S-Band Precipitation Profiler

Introduction

In general, a radar's sensitivity to small particulates increases as the transmitted wavelength, lambda, decreases and as transmitted power, antenna size, beam sample volume size, and integration time increase. Similar arguments can be made for backscatter from clear-air turbulence, keeping in mind the much weaker wavelength dependence that exists in this scattering regime. Although the Rayleigh lambda^-4 backscattering dependence favors the use of shorter wavelength radars for cloud observations, even longer wavelength radars, such as UHF wind profilers (~33.75 cm) have demonstrated some ability to detect clouds (Orr and Martner 1996; White et al. 1996). The main advantage of short-wavelength systems such as millimeter-wave radars (e.g., Moran et al. 1998) is their ability to obtain excellent sensitivity and spatial resolution without the use of large antennas or very powerful transmitters. Also, ground clutter is less of an issue at shorter wavelengths (Kropfli and Kelly 1996). Their primary disadvantage is severe attenuation by rain (but not by snow).

Operational precipitation surveillance has long been the province of centimeter-wavelength radars in the United States. Recently, the National Oceanic and Atmospheric Administration (NOAA) Aeronomy Laboratory combined wind profiler technology with S-band (lambda = 10 cm) radar hardware to create a new precipitation profiler (Ecklund et al. 1999). These profilers have amply demonstrated an ability to continuously monitor precipitation echoes overhead and have also indicated a substantial ability to observe at least the more strongly reflecting regions of clouds. The enhanced sensitivity necessary for cloud profiling is achieved by coherently integrating the received signals and by pulse coding the transmitted pulses to boost the average signal power.

In this regard, an S-band profiler bridges the gap that exists between millimeter-wave cloud radars, which reveal the structure of extremely weak, nonprecipitating clouds but are severely attenuated by rainfall, and operational weather radars, which, although unattenuated by rain, generally lack the sensitivity to detect much cloud structure. This article describes a new S-band profiler built by the NOAA Earth System Research Laboratory's Physical Sciences Division (PSL) that uses a switchable microwave coupler to extend the profiler's dynamic range in order to bridge this gap even more thoroughly. After a brief description of the radar and how it was calibrated, examples from recent field experiments are shown to elucidate the profiler's measurement capabilities.

Radar Description

The prototype for the PSL S-band profiler was built at the NOAA Aeronomy Laboratory (Ecklund et al. 1999). The PSL profiler uses a different antenna feed that consists of a rectangular waveguide and a splash plate. The splash plate is welded to the top of the waveguide without any other supporting structure. The dish is fully illuminated, resulting in a one-way, 2.5 degree beamwidth (full-width at half-maximum power). Additional characteristics of the profiler are listed in Table 1 . Excluding the paraboloid antenna, much of the design of the radar hardware and signal processing software is based on the existing technology used in the 915-MHz wind profilers (Carter et al. 1995).

Table 1. S-band profiler characteristics

Frequency (GHz)	2.875
Antenna diameter (m)	2.4
Average transmit power (W)	20
Peak power (W)	360
Beamwidth (deg)	2.5
Range resolution (m)	45, 60, 105, 420
Time resolution, nominal (s)	30
Doppler technique	FFT
Estimated sensitivity (dBZ*e* at 10 km)	−14

The radar receiver uses 8-bit, in-phase, and quadrature digital converters, which limit its dynamic range to 45 dB. Doppler signal processing adds an additional 22 dB. Therefore, the total dynamic range of the profiler is 67 dB. We have detected this range in the laboratory using a sinusoidal signal, but the dynamic range apparent in field measurements will always be less. The primary reason is that the probability density function for the intensity (or power) of atmospheric signals (in clear air and in precipitation) is exponential. This makes the concept of a saturation threshold somewhat ambiguous because, for a finite dwell time, some of the instantaneous signals will saturate the receiver.

We added a switchable, 30-dB coupler to the receiver to extend the dynamic range of the PSL S-band profiler. A coupler is a microwave device that allows most of the power to pass through one port, called the through port, with little attenuation. A small amount of the power (one thousandth, in this case) traveling in the forward direction is diverted to a second port, called the coupled port. We placed the coupler and a switch, to select between the through port and the coupled port, before the first low-noise amplifier in the receiver (see Fig. 1). This configuration adds only 0.2 dB of loss to the receiver. The receiver noise level changes by about 10% when switching between the coupled mode and the noncoupled mode. Accordingly, we can switch between modes without recalibrating the receiver.

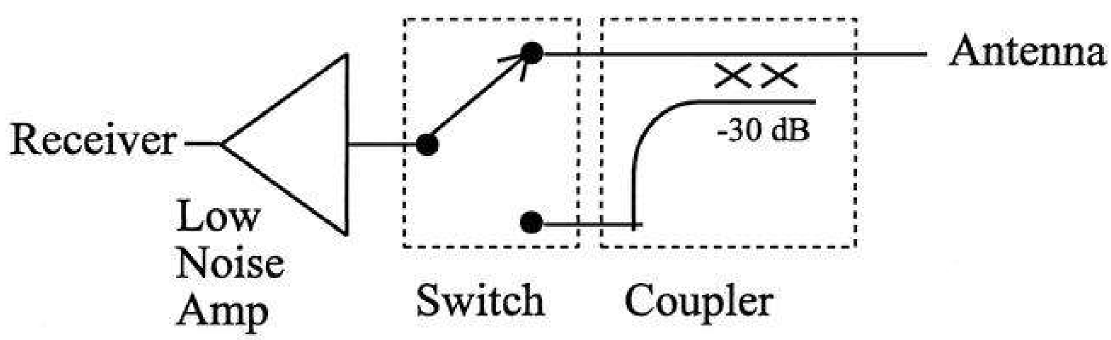

Fig. 1. Schematic of the switchable 30-dB microwave coupler used with the ETL S-band profiler. With the switch in the closed position (shown), the through port is sampled, and the signal enters the receiver without attenuation. With the switch in the open position, the coupled port is sampled, and the signal is attenuated by ~30 dB before entering the receiver

The microwave coupler and switch are simple and relatively inexpensive additions to the radar receiver. Yet we are unaware of any other attempts to use this technology to increase the dynamic range of a meteorological radar, making the coupler a unique feature of the PSL S-band profiler. Another option for increasing dynamic range is to use a logarithmic receiver. This method increases dynamic range but sacrifices sensitivity unless an additional linear receiver is sampled. By programming the S-band profiler to alternate between coupled and noncoupled operating modes, the dynamic range is increased using a single receiver and without sacrificing sensitivity.

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Publications

Extending the Dynamic Range of an S-Band Radar for Cloud and Precipitation Studies (SbandDynamicRange.pdf)

A 3-GHz Profiler for Precipitating Cloud Studies (SbandPrecipCloud.pdf)

A Comparative Study of Rainfall Retrievals Based on Specific Differential Phase Shifts at X- and S-Band Radar Frequencies (SbandXbandComparison.pdf)

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