ELECTROMATIC RADAR SPEEDMETER
THEORY AND OPERATION

Table of Contents

Published by the

Royal Canadian Mounted Police

Ottawa

by

Kind Permission of the Authors

BASIC THEORY OF RADIO WAVES

Definition

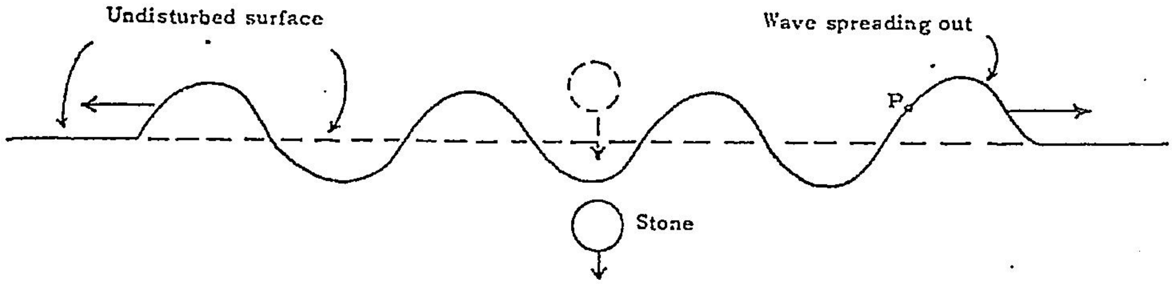
Radio waves consist of electromagnetic radiation and represent energy travelling in space. Like light or heat waves, they originate from a source and travel in a straight path unless reflected or refracted from this path. Their magnitude or strength decreases in direct propoition to the distance from the source and their power decreases as the square of the distance.

Unlike sound waves, which must have a medium, such as the atmosphere, in which to travel, radio waves can travel in a vacuum or free space. Radio waves are absorbed and decreased in magnitude by such atmospheric effects as rain and snow but the degree to which this may occur in a few hundred feet is extremely small and may be entirely neglected in the operation of the radar speed meter.

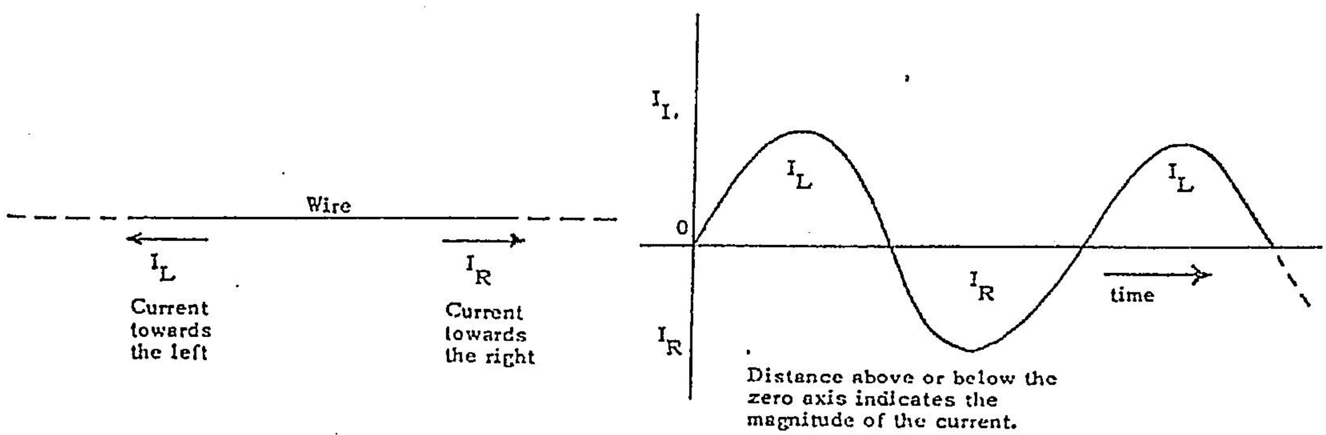
Radio waves are referred to as electromagnetic radiation because they are a combination of electric and magnetic fields.

The term "field" is used to describe a region in space where a certain type of phenomenon can be observed. The region near a permanent magnet, where magnetic effects (such as attraction of iron objects or the disturbance of a compass) can be observed is called a magnetic field. Similarly a static electric field exists around a body which has become electrically charged. Charges of this type are usually acquired by friction. A strong electric field will result in the breakdown of insulation such as may be seen in the form of tiny sparks when brushing a cat or dog in dry weather.

Most physical quantities to which the term "wave" can be applied are alternating, i.e. act first in one direction and then in the opposite direction. This is illustrated by the behavior of the surface of a pool of water after a stone has been dropped into it:

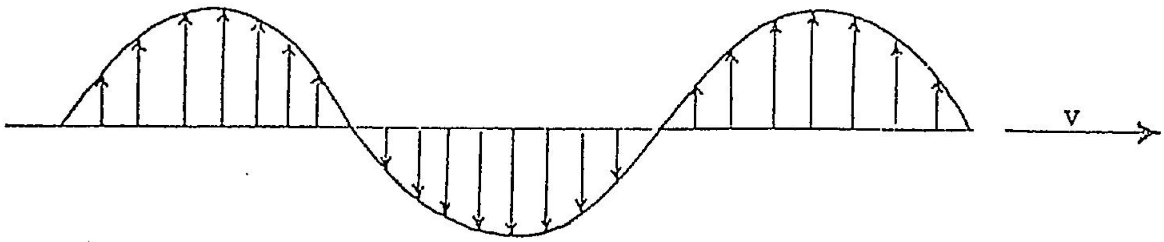


The waves in the water spread out from the source of the disturbance (STONE) and at any point such as P, the motion of the surface is an alternating vertical motion. Another common example of an alternating quantity is the current supplied to a light or electrical appliance fed from an "A.C." source. In this case the current flows first in one direction and then the reverse. In either direction the current builds up from zero to a maximum and then decreases to zero:

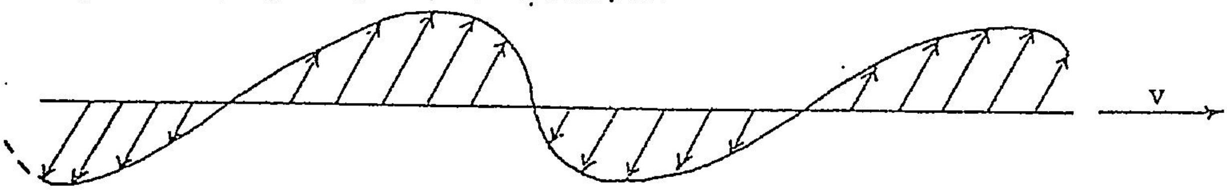


The graph showing how current varies with time has a special shape which is known as a "sine wave."

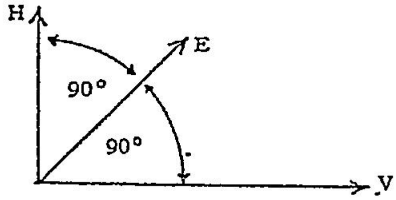
As stated above, a radio wave is a combination of electric and magnetic fields travelling in space. Both of these fields are alternating quantities. In addition they act in directions which are at 90° to each other and to the direction in which the wave is travelling. For example, the electric and magnetic components of a wave travelling to the right could be as follows:



Magnetic field (designated by "H") in the vertical plane



Electric Field (designated by "E") in the horizontal plane



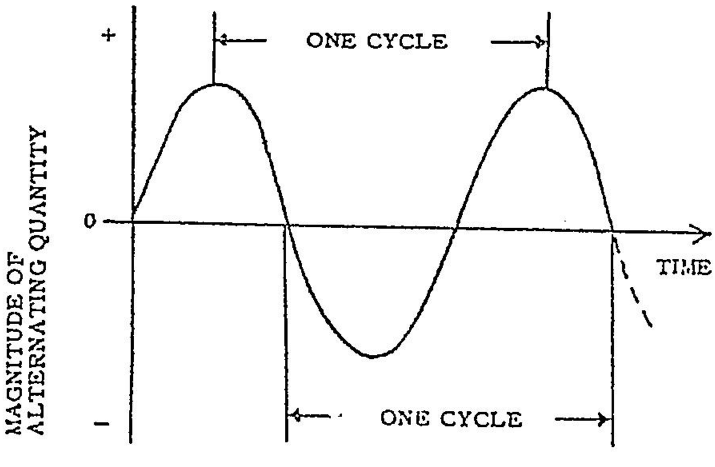
These arrows show, in a simple way, the directions of E and H relative to V, the direction (and velocity) of motion of the wave.

Characteristics of Radio Waves

(a) Speed (or 3×10^8 meters per second)

Speed is the ratio of distance to time. Radio waves travel at a constant speed of 186,000 miles per second, which is the same as the velocity of light. These waves travel in straight lines like light waves. Over the relatively short distances involved in the use of the speedmeter these waves, though invisible, may be considered to behave as light waves. Speed is designated by the symbol V.

(b) Frequency

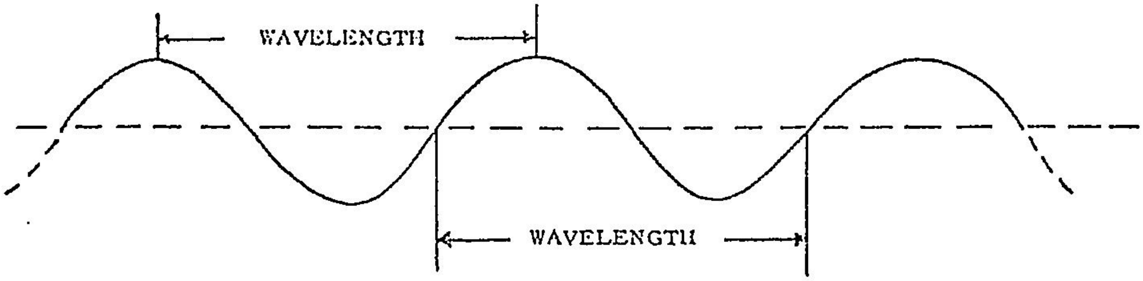


The frequency of a wave is the number that pass a given point in one second. One complete wave is called a cycle and frequency is expressed in cycles per second. For example the frequency of commercial A.C. power is 60 cycles per second and a radio broadcasting station may operate at a million cycles per second. Referring to the analogy of waves on water the number of times per second that a floating body would reach the crest of its vertical oscillation as the wave passes would be the frequency of the wave. One cycle is completed in a time of 1/f seconds, i.e. a cycle is measured in terms of time.

The frequency of a radio wave is determined by the source or transmitter which sends out the wave. The radio wave generated by the speedmeter has a frequency of 2,455 *million* cycles per second, which is more commonly spoken of as 2455 megacycles per second, one megacycle being one million cycles. Frequency is designated by the symbol f.

(c) Wavelength

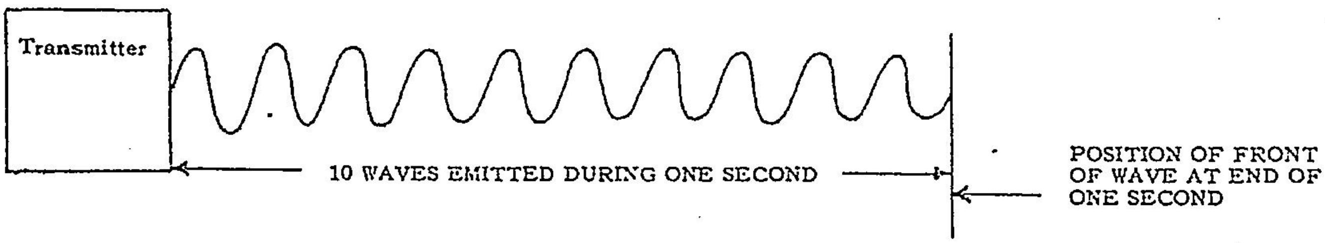
The physical distance between corresponding points on two adjacent cycles of a wave is known as the wavelength, since it is actually the length of one wave. Returning to the analogy of waves in water, it would be the distance between adjacent crests (or troughs of the wave).



Wavelength may be measured in terms of any unit of *length* such as feet or meters. It is usually specified in meters or centimeters. (1 inch = 2.54 centimeters and 1 foot = 30.48 centimeters). Wavelength is customarily represented by the symbol λ ("lambda").

(d) Relation between Speed, Frequency and Wavelength

Since the speed of radio waves is always 186,000 miles per second, and the frequency of a particular radio wave is established by its transmitter or source, then that radio wave must have a definite wavelength which is determined by its frequency. To illustrate this, assume that a transmitter is generating 10 complete cycles each second and is therefore operating at a frequency of 10 cycles per second.



It is seen that the front of the wave has moved out a distance of 10 λ from the transmitter during one second. (i.e. the velocity (= distance/sec.) is 10 λ). But 10 is the frequency in cycles per second. Therefore the general relationship is:

$V = f\lambda$ or $\lambda = V/f$

where V = velocity in meters per second

f = frequency in cycles per second

λ = wavelength in meters.

In meters per second, the velocity of a radio or light wave is 300 million or 3×10^8 meters per second. For the speedmeter, which has a frequency of 2455×10^6 cycles per second,

$$\lambda = \frac{3 \times 10^8}{2455 \times 10^6} = \frac{300}{2455} = .122 \text{ meters}$$

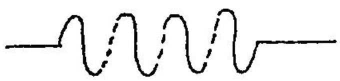
Since 1 meter = 39.37 inches, $\lambda = .122 \times 39.37 = 4.8$ inches

Source

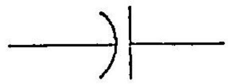
The simplest source of radio waves is an electric spark, whether a lightning discharge, a small spark between two wires or one caused by the friction of combing the hair. From such a spark, radio waves radiate outward in all directions, the spark being what may be called a transmitter. The effects of such sparks are noticeable in radi.. reception as "static".

Radio and radar transmitters must generate a wave of constant and known frequency. To do this they employ vacuum tubes in conjunction with electrical circuits to form what is called an "oscillator." The concept of oscillation in mechanical devices is probably more familiar and will be used to illustrate the conditions necessary for the maintenance of continued or sustained oscillations. A watch or clock is a very common device which acts as a continuous oscillator. In either case the energy necessary to cause the oscillations to continue is stored in the main-spring by "winding." The oscillator itself consists of a balance-wheel or pendulum. Energy from the main-spring is released once during each cycle of oscillation by means of a mechanism known as an escapement. The little push given to the oscillating part on each cycle keeps it going continuously. In the case of a watch there is an exchange of energy during each cycle between the balance wheel and the hairspring. The main-spring supplies whatever energy is lost due to friction.

The electrical oscillator which generates radio waves operates in an analogous manner. In place of the balance-wheel we have a coil of wire, known as an inductance (L) and in place of the hairspring we have a device known as a capacitor (C). A capacitor consists of two metal plates (or sheets of foil) separated by an insulator. It has the property of storing an electric charge when a voltage is applied to it.



INDUCTANCE

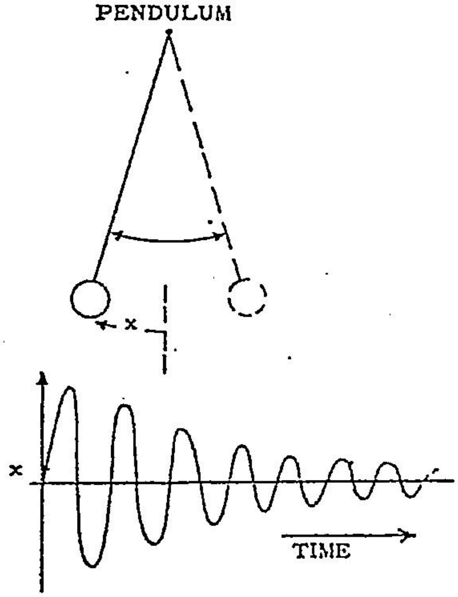


CAPACITANCE

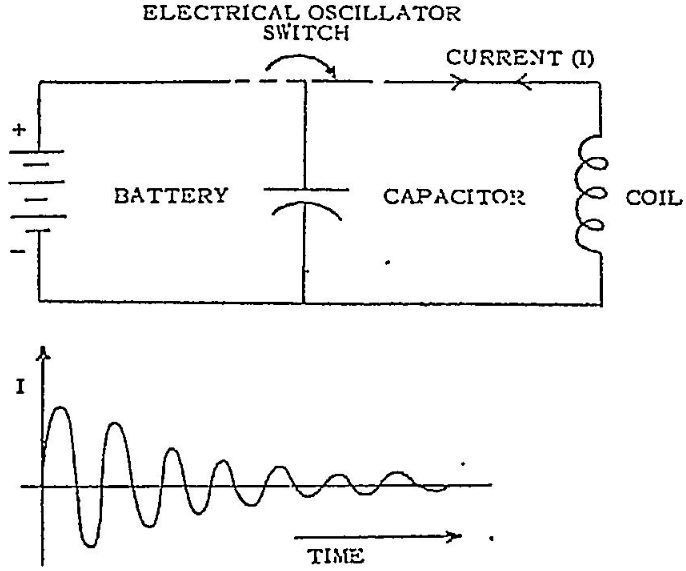
A simple pendulum cannot be used as a clock because it is necessary to also have a source of energy to keep it swinging. If the pendulum is deflected, it will swing for a time but eventually come to rest.

An electrical circuit consisting of an inductance and capacitance behaves in much the same way as a pendulum. If a capacitor is charged up from a battery and then connected across an inductor (coil) the current which flows will be oscillatory but will die out in a short time.

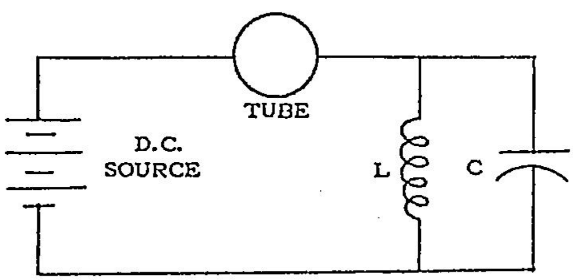
PENDULUM



ELECTRICAL OSCILLATOR



In the clock or watch, energy is released from the main-spring by means of the escapement to keep the oscillations at a constant amplitude. In the case of an electrical oscillator the energy is supplied from a battery or other source of direct current. Its release to the LC circuit is controlled by means of a vacuum tube and might be represented in principle as follows:



The frequency at which this electrical oscillator operates is determined by the values of L and C.

$$f = \frac{1}{2\pi\sqrt{LC}} \text{ cycles per second}$$

For very high frequencies, the values of L and C become very small. This electrical oscillator, capable of producing continuously, radio waves of a constant amplitude and known frequency is the basic source or generator of waves used in the speedmeter.

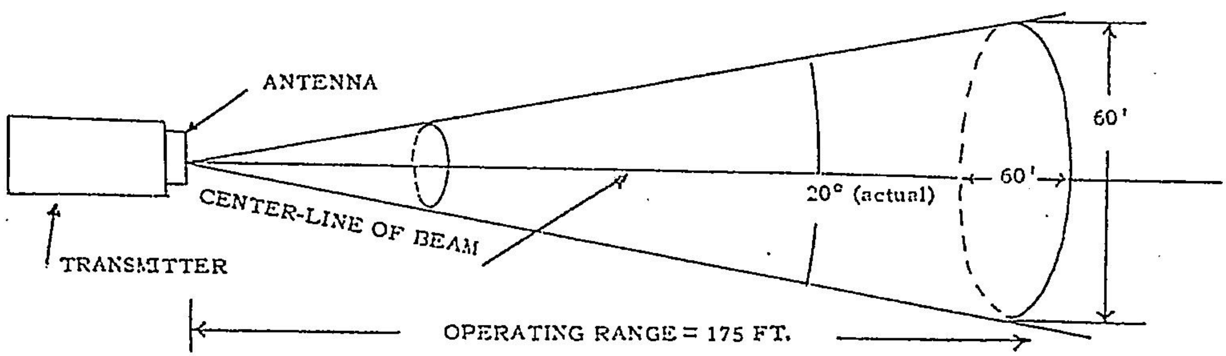
Antenna

An antenna is a device consisting of a certain arrangement of electrical conductors which are supplied with alternating currents by the oscillator or source of radio-frequency energy. Its purpose (in a transmitter) is to set up electromagnetic waves in space. Very often, as in the case of the speedmeter, the conductors which form the antenna are arranged so that the waves radiated from it are confined to a narrow beam as in the case of light sent out from a spotlight. Without an antenna, the transmitter would be about as effective as a light inside of an opaque box or a clock without hands.

Whatever ability a given antenna has to form the transmitted waves into a narrow beam also applies to its use in receiving signals from another source.

Some antennas, like vertical towers used in commercial broadcasting and the whip antennas used on automobiles, radiate a wave of the same strength in all horizontal directions and are called non-directional. Television antennas consist of several "elements" and are directional, i.e. must be pointed towards the transmitter from which they are to receive signals.

The antenna used in the speedmeter is highly directional and radiates radio waves which are confined to a cone-shaped beam which has an angular width of 20 degrees. It is housed in a weather-tight case on the front of the transceiver case.



Radar Waves or Microwaves

The only difference between radio waves used in commercial broadcasting and those used in radar and the speedmeter is that the latter are of very high frequency and hence short wavelength. Broadcasting waves have a wavelength of the order of 100 yards, while radar waves, or microwaves, have a wavelength of only a few inches or even less than one inch.

The use of microwaves in the radar speedmeter has two distinct advantages:

(a) Their behavior is much like that of visible light and they can be reflected from smaller objects more readily than long waves.

(b) They can be transmitted in the form of a beam more easily and effectively since a highly directive antenna for these waves is so much smaller than for long waves. The speedmeter antenna takes only a few cubic inches of space and is much more directional than a television antenna.

Reflection of Radio Waves

It is a very useful analogy to consider what may happen when a spotlight or flashlight is directed into the darkness. If we "see nothing" it is because no object is present to reflect part of the light from the source back to the eye. Whatever may be seen by light is only "visible" because it reflects light waves from some source into the eye of the observer.

Radio waves are reflected from practically all solid objects in the same way as light waves. When a beam of radio waves strikes an object, they will be reflected in random directions depending upon the shape of the object, but some of them will be reflected back towards the transmitter where they may be received by an antenna. Metals are the best reflectors of radio waves. Wet pavement would also be an excellent reflector.

Double, or even multiple reflections are possible, with, for example, the radio waves reflecting from one building to another and the returning waves, or "echoes" following a rather complicated course back to the source.

The magnitude or strength of the radio waves reflected from an object depends upon the strength of the waves reaching it from the source, and hence upon the distance from the source to the reflecting object since the strength of waves decreases in direct proportion to the distance from the source. The strength of the reflected waves also depends upon the ability of the object to reflect waves (as mentioned above, metal surfaces are the best) and upon the size of the object.

To be an effective reflector of waves, an object must have a dimension larger than the wavelength of the waves. The larger the object, the better reflector it will be. Since the speedmeter waves have a wavelength of only 4.8 inches, any highway vehicle will be large enough to give a good reflected signal.

Doppler Effect

The physical principle upon which the operation of the speedmeter is based is known as the doppler effect. (After Christian Doppler, an Austrian physicist who discovered it in 1842). In general terms, the doppler effect is the change in frequency which is observed when the source and receiver of waves are in motion relative to each other. Two simple examples will illustrate the principle:

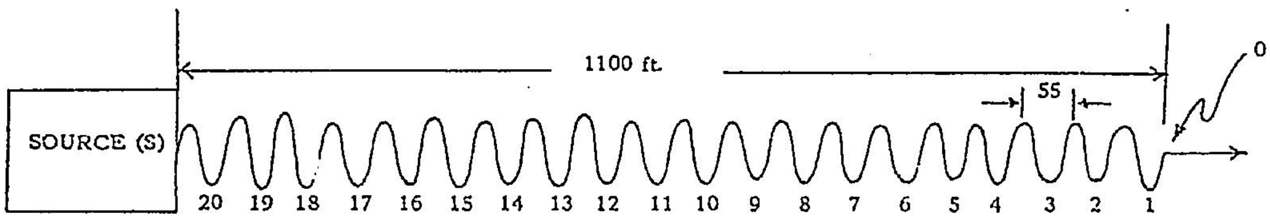
(i) It is a common observation that the pitch or frequency of a train whistle or auto horn is observed to be higher when the source of the wave (whistle or horn) is approaching the observer and lower as the source recedes from the observer.

(ii) Suppose that a wheel with a large number of spokes is turning at a constant speed. If a card is held in a stationary position so that it is struck in turn by each spoke, a certain pitch or frequency will be observed. If the card is moved opposite to the direction of rotation, a higher note will be produced. If the card is moved in the same direction as the rotation of the wheel, a lower pitch results because fewer spokes strike the card during each second.

In the use of the speedmeter, the doppler effect is involved twice, or in two ways. The transmitter, or source of radio waves is always stationary. Vehicles moving along the highway reflect a wave whose frequency differs from that of the source because the reflector is moving. Further, the reflecting vehicle appears to the receiver as a moving source of radio waves, and the frequency of the waves reaching the receiver differs from that of the waves reflected by the vehicle — again because of the relative motion between them.

The *difference* between the frequency of the waves which are sent out by the transmitter and the frequency of those which return to the receiver, after reflection from a moving object, will be referred to as the *doppler frequency.* This doppler frequency is directly proportional to the speed of the reflecting object. The speedmeter, besides transmitting the original waves and receiving the reflected waves, *measures* (by electronic circuits) the doppler frequency and converts this to meter readings which give miles per hour (of the reflecting vehicle) directly. To illustrate the doppler effect in more detail, consider the case of a sound wave in air:

Suppose that a source of sound waves is producing 20 waves per second, i.e. has a frequency of 20 cycles per second. The speed of sound waves in air is approximately 1100 feet per second. At the end of one second the front of the first wave which was generated at the source will be 1100 feet from the transmitter and the other 19 waves generated during that second will be strung out behind it as shown in the following diagram:



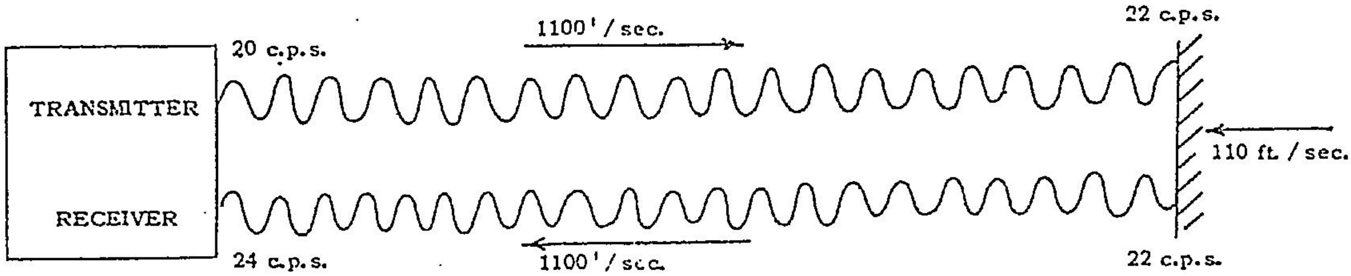
The wavelength is 1100 ÷ 20 = 55 feet. As the source continues to generate more waves, the original ones move farther away from the source (at a speed of 1100 ft. per second) and a stationary observer such as a 0 in the above diagram will have 20 cycles or waves passing him each second. Thus, the frequency observed by the stationary observer (0) from a stationary source (S) is the same as the actual frequency of the source.

Suppose now that the observer is moving *towards* the source at the rate of 110 ft. per second. In this case the observer would count 22 waves or cycles each second because, in addition to the normal passage of the wave he has advanced by a distance of two wavelengths towards the source. Similarly, if the observer were moving *away* from the source at 110 ft. per second, two of the waves which would pass his position if he had remained stationary would not have reached his new position by the end of one second and it would therefore appear to the observer that the frequency of the source were only 18 cycles per second.

Application of Doppler Effect to the Measurement of Speed

In the use of the speedmeter, the transmitter or source is always in a stationary position. Waves sent out from it are reflected from the vehicles moving along the highway and some of the waves reflected from these vehicles are returned to the speedmeter where their frequency is compared with that of the waves which are being sent out. The effect of a moving reflector will be illustrated by continuing to use the same numerical values as in the previous example:

With the source operating continuously at 20 cycles per second the number of waves arriving each second at a reflecting surface which is moving towards the source at 110 ft. per second is 22. Each one of these waves is reflected from this moving reflector and part of the reflection returns to the source. Thus the reflector is acting as a source for the reflected wave, but at 22 cycles per second. In addition, the reflector is moving towards the receiver, which has the same effect as the receiver moving towards the reflector. Thus the waves picked up by the receiver seem to have a frequency of 24 cycles per second. This may be illustrated as follows:



Similarly if the reflector were moving *away* from the source at 110 ft./sec. the apparent frequency of the reflected wave (as measured by the receiver) would be 20 – 2 – 2 = 16 cycles per second.

Thus the *same* difference between the frequencies of the transmitted and received signals is obtained for either direction of motion of the reflector.

THEORY RELATED TO FUNCTION OF SPEEDMETER

General Function

By utilizing characteristics of radar waves already discussed, and by electronically transforming reflected radio signals into visual and graphic indications, the Radar Speedmeter is able to give an instantaneous representation of a vehicle's speed.

Generation of Radar Waves

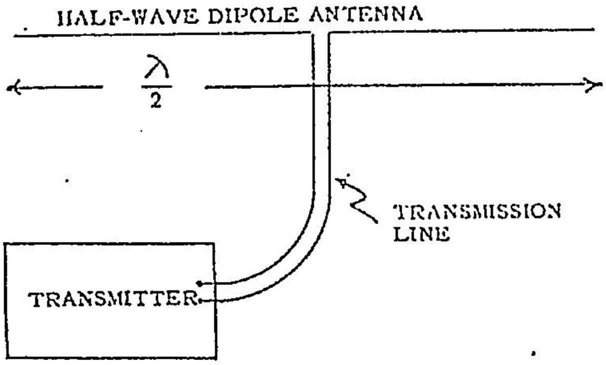
The action of the Speedmeter begins at the transmitter oscillator, which generates a continuous stream of high frequency oscillations of 2,455 megacycles.

The transmitter oscillator is exceptionally stable, and holds the frequency within 0.1%.

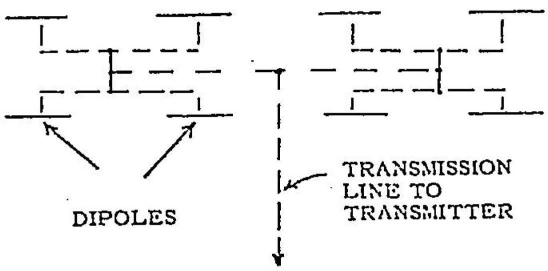
The transmitter power is very low (0.2 watts) compared to any standard radio transmitter, so that the range of the Speedmeter can be kept within the required bounds of approximately 175 feet. While the radar waves will carry on past this, most reflected signals will be too weak to have any effect on the receiver.

Transmission of Radar Waves

The transmitter oscillator feeds its energy, by means of a short co-axial transmission line, to an antenna which is mounted inside an enclosure on the front of the transmitter case. At high frequencies



the simplest antenna consists of a conductor, having a length of a half wavelength, which is fed with radio-frequency energy at its center by a transmission line fed by the transmitter oscillator. Such an antenna is known as a "half-wave dipole" and is used in many communications systems. It is directive, but one dipole antenna is not capable of producing a narrow beam of radio waves. The speedmeter antenna consists of a group of eight dipole antennas forming what is known as a "billboard" array. On a larger scale (lower frequency and longer wavelength) antennas of this type are used for the "short-wave" transmission from the CBC station at Sackville, N.B. The speedmeter antenna radiates a cone shaped beam which is 20 degrees wide. If visible, this beam would look like a solid cone of light from a spotlight, with its intensity on a given area getting less as it spreads out. The intensity of the beam, or the strength of radar waves striking a target decreases with distance from the source. The beam is made 20 degrees wide so that it will be as wide as the highway at the maximum range of the speedmeter. At a distance of 175 feet the width of a 20 degree cone is 60 feet (both vertically and horizontally).



The frequency of the radar waves is 2455 megacycles per second and their wavelength is 4.8 inches. These microwaves are of suitable wave length for easily forming into a beam and are well below target dimensions for good reflective properties.

Reflection and Frequency Shift

Two principles already discussed come into play simultaneously in obtaining a signal that can be used to determine the speed of a target or vehicle:

(1) The beam of radio waves must strike the moving vehicle, resulting in some of the waves being reflected back to the Speedmeter.

(2) These reflected waves, or signals, will be of a different frequency than the transmitted waves, by reason of the Doppler effect. It is this difference in frequencies that the Speedmeter translates into a speed indication.

Reception of Signals

The reflected signals are picked up by the same antenna, which acts as a receiving as well as a transmitter antenna.

Theory of Doppler Effect Applied to the Speedmeter

The waves sent out by the radar speedmeter travel at the velocity of light or 186,000 miles per second. The frequency at which the transmitter operates is 2455 Megacycles per second. The wavelength (λ) of these waves is

$$\frac{5280 \times 186000 \times 12 \text{ inches/second}}{2{,}455{,}000{,}000 \text{ cycles per second}} = 4.80 \text{ inches.}$$

A vehicle approaching the transmitter at 30 miles per hour is travelling at 30 × 5,280 × 12 ÷ 3600 = 528 inches per second. During one second this vehicle "bumps into" 2,455,000,000 waves *plus* the number of wavelengths by which it advanced against the train of waves coming towards it from the transmitter. Since the vehicle moves 528 inches during this second and the length of the wave is 4.8 inches, it bumps into an extra 528/4.8 = 110 waves. Therefore the total number of waves striking the vehicle during this second is 2,455,000,110.

Each of these waves arriving at the approaching vehicle is reflected and part of the reflection goes to the transceiver. As far as these returning waves are concerned their source is the vehicle and their frequency is 2,455,000,110 cycles per second. This number of waves starts out from the reflecting vehicle, each second and at the end of one second the leading wave would be 2,455,000,110 × 4.8 inches away from the vehicle. But during this second the vehicle has advanced a distance equal to the length of 110 waves. Therefore an additional 110 waves is crowded into the space that would have been occupied by 2,455,000,110 waves if the motion of the reflector had not been considered. In other words the frequency of the waves reaching the transceiver becomes 2,455,000,220 cycles per second.

The doppler frequency is the difference between the frequency of the waves sent out by the transmitter and those received by reflection. In this case, for a vehicle approaching at 30 miles per hour, it is 220 cycles per second. This frequency is directly proportional to the speed of the vehicle and is $\frac{220}{30} = 7.3$ cycles per second for each M.P.H. speed of the vehicle. This factor of 7.3 also applies to vehicles receding from the transceiver. The above explanation differs only in that the frequency is reduced rather than increased by the motion of the vehicle.

Effect of Change in Transmitter Frequency

The oscillator, circuit, which is the source of the microwave signal from the transceiver gives an output whose frequency does not vary by more than 0.1%. This is a very high degree of accuracy for portable equipment of this type. The effect of the possibility of this amount of error in the frequency of the transmitted signal is to give an error of the same amount in the wave-length of the waves and also in the doppler frequency. Thus the readings of the indicator and recorder could be in error (from this cause) by 0.1%. Even at 100 M.P.H. this is only 0.1 M.P.H. error, which is less than can be detected by reading the indicator or reading the recorder chart. Therefore any error due to possible changes in transmitter frequency are entirely negligible.

Obtaining a Difference Frequency or Doppler Note

The signal the antenna has picked up is of a different frequency than the transmitted frequency of exactly 2,455 megacycles, being a little more or a little less depending on which way the vehicle was going.

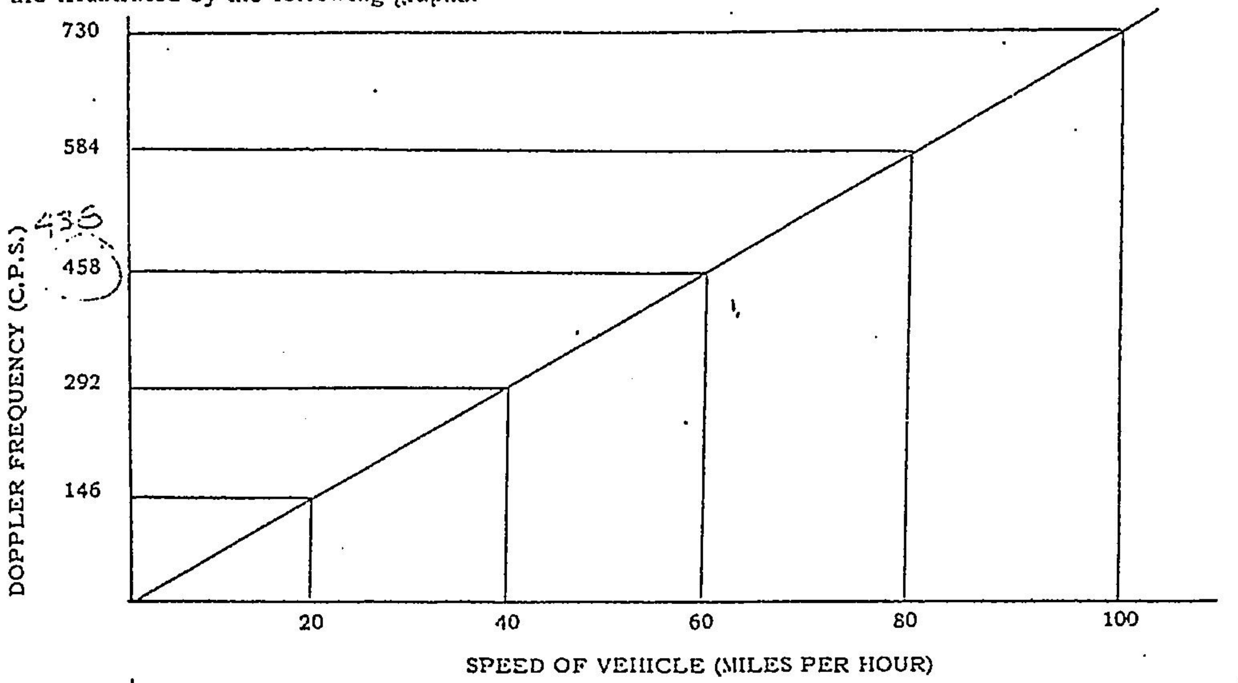
This signal is "mixed" with a portion of the transmitted frequency, and the difference emerges as a "difference frequency" or "Doppler Note." (It is called a "note" because it is of such low frequency that it is in the range of audibility if it were sent out of a loud speaker).

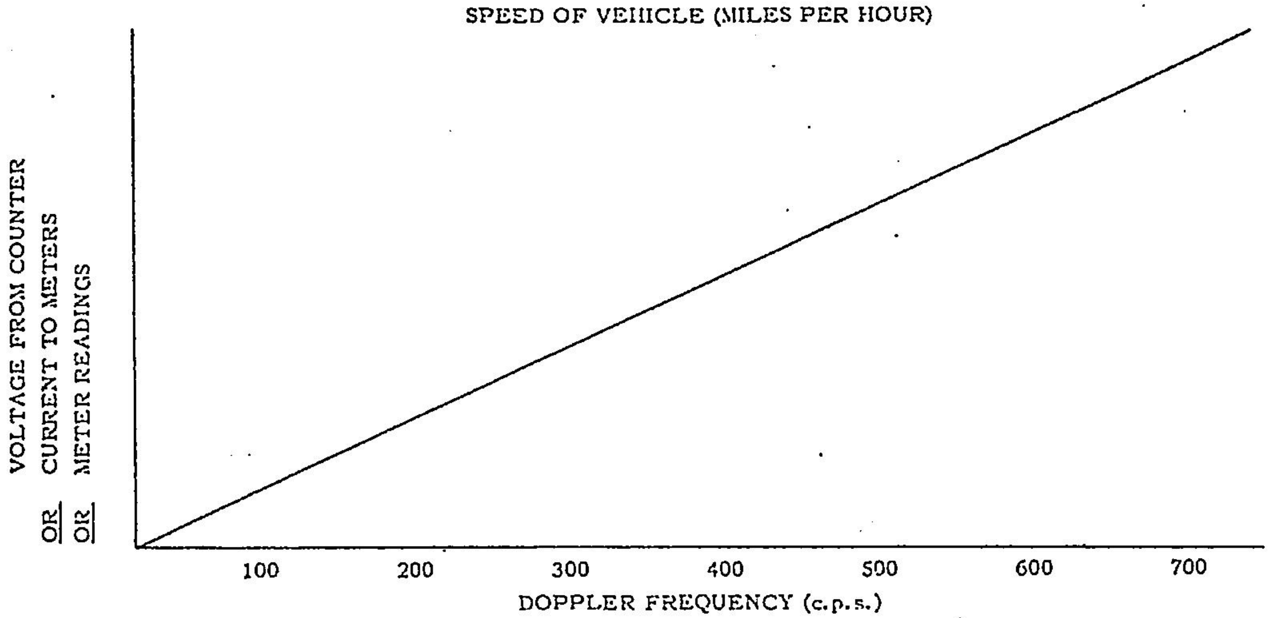
Thus, if the original transmitted frequency is exactly 2,455 megacycles, the reflected signal from a vehicle travelling at 10 M.P.H. would be 2,455 megacycles plus or minus 73 cycles per second. Mixing the two frequencies, we would get the difference, namely 73 cycles per second, which is the Doppler note for that speed.

Using the Doppler Note to Give a Speed Indication

The doppler note, after being obtained from a special circuit in the speedmeter, is first amplified because it is too weak to be useful. The doppler "note" is now in the form of alternating currents and voltages in the electronic circuits of the instrument. After amplification, the voltage representing the doppler note is applied to another circuit (called a "counter") which gives a D.C. voltage output which is directly proportional to the frequency of the note. The output of the counter is applied to the final electronic circuits which supply the currents to operate the indicating meter and the recorder.

Since the doppler frequency is directly proportional to the speed of the reflecting vehicle and the current supplied to the meters is made to be directly proportional to the doppler frequency, the deflections (or readings) of the indicator and recorder are directly proportional to the speed of the vehicle. These facts are illustrated by the following graphs:



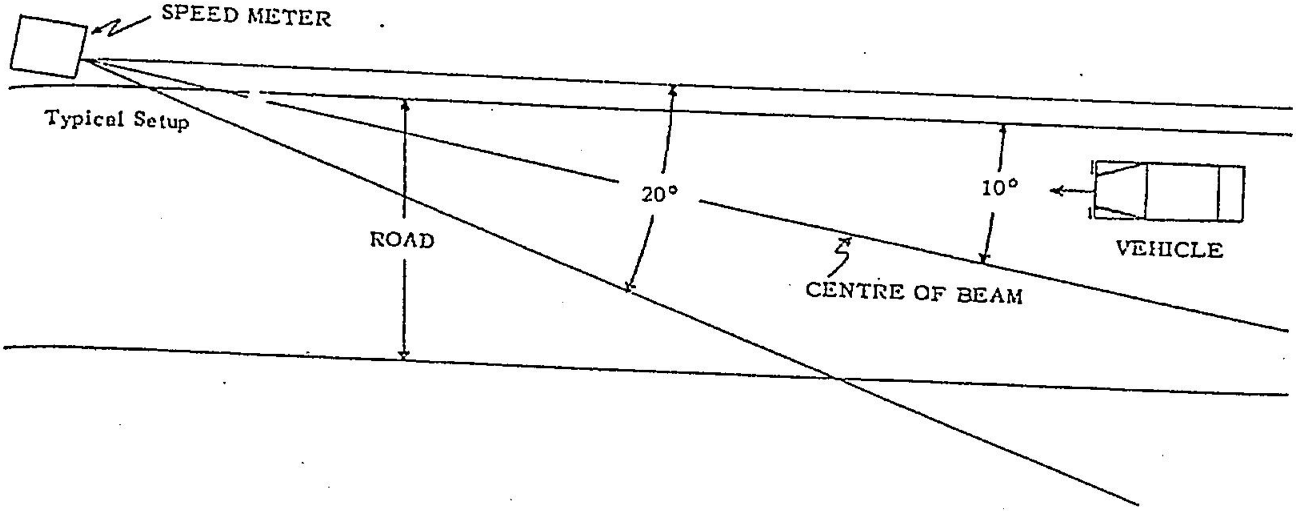


Horizontal Angle of Beam to the Road

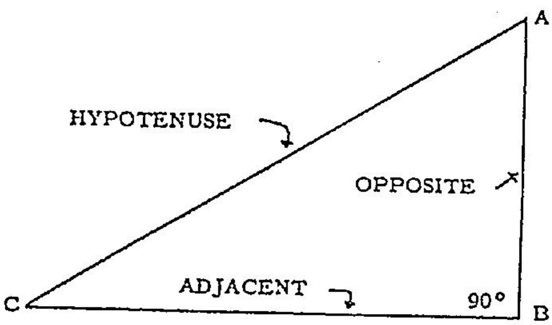
It was mentioned, in discussing the Doppler frequency shift, that the target must be moving in the path of the radar beam to effect a frequency change. This means that a vehicle would have to be approaching or receding along the center of the radar beam, which is not quite practical.

However, if the transceiver is set at the side of the road and beamed down the road, but 10° off the path of the moving vehicle, the error is less than 2%. This is a negative error in favour of the vehicle; it is called a cosine error, because the indicated speed is governed by the cosine of the angle of the beam to the road. The larger the angle, the more negative the error.

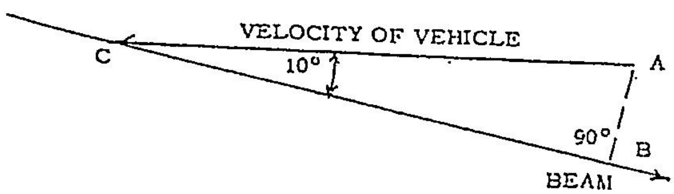
If the beam were pointing across the road, that is 90° to the road, we should, theoretically, get no indication of speed as the path of the vehicle is not in line with the path of the radio waves at all. However, due to the 20° angle of the beam itself we do get some speed indication.



It is seen that the vehicle is travelling at an angle of 10° from the center line of the beam. If the speed of the vehicle along the highway is 50 miles per hour, its speed relative to the radar beam is less than this and can be calculated by using a quantity known as the *cosine* of the angle between the beam and the direction in which the vehicle is travelling. In any right angled triangle there is a relation between size of the angles and the relative lengths of the sides. The cosine of the angle ACB in the above triangle is the ratio of length of the adjacent side to the length of the hypotenuse. Since the hypotenuse is the longest side of the triangle, the numerical value of the cosine of an angle is always less than 1. Cosines of angles have been calculated accurately and are available in mathematical tables.



In the use of the speedmeter, the velocity of the vehicle relative to the beam is less than its actual speed along the highway. In the diagram at the left, AC represents the actual speed of the vehicle. CB is the component of speed in the direction of the beam. Therefore,

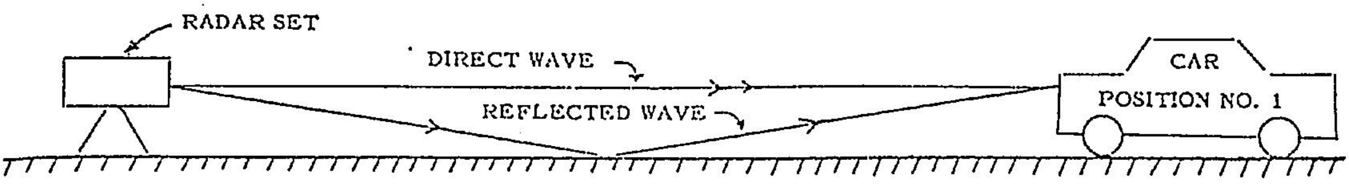


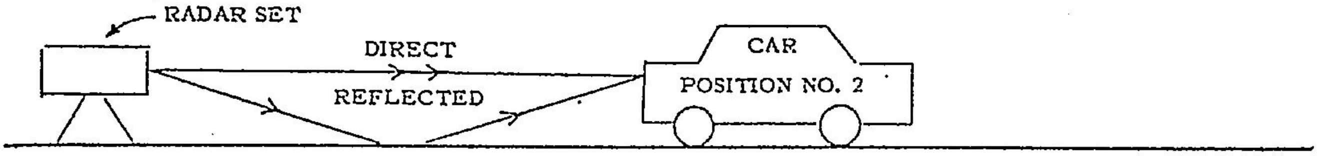
$$\frac{\text{Speed relative to the radar beam}}{\text{Actual speed of vehicle}} = \frac{CB}{CA} = \text{Cosine } 10° = .985 \text{ (from tables) or,}$$

speed relative to radar beam = 98.5% of actual speed of vehicle. This shows that because of the practical necessity of setting up the speedmeter on the shoulder of the road, the speeds observed by the speedmeter will be 1½% lower than the actual speeds. This is the "cosine error" referred to above and it *always* results in the measured speed being *less* than the actual – which is in favor of the motorist.

Vertical Angle of the Beam to the Road

As mentioned earlier, any solid object (including the earth) reflects radio waves. Also previously discussed was the radiation pattern of the antenna in a vertical plane. These two factors give rise to a peculiar phenomenon when the radar set is in use, due to reflections from the road.





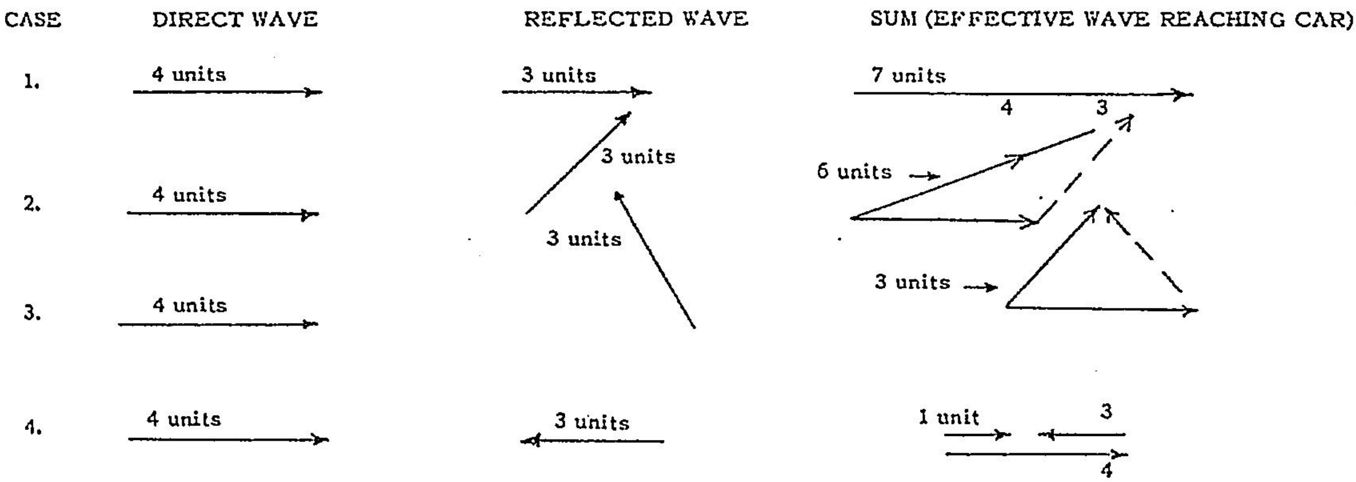
Consider the waves reaching the car when it is in position No. 1. The direct wave and reflected wave travel over the paths shown. These paths (direct and reflected) are of different length, the amount of difference determined by

1. The distance of the car from the speedmeter.
2. The height of the car.
3. The height of the radar set.

For any fixed distance between the car and the radar speedmeter the difference in path lengths between direct and reflected waves will increase with increasing height of either or both of the reflecting object (car) or the radar speedmeter.

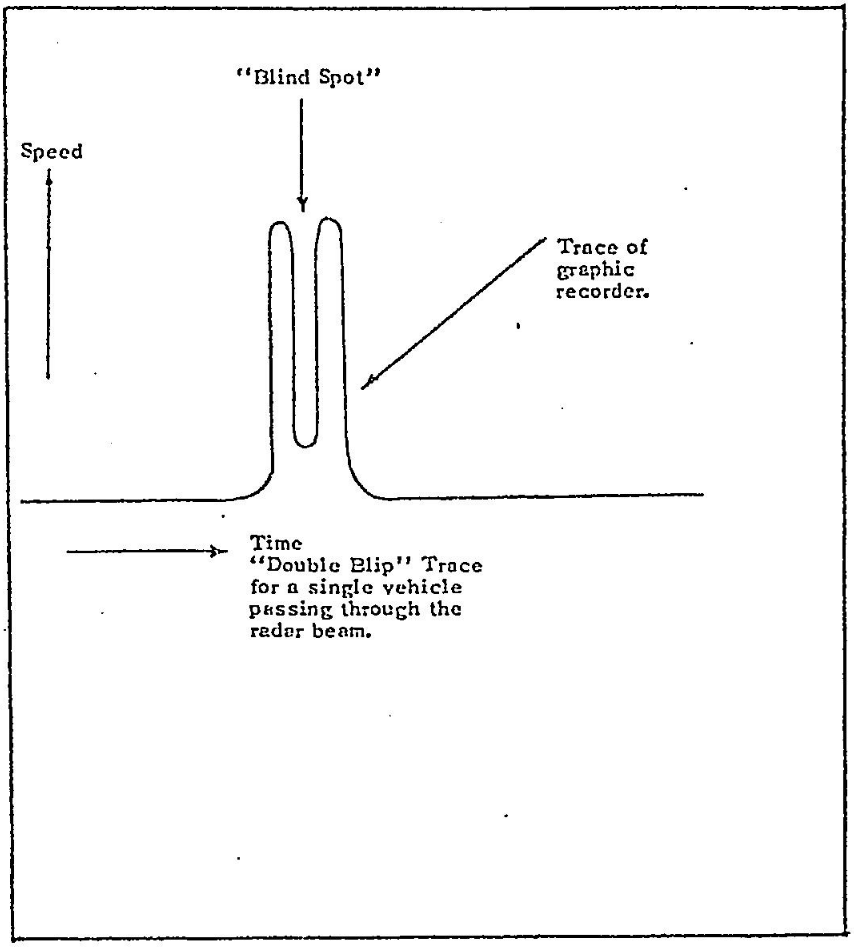
The operator obviously has no control over the distance of the reflecting object (car) or the effective height of the reflecting object (truck or car). He does, however, have control of the height of the speedmeter. The position of the speedmeter which makes both path lengths nearly the same is when the speedmeter is placed on the ground.

The effect of different path lengths is to cause the two waves arriving at the car to be at different points on the wave, therefore they do not add directly but add vectorially.



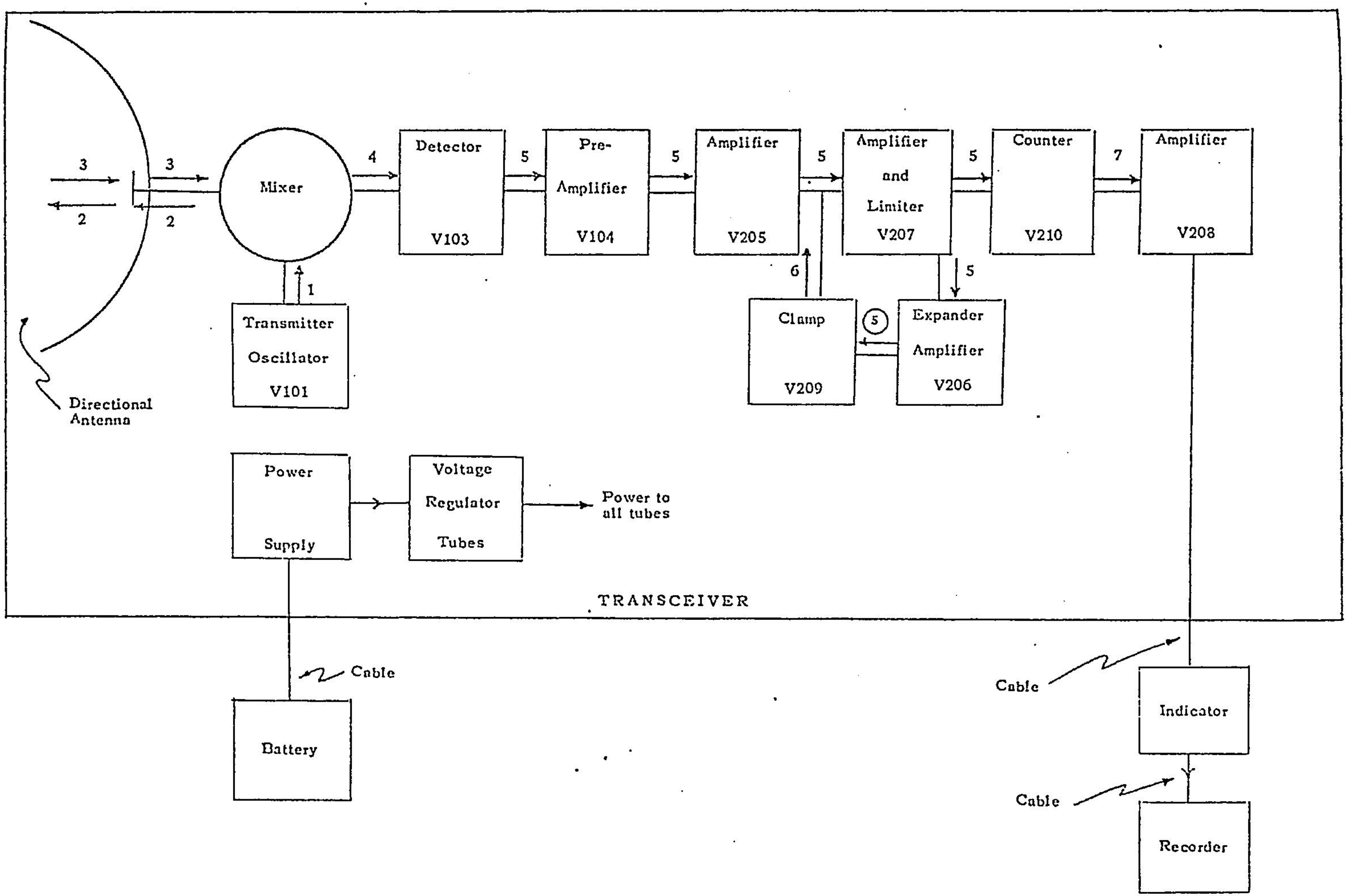
Case 1 shows the two waves arriving in unison (in phase) so that the effective wave striking the car is the numerical sum of each wave. Cases 2 and 3 illustrate conditions where the waves do not add directly. Case 4 is for the case where the two waves are in direct opposition to each other, resulting in a very small effective wave. It has been assumed in these diagrams that the reflected wave is somewhat smaller than the direct wave due to imperfect reflection. Normal road conditions will result in nearly perfect reflection which for case 4 above would result in effectively no wave arriving at the car for the particular conditions under consideration (distance, height of speedmeter, height of car) thus the speedmeter has effective "blind spots" where it does not see the approaching (or receding) vehicle.

The result of this is that, for a given setup, the radar speedmeter records the approaching vehicle, indicates its speed and then as the car enters the "blind spot" the reading disappears. As the car leaves the "blind spot" the vehicle "reappears" and the radar speedmeter again records its speed. Operators term this type of reading as a "double-blip" as two readings of speed are given for the one vehicle.



"Double Blip" Trace for a single vehicle passing through the radar beam.

To avoid this type of record, keep the position of the speedmeter as close to the road level as is practical consistent with good readings for the test car driven through the radar beam during initial setup.



BLOCK DIAGRAM OF SPEEDMETER

THEORY OF SPEEDMETER BY BLOCK DIAGRAM

Generation and Transmission of Radio Waves

The transmitter oscillator generates electrical oscillations of 2,455 megacycles (Arrow 1) which pass through the Mixer to the Directional Antenna. The Antenna transmits radio waves (Arrow 2), also of 2,455 megacycles, in a 20° beam towards the target.

Reception of Reflected Signals

The radio waves, or signals, reflected back from the target (Arrow 3) are picked up by the same antenna and pass into the Mixer. These signals differ from the transmitted signal of 2,455 Mc/s, being either larger or smaller by an amount equal to the Doppler frequency shift (depending upon whether the car is approaching or receding and upon its speed).

Detection of Doppler Frequency

In the mixer, part of the transmitted signal is combined with the received signal in such a way that two additional signals or "beat frequencies" are set up. (Arrow 4). These beat frequencies are mathematically related to the original signals causing them. One of these beat frequencies is the sum of the original frequencies; the other is the difference of the original frequencies. It is this latter beat frequency that is used in the radar speedmeter for this is in fact the Doppler frequency. On the diagram it is represented by arrow 5.

NOTE: If the target were receding at 10 m.p.h. the returning signal would be 2,455 megacycles minus 73 cycles per second. If it were approaching, the signal would be 2,455 megacycles plus 73 cycles. The Doppler frequency would *in both cases* be 73 cycles.

Amplification of Doppler Frequency

The returning signal, and hence the resulting Doppler note, is very weak. Therefore the latter must be amplified (made stronger) before it can be properly used. Accordingly, the Doppler note is passed through three stages of amplification before anything else is done with it. (This is done using vacuum tubes V–104, V–205 and V–207).

Automatic Suppression of Weak Signals

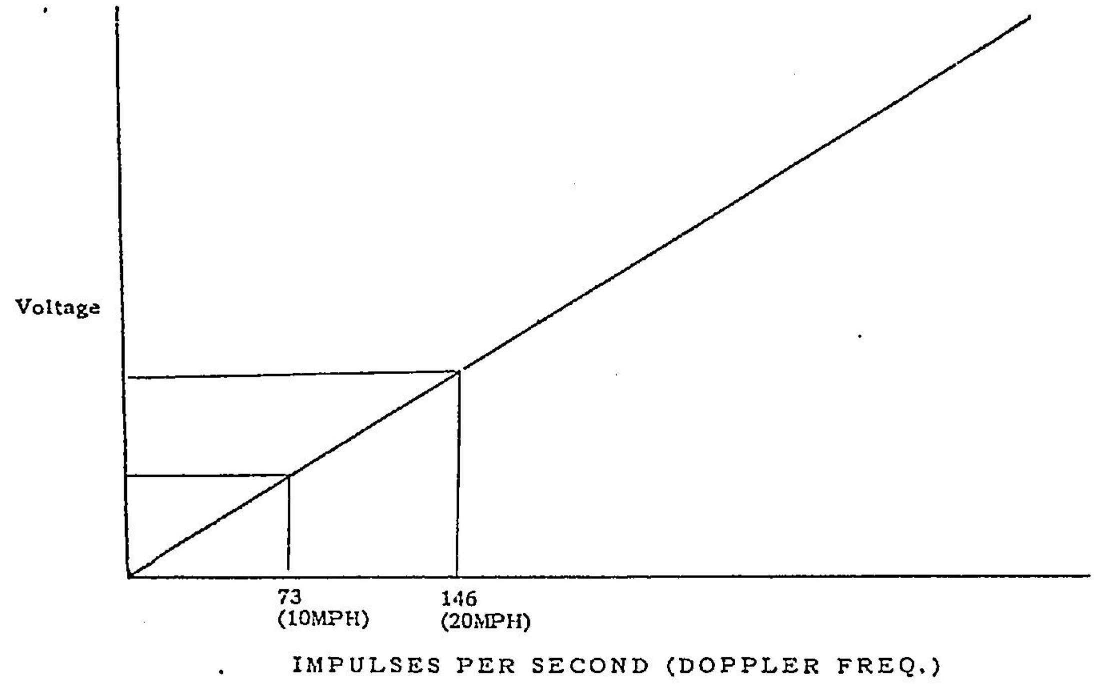
Some of the received signals, as from a vehicle too far away, or a bird flying through the beam, would be too weak to use even after amplification. Therefore, when there are no signals, or the signals are below a certain level, the amplifier V–207 is shut off, being held that way by its own characteristics and by a clamping tube, V–209. However, when the signals go above a certain level, V–207 begins to pass them, and at the same time opens up, through V–206, the clamping tube V–209 which causes it to receive full signal strength. This action essentially allows full output from V–207, or none at all, so that readings will always be positive.

Relating the Doppler Note to Voltage

After the last stage of amplification, with a strong and constant strength of signal obtained, the Doppler note passes into a frequency counter tube (V–210). This tube and its associated circuits add up the Doppler note as so many impulses per second into a steady voltage. If the Doppler note is 73 cycles (representing 10 m.p.h.) the counter will produce a certain voltage. If the Doppler note doubles in frequency to 146 cycles (representing 20 m.p.h.) then the counter will produce double that voltage. (Arrow 7 represents the voltage indication).

Relating Voltage to Speed

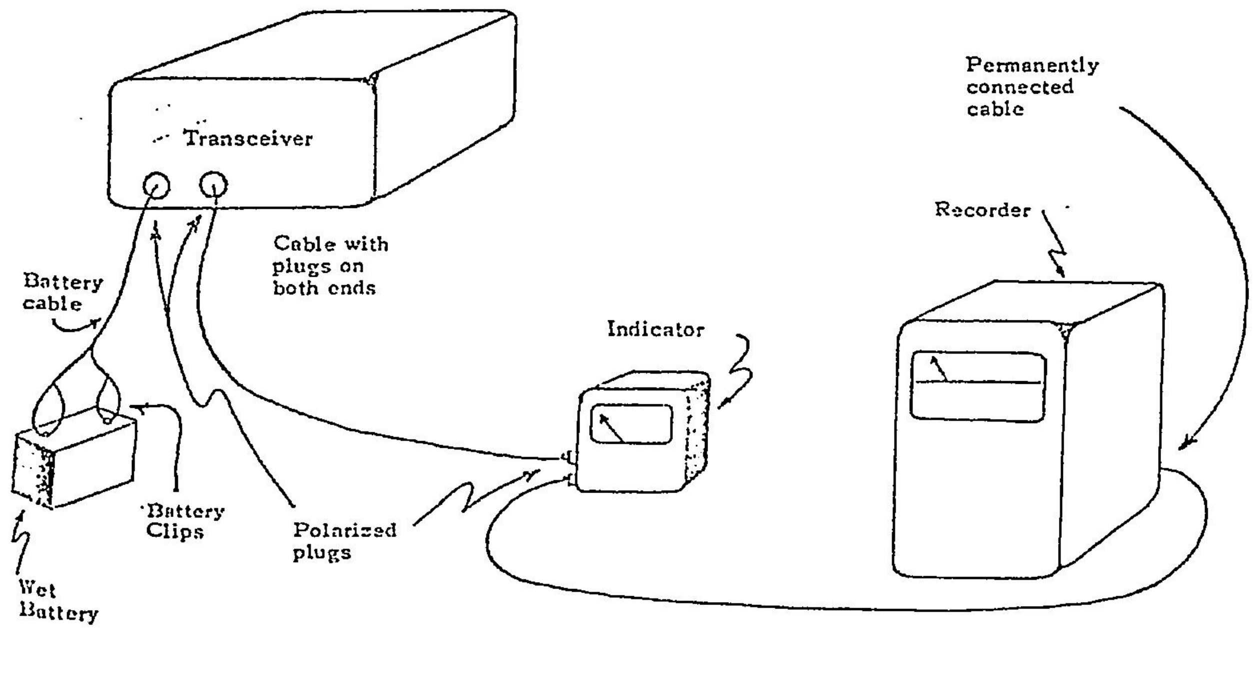
Having now a voltage that is directly related to speed, all that is required is a voltmeter calibrated in speeds rather than volts. V–208, which amplifies the voltage from the counter, along with the Indicator and Recorder meters working out of V–208, together form what is called a vacuum-tube voltmeter.



BLOCK DIAGRAM APPLIED TO SET

The Speedmeter consists of the following units:

(1) Transceiver
(2) Indicator
(3) Recorder
(4) Battery (unless 110 volts A.C. is being used)
(5) Interconnecting cables
(6) Tripod for transceiver
(7) Carrying cases
(8) Recorder supplies



Transceiver

Since the transmitter and receiver are housed in one unit, the latter is referred to as a transceiver. The connection is closer than their actually being in one case, for as we have seen, the antenna is used for both transmitting and receiving, as well as the necessary connection of the two in the mixer and detector circuits.

The main components of the transceiver are:

(1) Directional Antenna
(2) Transmitter Oscillator
(3) Mixer and Detector
(4) Receiver amplifier and counter circuits
(5) Power supply, and voltage regulator tubes

The function of the first 4 items above has been previously explained.

The power supply and voltage regulator tubes feed the correct low and high voltages to the transceiver tubes and circuits. Five voltage regulator tubes are used to keep voltages constant, and minimize any fluctuations that may occur from changes in outside supply voltages or from changes within the transceiver. The power supply itself is fed by an external 6 or 12 volt battery (depending on the set), or 110 volts A.C.

The transceiver has only two cables leading from it, one to the battery or 110 V.A.C. supply and the other to the indicator.

A switch at the back of the transceiver shuts off the current to the transceiver, indicator, and recorder.

The Indicator

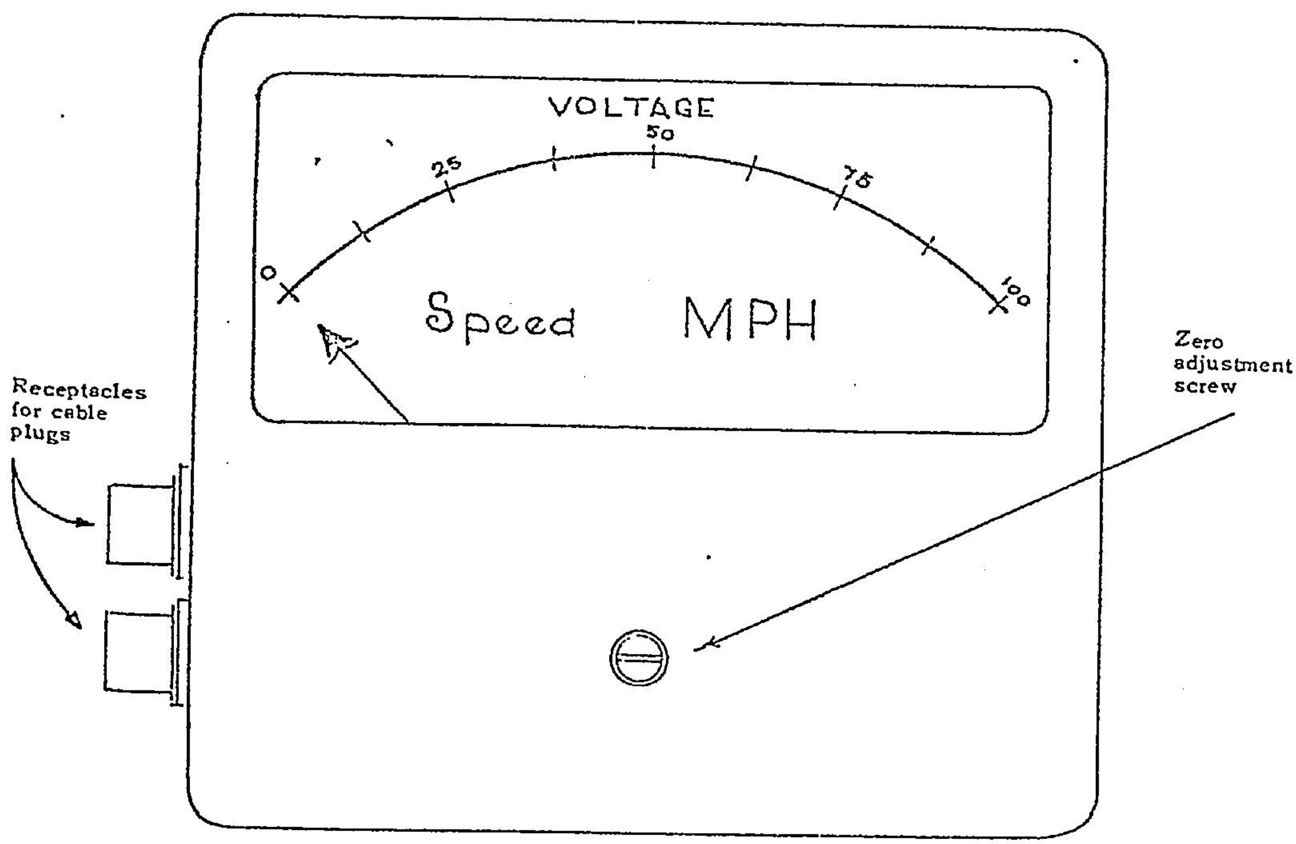
The amplified voltage signals of the transceiver counter are fed by a cable to the Indicator, which is simply a voltmeter. The hand of the meter is deflected in proportion to this voltage; and since this voltage has a linear relationship to the Doppler note, and hence speed, it is possible to have the meter scale calibrated in speed units. It is marked from 0–100 miles per hour, in 1 m.p.h. steps.

The indicator has internal illumination by two small bulbs, current being supplied from the transceiver.

Inside the Indicator is a cutout relay, which operates when the cable leading to the recorder is disconnected. This allows the indicator to be used without using the Recorder, correcting for the latter's being out of the circuit.

On the front case of the Indicator and in line with the pointer is a slotted "zero adjustment" screw, the purpose of which is to allow the pointer to be centered directly over the zero on the scale when the radar speed meter is set up and operating but where there is no moving object in the radar beam. Turning the screw clockwise or counterclockwise will alternately raise or lower the position of the pointer on the scale.

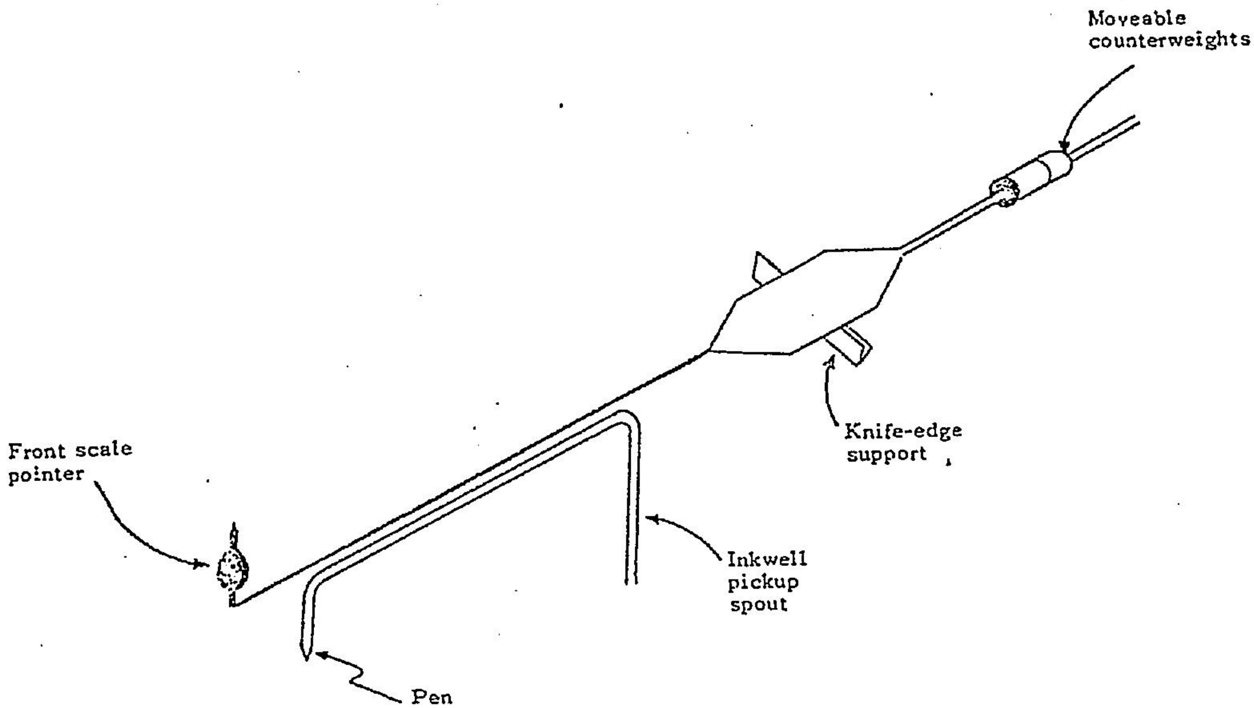
The Indicator has two cables connecting with it, one from the transceiver, and the other to the Recorder.



INDICATOR

The Graphic Recorder

The same voltage that causes the Indicator hand to deflect also causes the Recorder pen to deflect. This pen is merely the hand of a meter similar to the Indicator, the only electrical part of the Recorder being this meter movement. The hand of the meter, or pen, is hollow and picks up ink from a well so that it is able to leave a record of its reading on a moving graph. The pen is so balanced that it rests very lightly on the paper with a minimum of friction.

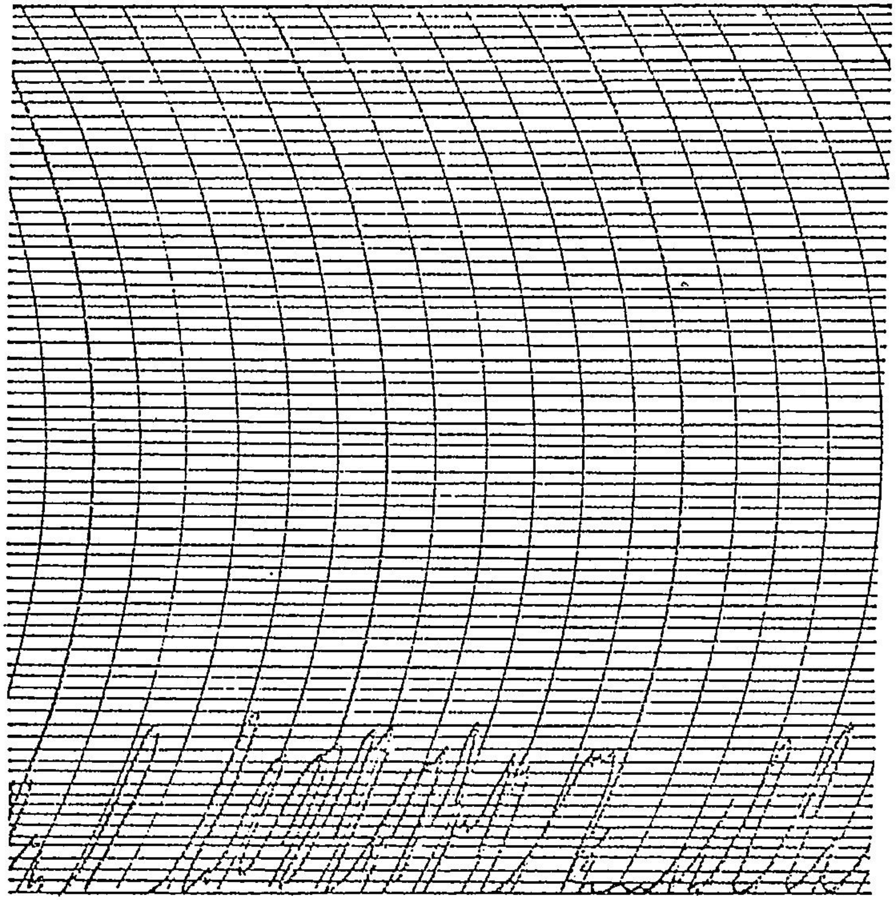


GRAPHIC RECORDER PEN

To help further overcome friction a small amount of alternating current (or hum) is added to the voltage signals from the transceiver. A minute and continuous vibration is thus supplied to the pen which helps it to ride over any rough spots on the paper. This hum is also present on the Indicator hand since it receives the same signals; and this device helps overcome possible friction in meter movements.

By a clockwork mechanism and a variety of interchangeable gears, the Recorder chart can be run at various speeds, but the normal speed is 1½ inches per minute. This speed has been found sufficient to spread out the targets' speed patterns so as to be best distinguished from each other. The Recorder chart is calibrated from 0–150 m.p.h. in 2 m.p.h. steps. Lengthwise, or in what represents time, the chart is divided by lines representing 1/6 minute per division, if the chart is being run at 1½ inches per minute.

As with the indicator, provision is made in the recorder to obtain a zero reading when the set is operating but no object is moving in the beam. This "zero adjustment" on the recorder takes the form of a long flat arm mounted on the inside face of the bottom of the recorder case. It is most readily visible (and accessible) by removing the paper take-up reel. This arm is pivoted about a point near the back and centrally located on the bottom of the case, and its adjustment moves it in a horizontal plane, and likewise the pen in a horizontal plane, allowing zeroing in a manner similar to that of the indicator. At any time when the pen is to be removed, it will be made much more readily accessible by operation of the zero adjustment control to bring it toward the center of the sheet.



The Recorder has only the one cable leading from it to the Indicator. This may be disconnected if only the Indicator is required.

Battery

The Model S-2 Speedmeter operates from a 6 volt storage battery, and the Model S-2 A from a 12 volt battery, and notice must be taken of which model is being used because of this. The meter nameplate which is located on the back of the instrument gives the type and operating voltage. A special power cable runs from the battery to the transceiver. Polarity on the batteries does not have to be observed.

Both models will operate from 110 volts A.C. by merely plugging in a special cable supplied for this purpose.

Batteries and the power consumption of the set will be discussed in a later section.

Interconnecting Cables

The cables associated with the various units are:

(1) Power Cable from Transceiver to Battery, or, if using 110 V, A.C., from Transceiver to Mains.
(2) Signal Cable from Transceiver to Indicator.
(3) Signal Cable from Indicator to Recorder which is permanently attached to the recorder.

Choosing a Location

A spot must be chosen where the radar beam has a clear and unobstructed sweep of the highway. Bearing in mind the useful range as being about 175 feet, the highway must be reasonably straight and level for this distance, so that the vehicle can remain long enough in the cone of the beam to give a true indication of speed.

The transceiver, as explained later on, should be about three feet above the highway and less than 10 feet from the travelled portion of it. Hence a high crowned road with a steep shoulder may present difficulties in mounting the unit.

Facilities for correctly parking the patrol car, whether the operator can conveniently observe traffic, etc., enter into the choosing of a location.

There are certain unwanted features of the landscape which must be watched for in deciding upon a location:

(1) High voltage transmission lines should not be too close.
(2) There should be no buildings close by, even behind the transceiver, since multiple reflections from them could give false readings. Metallic buildings and billboards must especially be watched for within the range of the beam, (175 feet).
(3) Any object in motion other than traffic should not be in line with the radar beam. Moving branches, swinging signs, pedestrians, cattle, farm machinery, etc., will give speed signals.
(4) Neon signs and fluorescent lights give speed signals, whether they are operating steadily or intermittently.
(5) Vibrating metal objects within a few feet of the transceiver, as could conceivably be obtained from mail boxes or wire fences with a wind blowing, can generate interfering signals.

Placement of the Units

CAUTION: In transporting and handling the units, they should not be jarred or treated roughly. *The Indicator must remain upright,* otherwise its ink will spill.

(1) Transceiver

The main points to observe in setting this unit up are to have it as close to the edge of the road as is safe and convenient, raised to a reasonable height, and placed on a firm base. It should not be more than 10 feet from the edge of the highway, and about 3 feet above the level of the highway.

Horizontal Angle of Radar Beam to the Road

The reason for placing it near the edge of the road is so that the beam may be directed as nearly as possible in line with the movement of traffic. If placed too far back, the angle of the beam to the road would be too much. With an angle of 10°, we get a negative speed error of approximately 2%.

Some experience is necessary in adjusting the angle of the beam for the best results. The target must remain in the beam long enough to obtain a peak reading, with a definite pause of the indicator and recorder pointers.

Also, the beam may be adjusted so that the effect of the line of traffic being studied may be more pronounced than that of the line going in the opposite direction. This is especially desirable on 4-lane highways.

The horizontal angle may be adjusted by sighting along the length of the transceiver case.

Vertical Angle of Radar Beam to the Road

The centre line of the radar beam should strike the highway about 150 feet away.

This vertical angle may be adjusted by sighting along the top of the transceiver.

Height of Transceiver Above the Highway

The height of the unit above the highway determines the effective range of the radar beam. At ground level, the range is roughly 75 feet; at 3 feet it is 150 feet; and at 30 feet as much as 350 feet. Although operated at various heights, between 3 and 4 feet give generally the best results.

Mounting of Transceiver

The unit may be placed on any firm surface in the correct relative position to the highway.

Various mounts are:

(a) The tripod supplied for the purpose is the most commonly used, and the transceiver case has a threaded hole in its base to fit it. The tripod legs are adjustable for height, and the transceiver mounting plate is adjustable horizontally and vertically.

(b) Guard rails, abutments, etc., offer convenient mounts. Even overpasses have been used on occasion.

(c) The patrol car itself has several positions that can be used. There is the top of the trunk lid, and inside the trunk itself if the lid is left open.

The ledge above the rear seat has been used, with the radar beam pointing through the rear window. However, the beam loses some of its energy in passing through the glass, with resultant loss of range. Due also to reflection effects from the window, readings may be abnormal, and the distance between the transceiver and window has to be adjusted in ½ inch steps until the readings are normal.

(2) Indicator

This unit is placed where the operator can conveniently see it, being usually on or above the dash, or hung on the rear view mirror.

It is important that it be viewed from the front, since, in viewing it from the side, there is an error due to misaligning of the pointer and scale graduations, which is called parallax error.

The indicator may be 20 feet from the transceiver if using the stardard cable supplied, or 120 feet with the added 100 foot extension cable.

(3) Recorder

This unit should be placed on a stable base, and in a level position. It should receive no jarring or vibration. If, for some reason, it is being used with the front open or off, there should be no appreciable draft present, since the light pen may be affected by it.

The cable between the Recorder and Indicator is 10 feet long, being fixed permanently to the Recorder at one end. However, a 100 foot extension cable is available if more distance is required between these two units. Usually it is placed near the indicator on the front shelf of the patrol car.

(4) Battery

Normally, a separate battery is used, and this is placed where most convenient for connecting to the transceiver.

There are two power cables available, a 20 and a 60 foot one.

The patrol car battery may be used if the engine is not running, and if this battery is known to be well charged.

Connecting the Units

With the units in position, the three cables are run in such a fashion that they cannot be damaged by sharp corners or by being run over by traffic.

The connectors themselves, and the connections within them, are especially subject to damage, and should never be placed or dragged on the ground. In disconnecting them from their sockets, it is important that they be pulled out by holding them, and not by pulling on their cables, as internal connections may be broken. They can only be plugged one way into their respective sockets, and are held in by making a clockwise half turn on their coupling nuts.

It is not possible to get a connector in the wrong socket because of different pin arrangements.

Clips are provided at the battery end of the power cable, and polarity need not be observed.

Before plugging in the cables, check to see that the transceiver switch is off.

Checks Before Turning On

With the units correctly positioned, and the cables securely connected, there is nothing to check or adjust before turning on except the Recorder.

(a) Check to see if there is enough paper for the period of operation required. The standard 100 foot chart will last about 12 hours if run steadily at the 1½ inches per minute speed.

(b) Wind up the clockwork mechanism for the chart drive if necessary.

(c) Add ink to the well if it is not about ¾ full, using the filler supplied.

(d) With the pen filler, draw ink through the pen until no bubbles are visible inside it. Start the chart drive, check that the pen is writing evenly, and leave the chart drive running on the slow speed position.

Checks After Turning On

The main switch at the back of the transceiver is turned to "ON" and the equipment allowed at least a 3 minute warm up period before any checks or adjustments are made.

The engine of the patrol car should not be idling, and when taking readings the radio transmitter should not be operating, nor one in the immediate vicinity.

The chart of the Recorder is now run at the fast 1½ inches per minute speed, and results observed.

Between target indications the Indicator and Recorder should give a zero reading. If this is not so, adjust each to read "Zero." The Indicator has a zero adjusting screw on its front face, and the Recorder has a zero adjusting arm inside the base. Adjusting these has no effect on the overall calibration of the two units. If the units cannot be zeroed, either some interference giving a speed indication is in the neighbourhood, or a service adjustment is necessary.

Test car runs at several set speeds are now usually made, and some adjustment of the transceiver angle may be necessary.

The speedmeter is now ready for normal operation.

POWER REQUIREMENTS

The electrical power required to operate the Speedmeter may be obtained from:

(1) *For Model S-2,* a 6-volt direct current source, normally a standard 6-volt storage battery. This model takes a current at 7.5 amperes from the battery.

(2) *For Model S-2 A,* a 12-volt direct current source, normally a standard 12-volt storage battery. This model takes half as much current, or 3.75 amperes from the battery.

(3) *Both Models S-2 and S-2A,* by using a special power cable supplied, may be plugged into a standard 110 volt alternating current outlet. On 110 volts A.C., both models draw about ½ ampere, (50 watts).

CAUTION: *Since a set could be damaged by using the wrong voltage supply, it is necessary to check the model and voltage of a strange or new set before using it. The required information is on the inside of the hinged cover that protects the transceiver cable sockets.*

Since the storage battery is a critical item in the set's operation, this discussion will be confined to its working and care.

Charge and Discharge

A storage battery is essentially a number of cells containing plates of metallic lead and lead dioxide immersed in a solution of sulphuric acid and water.

When the battery is fully charged all the acid is in solution, and the solution is consequently its heaviest (i.e. highest specific gravity).

When the battery is being discharged, the acid leaves the solution and combines with the lead plates. It is this combining, or chemical action, which generates the electrical current. As the battery discharges, the acid-water solution becomes weaker and lighter, (i.e. lower specific gravity), until there is no more acid in solution, at which stage the battery is completely discharged or "dead".

Charging is essentially the process of driving the acid back into the solution by means of a reversed electric current.

The chemical equation of this action (for any who may be interested) is:

$$\underset{(+\text{ plate})}{PbO_2} + \underset{(-\text{ plate})}{2H_2SO_4 + Pb} \rightleftarrows \underset{(+\text{ plate})}{PbSO_4} + 2H_2O + \underset{(-\text{ plate})}{PbSO_4}$$

Measuring The State of Battery Charge

Because the battery liquid (electrolyte) changes in makeup from the charged to uncharged state the change in density (weight per unit volume) can be used to measure the battery charge. "Density" is normally measured by a comparison of weight of an object to the weight of the same volume of water as is occupied by the object. This ratio

$$\frac{\text{Weight of object}}{\text{Weight of equal volume of water}}$$

is termed the specific gravity. The device used to measure the specific gravity of liquids is termed a hydrometer.

Its construction and components are shown in the diagram.

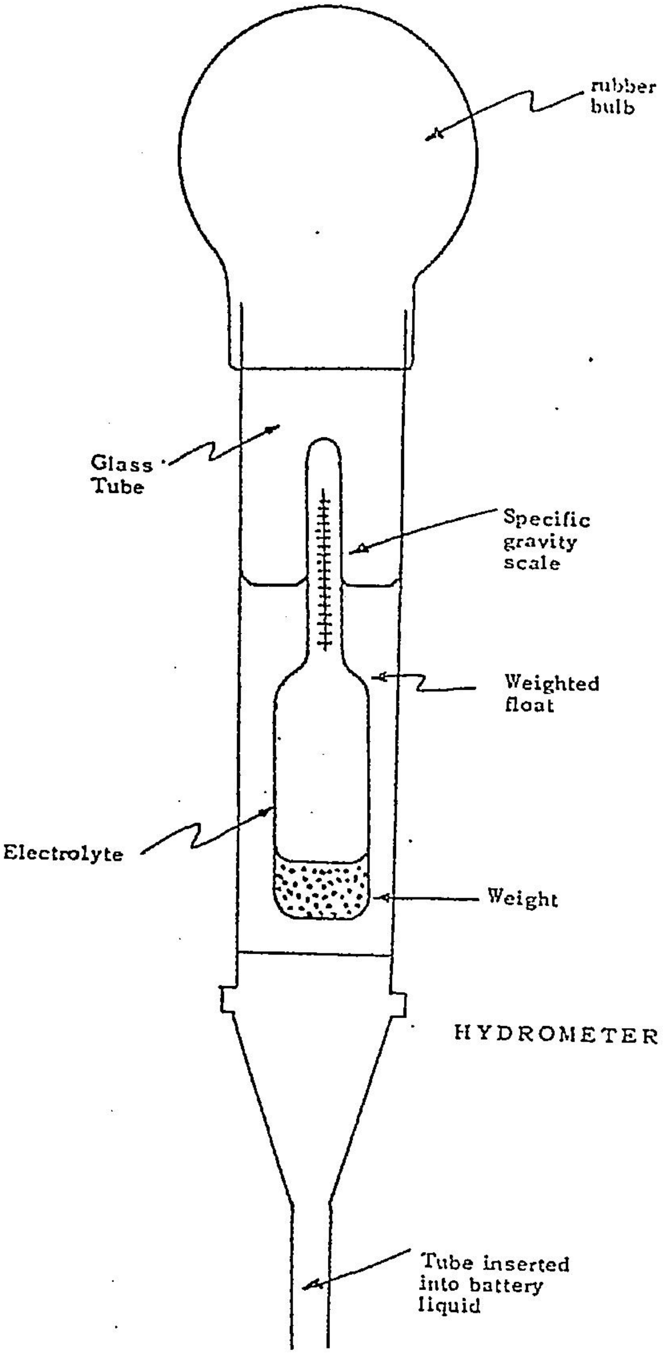
The scale of the float is marked off in units starting about 1.100 to 1.300 (frequently the decimal point is omitted giving readings from 1100 to 1300). The specific gravity of the electrolyte is that point on the scale to which the float sinks in the battery electrolyte. In testing it is most important that sufficient liquid be withdrawn from the cell to allow the "float" to float in the liquid otherwise an incorrect reading will be obtained. Extreme caution must be observed with the electrolyte to prevent its splashing or dropping outside the battery as it is very corrosive. It is a good safety precaution to wash one's hands after testing battery charge or removing battery caps.

A fully charged battery has a specific gravity of about 1.3 – read as 1300 on a hydrometer.

A half charged battery has a specific gravity of 1.2 – read as 1200.

A fully discharged battery has a specific gravity of 1.15 – read as 1150..

The speedmeter should not be operated on a battery reading below the half-charged condition, or 1200 on the hydrometer.



HYDROMETER

Battery Voltage

Voltage may be defined as electrical pressure. Each battery cell is about 2 volts: hence a 6-volt battery has 3 cells, and a 12-volt battery 6 cells.

A fully charged 6- or 12-volt battery has a voltage a little over 6- or 12 volts; while a half charged battery is a little under 6 or 12 volts.

The Speedmeter will give normal operation if supplied with 5.8 to 6.5 volts for Model S-2, or 11 to 14 volts for Model S-2 A. Operation within these limits can be assumed by using batteries from a fully charged condition down to the half charged condition. The only thing that may change slightly as the battery is used and its voltage drops, is the zeroing of the Indicator and Recorder, which can be adjusted as explained earlier.

Batteries should not be used to operate the Speedmeter while being charged since their voltage may be too high.

Battery Capacity (Ampere-Hours)

A battery's capacity is how much electrical current it can deliver for a given time, and is measured in Ampere-Hours.

An ampere-hour is a definite quantity of electricity, as a gallon is a quantity of a liquid. If a battery delivers one ampere for one hour, it has lost one ampere-hour. If it delivers 10 amperes for 10 hours, it has lost 100 ampere-hours.

This ampere-hour capacity of a battery is determined by its physical size, that is, the number and area of its plates. A standard 6-volt battery has a 100 ampere-hour capacity.

Battery Capacity in Relation to Speedmeter Operation

(1) *Model S-2.* This 6-volt model draws approximately 7.5 amperes. If it were run for 8 hours, it would consume 8 × 7.5, or 60 ampere-hours. This will a little more than half discharge a standard 100 ampere-hour battery, so that 8 hours would be the limit of operating time on a fully charged battery until the battery is in need of recharging.

(2) *Model S-2 A.* This 12 volt model draws only half of what the 6-volt model does, or 3.75 amperes. If it were run for 8 hours it would consume 8 × 3.75, or 30 ampere-hours. Standard 12-volt batteries have about 60 ampere-hours capacity, so that 8 hours of use would be the limit of operating time in this case also.

Battery Care

A few points in the care of batteries used for Speedmeter operation are:

(1) Before starting to use a battery, make sure battery is sufficiently charged by using a hydrometer.
(2) Do not use a battery after it is about half discharged, as determined by a hydrometer.
(3) Make sure the battery is in generally good physical shape and is kept clean. There should be no leaks, loose posts, and the plates should be well covered by the acid solution.
(4) Make sure the battery receives proper service, and is being charged at normal rates. Too many quick charges will damage the plates of a battery.

Response Time

With a single vehicle moving into the radar beam, the indicator pointer should rise quickly to the speed value, pause a moment, then drop back. The Recorder pen should do the same, except that it will act a little slower because of drag of the pen on the paper. A defined pause at the peak of the rise ensures that the reading was a definite one.

If, due to improper aiming of the radar beam, the vehicle is in the beam for too short a period, the speed signal will be of too short a duration to allow the pen to reach a peak value, and a negative error will result.

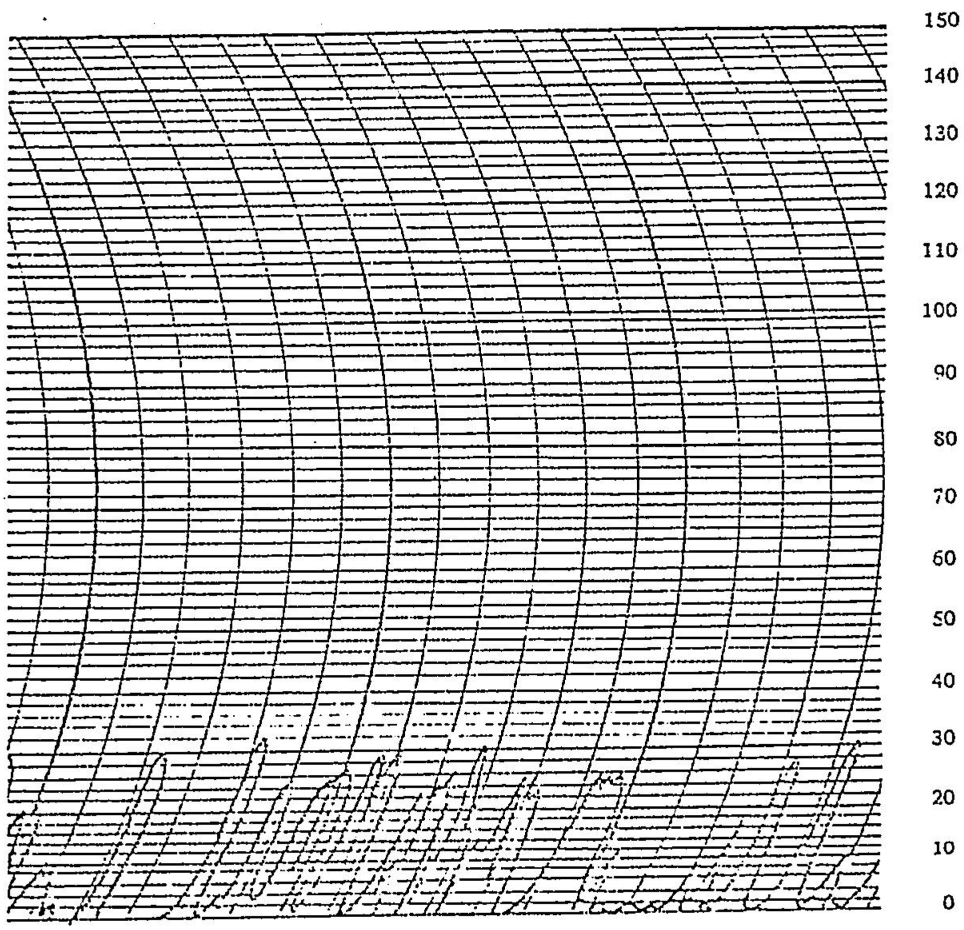
The same thing will happen if the pen is bearing too heavily on the paper, and hence moving too slowly.

Increased Sensitivity of Speedmeter to Faster Speeds

We have stated that, with the transceiver 3 feet above the highway, the effective range of the radar beam is about 175 feet. This means that at 30 m.p.h. (44 feet per second), the vehicle remains in the beam for 4 seconds, at 60 m.p.h. 2 seconds, and at 90 m.p.h. about 1 and ⅓ seconds.

It would seem, from the above, that the vehicle remains in the beam for too short a period for good response when travelling at higher speeds. The Speedmeter compensates for this by having been designed more sensitive to higher speed signals (i.e., higher frequency Doppler notes are amplified more). The stated range of 175 feet actually applies to speeds of 40 – 50 m.p.h. At speeds above this, the effective range is more than 175 feet because the higher frequency Doppler notes, though weaker, are amplified more.

By increasing the range for vehicles going at higher speeds, the Indicator and Recorder are given more time to indicate the peak speeds.



Separation of Speed Indications, or Resolution

When there is more than one vehicle moving in the radar beam, which particular one gives an indication depends on:

(1) Its nearness to the transceiver
(2) Its size, or target area
(3) Its speed.

(1) Since the Speedmeter responds to the strongest signal being received, the closest vehicle will generally give this, since the beam is more concentrated at that point and a stronger reflected signal is received.

(2) A large truck close behind a car, or a car behind a motorcycle may give its signal rather than the one in front because of its larger target area.

(3) If one vehicle is passing another, or if a car on one lane is going faster than another on the opposite lane, the faster vehicle will give its indication, rather than the slower one, provided they are all equally in the cone of the beam. This, as we explained, is because of the increased sensitivity of the Speedmeter to faster speeds.

Cars proceeding normally along the highway are usually spaced enough in proportion to their speed, to give defined separate speed indications on the Recorder. These speed pulses, or blips, as we may call them, may tend to run into each other if the cars are too close together. Even if the pen has not time to return to zero, but definitely drops, we may still read peak signals, however.

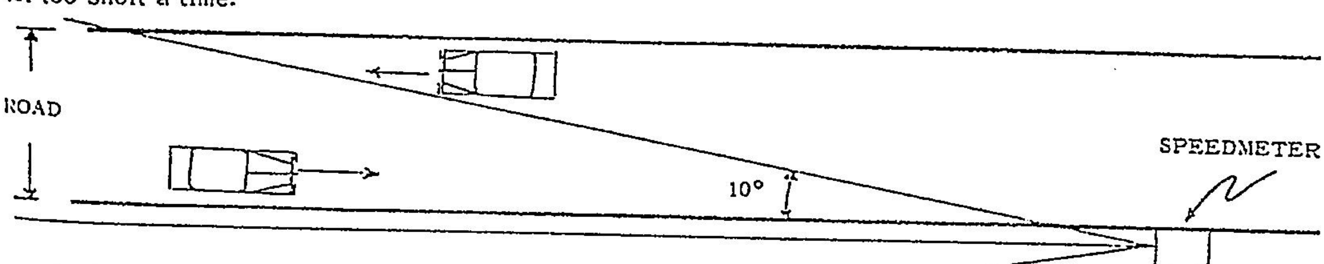
An experienced operator has no difficulty picking out the signal of a faster vehicle, unless the traffic is very heavy. But, as mentioned before, the radar beam may be aimed to pick up more on one lane than the other, it being especially necessary to do this on a 4-lane highway.

The deflection of the indicator or the trace on the recorder should show a definite pause at the maximum value for two reasons:

(i) To give a definite value for the speed of the vehicle.
(ii) To ensure that the indicator or recorder has, in fact, reached its maximum reading.

The trace on the recorder should be

Traces of the latter type may be obtained from an improper setup where the vehicles are within the beam for too short a time:

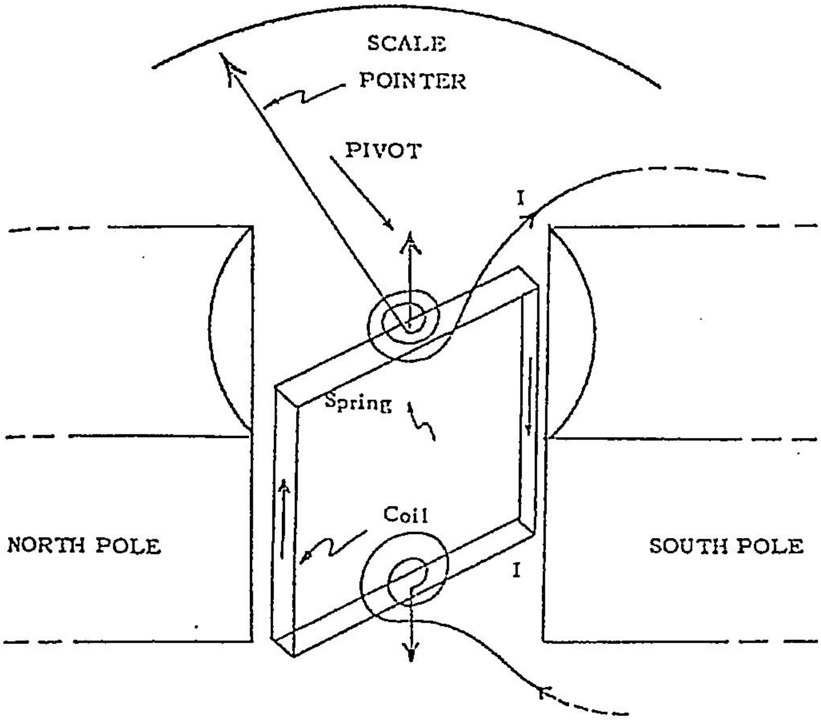


In this example the approaching traffic would give normal traces but the vehicles proceeding away from the speedmeter on the opposite side of the road would be in the beam for too short a time to give a full "flat-topped" deflection. This situation arises when the beam is directed about parallel to the road instead of at 10° to it.

Principle of Operation of Direct Current Meters

To complete the explanation of how readings are obtained on the indicator and recorder, one should appreciate what causes these instruments to deflect. The same direct current supplied by the electronic circuits of the speedmeter passes through both instruments. Both operate on the principle that when conductors carry a current and are situated in a magnetic field there will be a mechanical force exerted on the conductors. This is the same principle that is responsible for the operation of all electric motors. Both instruments have the magnetic field provided by strong permanent magnets. The parts of the meter in the recorder are much larger because enough force must be produced to move the pen over the paper.

The construction of a D.C. meter is illustrated by the following sketch:



A rectangular coil having several turns of wire is mounted on pivots and restrained in its position by spiral springs at the top and bottom, where pivots are also provided for the coil to rotate about a vertical axis. The springs are also connected to the ends of the coil and provide the path for current into and out of it. The coil is situated between the poles of a strong magnet. When current is passed through it as shown, the resulting forces on the coil cause it to rotate against the effect of the spiral springs. It reaches a steady deflection when the twist exerted by the coil equals that exerted in the opposite direction by the springs. The pointer or needle is attached to the coil and moves across a scale indicating the value of the current which is flowing in the coil or some quantity which is proportional to the current, which in the case of the speedmeter is the speed of the vehicle being observed.

It should also be appreciated that the moving parts (coil and pointer in the indicator and the coil and pen in the recorder) have inertia. The effect of inertia is to require some *time* for their motion to occur. This is why a full deflection may not be obtained when a vehicle is in the beam for only a short period. In this case the proper value of current flows in the coil, but it does not last long enough for the full deflection to be obtained.

SOURCES OF ERROR

From the Speedmeter

The set is designed with a view to high stability and accuracy. The maximum error that should be expected from it, is no more than 2 m.p.h. throughout the 0 – 100 m.p.h. range.

Under "Accuracy" the reasons for the set holding its calibration so well have been fully discussed.

From the Operator

While the sources of error here attributed to the operator will not happen if he is experienced, it may be wise to review adjustments and checks that would result in error if not attended to.

(1) Battery not in operating condition. If it is much below the half charged state, the readings would become low or unsteady. Loose or very dirty battery posts could result in unsteady readings, as well as if the battery clips on the power cable were not clamped to the posts securely.

(2) Cable connectors not tightly engaged in their sockets. Random fluctuations could result from this, giving a variable error.

(3) Transceiver not in correct position relative to the road. Too much angle of the beam to the road would give a larger negative cosine error than is normal (–2% for 10° beam.)

If the beam strikes the road too soon, or aimed in other ways so that the vehicle does not remain long enough in its range, the recorder pen will not have time to respond and reach peak value (negative error).

(4) Recorder not in level position, or on a surface that is vibrating will cause the pen to move incorrectly. Draughts on the pen will also cause errors (± errors).

(5) Recorder pen not counter-balanced correctly, and dragging too heavily on the paper (negative error).

(6) Insufficient warmup time (3 minutes or more) allowed before zeroing and speed trials (± error).

(7) Recorder and Indicator not zeroed at start of operation, and subsequently checked from time to time. (± error).

(8) Indicator not read from the front, resulting in Parallax errors (± error).

(9) Engine of patrol car left idling when its battery is used to supply the speedmeter. (Usually positive errors, up to 6%).

(10) Taking readings while the radio transmitter is in operation, either of patrol car being used, or one very close (+ error).

From the Location

(1) The road must be straight and level enough to allow the radar beam its full range along it, and allow the vehicle to remain in it long enough for full response. (Negative error).

(2) Presence of buildings nearby or other structures such as billboards, etc. False reflected signals could be received, sometimes indicating two cars when there is only one.

(3) Any other moving object in the radar beam, other than the vehicles being observed, such as moving tree branches, swinging signs, etc. (positive error).

(4) High voltage transmission lines nearby could cause fluctuations. (+ error).

(5) Fluorescent or neon signs may give speed readings if in the radar beam.

(6) Metallic vibrations within a few feet of transceiver, as from a vibrating wire fence, etc., could cause speed readings, or fluctuations.

From Traffic

(1) Cosine error. The path of the vehicle not being in line with the radar beam results in an error (negative error).

(2) A radio transmitter in operation in a passing vehicle could possibly affect the Speedmeter.

(3) A magneto ignition, as on some motorcycles, could cause interference.

(4) Some tests have shown that readings may be unreliable if two or more automobiles are as close as 50 feet *behind* the transceiver, giving reflection errors.

(5) There are possible sources of errors in discriminating between signals in heavy traffic, but they are not likely with an experienced operator.

In general, nearly all common sources of error favour the vehicle, most positive errors result from operator inexperience, allowing the car engine to idle, etc.

ACCURACY OF THE SPEEDMETER

Inherent Accuracy

The manufacturer's stated accuracy of the Speedmeter is plus or minus 2 m.p.h. throughout the speed range of 0 — 100 m.p.h. We can normally expect the set to work well within these stated maximum limits.

It is, on the whole, more accurate than a calibrated speedometer. The latter has its own internal accuracy limitations, which vary considerably with different speeds. But also, the speedometer reading depends very much on the state of the car's tires whose diameters can vary for several reasons, such as temperature, load, speed, etc. Furthermore, the maintaining of a steady speed is necessary in the reading of it, which is often difficult. Whatever its accuracy is, however, it provides a sure method of determining the basic accuracy of the Speedmeter.

Reasons for the Speedmeter's Accuracy

These are based on the principles involved, and the special design of the circuits.

(1) The constant speed of radar waves.
(2) The high speed of radar waves, resulting in practically instantaneous reactions.
(3) The fact that radar waves are, for this purpose at least, unaffected by weather conditions.
(4) The linear relationship between speed of target, frequency change, and indicating voltages produced within the set.
(5) The stability of the transmitter oscillator, which holds frequency within ± 0.1%. This full variation would represent only about 0.3 m.p.h. change at 35 m.p.h. If the oscillator shifts more than ± 0.1 in frequency, it ceases to function, and no speed indications are then possible.
(6) The "clamping" circuit that does not allow the set to respond to weak or uncertain signals.
(7) The high accuracy of the critical circuit components, such as resistors and condensors, which is ± 1%. Ordinary radio components are only about 10%.
(8) The higher sensitivity of the set to signals relating to higher speeds.
(9) The voltage regulation system, which takes care of external variations of voltage such as we get from a battery.

Operational Accuracy

The points have been discussed under "Sources of Error" whereby an operator could introduce inaccuracies, such as by

(1) Choosing a bad location along side buildings, etc.
(2) Failing to make necessary checks and adjustments.
(3) Reading the Indicator from the side (parallax error).

However, with a correct operational technique, it can be said that there is very little loss of accuracy here, and between what the set delivers and what is actually read, no more than 0.2 m.p.h. difference will result.

Accuracy of Speedmeter in Relation to Traffic Movement:

(A) *Single Vehicles.* The Speedmeter will read, within the previously mentioned limits of accuracy, the vehicle's speed relative to the path of the radar beam.

Since the vehicle moves at an angle to the radar beam, we have an error depending on this angle known as the "cosine" error. The accuracy lost here is less than 2% with the radar beam at 10° to the road.

The speed of the vehicle does not affect the accuracy of the recorded readings. If there is any tendency at all, it is for better accuracy above about 20 m.p.h.

(B) *Two or More Vehicles.* The same accuracy holds as in (A), with one vehicle following another, unless they are too close with resulting blending of signals.

If two vehicles are equally in the radar beam but going at different speeds, the faster one will be recorded at its top speed and not an average of the two speeds, as in some other sets, the Speedmeter being more sensitive to higher speed signals.

Advantages of the Speedmeter

Summing up, some of the advantages of the Speedmeter are:

(1) With reasonably experienced operators the set is an accurate instrument for determining speed.

(2) It is a relatively foolproof instrument, with a minimum of adjustments, and giving easily recognizable signs if faulty and requiring service. Very little shop service is required.

(3) It provides for a double check on speed by means of a visual Indicator and a graphic Recorder.

(4) By means of the Recorder, a permanent record of speed is obtained.

(5) The speed indications are almost instantaneous.

(6) It will continuously determine the speeds of a series of vehicles for long periods.

(7) Traffic speeds may be studied on either or both lanes of travel.

(8) There is no sacrifice of accuracy with high speeds.

(9) The operator is in a position to study speed indications and related vehicles when they are both approaching and receding, as well as operate a radio phone.

(10) The various units may be placed in a number of positions, and concealed if necessary.

(11) It will operate equally well under any weather conditions, day or night.

Limitations of the Speedmeter

(1) Operators require a certain training and experience.

(2) There are limits to the localities and the stretches of highway in which it can be used.

(3) Before each operation, the units must be set up and adjusted, the time for this being about 5 minutes. Also, the units must be taken down and packed after the operation.

(4) Another patrol car is normally necessary for speed checks, and for apprehending speeders.

(5) Batteries must be serviced and checked, and have a time limit of about 8 hours operating.

(6) Where traffic is too heavy, speed indications may be too close together to relate properly.