Remote Sensing—Part 1

ALL matter emits, absorbs, and reflects different wavelengths of electromagnetic radiation, each type in its own unique fashion. The combination of these properties provides an electromagnetic "signature" which permits various kinds of sensors to identify unknown matter from afar.

The study of electromagnetic signatures has given rise to the method of observation and measurement called *remote sensing*. In this two-part discussion, we will consider several types of remote sensing and describe the assembly of some circuits which can identify a portion of the electromagnetic signatures of various man-made and natural objects.

Elements of Remote Sensing. In its broadest sense, remote sensing is the perception of an object from a distance by means of a suitable sensing device. By this definition, observation devices ranging from the human eye to telescopes, cameras, and spectroradiometers are remote sensors.

Effective remote sensing usually requires that the sensor be capable of distinguishing a range of wavelengths emitted by, reflected from or transmitted through the object or matter being sensed. Photography, an early and still important remote-sensing method, provides a good illustration of the importance of spectral sensitivity.

A black-and-white aerial photograph, for example, displays as various shades of gray all the wavelengths to which the film is sensitive and which are emitted from or reflected by the matter within the camera's field of view. Such a black-and-white photograph can convey a considerable amount of information, but a *color* aerial photograph simplifies the location of man–made structures and can even permit the identification of various kinds of vegetation.

The use of black-and-white film in remote sensing can be made more productive by exposing the emulsion through a narrow-bandpass optical filter. Several such black-and-white photos of the same scene, each exposed through a different filter, can be superimposed to provide as much or even more information than a color photograph.

Another important form of remote sensing was developed in the last century when astronomers used glass prisms and diffraction gratings to break up the light from distant stars into its component parts. Hot gasses, whether on earth or in a star, emit characteristic wavelengths of radiation. Astronomers learned how to determine the composition of stars by analyzing the spectra of their emissions. *Spectrometry*, as this research tool is called, has become far more sophisticated in recent years due to the development of more sensitive equipment. The basic technique, however, remains unchanged.

Remote-Sensing Methods. Figure 1 illustrates four important remote-sensing methods. The *passive reflection* method is probably the most widespread. In this method, the object being observed, called the *target*, reflects ambient radiation emitted by the sun or a nearby source of artificial light. The *active reflection* method is more specialized, because in it the target is illuminated by a source of artificial light designed specifically for this purpose. In both of these methods, target characteristics can be determined by the way various wavelengths are reflected.

The *emission* method is totally passive and relies only upon radiation emitted by the target. So long as the detector is sufficiently sensitive, this method will detect *anything* from ice cubes to stars, for all matter at a temperature greater than absolute zero emits electromagnetic radiation. It permits the temperature of a target to be determined from afar. Also, if the target is heated to incandescence, the characteristic spectral lines it emits permit its constituents to be identified.

The *transmission* method, which is commonly used to detect dust, gases, precipitation and other matter in the earth's atmosphere, requires a separate source and detector. Sometimes, the source can be the sun or some other natural or artificial light source suitably placed with respect to the target. Generally, however, the source is designed specifically for the purpose. In any case, the target can often be identified by the way it absorbs and scatters different wavelengths of light.

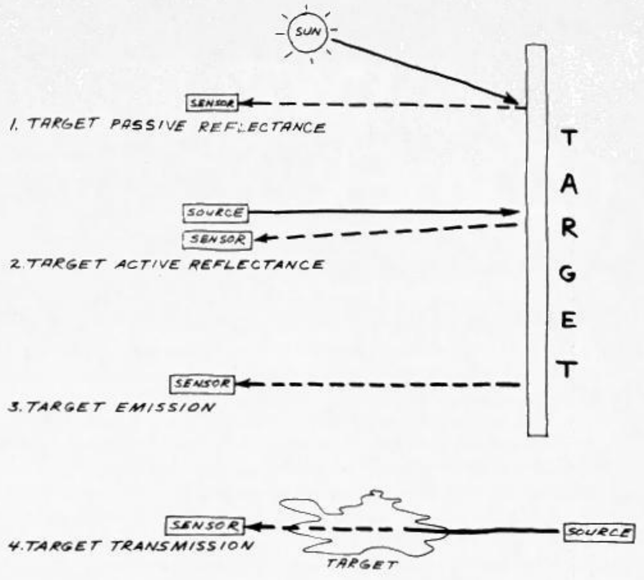


Fig. 1. The principal kinds of remote sensing.

Many variations on these basic methods are possible. For example, the active-reflection method may employ a wide-band, "white" light source and a single detector, before which various narrow-bandpass filters are placed. While the detector is pointed at a fixed target (which is illuminated by the source), detector-output measurements are taken each time a different filter is moved into position.

Alternatively, the filters can be placed before the light source. Another variation is to eliminate the filters entirely and illuminate the target with a narrow-band source such as a laser. If necessary, sunlight or artificial ambient light can be blocked by a suitable narrow-bandpass filter placed in front of the detector.

As you can see, there are many ways to implement remote sensing. We will first consider active- and passive-reflection remote sensing, two methods which are also known as *reflection spectroscopy*.

Reflection Spectroscopy. I first became interested in reflection spectroscopy while evaluating the performance of various kinds of infrared travel aids for the blind. To predict the range of such a device, it is necessary to know the optical reflectance of many different materials at the wavelengths employed by the aid. The most common wavelengths are 880 and 940 nanometers in the near infrared. Very efficient, powerful LEDs which emit radiation at these wavelengths are readily available.

Figure 2, for example, shows the spectral reflectance of a typical green leaf. This plot nicely illustrates how well such leaves reflect incident radiation at near-infrared wavelengths. It also shows that a leaf has a distinctive *reflection signature*. Chlorophyll, the key chemical constituent of green plants, readily absorbs blue and red wavelengths. The small peak in reflectance at 550 nanometers produces the characteristic coloration of photosynthetic plant life.

The much larger peak beyond 700 nanometers is in the

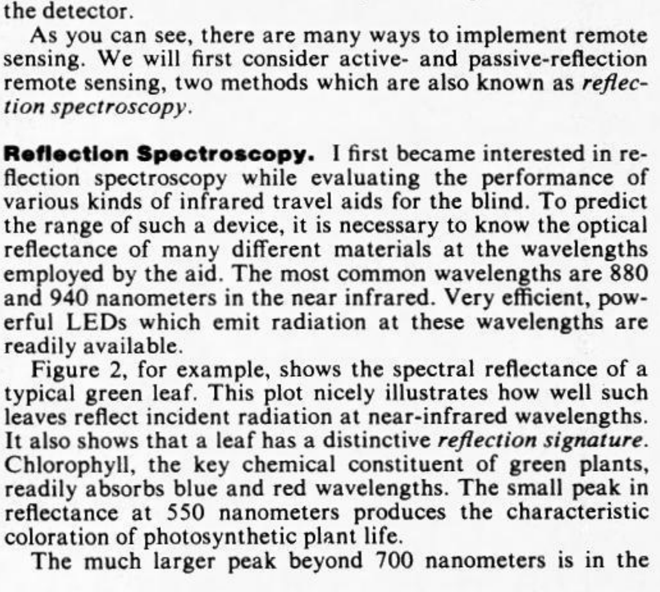


Fig. 2. Spectral reflectance of a typical green leaf.

near infrared, and is therefore invisible to the unaided eye. This spectral region, however, is readily detectable by means of infrared film or an infrared image converter such as a starlight scope. The peak explains why vegetation appears bright white on infrared film or when viewed through an infrared-to-visible-light image converter.

The large difference in reflectance values at 650 nanometers and in the 750-to-1200-nanometer band means that a GaAsP red LED and an (AlGa)As or GaAs:Si near-infrared emitter can be used in their light *detector* (either reverse-biased or photovoltaic) mode as the heart of a detector circuit which indicates the presence or absence of green vegetation. As you may recall from previous columns, LEDs make excellent narrow-band detectors.

The same result can be achieved with two silicon detectors, one covered with a 600-to-670-nanometer bandpass filter, the other covered with a near-infrared bandpass filter. This approach, however, is more expensive—suitable filters may cost as much as $50 or more.

Using LEDs to Detect Vegetation. To determine if a GaAsP LED could be teamed with a GaAs:Si LED to detect green vegetation, I tried an experiment that you might want to duplicate. In this experiment, I used the variable-gain operational amplifier shown in Fig. 3.

First, a GaAsP LED enclosed in a clear (*not* diffuse) red encapsulant was connected to the input of the amplifier. The diode was then pointed at the white side of a Kodak Neutral Test Card (available at most camera stores) which was illuminated by a single incandescent lamp. All other lights were extinguished.

The Kodak test card has a reflectance of 90 percent in the visible and near-infrared regions of the spectrum. Therefore, I adjusted *R1 and* the distance of the light from the card to achieve a meter reading of 0.9 milliamperes. I then removed the card and placed a fresh leaf from a Japanese ligustrum in its place. The meter indicated 0.05 milliamperes, which signifies a reflectance of 5 percent.

I then repeated this procedure with the GaAs:Si LED. This time, I measured a reflectance of 52 percent. Both reflectance measurements coincide well with published values. And though GaAsP LEDs are less sensitive than GaAs:Si LEDs, this simple experiment proved that *both* LEDs can be used in tandem to measure the reflectance of green leaves.

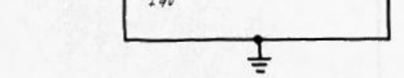


Fig. 3. Simple green detector circuit as described in text.

A Practical Green-Leaf Detector. The "truth table" for a dual-wavelength, leaf-signature detector is:

Reflectance

A **650 nm (red)**	**B** **940 nm (near infrared)**	**Leaf present?**
Low	Low	No
Low	High	Yes
High	Low	No
High	High	No

The Boolean function for this table for an active low output is

$$\left(\overline{A \cdot \overline{B}}\right)$$

(Continued overleaf)

Figure 4 shows a practical green-leaf detector circuit. As in the previous experiment, two LEDs function as narrow-band wavelength detectors.

In operation, each LED is reverse-biased and connected to a series resistor (*R1* and *R5*) across which a voltage drop appears when light striking the LED generates a photocurrent. The series resistor for the GaAsP LED (*R1*) has a much larger resistance than that for the GaAs:Si LED (*R5*) because the GaAsP LED is not as sensitive to light.

The output voltages generated by the two LEDs are applied to the inverting inputs of two comparators (*IC1A* and *IC1B*). When the light level is sufficiently high, the outputs of the two comparators go low. Otherwise the outputs remain high.

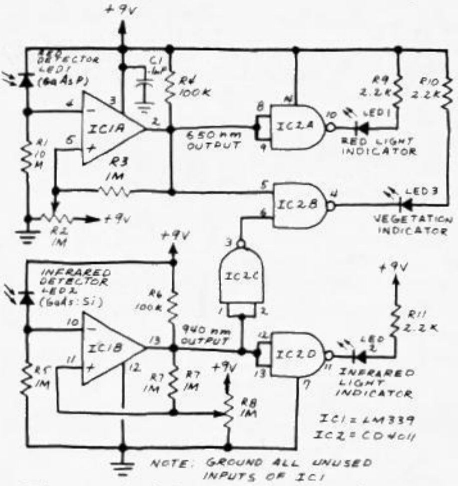


Fig. 4. Circuit for remote sensing of green vegetation.

The required Boolean function for the truth table is implemented by two of the four NAND gates in a 4011 (*IC2B* and *IC2C*). When both detectors receive reflected light from a leaf illuminated by sunlight or a bright incandescent lamp, the output of comparator *IC1A* stays high and that of *IC2B* goes low. This combination is decoded by NAND gates *IC2B* and *IC2C*, and VEGETATION INDICATOR *LED3* glows. The LED is dark for any other combination of inputs.

For preliminary work, assemble the circuit in Fig. 4 on a solderless breadboard. The two detector LEDs should be mounted next to one another and installed in an opaque housing such as a short length of heat-shrinkable tubing.

Before it can be used, the circuit must be calibrated. The calibration procedure is greatly simplified by the three LEDs. Begin by rotating the wiper of trimmer potentiometer *R2* until *LED1* just begins to glow. Then rotate the wiper of *R8* until *LED2* just begins to glow. Indicator *LED3* should now be dark.

Now place a white card a few centimeters from the two detector LEDs, and illuminate the card with a bright incandescent lamp or sunlight. Both *LED1* and *LED2* should darken, and *LED3* should remain dark. If either *LED1* or *LED2* remains on, adjust the appropriate potentiometer until the LED functions properly. If this fails to solve the problem, make sure the fields of view of the chips in each LED are not blocked by the edge of the opaque tube. Also, make sure light is not entering the rear of the opaque tube and illuminating the LEDs from behind.

The circuit is now ready for use. Leave the light source in place and remove the white card. Both *LED1* and *LED2* should glow. Then place a fresh green leaf where the card was located. Indicator *LED1* should continue to glow, and *LED2* should darken. Diode *LED3* will glow to indicate the presence of a leaf.

With careful adjustments, the circuit will detect a single leaf up to 10 centimeters away. Under the proper conditions, trees and shrubs illuminated by bright sunlight can be detected over much greater distance.

To Be Continued. Next month, we will look at a remote-sensing circuit designed by NASA to distinguish between green vegetation, bare ground, water, and clouds or snow. We will also experiment with a simple dual-LED method for detecting water vapor. ◇

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.

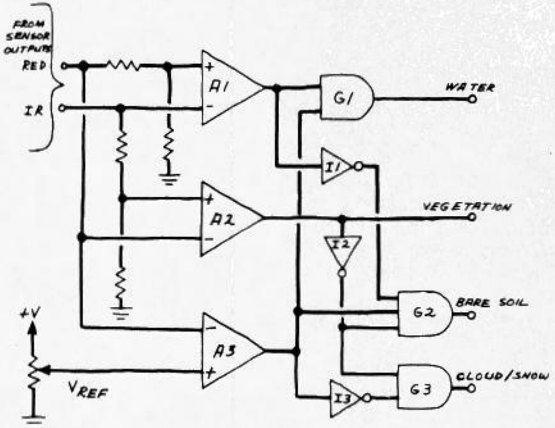


Fig. 1. Earth satellite picture classification circuit.

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.

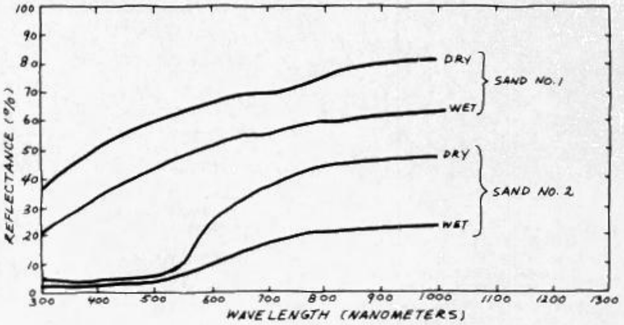


Fig. 2. Spectral reflectance of two different sands.

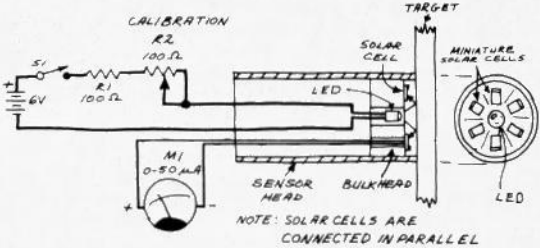
Figure 2 shows the reflectance curves of two highly reflective soils (actually, sands). Sand number 1 is white beach sand from Ft. Walton Beach, Florida. Sand number 2 is a darker sand from Monument Valley, Utah. Note that both sands, like all other soils, reflect less light when they are wet. These 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.



NOTE: SOLAR CELLS ARE CONNECTED IN PARALLEL

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.

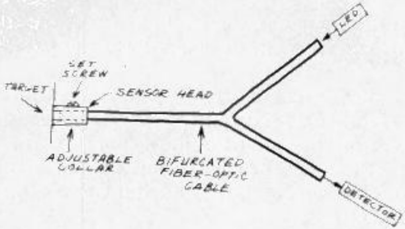


Fig. 4. How to build a fiber-optic reflectometer.

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.

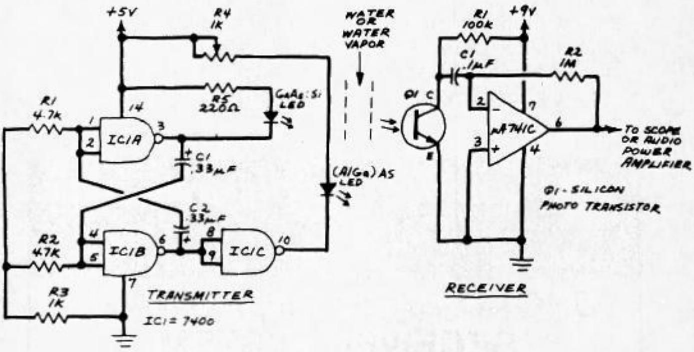


Fig. 5. Dual-wavelength water-vapor detector.

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. ◇