RADIO WAVE PROPAGATION

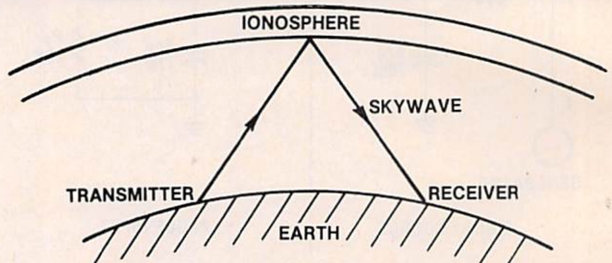

Fig. 3

THERE ARE FIVE BASIC WAYS BY WHICH A RADIO WAVE CAN travel from a transmitter to a receiver. The five *propagation modes* are space wave, surface wave, sky or ionospheric wave, scatter, and satellite transmission. The best mode for a particular communications link depends on the carrier frequency of the transmission and the distance involved.

Methods of Propagation

When the transmitter and receiver are located in *line-of-sight* of each other, with no obstruction between them, radio waves can propagate in a straight line, although a radio wave (or wave) reflected from the ground is also possible (Fig. 1).

The direct line-of-sight wave and the ground-reflected wave are known collectively as the *space wave*. Those are obviously not the only two paths of travel possible, otherwise no radio signal would reach a point such as R^{1}, over the optical horizon of the transmitter. One mode of over-the-horizon propagation is the *surface wave*, which travels in close proximity to the Earth's surface and follows the curvature of the Earth (Fig.2).

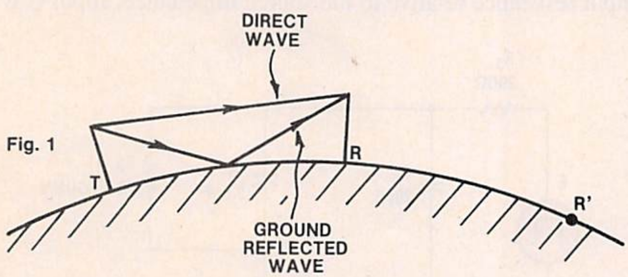

Fig. 1

Radio waves may also reach a receiver by being reflected from the ionosphere, a region of charged particles in the upper atmosphere. The radio wave, in this case, is referred to as the *sky wave*, and follows the path shown in Fig.3.

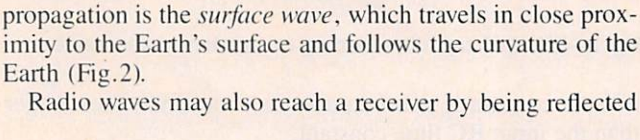

Fig. 2

In addition, radio waves can be transmitted far beyond the optical horizon by *scatter propagation*. Although not a reliable method of propagation, because of variations in the scattering properties of the atmosphere, it is used when other methods are not available.

Finally, the newest method of radio propagation involves Earth satellites. An artificial satellite placed in orbit at an appropriate height above the Earth picks up the transmitted signal, amplifies it, and then retransmits it back to Earth (Fig. 4).

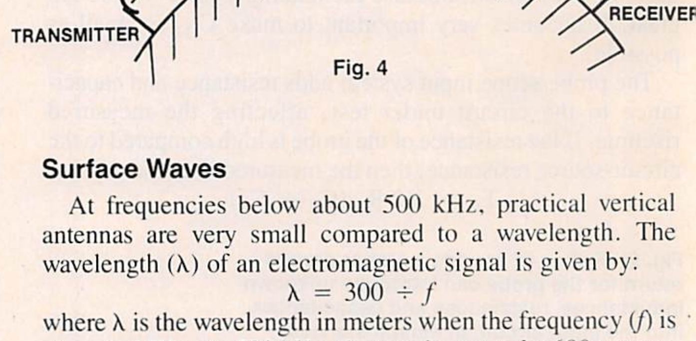

Fig. 4

Surface Waves

At frequencies below about 500 kHz, practical vertical antennas are very small compared to a wavelength. The wavelength (λ) of an electromagnetic signal is given by:

$$\lambda = 300 \div f$$

where λ is the wavelength in meters when the frequency (f) is given in MHz. At 500 kHz, that works out to be 600 meters. A full-wave vertical antenna would have to be 1,968.5 feet tall, and they are practical at selected transmitting sites only.

Practical antennas are smaller than that and, under those conditions, the wave reflected from the ground and the direct wave cancel each other out, leaving only the surface wave. A

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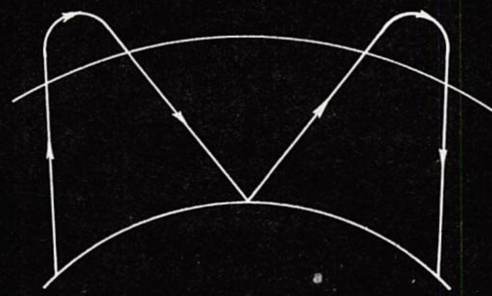
Radio propagation is considered by many to be a complex and difficult to understand subject. We unveil the simple facts and discuss the various modes by which radio signals are transmitted.

By Elmo Jansz, VK7CJ



radio wave consists of an electric field and a magnetic field. The electric field is perpendicular to the surface of the Earth and antennas used for surface wave propagation are generally vertical metal towers.

As the surface wave moves away from the transmitter, the magnetic field is cut by the surface of the Earth, and that leads to induced current being generated in the Earth's surface, which amounts to a power loss. The power is lost to the ground as the surface wave moves forward and the resultant effect is that the surface wave tilts over as it moves forward and could eventually be totally absorbed (Fig. 5).

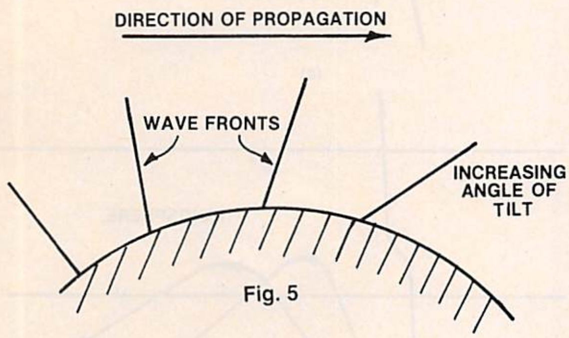


Fig. 5

The extent to which the surface wave is attenuated depends on the type of surface it passes over. When propagation takes place over sea water, which is a good conductor, and the frequency is below about 100 kHz, the surface absorption and attenuation due to the atmosphere is very small, and the angle of tilt is the only limiting factor!

The angle of tilt is directly proportional to the frequency. At the low-frequency end of the spectrum, waves are able to travel very large distances, even right around the Earth, if the transmission conditions are correct.

Frequencies in that band are, thus, particularly useful for maritime communications and worldwide time and frequency standards. Ships use about 10 to 100 kHz for navigation and communications, and shore-based time and frequency standard stations use fairly high transmitter powers—generally about 1-million watts—to reach ships at sea.

The Omega navigation system uses VLF radio waves to communicate with submarines at depths of up to 500 meters. (The submarine's towed antenna is at a lesser depth than that, however). Omega stations operate on carrier frequencies between 10 and 14 kHz. By measuring the phase differences between signals from several Omega stations, a mobile receiving station can establish its position quite accurately.

Similar considerations apply to the medium wavelengths. In such cases, the physical length of the antenna is made proportional to the wavelength, and practical quarter- and half-wavelength antennas are feasible. The amplitude-modulated broadcast bands used for domestic radio transmission are in that frequency range.

Ionospheric Propagation

The ionosphere plays a major role in transmission in the frequency range of 500 kHz to 30 MHz. The ionosphere is the upper region of the Earth's atmosphere in which gases are ionized by radiation from outer space, principally solar radiation. The region extends from about 30 km above the surface of the Earth.

The ionosphere itself is divided into several layers in which the maximum intensity of the ionization varies. These layers are designated D, E and F in order of height. During the daytime, the F layer splits into two separate layers called F1 and F2. At times, a peak electron density has been observed in the D layer, indicating that the region from 50 to 70 km above the Earth's surface could be considered as a distinct layer, the C region. Figure 6 shows a graph of electron density against height above the Earth.

Remember that Fig. 6 shows an average situation. The actual propagation conditions depend on many variables, some of the more common being time of day, seasonal influences, the latitude, and the 11-year sunspot cycle. Day-

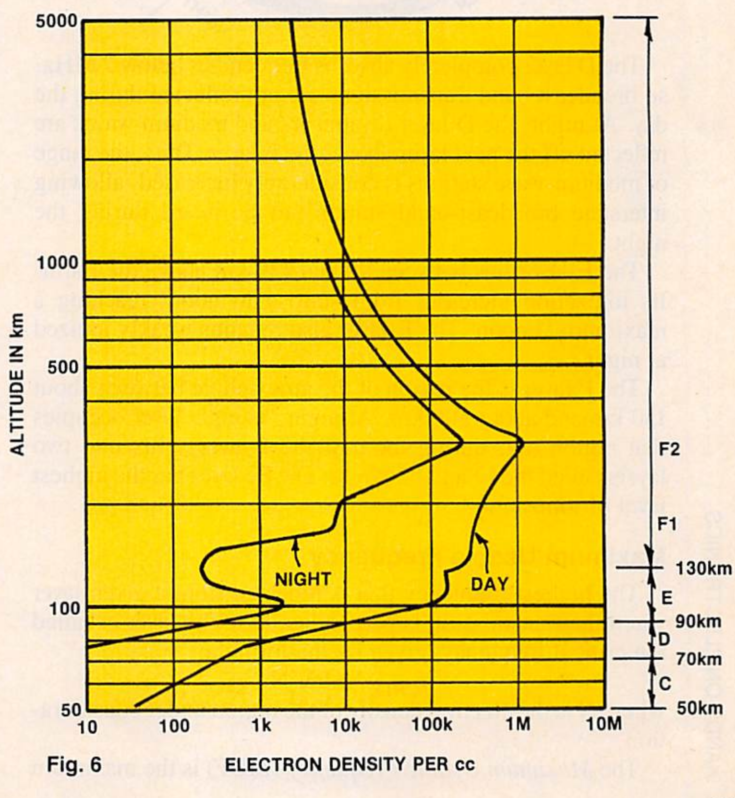


Fig. 6 ELECTRON DENSITY PER cc

to-day variations in the ionosphere are referred to as *diurnal variations*.

Let us briefly examine the mechanism that gives rise to these layers. At great heights above the Earth, the ionizing radiation is quite intense, but the atmosphere is rarified. Consequently, the few gas molecules present cannot create a significant ionization density.

As the height decreases, the atmospheric pressure and the ionization density increases until a height is reached where ionization is at a maximum. As the height is further decreased, atmospheric pressure increases but the ionization density decreases, because the ionizing radiation is absorbed in the process of ionizing the upper atmosphere.

The existence of several layers is explained by the fact that the atmosphere is made up of a mixture of gases, each of which behave in a different manner when exposed to ionizing radiation. Fig. 7 shows the relative positions of the various layers.

The D layer is the lowest of the recognized regions, lying between 70 and 90 km above the Earth. The atmosphere in that region is comparatively dense and ions rapidly recombine to form uncharged molecules. Maximum ionization is at noon, diminishing as the sun sets and vanishing completely at night.

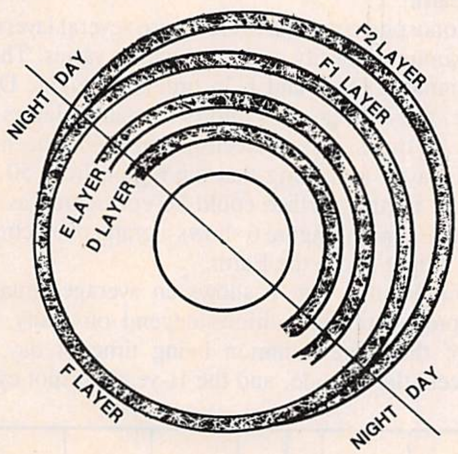


Fig. 7

The D layer completely absorbs frequencies below 2 MHz, so broadcast band transmissions are not reflected during the day. At night, the D layer disappears and medium waves are reflected off the next layer above, the E layer. Thus, the range of medium-wave stations is considerably increased, allowing interstate broadcast-band stations to be heard during the night.

The E-layer lies between 90 and 130 km above the Earth. Its ionization increases from sunrise to noon, reaching a maximum at noon. The E-layer also remains weakly ionized at night.

The F-layer is the region of the atmosphere between about 130 km and about 500 km. At night, a single layer occupies that region but, during the day, the F-layer splits into two layers called the F1 and F2 layers. The F2 layer has the highest level of ionization.

Maximum Usable Frequency

The highest frequency that is reflected from a given layer when the transmission is perpendicular to the layer is called the critical frequency, given by the formula:

$$f_{CRIT} = 9\sqrt{N}$$

where N is the electron density of the region under consideration.

The *Maximum Usable Frequency* (MUF) is the maximum frequency that can be reflected off a particular ionospheric layer. The actual frequency of transmission is generally chosen to be about 15% less than the MUF. Whether or not a wave will be reflected off a particular layer depends also on the angle of incidence. The Fig. 8-a diagram shows what happens when the angle of incidence remains fixed but the frequency is changed. In Fig. 8-b, the diagram shows the situation when the frequency is kept fixed and angle of incidence is varied.

The MUF and the critical frequency are related by the equation: $MUF \times \cos i = f_{CRIT}$

where i is the angle at which the wave enters the ionized layer.

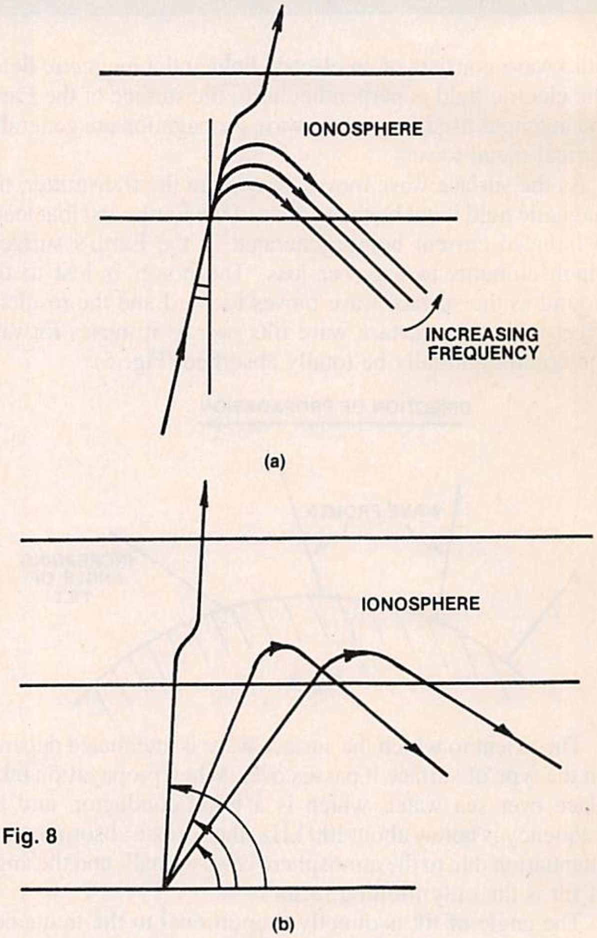


Fig. 8

Virtual Height

Virtual height is the height from which the radio wave would appear to be reflected if it had undergone a perfect (mirror-type) reflection (Fig. 9). However, the wave does not undergo a perfect reflection, but allows a curved path such as A-B-C-D-E. The actual height from point C to ground is, therefore, *less* than the *virtual* height, *h*. *(See page 38)*

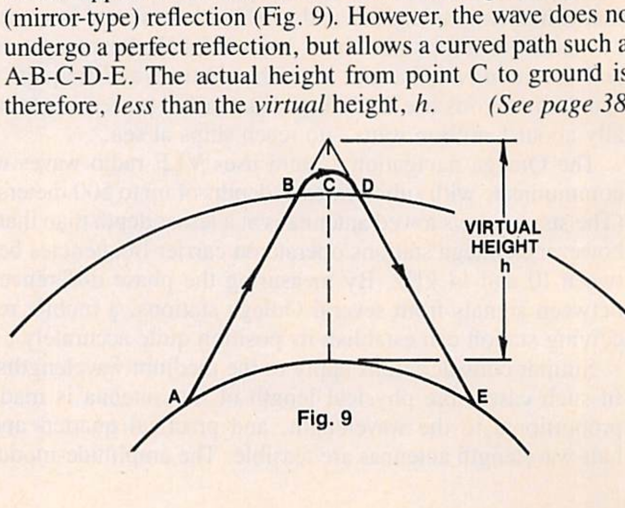


Fig. 9

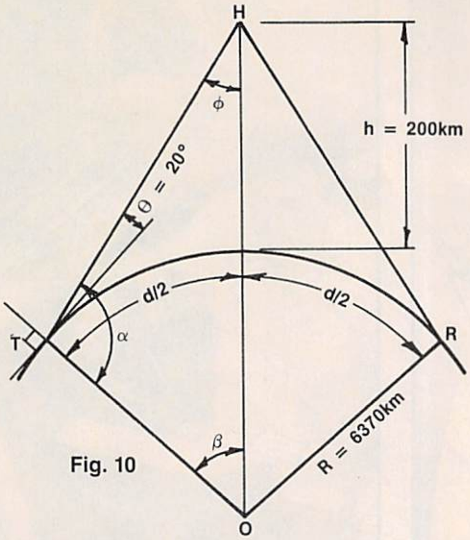


Fig. 10

The virtual height is, however, used in calculating the transmission path between two stations. In Fig. 10, the transmission path between transmitter (T) and receiver (R), as measured along the surface of the Earth, is shown as *d*. θ is the angle made by the antenna main beam at point T, h is the virtual height, and R the radius of the Earth.

The transmission path (TR) can be calculated as follows:

$$\text{angle } \alpha = 90° + 20° = 110°$$

$$\text{and side OT} = R = 6370 \text{ km.}$$

The angle ϕ can be found from the sine theorem:

$$6570/\text{Sin } 110 = 6370/\text{Sin } \phi$$

which gives $\phi = 65.65°$. Thus, β is equal to:

$$180 - (110 + 65.65) = 4.34°,$$

or .0758 radians. TR can now be found from the equation:

$$\text{Angle in radians} = \text{Arc/radius.}$$

Thus, $.0758 = (d/2)/6370$, ie. $d = 965.9$ km, which is the path TR.

Measurement of virtual height is usually carried out by an instrument called an *ionosonde*. A pulse of about 150 μs is transmitted vertically upwards. The reflected wave is received very close to the transmission point and the time required for the round trip is measured. The virtual height is given by:

$$h = Ct/2$$

where C is the speed of light and t is the time in seconds.

The *ionosonde* can sweep over a frequency range, for example 1 MHz to 20 MHz, in about three minutes and has facilities for plotting virtual height against frequency, resulting in a plot that's called an *ionogram*.

There is a minimum distance over which communication at a given frequency can be established by means of the sky wave. Usually the MUF is used for the link. If an attempt is made to shorten that distance by using a smaller angle of incidence, the radio wave will not be returned from the ionosphere, but will pass through it and into space. That minimum distance is called the *skip distance* (Fig. 11). For a certain transmission frequency, each ionospheric layer has a different skip distance.

For communication between two points separated by more than about 4000 km, two or more hops are required as shown in Fig.12. The number of hops possible depends on the transmitter power and the losses at each ionospheric reflection and surface bounce.

Ionospheric Disturbances

The ionospheric variations described above are not regular or smooth as assumed, and calculations based on those assumptions yield only approximate results. Some irregularities travel through the ionosphere at speeds greater than 1 km/s and are referred to as *Travelling Ionospheric Disturbances*, which have not been fully determined, although some contribution is assumed to be made by gravity, electric currents, plasma instabilities, and solar activity.

Complete loss of signal has been observed to accompany solar flares. Those fade outs occur very suddenly and are known as *Sudden Ionospheric Disturbances* (SID's). They are also referred to as Dellinger fade outs and Mogul-Dellinger fade outs, after Dellinger and Mogul who observed them in the U.S. and Germany respectively.

During solar flares, protons are also emitted by the Sun, and reach the Earth about 30 hours after the flare, affecting the Earth's magnetic field, which results in what is termed a *magnetic storm*. Magnetic storms affect radio waves, especially at higher latitudes.

Another form of ionospheric irregularity is called *Sporadic-E*. Thin, highly-ionized regions are formed in the E-layer that can reflect very high frequency signals, which would normally pass through the ionosphere. Those irregularities are formed with no periodicity; hence, the name, *sporadic*. Due to those *freak* conditions, distant VHF TV stations can sometimes be received.

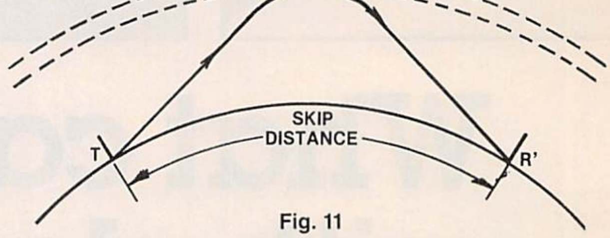


Fig. 11

Ionospheric or sky-wave propagation has been used since the early days of radio, when large distances had to be covered. Recent applications of satellites have overshadowed some of them but, because of its low cost and simplicity, sky-wave propagation continues to be used. Radio amateurs use sky-wave propagation to achieve world-wide communication with very modest transmitter powers.

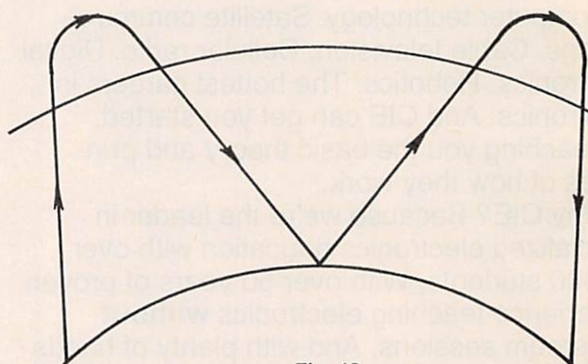


Fig. 12

Probably the major application, and the one that will continue for many years, is that of marine communication.

The Space Wave

Sky-wave or ionospheric propagation is not possible at

(Continued on page 104)

RADIO WAVE PROPAGATION

(Continued from page 38)

frequencies above about 30 MHz, in what are called the VHF and UHF bands. Those frequencies pass through the ionosphere. Propagation at VHF and above is restricted to the space wave, which travels in the lower region of the atmosphere (called the troposphere).

Slight refraction of radio waves occurs in that region due to the refractive index of the atmosphere, resulting in *radio line-of-sight* that is somewhat longer than the *optical line-of-sight*.

Space-wave propagation is used for FM broadcasting, TV broadcasting, land mobile radiotelephones, and point-to-point microwave links. Normally, one or more base stations are used, mounted on a tall building or hill to increase the effective range of the system.

In scatter propagation, frequencies between 350 MHz to 10 GHz are used. A high-power radio wave is transmitted upwards and a very small fraction of the transmitted energy is forward scattered by the troposphere and directed downward towards the Earth.

The forward scattered energy is received by a high-gain antenna, normally a parabolic type. The distance between the transmitting and receiving stations is about 300 to 500 km and nearly always covers geographically hostile terrain such as mountains, jungle, etc. That mode requires high-power transmitters and high-gain, low-noise receivers, and is normally used when no others are available.

Satellites

Communications satellites can be divided into two basic classes called asynchronous and synchronous satellites. The former continuously change their position with respect to the Earth, which leads to antenna tracking problems. The latter type rotates about the Earth's axis at the same speed and direction as the Earth. Under these conditions, the satellite remains in a fixed position relative to the Earth's surface and can thus be used as a repeater station.

Three such satellites can be located at an angle of 120° to each other to give complete coverage of the Earth. The transmitting and receiving equipment on board a satellite repeater is similar to that used on a ground station, except that miniaturization is used as far as possible and power requirements kept to a minimum. The same antenna is used for transmitting and receiving. Frequencies used are normally 4 to 6 GHz, with transmission and reception on two different frequencies.

At the present time, all overseas TV broadcasts are via satellite and so are a larger number of telephone conversations. The round trip distance for a satellite link is on the order of 70,000 km and that leads to a transmission delay in the link. Echo suppressors are used in telephone links to reduce delayed echo to an acceptable level.

Finally, it is worth mentioning the amateur satellites used by radio amateurs, which are popularly called the *Oscar Series*—Orbiting Satellites Carrying Amateurs Radio. Unlike the type discussed above, these travel across the equator and contact between two stations can be held only for a short time.

You have just completed a very brief, but thorough, description of how radio waves travel from one point on the Earth's surface to another. For most readers, this discussion is sufficient. For those of you who get involved with amateur communications supplementary reading and learning is in the cards. ■

TROUBLESHOOT YOUR CAR

(Continued from page 59)

serious problems, which are generally masked by the more conventional, analog multimeter.

When it comes to what accountants call "the bottom line," doing your own electric/electronic checks and tests pays off in big dividends because you can avoid paying for what you don't need. For example, replacing a worn alternator belt is a lot cheaper than replacing the alternator, and replacing a radiator's heat sensor yourself can easily save a shop charge of $50 for the diagnosis. The fact is, what you can save on a single electric/electronic repair can easily pay for a quality digital multimeter and its accessories. ■

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