) through LabView software. Digital Signal Processing (DSP) & data processing steps are Analogue to digital conversion, Digital Down conversion, Decoding, Coherent integration, spectral estimation, spectral averaging, moments estimation etc. After signal processing, computation of basic radar variables Reflectivity (Ze), Radial Velocity (Vr) , Spectral Width (SW) and derived Polarimetric variables like Z_{dr}, LDR, K_{dp}, Φ_{dp}, ρ are computed and displayed through the LabView based Display system.

System has a provision for injection of calibrated test signals in the receiver chain close to antenna point for internal calibration. During internal calibration gain and phase difference between the two receiver channels would be measured, stored and applied on the raw data for computation of various parameters. Overall receiver dynamic range is greater than 92 dB. The photograph of the system placed outdoor is shown in figure 4. The dimension of the rack is 600mm × 600 mm × 1600mm. System being outdoor care has been taken to make it leak tight. A panel AC has been attached to one of the sides of the rack to maintain temperature within 24^0C to 30^0C. Once the full system was integrated, transmit power was measured at the transmit monitor port provided in the system. It is shown in the figure 5. Signal was injected at the receive test port located close to antenna port to check the receive chain. The entire receive chain was found to be OK. System was operated during the month of June and the very first observation of the cloud was seen in the V-polarized reflectivity on 07^{th} June 2013 (Day of monsoon onset) is shown in figure 6. The low level stratus cloud with mid level Nimbo-stratus cloud is visible at this time. This was clearly observed in both SNR and reflectivity.

IV CONCLUSIONS

The proto type Ka-band cloud radar system for low level cloud observations has been developed by SAMEER Mumbai. The system is based on solid state amplifier with transmit power of 4watt. System is proved with its results by showing the stratus clouds during the monsoon onset on 7^{th} June 2013 at Mumbai. This gives the confidence to indigenous development of this technology for all the cloud types at different seasons with the capabilities of high transmit power and scanning mode in near future

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BIODATA

Dr. Arvind Agarwal received M. tech in 1985 from university of Delhi and joined SAMEER in the same year as Scientist-B. He worked in the development of MST radar system followed by 400 MHz wind profiler system. He was also involved in the development of Ku-band phased array and Ka-band radar systems.

Figures:

Figure 1. Reflectivity with range variation

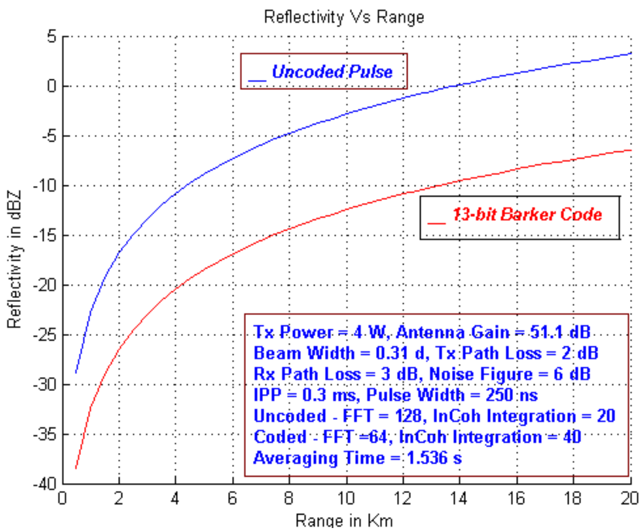


Figure 3. Dynamic range measurement of the reciever

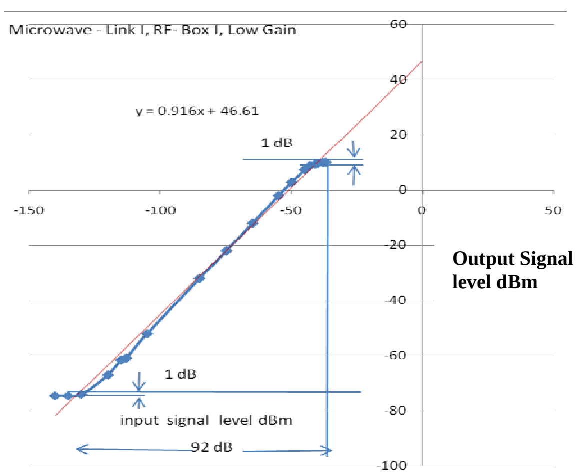


Figure 4. Photograph of ka-band radar for profiling of low level cloud

Figure 5. Plot of Transmit pulse

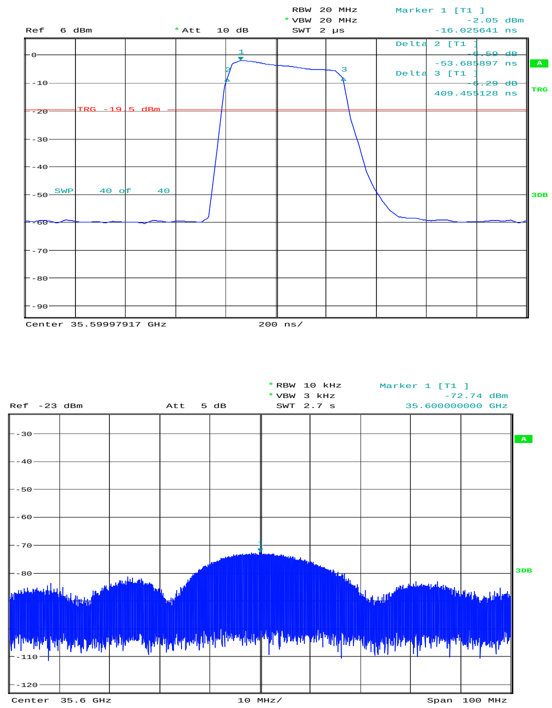
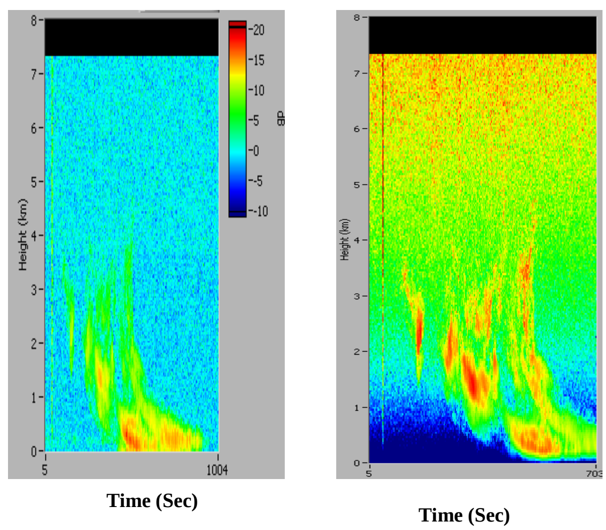


Figure 6. Time Height Plot of zenith looking cloud radar on 7th June 2013 1430 IST a) SNR b) Reflectivity



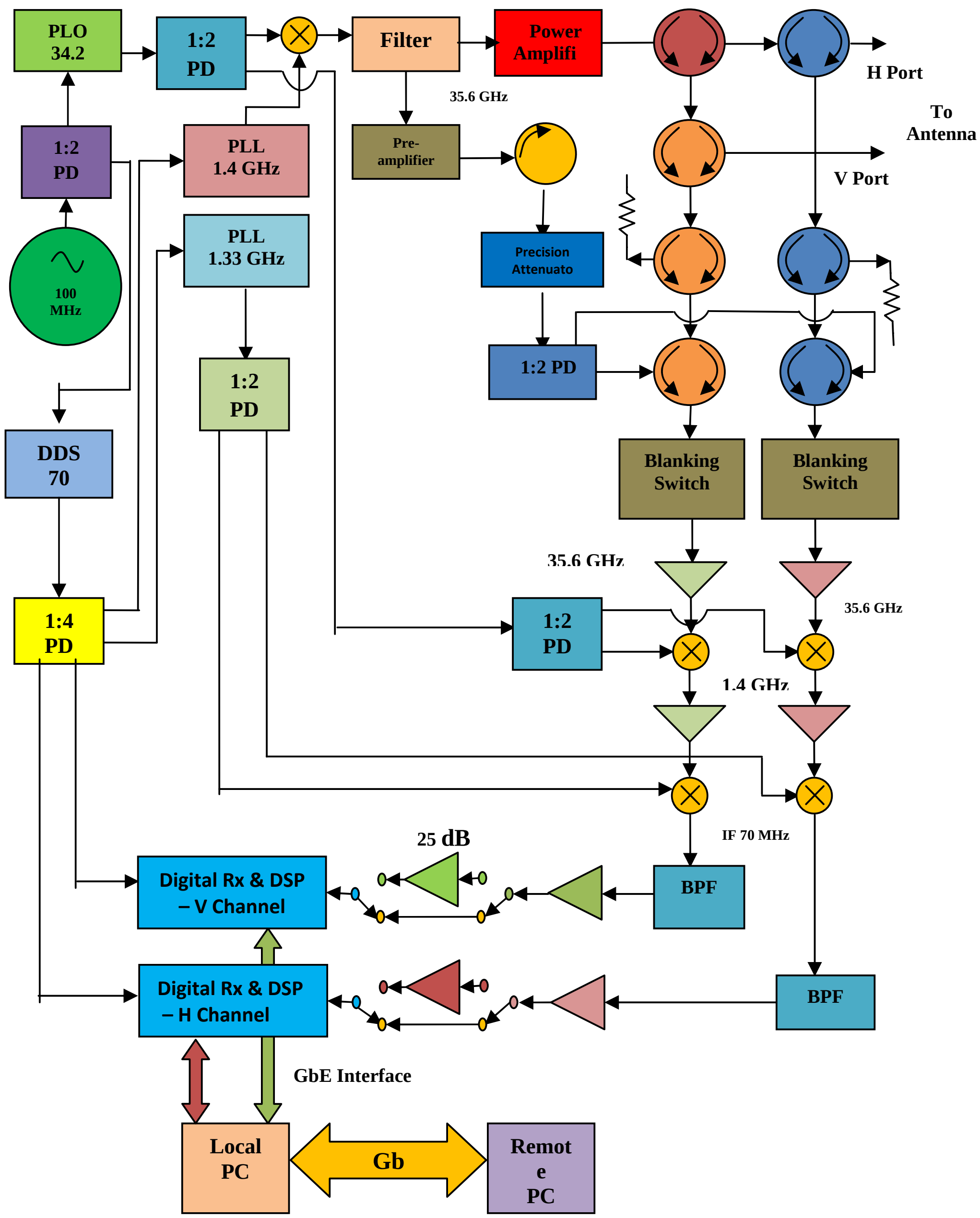


Figure 2. Block diagram of ka-band radar for low level cloud profiling

Tables:

Table1. Cloud radar specifications

Frequency	35.6 GHz
Antenna type	Cassegrain feed, 1.8m Parabolic dish
Beam direction	Fixed, Zenith
Antenna gain	51.1 dB (measured)
Antenna HPBW	0.31^0 (measured)
Measured First SLL	Better than - 21 dB
On-axis cross polar component	Better than -30 dB
Polarization	Dual, Linear: H- and V-,
Transmission	Alternate H- and V-
Reception	simultaneous H- and V-
Transmit Plumbing losses	2 dB
Overall receiver noise figure	7 dB
Transmitter	4 Watts pulsed, Solid-state power amplifier
Modulation	Pulse and coded pulse(8 and 13 bit)
Pulse width	0.25, 0.5, 1.0, 2.0 µs (uncoded)
PRF	Variable, maximum 5 KHz(limited by ka-band switching circulator)
Transmit coding	Complimentary, Barker
Receiver	Two –channel digital receiver
Data digitization	14.bit
Minimum Range Resolution	37.5 meters
Number of range gates, typical	200 uncoded, 100 coded
Time domain integrations	1,4,8 (variable)
Doppler Processing	FFT: 32,64,128,256,512(Selectable)
Windowing	Hamming/Hanning
Nyquist vertical velocity; resolution	5.38m/sec; 0.1m/s
Integration time	1 s minimum , online
Sensitivity(calculated)	-16 dBz @6 kms, 0.25 µs pulsewidth