EXPERIMENTER'S CORNER

By Forrest M. Mims

Remote Sensing—Part 2

LAST month, we discussed the basics of remote sensing. We also assembled a dual-wavelength green-leaf detector which relies upon the unique *reflectance signature* of green vegetation.

Leaves, as you might recall, reflect red light poorly but reflect near-infrared radiation very well. This generates a characteristic reflectance signature which makes it possible to use a red LED and a near-infrared LED as a pair of narrow-band radiation *detectors*. This is done in the leaf-detector circuit described last month in Part 1 of this series.

NASA's Image Classification Circuit. An expanded version of the leaf-detector circuit has been developed for NASA's Langley Research Center by Roland L. Hulstrom, Roger T. Schappell and John C. Tietz of the Martin Marietta Corporation. Like the circuit I described, NASA's circuit also teams a red sensor and a separate near-infrared sensor to detect green vegetation. Moreover, these two detectors also permit the detection of water, bare land, clouds and snow.

Figure 1 is the schematic for this new circuit as given in a recent NASA Tech Brief. The circuit, an expanded version of which is slated to be flight-tested aboard one or more Space Shuttle missions, is designed to automatically reduce the quantity of unwanted imagery transmitted to earth from camera-carrying earth satellites.

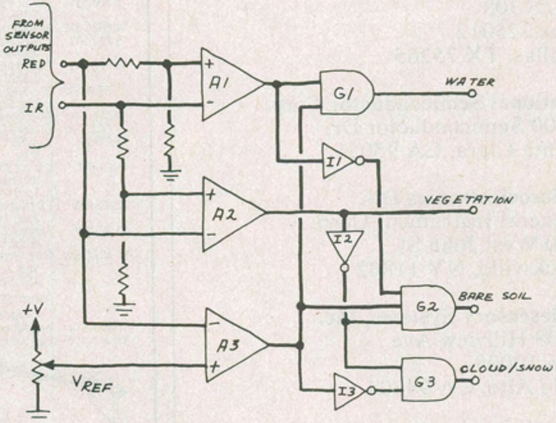

Fig. 1. Earth satellite picture classification circuit.

NASA explains the objective behind the design of the new circuit as follows. Earth-observation satellites generally do not make decisions about the usefulness of the data being sent to earth. As a result, a significant amount of time and money is spent in sorting out the useful data. A great saving could be realized if circuits aboard the satellite could recognize useless imagery or actually look for specific features. The circuits do not have to be very smart to be useful. For example, about 70% of the earth's surface is water. Of the 30% that is not water, about one-third to one-half will be obscured by clouds at any given time.

This means that a satellite might get one clear picture of land out of perhaps five or six observations. The amount of unwanted, more or less useless data that is stored, processed and indexed could, therefore, be greatly reduced by a circuit that simply blocked transmission of the 80% of the images that is of water and clouds.

A simple circuit has been developed to classify picture elements by spectral signature alone. No pattern recognition is required. Computer simulations and field measurements have confirmed that the four basic features—vegetation, bare land, water and clouds or snow—can be separated by radiance measurements at two discrete wavelengths: 650 and 850 nm.

It's very significant that the reflectance signatures of four key topographic features can be classified by examining only two wavelengths of their reflected radiation. From last month, you already know that green vegetation has a very low reflectance at 650 nanometers—typically less than 5 percent. At 850 nanometers in the near infrared, the reflectance of vegetation is typically from 45 to 55 percent.

Soil usually has a higher reflectance at near-infrared wavelengths than in the visible portion of the spectrum. The transition between low and high reflectance is more gradual than for vegetation, and occurs in the visible region. This means that the difference in soil reflectance at 650 and 850 nanometers is not as dramatic as it is for green leaves.

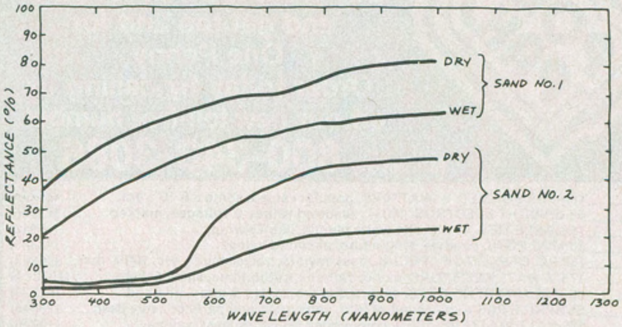

Fig. 2. Spectral reflectance of two different sands.

Figure 2 shows the reflectance curves of two highly reflective soils (actually, sands). Sand number 1 is white beach sand from Ft. Walton Beach, Florida. Sand number 2 is a darker sand from Monument Valley, Utah. Note that both sands, like all other soils, reflect less light when they are wet. These reflectance curves, and many others, can be found in "The Spectral Reflectance of American Soils" by H. R. Condit (*Photogrammetric Engineering*, Sept. 1979).

Water's reflectance at 650 and 850 nanometers is the reverse of that of leaves, because water reflects red light but absorbs near-infrared wavelengths. Clouds and snow have much higher reflectances than soil, but the differences in reflectance at 650 and 850 nanometers are similar to that of some soils.

Remarkably, the two wavelengths selected by NASA for its Image Classification Circuit are very close to the optimal detection regions of the GaAsP LED (650 nanometers) and the new (AlGa)As "super" LED (880 nanometers). A practical version of NASA's circuit can be made by using two such

LEDs as detectors. The green-leaf detector circuit described last month shows how LEDs can be coupled to a circuit like the one shown in Fig. 1.

A detailed report on NASA's image-classification circuit is available for $6.00 (paid in advance) from the National Technical Information Service, Springfield, VA 22161. The report is entitled "Experimental and Simulation Study Results for Video Landmark Acquisition and Tracking Technology" (NASA CR-158997). Request the publication by name and by the identification number LAR-12589.

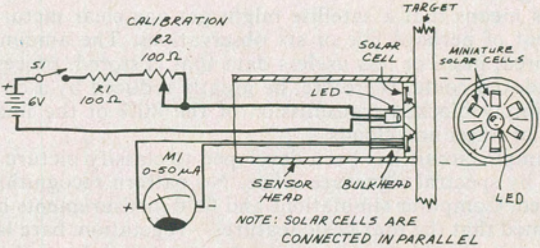

Fig. 3. Construction of a simple, low-cost reflectometer.

An Inexpensive Narrow-Band Reflectometer. Sometimes, it is important to know the reflectance of an object at only one wavelength. Since 1970, I have measured the reflectance at 940 nanometers of scores of different objects. These measurements make possible the accurate prediction of the detection range of various infrared travel aids for the blind.

Soon, I plan to repeat many of these measurements at the 880-nanometer wavelength emitted by the new, (AlGa)As high-power emitters. I will use the simple reflectometer illustrated in Fig. 3. This ultrasimple system requires no sophisticated electronics. The reading on the 0-to-50-µA meter is doubled to obtain the target's reflectance in percent.

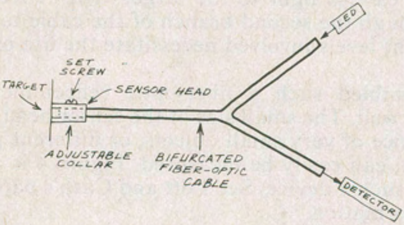

Fig. 4. How to build a fiber-optic reflectometer.

To make a reflectance reading, the sensor head is first placed against a Kodak photographic test card or a similar target with a known reflectance. The CALIBRATION potentiometer is adjusted until the reference target's reflectance is indicated on the meter. If, for example, the reference target has a reflectance of 90 percent (as does the Kodak test card), the CALIBRATION control should be adjusted for a meter reading of 45 μA.

You need not duplicate exactly the arrangement shown in Fig. 3 to make a working reflectometer. To reduce erroneous readings to a minimum, the solar cells should be mounted in a ring around the source LED. It is important that ambient light be kept away from both the target and the solar cells when measurements are being taken.

When making a measurement, place the sensor head firmly against the target. The output of the LED will fluctuate with changes in temperature and battery voltage, so the circuit should be recalibrated just before each reading is taken.

L. A. Lott and D. L. Cash have described a more sophisticated reflectometer in a paper entitled "Spectral Reflectivity Measurements Using Fiber Optics," which appeared in the April 1973 issue of *Applied Optics* (pp. 837-840). In their device, one branch of a "Y"-configured, *bifurcated* fiber-optic cable carries light to the target. The reflected light is carried through the second branch of the cable to a detector. The low light levels involved necessitate the use of a detector amplifier.

I've assembled such a fiber-optic reflectometer, and it works quite well. The small size of the sensor head means that the reflectance of very small objects, or different parts of the same object, can easily be measured. Figure 4 is a simplified diagram of such a device. See Lott and Cash's paper for more detailed information.

Remote Sensing of Water Vapor. If you read the "Solid-State Developments" in the February 1981 issue of this magazine, you may recall that 940-nanometer radiation is strongly absorbed by water vapor in the atmosphere, but that absorption at 880 nanometers is negligible. This provides a characteristic signature which permits the remote sensing of water vapor by dual-wavelength *transmission spectroscopy*.

Figure 5 is a simple circuit I've designed to demonstrate this method of detecting water vapor. It is a dual-wavelength transmission spectrometer with an audio output.

In operation, a GaAs:Si 940-nanometer emitter and an (AlGa)As 880-nanometer emitter are both pointed at a silicon phototransistor that drives an amplifier. The two LEDs are alternately driven by pulses with a duty cycle of 50 percent that are generated by an astable multivibrator made from two of the four NAND gates in a 7400.

Initially, the receiver will generate a tone coinciding with the pulse rate at which the LEDs are driven. The position of the silicon detector is then adjusted to null out the tone.

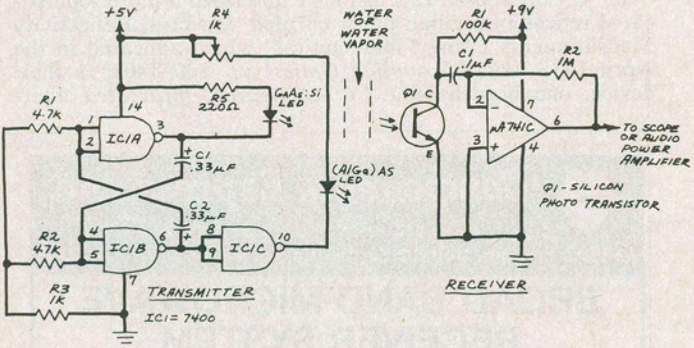

Fig. 5. Dual-wavelength water-vapor detector.

Operation of the circuit can be demonstrated by placing a small, transparent container between the two LEDs and the detector. If necessary, align the detector to cancel any tone output from the receiver. When water is poured into the container, radiation from the 940-nanometer LED will be suppressed, but that from the 880-nanometer emitter will be largely unaffected. Consequently, the null condition will be disturbed and a tone will be emitted by the receiver.

This simple circuit proves that an 880-nanometer LED can be teamed up with a 940-nanometer LED to detect water. Detecting water *vapor* is more difficult, but it can be done. One way to demonstrate the detection of water vapor is to allow steam to pass between the two LEDs and the silicon detector. More sophisticated versions of this dual-wavelength circuit are possible, but I will leave their design to those of you interested in remote sensing.

Summing Up. In this two-part series, we have only touched upon the field of remote sensing. Although you might not derive much practical benefit from the circuits with which we have experimented, you should now have a better appreciation of how some remote-sensing devices operate.

Remote sensing is an excellent subject for science-fair projects and low-cost research. Many good articles and some books on the subject have been published. For more information, visit a good technical library. Perhaps you will be able to design a simple remote sensor for detecting soil moisture or crop diseases. ◇