Radar Receiver Calibration in Pulsing Mode

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Abstract: This paper analyzes the calibration of the W-band Wyoming Cloud Radar receivers, specifically the analog logarithmic amplifiers/detectors (log-detectors), operating in pulsed mode. Two MITEQ log-detectors were tested; one with 22 MHz and a second with 40 MHz bandwidth, both operating at 120 MHz central frequency. It was found that both detector models exhibited some change in behavior when detected 250ns pulses (puled mode, PM) compared to continuous wave (CW) signals. The 120/22 detector changed the slope of its logarithmic transfer function by as much as 10% while the 120/40 amplifier became more non-linear, deviating from a linear transfer function up to an additional 1 dB. It was therefore concluded that the receivers should be calibrated in pulsed or continuous wave mode, depending on the application, and that a non-linear receiver calibration lookup table is the best approach to minimize the errors for the full dynamic range of analog logarithmic detectors.[¤]

INTRODUCTION

Accurate calibration of remote sensors is critical to the proper interpretation of their measurements. Cloud radars require both, high quality relative and absolute calibrations [2] in order to allow high precision and accuracy in the inversion of backscattered power measurements into cloud physical properties.

The Department of Atmospheric Science at the University of Wyoming operates a 95 GHz pulsed polarimetric Doppler radar for cloud studies. The Wyoming Cloud Radar (WCR) is used primarily as an airborne instrument for cloud research on the Wyoming KingAir Research Aircraft operated under a cooperative agreement with the National Science Foundation as a national facility.

WCR transmits 100, 250 or 500 ns pulses with a peak power of 1.6KW, in groups of 4 or 6 pulses and pulse separation as short as 50 μs. The radar has two coherent receiver channels, both employing two-staged super heterodine downconvesion for simultaneous and coherent measurement of the vertical (V) and horizontal (H) components of the received field. The first stage of the receivers down-converts the 94.92 GHz carrier frequency to 1.2 GHz and the second stage converts it to 120 MHz, which then passes the signal to a filter bank. The received power in each channel is detected at 120 MHz with a wide-dynamic range logarithmic amplifier/detector (log-detector), while a linear phase detector is used to measure phase of the received signal. A simplified block-diagram of the radar IF detection unit is shown in Fig. 1. More details about the WCR are given in [1] as well as on the web at http://www-das.uwyo.edu/wcr.

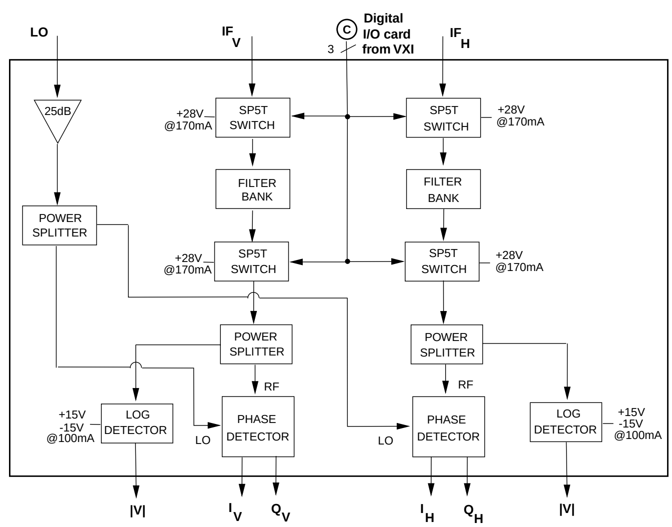

Figure 1. Block diagram of WCR IF unit.

In this paper we will focus on the calibration of the WCR receiver and its effect on radar reflectivity measurement accuracy. Even a small slope error in this calibration can become important since radars are often calibrated using point targets with known cross section, e.g., corner reflector [2]. To avoid the effect of ground clutter and other interference, the calibration target is often mounted relatively close to the radar, thereby producing a strong return signal near the top of the receiver dynamic range. Consequently, just a few percent error in the transfer function slope of the log-detectors will cause several dB error in the measured

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power of weak signals, near the other end of the dynamic range.

RECEIVER CALIBRATION

The receivers were calibrated using continuous wave (CW) and pulse (PM) signals. The manufacturer specifications of the two log-detectors are given in Table 1, where 'BW' is the amplifier input bandwidth, 'Range' refers to the linear dynamic range, 'Fall' is the fall time, 'Linear' is the linearity errors, and 'Current' is the maximum current used by the device.

Table 1. Selected MITEQ Log Amplifier Parameters

Model	Freq. MHz	BW MHz	Range dB	Linear dB	Fall ns	Current mA
LIFD-120/20	120	22	>70	<±0.5	<150	100
MLIF-120/40	120	>40	70	<±1.0	63	336

Continuous Wave Calibration

CW calibration was carried out using a Synthesized Signal generator (SSG) with calibrated output dynamic range from –75 dBm to +13 dBm at 120.000 MHz. It was assumed that the receivers (up to the log-detectors) were linear and matched over the dynamic range of the detectors. The SSG signal was fed to the inputs of the IF unit and then the output of the detectors were digitized and mapped to mW using the manufacturer specified linear approximation for the detector transfer function. Fig. 2 shows the results of this calibration for the two log-detectors. The upper panels show the actual measured values and their best linear fits. The lower panels show the deviations from linear over the manufacturer specified dynamic range. For both detectors, the non-linear deviations match the vendor specified transfer function (we reproduced the factory measurements). We also tested the effect of temperature on the log-detector transfer functions over the normal operating temperature range (25°C to 40°C). While the LIFD amplifier did not exhibit measurable dependence, the MLIF transfer function changed as much as 0.06 dB per 1°C at certain power levels.

Pulse Mode Calibration

Pulsed calibration was conducted with an external, trihedral corner reflector target and a set of calibrated IF (120 MHz) attenuators. The radar transmitted 250 ns pulses at 20 kHz pulse repetition frequency (typical operating mode). The returned signal was integrated for about 10 seconds. The transmitted power was monitored and was measured to deviate less than 0.2 dB. The corner reflector (CR) was placed about 150 m from the radar (60 m antenna far field) mounted on a 4.5m mast (0.7° beamwidth). The pole was tilted with respect to the vertical and produced a return signal at least 20 dB weaker than the CR. The radar was in a fixed position and the return from the CR was steady (less than 1% uncertainty). After the front-end of the receivers the signal was passed through a set of calibrated attenuators and then fed to the IF detection unit like the CW calibration. The attenuators covered the dynamic range of the log-detectors just as the SSG did during CW measurements. The results of this calibration are shown on Fig. 3. LIFD amplifier did not change considerably its linearity errors in pulsed mode (Fig. 3 left graphics, lower panel) except near the top of the dynamic range. On the other hand the slope of the linear fit in logarithmic scale changed more than 9% (solid line in Fig 3; dashed line is the CW calibration fit). The difference between CW and PM calibrations for LIFD is illustrated in Fig. 4 (left graphics). Thus the use of the CW calibration will cause up to 6 dB error for weak signals given that the absolute calibration is performed at the high end of the dynamic range. For this case a 2-piece linear fit in PM will work better and can reduce the considerable errors at the high end and eliminate the bias (~0.5dB) over the rest of the dynamic range. MLIF amplifier did not change its slope (there is about 2% uncertainty in the slope measurements) in pulsed mode (Fig. 3 right graphics), but the linearity errors increased by 0.5 to 1 dB. This seems to be due to the overall higher non-linearities for this amplifier and small shift in the peaks and valley in PM. The error of using CW instead of PM calibration for this log-detector is less than ±2 dB.

CONCLUSION

The performance of two analog logarithmic detectors were evaluated with continuous wave and pulsed signals through their dynamic range. Even though their input bandwidths suggest that CW and PM operation should be similar, it was found that the detectors have to be calibrated in pulsed mode, when used as part of a pulsed radar, to avoid significant errors. To further improve the precision of radar reflectivity measurements, a non-linear lookup table should be used to characterize the detector transfer function. This will not only reduce measurement errors due to detector non-linearity but will also extend the dynamic range of the radar.

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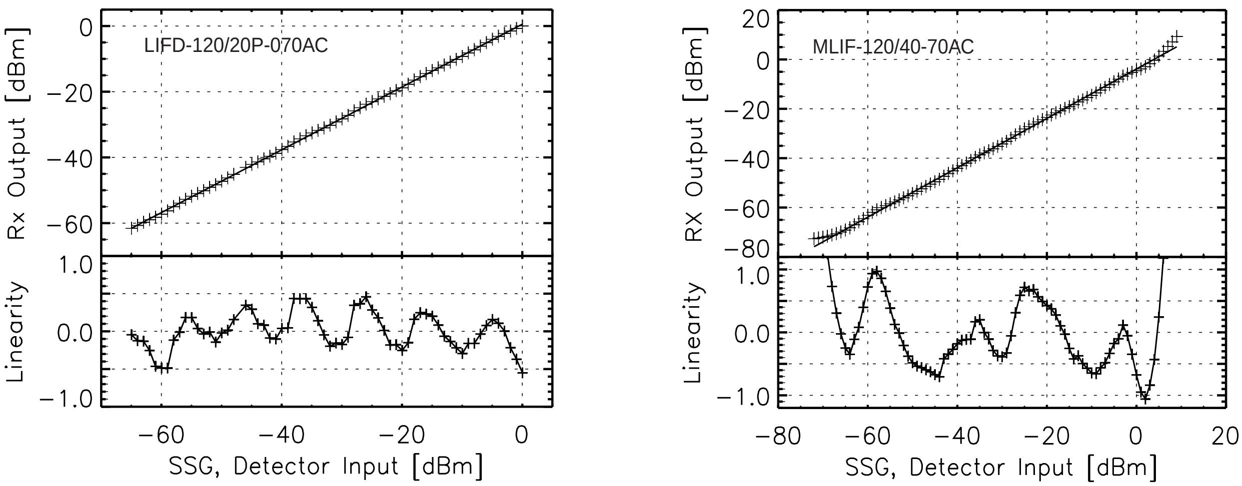

Figure 2. Continuous wave (CW) calibration of LIFD-120/20 and MLIF-120/40 logarithmic amplifiers.

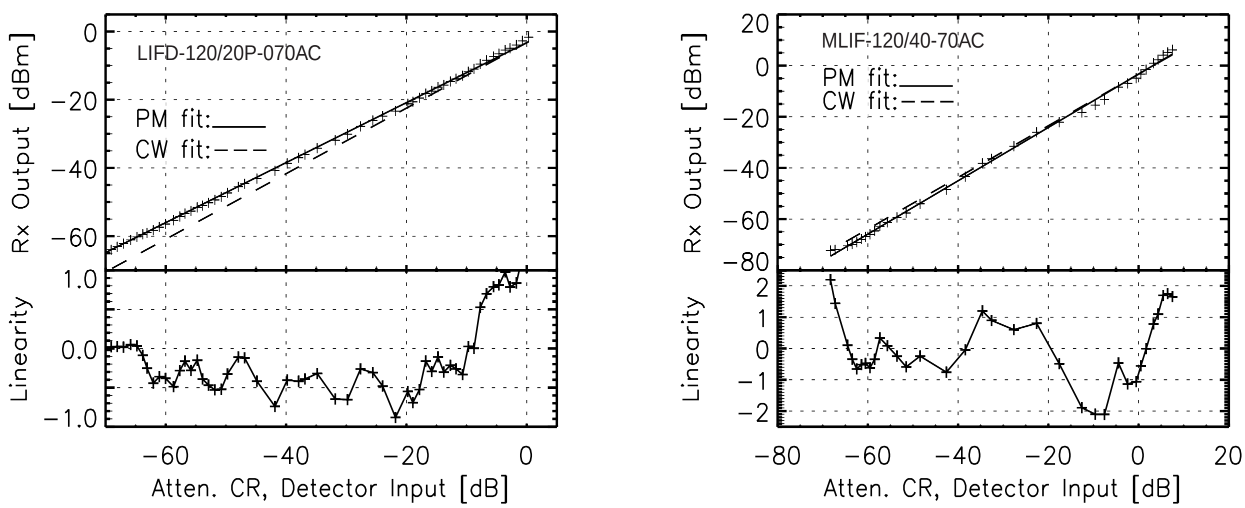

Figure 3. Pulsing mode(PM) calibration of LIFD-120/20 and MLIF-120/40 logarithmic amplifiers.

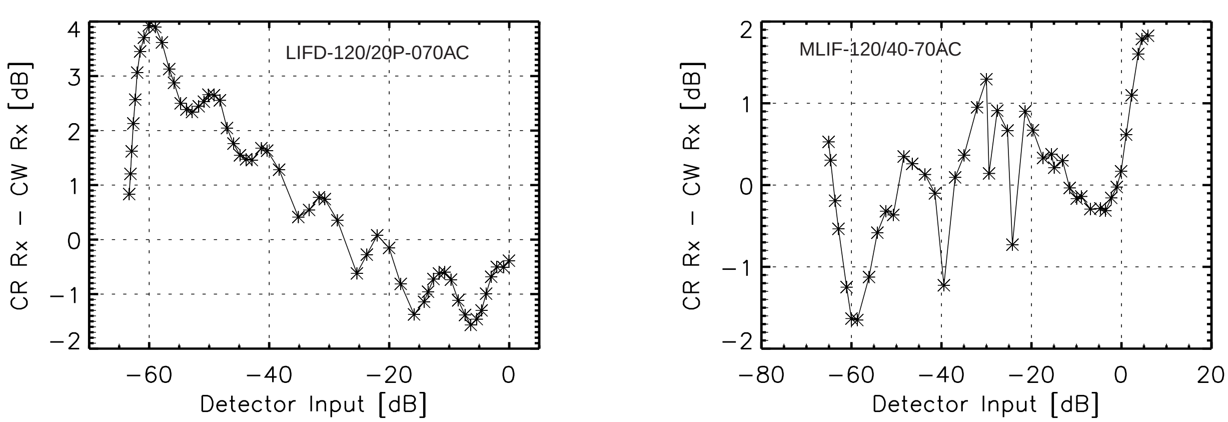

Figure 4. Difference between PM and CW calibration of LIFD-120/20 and MLIF-120/40.