infrared frequencies for other metals. The ratio obtained at 890 GHz is 2.2 to 1. The scatter of measurements lie within ± 20 percent, although the limitations outlined suggest that the uncertainty in the actual value may be somewhat greater than this. Improvements in measurement technique and geometric arrangements will reduce this uncertainty.

The technique should be applicable for the measurement of surface resistivity of many metals over the short-millimetric to optical region. A preliminary measurement with an He–Ne laser has been made and has given a value of 8 Ω/square for gold, also shown in Fig. 6. In this region of the frequency spectrum the assumed formulas are questionable. By an appropriate arrangement, the absolute measurement of surface resistivity should be possible.

The modified pyroelectric detector arrangement with a metal front surface of known reflectivity should find use for the absolute measurement of submillimetric power at microwatt levels. This proposal is being investigated.

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Reflectivity of Common Materials in the Submillimeter Region

M. D. BLUE AND S. PERKOWITZ

Abstract—**The appearance of an illuminated scene at submillimeter wavelengths is determined by surface reflectivity. Reflectivities of some man-made and natural materials have been measured. The results provide some insight for evaluating possible applications of submillimeter radiation.**

INTRODUCTION

THE gradual realization of practical submillimeter-wave sources, including optically pumped lasers throughout the submillimeter region [1], and relativistic electron-beam devices [2], gives rise to the possibility of practical terrestial systems operating within the atmospheric windows [1]. Systems calculations are handicapped by a lack of data concerning dielectric properties of common materials in this spectral region. Recent transmission data and active imaging experiments indicate the potential utility of this technology [3]. The work reported here represents an initial attempt to characterize the far-infrared submillimeter reflectivity of common materials, and can be used as a guide for initial estimates of system performance. The contrast expected in imaging systems in this wavelength region between man-made and natural objects is of interest and is difficult to predict. In addition to military applications, several applications for civil systems might be envisioned, such as a system for locating and identifying aircraft on remote airport taxiways and runways during periods of severe weather.

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M. D. Blue is with the Georgia Institute of Technology, Atlanta, GA 30332.
S. Perkowitz is with Emory University, Atlanta, GA 30322.

EXPERIMENTAL METHODS

The room-temperature reflectivity measurements employed a modified Grubb Parsons Mark II Fourier-transform spectrometer [4]. Light-pipe optics carried the radiation to a sample holder which was open to the atmosphere so that the sample could be studied under natural conditions. Conventional disiccant and a constant flow of dry nitrogen gas were used to eliminate water-vapor absorption from the sample light pipe and holder and the remainder of the spectrometer was evacuated. The radiation impinged on the samples at an angle of 12°, negligibly different from normal incidence. The sample holder was mounted horizontally to accomodate loose samples such as sand. The detector was a Unicam quartz-window Golay cell with the usual polyethylene filtering. All data were taken at a resolution of 8 cm^{-1}. A sample in/sample out

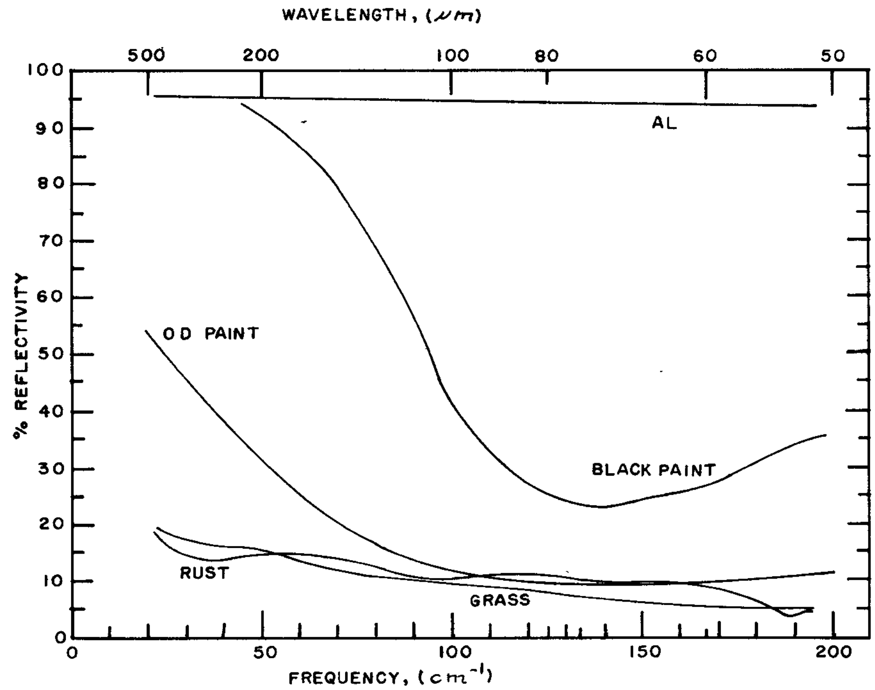

Fig. 1. Normal reflectivity in percent for common materials. Included are a normally oxidized aluminum surface (Al), aluminum sprayed flat-black paint (Black Paint), olive-drab paint on brass (OD Paint), a freshly cut blade of grass (Grass), and a rusty iron surface (Rust).

TABLE I
FAR-INFRARED REFLECTIVITY OF SOME COMMON MATERIALS

Natural Materials	
Sand	2% (overall reflectivity 20-200 cm^{-1})
Soil	2% (overall reflectivity 20-200 cm^{-1})
Wood	
Oak, Mahogany, Fir	2% (overall reflectivity 20-200 cm^{-1})
Rosewood	5% (overall reflectivity 20-200 cm^{-1})
Leaf	
Maple - fresh, dry (green); Grass - fresh, dry (green)	See text, 20% (at 100 cm^{-1})
Man Made Materials	
Asphalt	5% (overall reflectivity 20-200 cm^{-1})
Painted metal	
Flat black on Al, Army OD on brass, Rusted iron, Oxidised Al	Refer to Fig. 1.
Concrete	Similar to Rusted Iron

method was used to obtain the reflection coefficient, with the reference value supplied by a polished stainless-steel mirror. Such a mirror has a nearly constant far-infrared reflectivity of about 97 percent and so can be treated as a 100-percent reflector with little error.

EXPERIMENTAL RESULTS

A list of materials examined in this study is presented in Table I. Both natural and man-made materials were considered. Natural materials include typical surfaces as seen in earth backgrounds. Man-made materials include asphalt and concrete as well as metal surfaces.

The normal reflectivities for several metal surfaces as well as for grass are shown in Fig. 1. It can be seen that flat-back paint on aluminum reduces the reflectivity to a value below that of a normally oxidized aluminum surface in the submillimeter region. Similarly, flat olive-drab paint reduces the reflectivity of clean brass which, like all high-conductivity materials, has very high reflectivity throughout this region. However, these two paints have quite different spectra.

For many natural surfaces, it is likely that the surface-scattering effects dominate the reflectivity. For example, the reflectivity of concrete closely parallels rusty iron over this spectral region. As these materials are quite different, it is possible that the normal reflectivity is dominated by surface-roughness effects.

Fig. 2 shows the reflectivity spectra for several of the organic materials examined in this study along with the reflectivity of concrete. Fresh grass shows a reflectivity which is typical of several of these materials. Reflectivity of dry grass was similar, both samples showing a decrease in reflectivity from near 20 percent at 20 cm^{-1} to 3 percent at 200 cm^{-1}. As shown in Fig. 2, a dry maple leaf has a modest peak in reflectivity of 16 percent at 100 cm^{-1} dropping to 10 percent at 50 and 150 cm^{-1}. This peak did not appear in the fresh specimen. Reflectivity measurements on the organic materials did not show any obvious correlation with chlorophyll transmission spectra where a strong structure at 200 cm^{-1} has been observed [5].

In general, all organic samples along with sand, mud, asphalt, and concrete have lower reflectivities than the

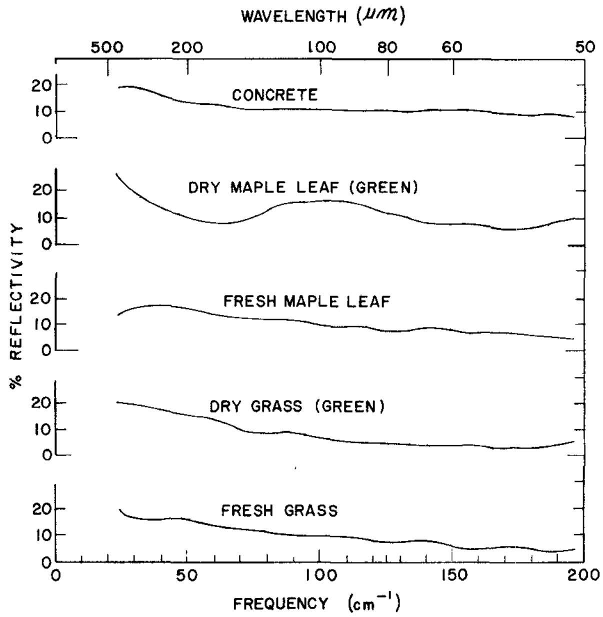

Fig. 2. Normal reflectivity in percent for typical organic materials, and a concrete surface for comparison. Both fresh and dried samples of the same specimens are shown. A rise in reflectivity going toward small wavenumbers was a typical trend for these samples.

metal and painted metal surfaces examined within the limited scope of this study.

Summary and Discussion

This study examined normal reflectivity for a small group of natural and man-made samples from 20 to 200 cm^{-1} at room temperature. Many interesting questions are raised by these data which suggest several directions for further work. Among these are extensions to longer wavelengths, off-axis reflection, temperature effects, and additional samples. The transition between reflectivity related to the metal and reflectivity characteristic of the surface paint takes place in the submillimeter region in our metal samples, and additional data would be helpful. For the painted surfaces shown in Fig. 1, the increase in reflectivity at long wavelengths could be related more closely to paint thickness than dielectric properties. The olive-drab paint layer was much thicker than the layer of black spray paint, and the shift to higher reflectivity occurs at an appropriately longer wavelength.

For more a complete characterization of the optical properties of common materials, it would be helpful to make transmission as well as reflection measurements. A high-power optically pumped laser is especially useful for precise transmission work. Such a laser has been used to measure the transmission of liquid water [6] which plays an important role in our natural samples. Recent preliminary results show that fresh leaf can transmit as much as 7 percent between 39 and 104 cm^{-1} [7].

The most significant result to date appears to be the clear separation in the value of normal reflectivity between metal surfaces and typical natural materials representative of terrestrial backgrounds. This result suggests that detection and imaging systems operating in this wavelength region can distinguish man-made objects from their backgrounds.

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