RADAR BACKSCATTER FROM RAIN

Meteorological phenomena can seriously limit radar performance. The principal effects are attenuation of signals by clouds, rain, snow, and the atmosphere and production of unwanted echoes by reflection from raindrops, hail, and snowflakes. Attenuation effects become quite significant above X-band (9300 MHz), but backscatter from snow and rainfall generally dominate the detection and tracking problem at frequencies down to L-band (1300 MHz). To compound the problem, the backscatter spectrum from precipitation and chaff is broadened, mainly because of wind shear and air turbulence, limiting the ability of doppler processors to separate targets from clutter on the basis of their relative velocities.

During 1966 and 1967 the Radar Techniques Group of the Applied Physics Laboratory performed a series of experiments to describe the characteristics of rain clutter. The investigation was conducted principally by F. E. Nathanson, Assistant Supervisor of this Group, and J. P. Reilly, assisted by J. Whybrew and A. Chwastyk, who designed much of the radar equipment and programmed the control and data-processing equipment.* Efforts were concentrated on three aspects of the rain clutter backscatter phenomena: doppler spectrum spread, spatial uniformity, and frequency correlation. A coherent radar at 5800 MHz having a 1.4°, two-way beamwidth was used for these experiments.

Doppler Spectrum Spread

The doppler spectrum spread of precipitation echoes at low elevation angles is usually dominated by wind shear and turbulence. The doppler velocity spectrum variance, σ_v^2, can be approximated by the sum of the variances of the shear and turbulent components by

$$\sigma_v^2 = \sigma_{shear}^2 + \sigma_{turbulence}^2.$$

Wind shear describes the almost universal and year-round tendency of the wind velocity to change with altitude, usually increasing with height. An altitude of maximum wind velocity is always present, although it experiences seasonal changes in height and intensity. The change in wind velocity with height can often be approximated by a constant gradient. The effect of wind shear is illustrated in Fig. 1 where V_w is the wind velocity and V_r is the component of the wind velocity along the radar beam direction. If we assume that the wind velocity gradient within the beam is constant, then for a Gaussian antenna pattern the standard deviation of the velocity spectrum due to wind shear, is given by

$$\sigma_{shear} = 0.42\, k\, R\phi_2,$$

where k is the shear gradient in m/sec/km, R is the slant range in km, and ϕ_2 is the two-way, half-power antenna elevation beam width in

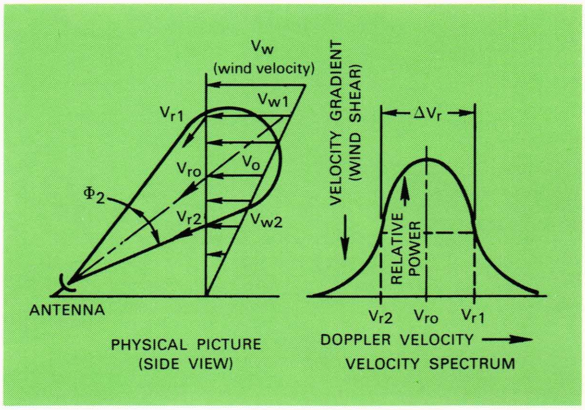

Fig. 1—Effects of wind shear on the doppler spectrum.

---

*This investigation is reported in more detail in "Radar Precipitation Echoes: Experiments on Temporal, Spatial, and Frequency Correlation," by F. E. Nathanson and J. P. Reilly, *IEEE Trans. Aerospace and Electronic Systems* **AES-4**, No. 4, July 1968, 505–514.

radians. This formula indicates that wind shear effects should dominate at long ranges.

The turbulence component, which arises from turbulent eddy currents in the wind, dominates at short ranges. This component is nearly independent of height and is not very sensitive to the dimensions of the illuminated volume. The average turbulence component lies in the range of from 0.7 to 1.0 m/sec, with the larger value applying to altitudes below 3 to 4 km.

Figure 2 summarizes measurements of σ_v taken on several days. One theoretical curve is drawn using the shear gradient k = 5.7 m/sec/km which applies when the radar points along the wind direction. Another curve is drawn using the shear gradient 4.0 m/sec/km, which serves as a useful approximation for an arbitrary radar azimuth.

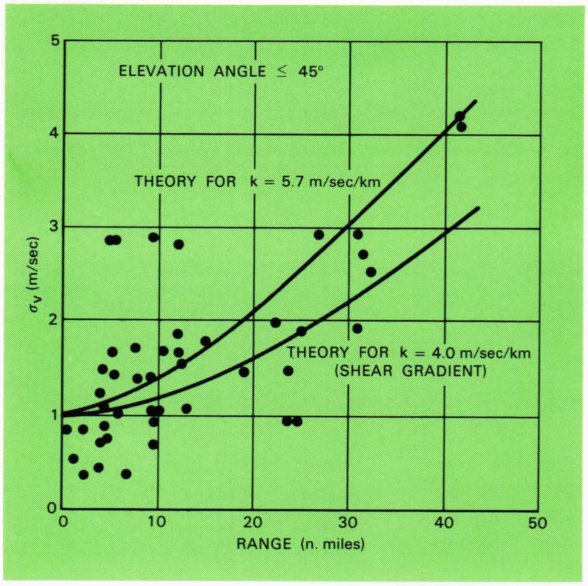

Fig. 2—Spectrum standard deviation for rain echoes—composite graph from several tests.

Because of the range dependence of the clutter doppler spectra, techniques that distinguish targets from clutter by virtue of differences in their doppler spectra are also range dependent. One effect is that the clutter rejection ability of a moving target indicator generally degrades as range is increased.

Spatial Uniformity of Precipitation Echoes

Many techniques proposed for detection of targets in clutter depend on the clutter being spatially uniform. To measure spatial uniformity, "rain profiles" were taken by transmitting a pulse train and fixing a range gate at a selected minimum range. The magnitudes of the amplitude of the echoes from 100 to 200 pulses were added and the sum stored in a digital computer. The range gate was then moved 1/2 to 1 pulse length, and the procedure repeated. This process, which took from 10 to 60 seconds, was continued until the desired profile was obtained.

Figure 3 illustrates the nonuniformity in the backscatter from a heavy "uniform" rain as a function of slant range. Similar graphs from other rainstorms show even less uniformity. The data in the figure were adjusted to compensate for the known range dependence of backscatter power and scattering volume. A noteworthy feature is the "bright-band" effect which produces a marked increase in backscatter in a narrow altitude range near the freezing level, in this case about 11,000 ft. The "bright-band" arises from backscatter from snowflakes which acquire a coating of water as they fall through the level at which melting occurs. The coating of water increases the dielectric constant and results in a greater reflectivity over that from either rain or snow. Aside from the "bright-band" effect, the variations in the backscatter coefficient show that the assumption of uniform backscatter is usually unwarranted.

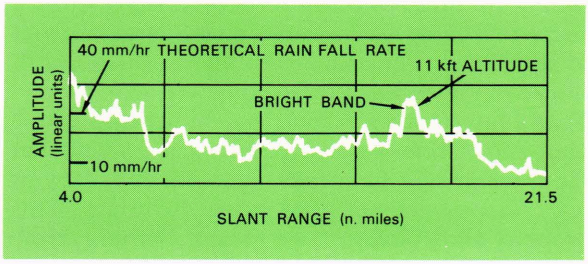

Fig. 3.—Heavy uniform rain backscatter coefficient with bright band.

Frequency Correlation of Precipitation Echoes

In many radar applications it is desirable to get a good estimate of the mean value of rain or snow backscatter in as short a time as possible in order to establish a detection threshold. This can be accomplished if a large number of statistically independent echoes from successive pulses can be detected and summed. However, the difficulty in doing this rapidly at a fixed frequency is that the precipitation echoes remain correlated for a number of milliseconds. Thus, a long time would be required to obtain statistically independent or uncorrelated echoes. By shifting the transmission frequency it is possible to obtain the results in a much shorter time. The extent to which a set of echoes resulting from a certain transmitted frequency is correlated with another set whose frequency has been shifted by Δf is described by the frequency correlation function, $\rho(\Delta f)$, which can be written as

$$\rho(\Delta f) = \left(\frac{\sin \pi\tau\Delta f}{\pi\tau\Delta f}\right)^2,$$

where τ is the pulse duration. The transmissions are assumed to be rectangular pulses occurring very closely in time with the echoes arising from a single reflecting volume containing a large number of scatterers. The experimental values of $\rho(\Delta f)$, shown in Fig. 4, agree reasonably well with theory. To obtain statistically independent samples of the backscatter from a given volume, it is evident that the transmission frequency must be shifted by at least the inverse of the pulse duration. This property allows information to be gathered rapidly by frequency shifting instead of by observing at a single frequency for a long time. Frequency stepping may enhance the performance of some techniques, such as post-detection integration, in which numerous statistically independent clutter samples are desired.

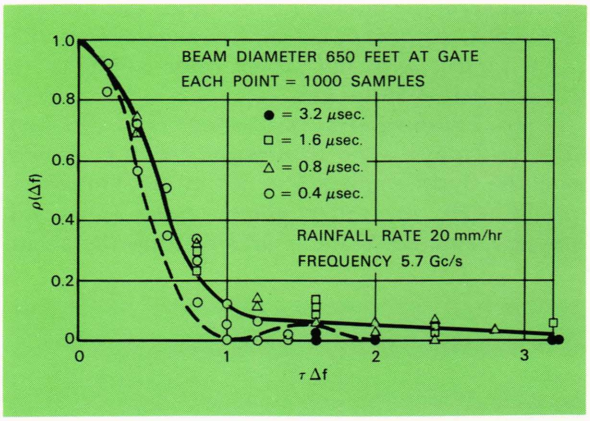

Fig. 4—Frequency correlation coefficient of rain echoes.

ADDRESSES

Principal recent addresses made by APL staff members to groups and organizations outside the Laboratory.

A.A Westenberg, "Applications of ESR to Gas Phase Kinetics," Chemistry Colloquia at *Harvard University,* Jan. 4, *Catholic University,* Jan. 16, and *Princeton University,* Apr. 16, 1968.

N. Rubinstein, V.G. Sigillito, and J.T. Stadter, "Upper and Lower Bounds to Bending Frequencies of Non-Uniform Shafts and Applications to Missiles," *38th Symposium on Shock and Vibration,* St. Louis, Mo., May 1-2, 1968.

T.G. Bugenhagen, "Using the Enemy's Cost and Effectiveness to Weight Threats," *Spring Meeting, Operations Research Society of America,* San Francisco, Calif., May 1-3, 1968.

W.H. Avery, "Integrated Urban-Suburban Transportation System," *National Capitol and Baltimore Sections, American Institute of Aeronautics and Astronautics, Applied Physics Laboratory,* Howard County, Md., May 16, 1968.

G.L. Dugger, "Supersonic Combustion Ramjets," *AIAA Section, Colorado State University,* Denver, Colo., May 24, 1968.

D.M. Howard, "A Torsion Wire Damper for the DODGE Satellite," *Third Aerospace Mechanisms Symposium, Jet Propulsion Laboratory,* Pasadena, Calif., May 24, 1968.

P.M. Bainum, W. Stuiver, and R.E. Harkness, "Stability and Deployment Analysis of a Tethered Orbiting Interferometer Satellite System," *Eighth European Space Symposium,* Venice, Italy, May 27-29, 1968.

E.A. Bunt, "Plasma Arc Heating for Hypersonic Flight Simulation," *Mechanical Engineering Dept., University of Natal,* Durban, South Africa, May 27-June 3, 1968.

R.E. Fischell, "Spacecraft Control Systems," *International Colloquium on Attitude Evolution and Satellite Stabilization, Centre Nationale d' Etudes Spatiales,* Paris, France, May 28-31, 1968.

W.J. Moore, "Proposed Specification for Error Signals Resulting from Common Mode Voltage in Passive Signal Handling Equipment," *14th National Aerospace Instrumentation Symposium,* Boston, Mass., June 2-5, 1968.

R.E. Hicks, "Substrates for Large Scale Arrays," *National Electronic Packaging Conference (NEPCON),* New York, N.Y. June 4-6, 1968.

D.D. Zimmerman, "Trends in Techniques for Thin Film Large Scale Hybrid Arrays," *National Electronic Packaging Conference (NEPCON),* New York, N.Y., June 4-6, 1968.

C.J. O'Brien, "Management Newsletters," *Workshop, International Council of Industrial Editors,* Dallas, Texas, June 10, 1968.

C.J. O'Brien, "Employee Communications in the United States," Address to a Delegation of the *Japanese Federation of Employer Associations,* Dallas, Texas, June 12, 1968.

K. Moorjani and C. Feldman, "Optical Constants of Amorphous Boron," *Third International Symposium on Boron,* Warsaw, Poland, June 25-29, 1968.

R. M. Fristrom, "Molecular Beams and Chemical Problems," *Physkalische Institut,* Bonn, Germany, July 10, 1968.