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Frequency Spectrum Analyzer for Doppler Lidar

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U.S. DEPARTMENT OF COMMERCE
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FREQUENCY SPECTRUM ANALYZER FOR DOPPLER LIDAR

M. J. Post, R. E. Cupp, R. L. Schwiesow

This report describes an electronic apparatus that analyzes Doppler returns from an infrared lidar system. By processing each spectral frequency channel with a 100 percent duty cycle rather than with a swept filter analyzer, considerably better S/N is obtained.

1. INTRODUCTION

In Doppler systems, the frequency of the received signal is shifted from the transmitted frequency by an amount proportional to the line-of-sight velocity component of a moving target. Typically, the output signal is the frequency difference between the transmitted and received beams. For our CW lidar, which transmits at a wavelength of 10.59 μm and detects scattering from natural aerosols carried with the wind, this Doppler frequency lies in the range 0 to 20 MHz.

The received signal for such systems is often weak and intermittent, complicating the task of analyzing the signal for its frequency spectrum. Conventional spectrum analyzers scan the signal with a swept narrowband filter, so that a particular frequency band (or channel) interrogates the signal only a small percentage of the time, typically 0.5 percent. Unfortunately, in the case of intermittent signals, a given frequency component will be present only sporadically, so that whether or not it is observed depends on its timing with respect to the scanning filter system.

More specifically, conventional analysis techniques (swept filter) lose 11.5 dB of signal-to-noise ratio (S/N) for intermittent signals, the square root of the duty cycle. Most of our signals are of this type, since they arise from the infrequent transit of large, natural aerosol "tracers" through the small focal volume of the lidar. The limiting noise for this system is constant "shot noise" generated at the detector.

We developed our analyzer to overcome these signal losses due to low duty cycle. By processing all channels in parallel instead of in succession, it results in 100 percent duty cycle for each channel. The individual channels are then sampled in succession to display the spectra in the conventional manner of intensity versus frequency. Although the design for this analyzer is straightforward and the components are standard, the combination and operation of the elements are novel. No commercial analyzer that we have been able to identify is capable of both such wide bandwidth and such high duty cycle, and to our knowledge, no similar device has been previously reported in the literature. The closest similar processor is a surface acoustic wave device (dispersive delay line) with lower duty cycle, and it is available only on a custom basis. This spectrum analyzer does not have the variable frequency range and bandwidth of the swept-filter type, but its capabilities are not essential to our application.

2. SYSTEM CONFIGURATION

The system configuration of our analyzer is depicted in Figure 1. The parallel-processed channels are shown on the far right side. It was decided arbitrarily that 64 discrete channels would yield sufficient frequency resolution for analysis of the Doppler signal.

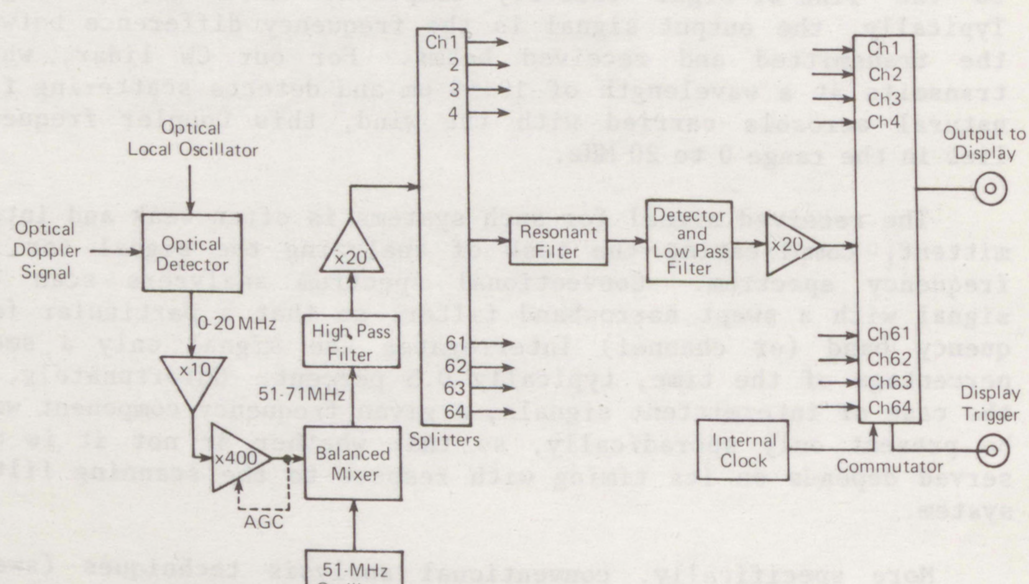

Figure 1. Block diagram of Doppler lidar spectrum analyzer.

The Doppler signal is shifted upward approximately 51 MHz from the original 0 to 20 MHz signal to reduce both the fractional bandwidth of each channel and the physical size of the processing elements. To accomplish this shift, the a.c. signal from the detector is first amplified and then mixed with a 51-MHz crystal controlled oscillator to produce sum and difference frequencies. The difference frequencies below 51 MHz are rejected by a high-pass filter, while the sum frequencies are amplified and distributed in parallel to the bank of processing elements. Distribution is effected with ordinary 75-ohm TV antenna splitters. To prevent overloading the detectors, automatic gain control is applied to the RF signal before distribution under strong signal conditions.

Each channel consists of a high-frequency detector, a d.c. amplifier, and a near end-fed, shorted, tuned coaxial line, which acts as the filter. This filter resonates at a particular frequency and, when that frequency is present in the distributed signal, a resonant level is detected. The filter bandpass is approximately Gaussian, with adjacent filters set to cross over at the 3 dB points. A frequency spike will therefore contribute signals to several adjacent channels and is displayed with considerable bandwidth. However, this poses no problem since most velocity spectra in the atmosphere are broad because of flow turbulence.

Associated with each detector and amplifier is a 0.1-sec integration time constant. Each channel averages the detected signal levels over this period of time. The d.c. amplifiers used in the detection circuits have low thermal drift and a d.c. offset capability to standardize their no-signal levels. Feed and signal pickoff locations, with respect to the shorted end of the line, are critical to maintain desired bandwidth (resonant Q). Table I shows the empirically determined feed, pickoff, and overall lengths for the first 16 coax-filter elements used, corresponding to the first 16 m/s of the velocity spectrum. We use an applied signal for final trimming to length to insure accuracy. One-inch diameter foam-filled coaxial cable is used to obtain the required Q.

The 64 amplified detector levels are placed on the terminals of a 64-position electronic commutator. The pole of the commutator is the output of the spectrum analyzer. As the commutator cycles through the 64 channels, an oscilloscope is swept synchronously to display the entire spectrum of detected levels as a 64-bar histogram. The commutator may be driven at a variable rate, but it normally cycles through the entire filter bank five times per integration time constant. This rate yields a flicker-free display on the oscilloscope, and permits recording without resolution degradation on a 5-kHz magnetic tape.

TABLE I. EMPIRICALLY DERIVED PARAMETERS OF THE FIRST 16 RESONANT FILTER ELEMENTS

Filter No.	Frequency, MHz	Length (m)	Feed Tap (cm)	Pickoff Tap (cm)
1	50.340	1.169	1.98	7.92
2	50.529	1.167	1.97	7.90
3	50.718	1.160	1.96	7.87
4	50.907	1.159	1.96	7.85
5	51.096	1.154	1.94	7.82
6	51.285	1.146	1.95	7.80
7	51.473	1.144	1.94	7.75
8	51.662	1.139	1.93	7.72
9	51.851	1.136	1.93	7.70
10	52.040	1.131	1.92	7.67
11	52.229	1.127	1.91	7.65
12	52.418	1.124	1.91	7.62
13	52.606	1.123	1.90	7.59
14	52.795	1.116	1.89	7.57
15	52.984	1.111	1.88	7.54
16	53.173	1.106	1.88	7.52

3. COMPARISON OF DATA

The superiority of this analyzer over the best similar commercial unit is demonstrated in Figure 2. These oscilloscope traces (linear intensity vs. frequency) were taken simultaneously for the conventional spectrum analyzer (a and b) and for our parallel processing analyzer (c and d). Common to both analyzers was a 7-dB noise figure preamplifier. These spectra were obtained for weak signal conditions (backscattering from "clear air" aerosols at 100 m range). The conventional analyzer was operated at 100 ms per scan to be consistent with the 100-ms time constant of our parallel filter system. At least 7 dB of the 11.5 dB loss in S/N ratio inherent in the conventional analysis was recovered in our parallel analysis.

Trace 2(b) shows unity S/N, while trace 2(d) has approximately 8 dB S/N. The apparent noise on the higher frequency portion of the spectrum in 2(c) and 2(d) is long-term differential thermal drift, which may be subtracted from the data mathematically or eliminated with improved electronic design. The multiple traces reflect the intermittency of the scattered signal, smoothed by the 0.1-sec time constant of the detector.

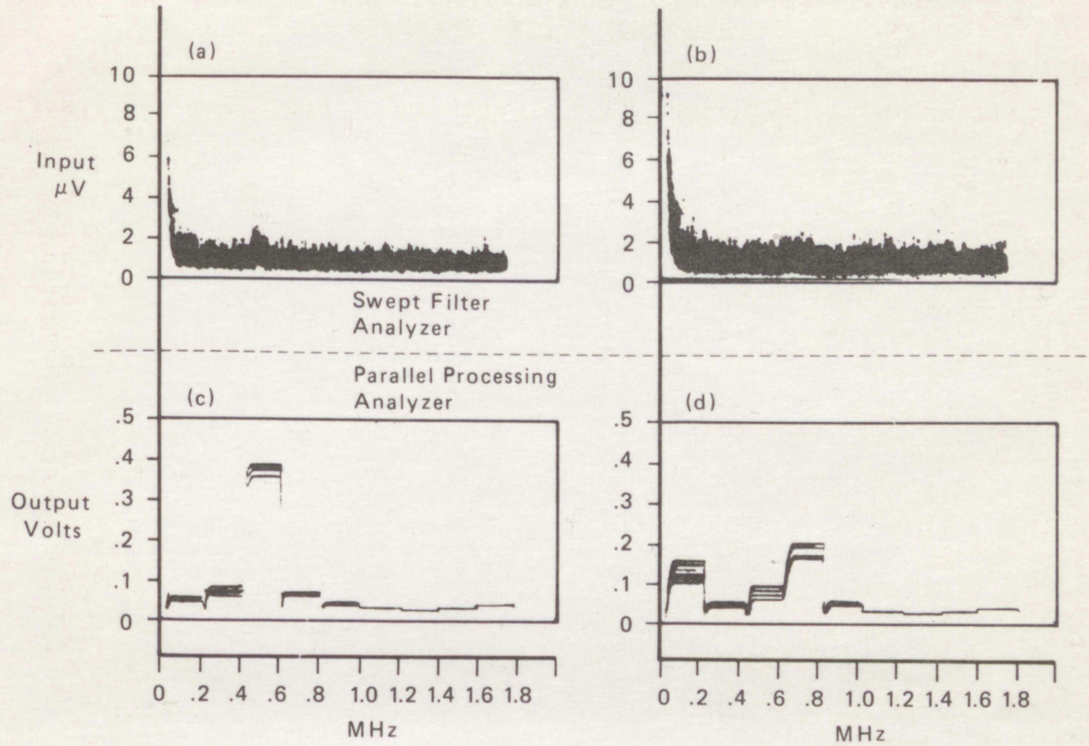

Figure 2. Spectra processed by serial (a,b) and parallel (c,d) analyzers.

The frequency stability of the filter bank has been tested over a period of several months and has been excellent. Still to be performed is extensive field calibration of the entire analyzer to determine the effects of temperature, humidity, or other operating conditions on the produced spectra. However, with only rezeroing of the individual d.c. amplifiers for changes in ambient temperature, the analyzer has performed satisfactorily in the field. Therefore, if versatility is not required, this type of analyzer offers specific advantages over conventional analyzers, in terms of both signal-processing efficiency and cost.

4. ACKNOWLEDGMENTS

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