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Faculty of Engineering

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TRAFFIC POLICE RADAR

Graduation Project
EE- 400

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Nicosia – 2006

ACKNOWLEDGEMENTS

First of all I would to thank god for guiding me through my study.

Also, I feel proud to pay my special regards to my project adviser "Assoc. Prof. Dr. Sameer Ikhdair". He never disappointed me in any affair. He delivered me too much information and did his best of efforts to make me able to complete my project. He explained my questions patiently in radar and physics and electromagnetic, He has Devine place in my heart. I am really thankful to my teacher.

Also I want to pay special regards to my family specially my mother who is enduring these all expenses and supporting me in all events. I am nothing without her prayers. She also encouraged me in crises. I shall never forget her sacrifices for my education so that I can enjoy my successful life as she are expecting. I wish my mother lives happily always, and I want to pay a special regard to my brothers that really Im nothing without them.

The best of acknowledge, I want to honor those all persons who have supported me or helped me in my project. I also pay my special thanks to my all friends who have helped me to complete my project.

I also want to thank my friends in NEU: Sami al jundi, Zeyad al-kayyali, Muhammad abu Hussein, Omar Touqan, gorkem ozdegoglu, being with them makes my study life in NEU full of fun.

At the end I am again thankful to the doctors and professors encouraged me to complete my project.

ABSTRACT

Doppler radar uses the Doppler effect to return additional information from a radar system. The Doppler effect shifts the frequency of the radar beam due to movement of the target, allowing for the direct and highly accurate measurement of speeds.
Doppler radars were originally developed for military radar systems, but have since become a part of almost all radar systems, including weather radar and radar guns for traffic police and sports.

In radar where a moving target is involved, the signal undergoes the Doppler shift when impinging upon the target. This target becomes the "source" of the reflected waves, so that we now have a moving source (the pilot and the aero plane), moving and a stationary observer (the stationary radio receiver).

INTRODUCTION

The Austrian scientist Christian Doppler discovered the Doppler effect in the 19^{th} century. If you have ever listened carefully to the sound of a siren or high-pitched racecar engine as it approaches and then recedes from you, you have experienced the consequences of the Doppler effect. You probably noticed that the pitch (frequency) of the sound gets higher as the source of the sound approaches you and then gets lower as source moves away. This effect is caused by the effects the speed and direction of the sound source have on the sound waves.

The Doppler effect is the change in the apparent frequency of a wave as observer and source move toward or away from each other. If the source is the wave is moving toward the observer, the waves will appear closer together, forming shorter wavelengths. If the source of moving away from the observer, the waves will appear stretched out to longer wavelengths. An example of the Doppler effect can be seen at a railroad crossing. As the train approaches, the sound of the train's whistle will become high pitched because the wavelengths are getting shorter. The train's whistle will become low-pitched as the train passes since the wavelengths are becoming longer.

Doppler effect is a well-established phenomenon, and has found many applications. Physical mechanism of Doppler effect for sound waves is very transparent as explained in elementary textbooks, however for light waves due to theory of relativity and rejection of aether hypothesis there arise subtle problems in its interpretation. The most cogent argument for Doppler effect in the case of electromagnetic (EM) waves is based on the invariance of the phase of the wave (treating frequency and wave vector as a four-vector) under Lorentz transformation. Considering the fact that all the known mechanisms to change the frequency of a monochromatic EM wave depends on a dynamic interaction process or an active circuit (or optical) element, purely kinematics origin of frequency shift is intriguing. If the claim is made for a Radar is a equipment used in such detection since it is a method of detecting distant objects and determining their position, velocity, or other characteristics by analysis of very high frequency radio waves reflected from their surfaces.

The first chapter of this project is the background chapter, which include many types of radars like Doppler radar and dual wavelength polarized radar, biostatic radar, properties of Biostatic Radar.

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CHAPTER 1
RADAR FUNDAMENTAL

1.1 Overview

Radar is an acronym for radio detection and ranging. It is a system used to detect opjects, range determine there ranges, and map objects such as aircraft and rain. Strong radio waves are transmitted, and a receiver listens for any echoes. By analysing the reflected signal, the reflector can be located, and sometimes identified. Although the amount of signal returned is tiny, radio signals can easily be detected and amplified. Radar radio waves can be easily generated at any desired strength, detected at even tiny powers, and then amplified many times. Thus radar is suited to detecting objects at very large ranges where other reflections, like sound or visible light, would be too weak to detect.

1.2 Types of Radars

1.2.1 Doppler Radar

Doppler zing existing radar adds the capability of measuring wind direction and speed by measuring the Doppler effect. The radar measures what is called radial velocity. This is the component of the wind going either toward or away from the radar. There are currently two different types of radar that are being experimented with. The first type that is in the final stages of development is dual-polarized radar. The other that is being worked on is biostatic radar.

1.2.2 Dual Wavelength Polarized Radar

Since the current WSR-88D's is to be upgraded to this type of radar by the year 2005, it would be helpful to take a look at what this upgrade will do for us. With dual-polarization, there is the use of two or more wavelengths. This permits the extraction of additional information about the different meteorological targets. The radar echo of the targets changes with wavelength. The reflectivity of small targets, targets that are much smaller than the radar wavelength, is similar at two different wavelengths. For large targets like wet snowflakes and hail, the reflectivity differs. This helps solve the problem mentioned above referring to the raindrop size and its reflectivity. Size of the particle will be something that the radar can determine. This will allow for more information on the storm processes, and help forecast and warn on storms better. Also, with the dual-polarization, there is a dual-wavelength signature for large hail . Currently in on-going research, this type of radar can see more than just rain in the clouds. Dual-polarized radar can determine the following parts of a thunderstorm: Cloud Drops, Drizzle, Light Rain, Moderate Rain, Heavy Rain, Hail, Rain/Hail, Grapple/Small Hail, Grapple/Rain, Dry Snow, Wet Snow, Ice Crystals, Irregular Ice Crystals, Super-Cooled Liquid Water Droplets, and Insects.

1.2.3 Biostatic Radar

This is probably the newest instrument on the horizon for radar since it was created in 1994. In the past, a problem occurred in detecting the wind structure of a thunderstorm with a single Doppler radar as shown in figure 1.1.

Figure1.1 Doppler radar.

There was a problem because if the winds were flowing perpendicular to the radar beam, it could not resolve which direction they were flowing from. This problem is corrected with biostatic radars. In a biostatic system, there is at least one biostatic receiver and one single traditional monotonic weather radar. In this system, the weather radar transmits a narrow beam and receives the backscattered radiation. At the same time, one or more passive biostatic receivers recover some of the other scattered radiation. Since this gives multiple angles on the wind, many components of the wind can be measured simultaneously. This creates the possibility of directly measuring 3-D winds with a single radar system. There currently is only one biostatic radar network set up in the world. That network is set up around the Montreal airport in Canada. The preliminary results have been very promising; especially in areas like airports that require a good understanding of wind flow. An example of the data is below. One can see below in the data the direction and speed of the winds. This solves the problem that single Doppler's have. Single Doppler's can only see wind direction toward or away from the radar. Doppler radar can be divided into several different categories according to the wavelength of the radar. The different bands are L, S, and C, X, K. The names of the radars originate from the days of WWII.

1.2.3.1 Properties of Biostatic Radar

1.2.3.1.1 Biostatic Radar Geometry

The properties of biostatic radar have been described in detail by Willis and by Dunmore. Jackson has analyzed the geometry of biostatic radar systems, and his notation has been widely adopted.

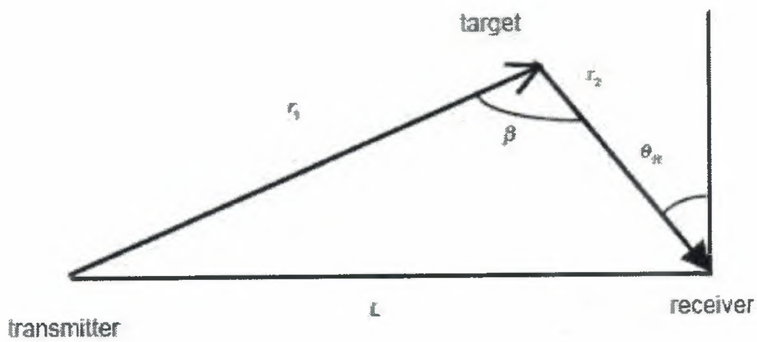


Figure 1.2 Biostatic radar geometry.

$$r_2 = \frac{(r_1 + r_2)^2 - l^2}{2(r_1 + r_2 + l \sin \theta_R)} \tag{1.1}$$

Contours of constant biostatic range are ellipses, with transmitter and receiver as the two foci; the biostatic radar equation is derived in the same way as the monotonic radar equation.

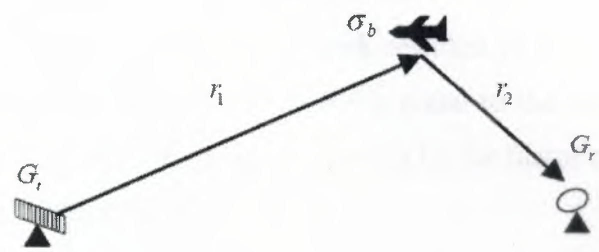


Figure 1.3 Biostatic radar equation.

$$\frac{P_r}{P_r} = \frac{P_r G_r G_t \lambda^2 \gamma_0}{(4\pi)^3 r1^2 r_2{}^2 K T_0 B F} \tag{1.2}$$

The factor $\frac{1}{r_1 r_2}$ and hence the signal-to-noise, has a minimum value for T $r_1 = r_2$ thus the signal-to-noise ratio is highest for targets close to the transmitter or close to the receiver,. Doppler shift depends on the motion of target, transmitter and receiver (Figure 1.4), and in the general case the equations are quite complicated.

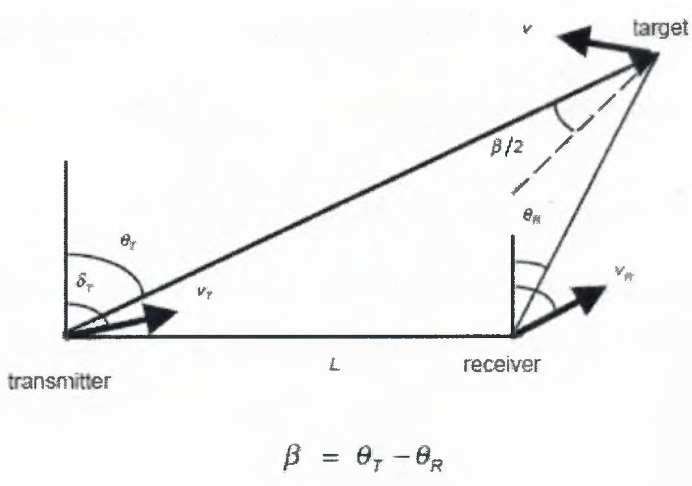


Figure 1.4 Biostatic Doppler.

In the case when only the target is moving the Doppler shift is given by:

$$f_D = \left(\frac{2V}{\lambda}\right) \cos l \cos\left(\frac{\beta}{2}\right) \tag{1.3}$$

1.2.3.1.2 Biostatic Radar Cross Section

The biostatic RCS of targets has been studied extensively, though relatively little has been published in the open literature. Early work resulted in the biostatic equivalence theorem, which states that the biostatic RCS *b s* is equal to the monotonic RCS at the bisector of the biostatic angle *b*, reduced in frequency by the factor cos (*b*/2), given:

(i) Sufficiently smooth targets.

(ii) No shadowing.

(iii) Persistence of retro reflectors.

These assumptions are unlikely to be universally valid, particularly for stealthy targets, so the results should be used with care.

1.2.3.1.3 Forward Scatter

A limiting case of the biostatic geometry occurs when the target lies on the transmitter-receiver baseline, whilst this means that range information cannot be obtained, the geometry does give rise to a substantial enhancement in scattering, even for stealthy targets, due to the forward scatter phenomenon. This may be understood by reference to Basinet's principle, which shows that a perfectly absorbing target will generate the same forward scatter as a target shaped hole in a perfectly conducting screen. The forward scatter RCS is approximately $\sigma_0 = 4\pi \frac{A}{\lambda}$, where *A* is the target projected area, and the angular width v_s of the scattering will be of the order of $\frac{\lambda}{D}$ Radians, where *d* is the target linear dimension. Figure 1.5 shows how these vary with frequency, for a target of the size of a typical aircraft, and shows that frequencies around VHF / UHF are likely to be optimum for exploiting forward scatter.

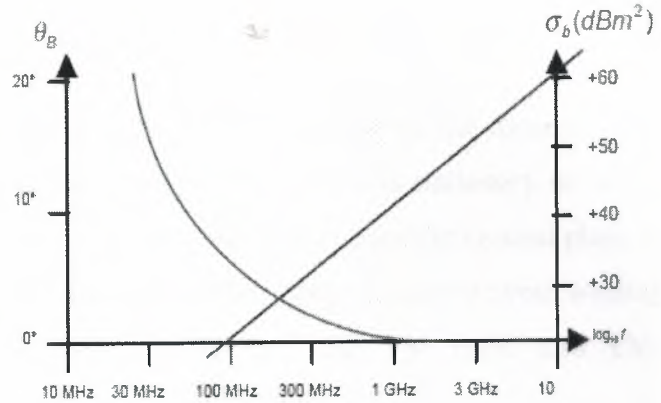


Figure 1.5 Variation of forward scatter RCS and angular with of response d=10m, A=10m^2

1.2.3.1.4 Biostatic Clutter

Biostatic clutter is subject to greater variability than the monotonic case, because there are more variables associated with the geometry. The clutter RCS σ_C is the product of the biostatic backscatter coefficient σ_b σ_B and the clutter resolution cell area A_C both σ_B and A_C are geometry dependent, with the maximum value of σ_B occurring at specula angles. There is relatively little experimental data available, and little work has been done in developing models for biostatic clutter. And some reason to suppose that biostatic sea clutter may be less 'spiky' than equivalent monotonic sea clutter, and hence that biostatic geometries may be more favorable for detection of small targets – but this remains to be investigated. There is thus much scope for new work on biostatic clutter; to gather data, to analyze the results, and to develop biostatic clutter models.

1.2.3.2 Passive Coherent Location

The use of broadcast or communications signals as 'illuminators of opportunity' has become known as 'passive coherent location' (PCL) or 'hitchhiking', and there has been Particular interest in this aspect of biostatic radar in recent years. The properties of transmissions for these purposes can be assessed in terms of

(i) Power density at the target.

(ii) Spatial and temporal coverage.

(iii) waveform. The power density at the target is evaluated from: $\Phi(in\frac{w}{m^2})$

$$\Phi = \frac{P_1 G_1}{4\pi r^2} \tag{1.4}$$

The spatial and temporal coverage will depend on the location of the transmitter, its radiation pattern, and (for example) whether it is stationary or moving and whether it operates for 24 hours per day or not. In some cases the vertical plane radiation pattern of TV or radio transmissions is deliberately shaped so as to avoid wasting power above the horizontal, the coverage achieved by VHF FM radio and TV transmissions is substantial.

This is because such systems have to be designed to cope with non line-of-sight propagation and very inefficient antenna and receiver systems. Cell phone base stations are also potentially useful as PCL illuminators; whilst these are of rather lower power, there are many of them, especially in urban areas. Satellite-borne illuminators, such as DBS TV, satellite communications and navigation and space borne radar are also of interest.

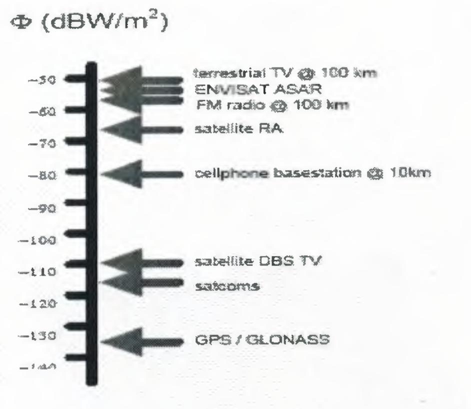


Figure 1.6 Power density ϕ for various PCL illuminators.

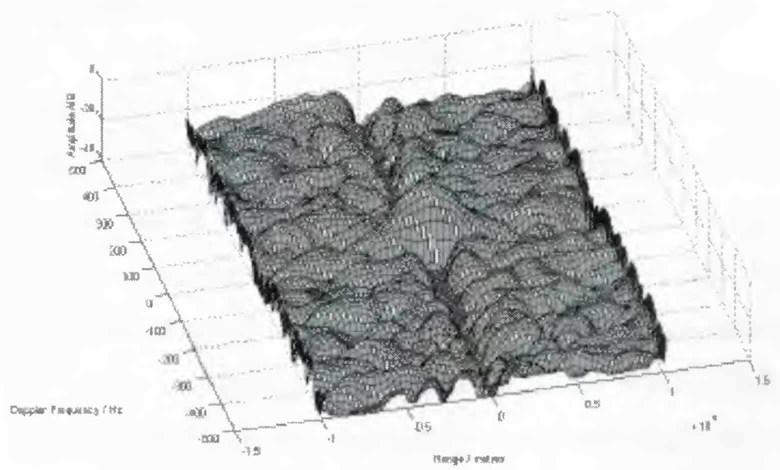
The waveform parameters of interest are the frequency, bandwidth, ambiguity function, and stability, in some cases it may be appropriate only to use a portion of the available signal (for example, to avoid ambiguities associated with the line and frame repetition rate of analogue TV modulation). In such cases the transmit power value used in Eq (1.4) should be appropriate. Figure 1.6 shows the values of ϕ for various PCL illuminators, under various assumptions. These are calculated on the basis of a single channel, the whole signal bandwidth, and no processing gain. The detection performance can then be estimated from:

$$(r_2)_{\max} = \left[\frac{\phi \sigma_b \lambda^2 G_p}{(4\pi)^2 (\frac{S}{N})_{MIN} K T_0 B F} \right]^{\frac{1}{2}} \quad (1.5)$$

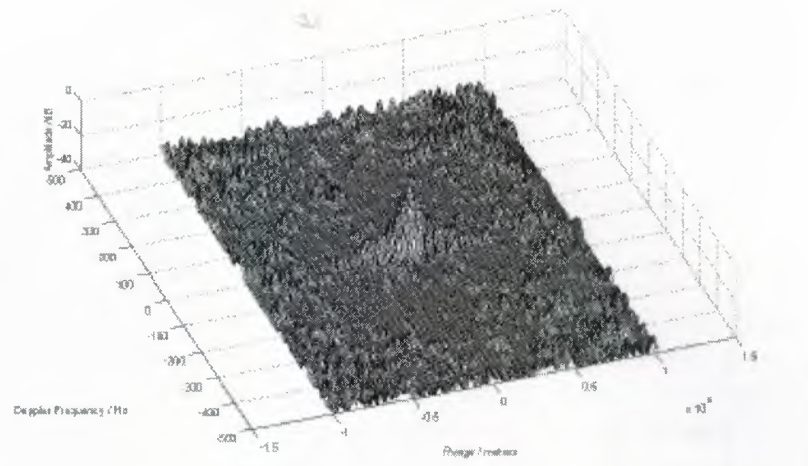
where *Gp* denotes the processing gain, which is the product of the waveform bandwidth and the integration dwell time, the integration dwell time in turn depends on the waveform coherence and the target dynamics. As a rule of thumb, the maximum integration dwell time is given by:

$$T_{MAX} = \left[\frac{\lambda}{A_R} \right]^{\frac{1}{2}} \quad (1.6)$$

where *AR* is the radial component of target acceleration. From these equations the coverage can be predicted in terms of Ovals of Cassini around transmitter and receiver.



(a)



(b)

Fig. 1.7 Typical ambiguity functions: (a) BBC Radio 4 transmission (93.5 MHz) and (b) digital audio broadcast transmission (222.4 MHz).

The waveform properties of a variety of PCL illuminators (VHF FM radio, analogue and digital TV, digital audio broadcast (DAB) and GSM at 900 and 1800 MHz) have been assessed by digitizing off-air waveforms and calculating and plotting their ambiguity functions. The receiving system was based on a HP8565A spectrum analyzer, digitizing the 21.4 MHz IF output by means of an Chetek ECDR-214-PCI digitizer card mounted in a PC. The system has the advantage of great flexibility, since the center frequency and bandwidth of the receiver can be set by the controls of the spectrum analyzer. The rather high noise figure of the spectrum analyzer is not a disadvantage, since all of the signals are of high power and propagation is line-of-sight. Figure 1.7 shows typical ambiguity functions derived using this system of (a) BBC Radio 4 at 93.5 MHz, for which the programmed content is speech (an announcer reading the news), and (b) a digital audio broadcast (DAB) signal at 222.4 MHz. Both show range resolution appropriate to their instantaneous modulation bandwidths (9.1 and 78.6 kHz respectively), though the difference in the side lobe structure is very evident, showing that the digital modulation format is far superior because the signal is more noise-like.

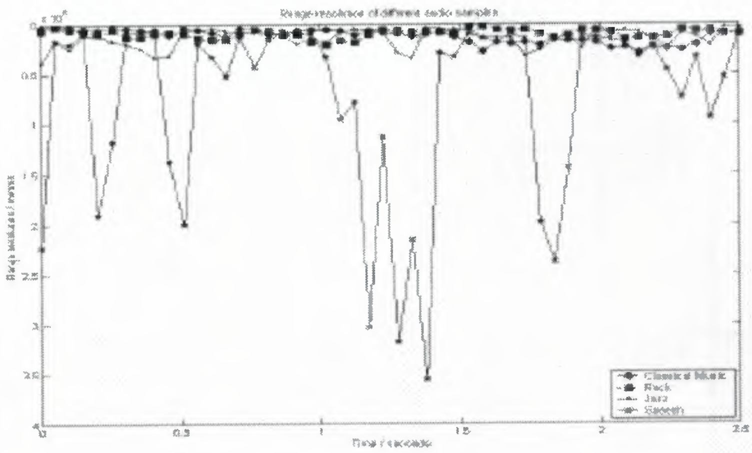


Figure 1.8 Variation in range resolution against time for four types of VHF FM radio modulation.

It is also important to know how these properties vary with time, as variations in the form of the ambiguity function will determine the radio system performance. Fig. 1.8 shows variation in range resolution of four VHF FM radio transmissions, calculated from the 3 dB width of the zero Doppler cut through the ambiguity function, over a 2.5 second interval., It is evident that for the three types of music the range resolution varies by a factor of two or three, but for the speech modulation the range resolution is badly degraded during pauses between words, by a factor of ten or more. Furthermore, when we also take into account the dependence of the ambiguity function on geometry, it can be seen that there is scope for adaptively choosing the signals from a variety of transmitters in a multistatic PCL system, selecting those for which the geometry and instantaneous modulation are favorable.

Signal	Frequency (Mhz)	Range resolution (km)	Effective bandwidth (kHz)	Peak range side lobe level (dB)	Peak Doppler side lobe level(dB)
FM radio: speech (BBC Radio 4)	93.5	16.5	9.1	-19.1	-64.5
FM Radio: classical music	100.6	5.8	25.9	-23.9	-32.5
FM Radio: rock music	104.9	6.55	22.9	-12.0	-26.0
FM reggage (choice FM)	107.1	1.8	83.5	-27.0	-39.5
DAB	219.4	1.54	97.1	-11.7	-38.0
Analog TV: chrominance sub-carrier	491.55	9.61	15.6	-2.0	-9.1
Digital TV(DVB-T)	505.0	1.72	87.1	-18.5	-34.6
GSM 900	944.6	1.8	83.3	-9.3	-46.7
GSM 1800	1883.6	2.62	57.2	-6.9	-43.8

Table 1.1 Properties of ambiguity functions of various types of broadcast and communication signals.

and other weather phenomenon. This band is also shared with some police speed radars and some space radars.

1.3.5 K Band Radars

Operate on a wavelength of .75-1.2 cm or 1.7-2.5 cm and a corresponding frequency of 27-40 GHz and 12-18 GHz. This band is split down the middle due to a strong absorption line in water vapor. This band is similar to the X band but is just more sensitive. This band also shares space with police radars.

1.4 The Radar Equation

The fundamental relation between the characteristics of the radar, the target, and the received signal is called the radar equation. The geometry of scattering from an isolated radar target (scattered) is shown in the figure1.8, along with the parameters that are involved in the radar equation.

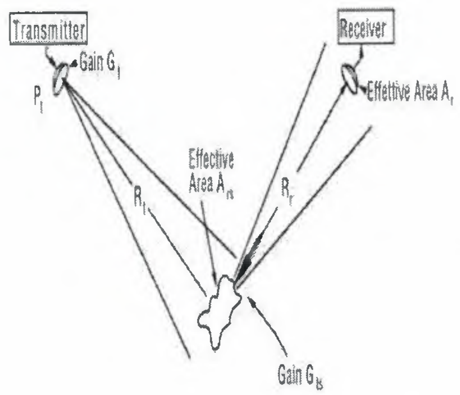


Figure1. 9 The geometry of scattering from an isolated radar target (scattered).

When a power P_t is transmitted by an antenna with gain G_t, the power per unit solid angle in the direction of the scattered is $P_t\ G_t$, where the value of G_t in that direction is used. At the scattered,

$$S_S = (p_t G_t)\left(\frac{1}{4\pi R^2}\right) \tag{1.7}$$

where S_S denotes the power density at the scattered. And R denotes the sphere radius.

The spreading loss $\frac{1}{4\pi R^2}$ is the reduction in power density associated with spreading of the power over a sphere of radius R surrounding the antenna. To obtain the total power whereas for the radar it is:

$$\left(\frac{1}{4\lambda}\right)^2\left(\frac{1}{R_t}\right)^4 \qquad (1.12)$$

Hence, the spreading loss for a radar is much greater than for a communication link with the same total path length.

The power entering the receiver can obtained by:

$$P = SA \qquad (1.13)$$

where A_r denotes the effective aperture of the receiving antenna, not its actual area. Not only is this a function of direction, but it is also a function of the load impedance the receiver provides to the antenna; for example, P_r would have to be zero if the load were a short circuit or an open circuit The factors associated with the scattered are combined in the square brackets. These factors are difficult to measure individually, and their relative contributions are uninteresting to one wishing to know the size of the received radar signal. Hence they are normally combined into one factor, the radar scattering cross section can be obtained by:

$$\sigma = A_{ts}(1 - f_0)G_{ts} \qquad (1.14)$$

The cross-section s is a function of the directions of the incident wave and the wave toward the receiver, as well as that of the scattered shape and dielectric properties. The final form of the radar equation is obtained by rewriting the Eq. 1.15 using the definition of the Eq. 1.7

$$P_t = \frac{PGA}{(4\pi)^2 R^2 R^2}\sigma \qquad (1.15)$$

The most common situation is that for which receiving and transmitting locations are the same, so that the transmitter and receiver distances are the same. Almost as common is the use of the same antenna for transmitting and receiving, so the gains and effective apertures are the same, that is:

$R_t = R_r = R$

$G_t = G_r = G$

$A_t = A_r = A$

Since the effective area of an antenna is related to its gain by:

$$A = \frac{\lambda^2 G}{4\pi} \qquad (1.16)$$

we may rewrite the radar Equation (1.7) as :

$$P = \frac{PG^2\lambda^2\sigma}{(4\pi)^3 R^4} = \frac{PA^2\sigma}{4\pi\lambda^2 R4} \tag{1.17}$$

where two forms are given, one in terms of the antenna gain and the other in terms of the antenna area, the radar equations (Eq. 1.7 and Eq.1.8) are general equations for both point and area targets. That is, the scattering cross-section s is not defined in terms of any characteristic of a target type, but rather is the scattering cross-section of a particular target. The form given in the Equation 1.8 is for the so-called monotonic radar, and that in Eq.1.6 is for biostatic radar, although it also applies for monotonic radar when the conditions for R, G, A given above are satisfied.

CHAPTER 2
DOPPLER RADAR

2.1 Overview

Doppler radar uses the Doppler effect to return additional information from a radar system. The Doppler effect shifts the frequency of the radar beam due to movement of the target, allowing for the direct and highly accurate measurement of speeds.

Doppler radars were originally developed for military radar systems, but have since become a part of almost all radar systems, including weather radar and radar guns for traffic police and sports.

2.2 Basic Concepts of Doppler Radar

Early radar systems sent out powerful radio pulses that were reflected off targets; the reflected signal was then detected on a separate antenna. Systems soon evolved to use the same antenna to act as both a broadcaster and receiver, with electronics, a duplexer switching between the two modes. These pulse radar systems had several drawbacks, however. Since the system couldn't broadcast and receive at the same time, the pulses had to be fairly short so the transmitter could be switched off, and the receiver switched on, before the transmitted pulse returned from its trip out to the target and back. This meant that the total energy reflecting off the target was reduced. The pulses could be extended to return more energy, but this reduced the range. Another problem was that the pulses would reflect off of any solid object, including the ground, so they had to be pointed up in order to detect airborne targets, allowing aircraft to escape detection close to the ground. While this was only a minor problem for ground-based radars, aircraft radars could not see targets below them. Using the Doppler effect allows both of these problems to be avoided. Instead of sending out pulses, the radio signal is continuous, thereby maximizing the amount of energy returned from the target. For this reason the system was often referred to as continuous-wave radar when it was first being introduced. The target is seen because the returned signal will be frequency shifted due to the Doppler effect, allowing it to be picked out of the outbound signal by filtering. Since the amount of shifting is dependent on the relative speed of the target, the minimum detectable speed is a function of the narrowness of the filtering the equipment is capable of.

In aircraft use, the filters can be set to filter out any signal with the exact same speed as the aircraft, thereby filtering out the reflection from the ground. This allows the radar to look straight down, detecting aircraft that were formerly invisible. As with pulse radar systems, many Doppler systems also pulse their signal to allow the use of a single antenna in these roles. Since the Doppler system requires a speed difference between the antenna and target in order for there to be a phase shift to detect, it is possible to spoof them by flying parallel to the radar, or laterally "across the front". For this reason most aircraft radar systems use both the returned pulse and the Doppler shift to detect targets.

2.3 Types of Doppler Radar

2.3.1 Doppler Radar As Weather Radar

Simple weather radar can detect precipitation or objects just by the reflection of microwaves. Most weather radars employ pulsed microwave signals. With more precipitation or a bigger object, there is more reflectivity. As in the case with heavy rain or hail, more signals is reflected back to the radar dish.

In meteorology, the Doppler effect becomes especially useful. While doppler radar can still detect reflectivity, other information is collected from the returning microwave signal's Doppler shift. The information is then used by computers to derive wind velocity in real time. The velocities that can be detected by a single dish are velocities directed away from the dish or toward the dish. Even though most weather radar has the ability to collect Doppler wind velocities, it is usually not used for display to the public since it is difficult for even the most experienced meteorologist to quickly understand. Typically, research meteorologists depend more heavily on the Doppler data for wind vector retrieval. Also, for example, some products from Doppler data are used to indicate (on the reflectivity display) regions of wind shear. Most TV meteorologists refer to their radar products as Doppler, when in reality their displays are just reflectivity. Doppler radar can also detect radial velocity.

2.3.2 Doppler Radar As Traffic Police Radar

Traffic police radars are remote sensors that emit electromagnetic waves (radio, microwave, or light) in order to measure reflections for detection purposes (presence, location, motion, etc.)

2.4 A Doppler Radar Tower

In meteorology, the Doppler effect becomes especially useful. While doppler radar can still detect reflectivity, other information is collected from the returning microwave signal's Doppler shift. The information is then used by computers to derive wind velocity in real time. The velocities that can be detected by a single dish are velocities directed away from the dish or toward the dish. This product is known as radial velocity. Another derived product uses radial data to calculate the storm cell's propagation speed, which is then subtracted from the radial velocity. This yields storm relative velocity which is useful for identifying rotation in super cell thunderstorms, even though most weather radar has the ability to collect Doppler wind velocities, it is usually not used for display to the public since it is difficult for even the most experienced meteorologist to quickly understand. Typically, research meteorologists depend more heavily on the Doppler data for wind vector retrieval. Also, for example, some products from Doppler data are used to indicate (on the reflectivity display) regions of wind shear. Most TV meteorologists refer to their radar products as Doppler, when in reality their displays are just reflectivity.

2.5 Doppler Examples

Everyday life has multiple examples of the Doppler phenomenon with sound; the whistle from a moving train is a good example. As the train approaches a stationary listener, the pitch (frequency) of the whistle sounds higher than when the train passes by, at which time the pitch sounds the same as if the train were stationary. As the train recedes from the listener, the pitch decreases. Car horns exhibit the same phenomenon, as does all sound. Note that in the above example if a car horn is stationary and a listener is on the train, the Doppler principle still applies. As the listener on the train approaches the stationary horn, the pitch of the horn sounds higher; as the train recedes from the stationary horn the pitch sounds lower (to anyone on the train). Electromagnetic waves radiated by traffic radar, as well as sound waves, obey the Doppler principal, although electromagnetic waves travel at the speed of light and audio waves travel at the speed of sound.

The Doppler effect is a frequency shift that results from relative motion between a frequency source and a listener. If both source and listener are not moving with respect to each other (although both may be moving at the same speed in the same direction), no Doppler shift will take place. If the source and listener are moving closer to each other, the listener will perceive a higher frequency the faster the source or receiver is approaching the higher the Doppler shift. If the source and listener are getting farther apart, the listener will perceive a lower frequency the faster the source or receiver is moving away the lower the frequency. The Doppler shift is directly proportional to speed between source and listener, frequency of the source, and the speed the wave travels (speed of light for electromagnetic waves).

2.6 Stationary Doppler Radar

Traffic police radar emits an unpopulated continuous wave (CW) and measures' reflections (echoes). Reflections are frequency shifted (Doppler shift) if the target is moving; the faster the target is traveling, the more the frequency shifts. A target traveling toward the radar shifts the frequency higher while a target traveling away from the radar shifts the frequency lower (compared to transmit frequency).

The radar, by design, simultaneously transmits a continuous signal while receiving continuous signal echoes.

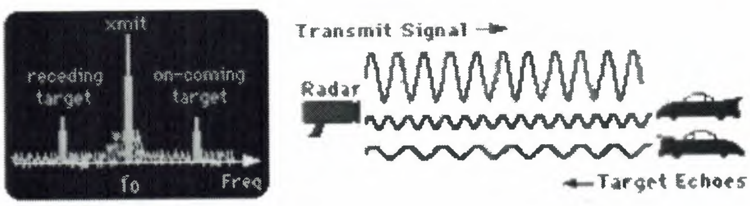


Figure 2.1 Radar signal

2.6.1 Target Echo Frequency

A Doppler shift occurs only if the target is moving. f_d is positive (+) for approaching targets and negative (-) for receding targets.

the functions of radar can be denotes by:

$$f_t = f_0 + f_d \tag{2.1}$$

for approaching targets.

$$f_t = f_0 - f_d \tag{2.2}$$

for receding target.

2.6.2 Radar Doppler Shift

Frequency is a function of radar transmit frequency (f_0), speed of wave c is equal to speed of light), and target velocity (v_t).

Note, v_t is positive (+) for approaching targets and negative (-) for receding targets.

$$f_t = \pm 2v_t\, f_0/c \tag{2.3}$$

$$v_t = \pm c\, f_d/2f_0 \tag{2.4}$$

where v_t denotes the target velocity, and *c* the speed of light.

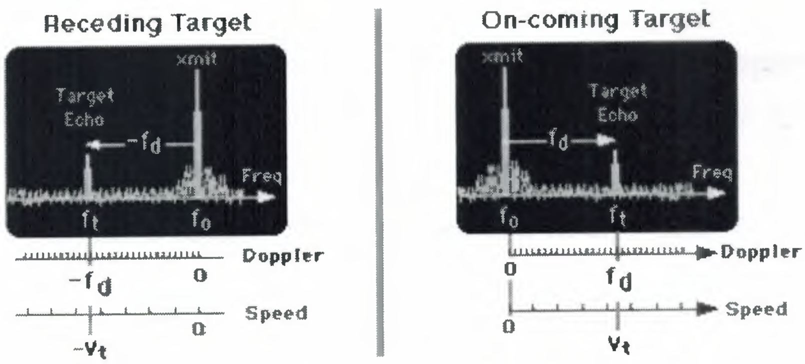


Figure 2.2 Factionary radar spectrum.

$$f_t = f_0 \pm 2v_t\, f_0/c \tag{2.5}$$

Approaching (on-coming) targets have a positive Doppler shift (target echo higher frequency than transmit); receding (going away) targets have a negative Doppler shift (target echo lower frequency than transmit). If the velocity term v_t is positive (+) target is approaching the radar; if the velocity term v_t is negative (-) target is receding (going away from) the radar.

Ground echoes are usually the strongest signal return, but since the ground is not moving these echoes are not Doppler shifted (ground returns are at frequency f_0) and may be drowned out by transmitter leakage, with moving-mode radar the ground echo is frequency shifted by the speed of the patrol car.

2.7 Doppler Shift

Consider a star (or any light source) that is moving at some velocity through the surrounding space. The time gradient (TG) associated with the star determines the forward speed of the emitted light relative to the star. The TG moves with the star, and the light expands from the star forming a sphere of light with the star at its center. When the light leaves the star's *TG* and enters the *TG* of the surrounding space, the light will continue expanding as a sphere, but the star will no longer be centered within that sphere. The star will move off center in the direction of the star's velocity, the space's *TG* will then determine the forward speed of the light. Thus the light accelerates when leaving a moving body in a direction opposite to the velocity (red shift), and decelerates when leaving in the same direction as the velocity (blue shift, the extent of this is dependent on the star's velocity and the angle of exit with respect to the velocity vector.

A reverse acceleration or deceleration occurs as the light reaches the observer's location if that location is also in motion, while the emitting star's TG controls the light speed, the increase in velocity as it travels outward from the star can be considered as a gravitational shift. Any change in forward speed as a result of the transition from the star's *TG* to the space's *TG* and then to the observer's *TG* is usually referred to as a 'Doppler shift'.

Thus the 'Doppler shift' occurs as a result of the effect of time gradients on the speed of a photon. There is an inverse gravitational shift as the light travels through the time gradient at the observer's location to the observer. The usual explanation for the 'Doppler shift' with light would seem to relate the shift to the rate at which photons reach the detecting apparatus, which is highly unlikely, light is emitted when a single transition occurs such as an electron going from one orbital state to another and an energy quantum, or photon, is emitted. The properties of that photon would not seem to depend upon when any other photons are emitted; this is different than the production of sound or anything else that depends upon a continuous oscillation. In that case, the movement of the emitter toward or away from an observer would alter the frequency that is detected by the observer. This is unlikely to occur with photons, which are unlikely to travel from the emitter to the detector in a continuous wave generated by a continuous oscillation at the emitter. See illustration 2 at the end of this section, actually, the fact that wavelength shifts are detected would appear to be a persuasive observational indication that the speed of light is variable, at least for higher energy radiation, the situation with the lower energy radiation is considered in the section Implications – Radar.

The consideration of light in terms of continuous waves provides a means of mathematically describing many aspects of the behavior of light, but viewing the physical nature of light as continuous waves may not be justified. For instance, the diffraction of light by a grating is generally described in terms of continuous waves that are all in phase passing through the grating. By considering the interference effects on the light at different angles after passing through the grating, the grating formula can be easily derived, on the other hand, experiments with single photons passing through two slits show that diffraction will occur with single photons. The process normally used to derive the grating equation does not easily explain this. Perhaps the observed diffraction pattern is actually the sum of the results of each photon taking their individual paths beyond the grating without the interactive interference process with the other photons being a major factor, considering the results on the basis of continuous waves may provide correct results but may not represent the actual physical process, which may not be truly understood yet. Although it is clear that photons can behave like waves and/or particles during the interaction and detection phase of their life, it is not clear what they are like after being generated and during the transit phase, it does not seem unreasonable to expect that any explanation of the behavior or light should apply with equal validity to a group of photons or to a single photon. The diffraction formula as applied to light interacting with a grating would seem to depend upon an orderly (in phase and coordinated, or coherent) approach of the photons to the grating, or upon the grating somehow regulating their interaction to produce the appropriate positioning and phasing for the formula to apply. It is difficult to see how this can actually occur with most light sources. Thus the discussions about the 'Doppler shift' in this site are oriented toward considering the behavior and properties of individual photons, or energy quanta, photon leaving an emitter would pass through the time gradient associated with the emitter with increasing velocity as the clock rate decreased. After passing from the influence of the emitter into the surrounding space it would travel at a velocity determined by the clock rate in that space. Upon reaching an observer, the speed would decrease according to the time gradient associated with the observer. If either the emitter or observer were in motion, there would also be an acceleration or deceleration upon moving from one time gradient to another that would depend upon the velocities of the emitter and observer.

The observed wavelength shift would also be sensitive to any velocity change while traveling through the space between the time gradients associated with the emitter and observer, this suggests an interesting possibility. If the universe is expanding, then the matter within it must have been denser in the distant past. This might have resulted in the speed of light through space being slower than it is today. As the universe expanded, the density of matter in the light path would become less and the speed of light would increase. This could mean that a greater red shift for more distant emitters might not be solely due to the relative velocity of the emitter and observer and gravitational shifts, but to the change in the speed of light as it traveled through space over the time it has taken for the light to reach the observer. The following illustration shows the effect of the time gradient associated with a star and the star's velocity on the wavelength of an emitted photon he increase in speed is essentially the same in all directions while the photon is within the star's time gradient, and thus the increase in wavelength is also the same.

When the time gradient in the space around the star becomes the predominant one, the speed of the photon and its wavelength will change according to the direction in which it leaves the star, the wavelength changes are somewhat exaggerated so that the specific direction of any changes are apparent. Directional changes due to any possible 'photon shift' are not shown.

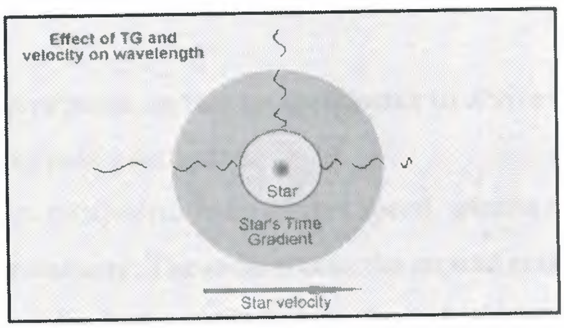


Figure 2.3 Effect of TG and velocity on wavelength illustration 1

The following animated illustration shows the emission of sound and light from a source. Continuous movement of the sound source (speaker diaphragm) to the right would cause the sound waves to be closer together, thus making the pitch higher to an observer on the right. Continuous movement of the atom emitting the photons to the right would not have a similar effect on the photons, since the spacing of the photons presumably has no effect on observations of the wavelength associated with the photons.

The emission of light does not occur as a result of oscillations but of transitions from one energy state to another. These transitions do not occur with any particular or regular frequency. Of course the actual travel of the photons would be much faster relative to the sound waves than shown in the illustration.

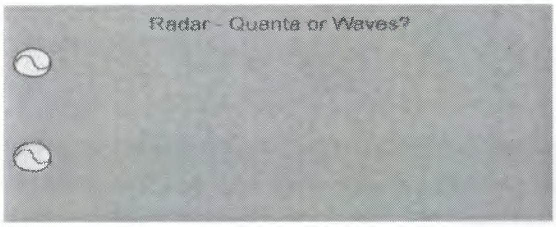


Figure 2.4 Regular frequency illustration 2

2.8 Moving-Mode Doppler Radar

Moving-mode radar is slightly more complicated. The target echo frequency is shifted by the relative speed between the target and radar. Target relative speed (to radar) is the sum of target and patrol car speed for opposite direction targets. For same-lane (direction) targets relative target speed is the difference between target and patrol car speed.

2.8.1 Moving-mode Radar Depends On Two Measurements To Derive Target Speed

The moving mode radar depends on two measurements to derive target speed:

(1)ground echo measures patrol car speed.

(2) target echo measures relative (to radar) target speed, ground echoes are Doppler shifted by the patrol car velocity. The radar tracks the ground echo to determine patrol car (radar) velocity; the radar uses patrol car velocity and relative (to radar) target speed (target echo) to calculate actual target speed.

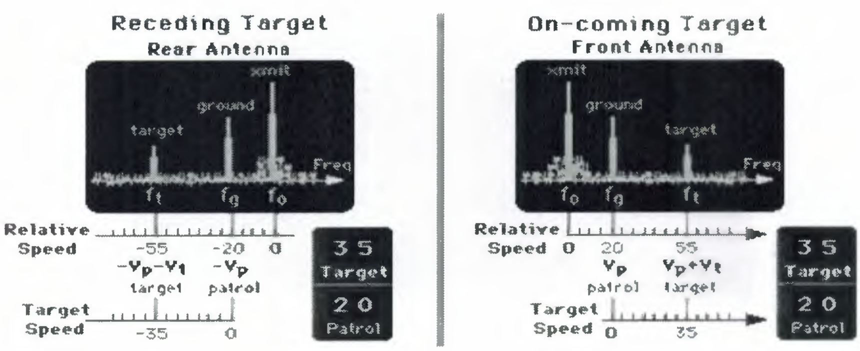


Figure2.5 Moving mode spectrum opposite direction target

Target relative speed to radar can be obtained by:

$$v_r = v_p + v_t \tag{2.6}$$

where v_r denotes the v relative.

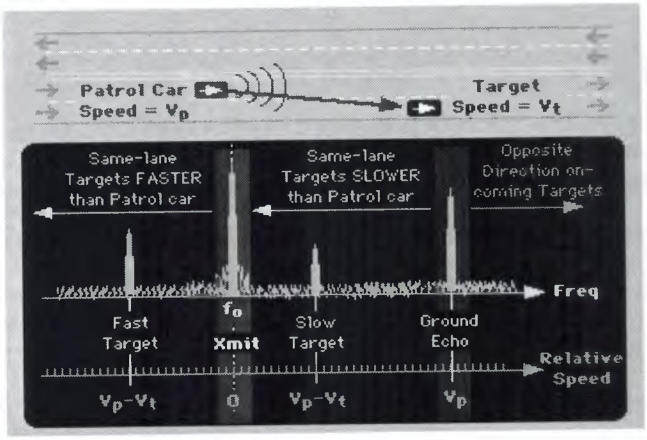


Figure 2.6 Moving mode spectrum same direction (lane) target front antenna.

Target Relative Speed to Radar can be obtained by:

$$v_r = v_p - v_t \tag{2.7}$$

Note that on-coming (opposite direction) targets have a negative speed (compared to same-lane targets). This type of radar can (if built-in) distinguish between same-lane targets and opposite direction targets.

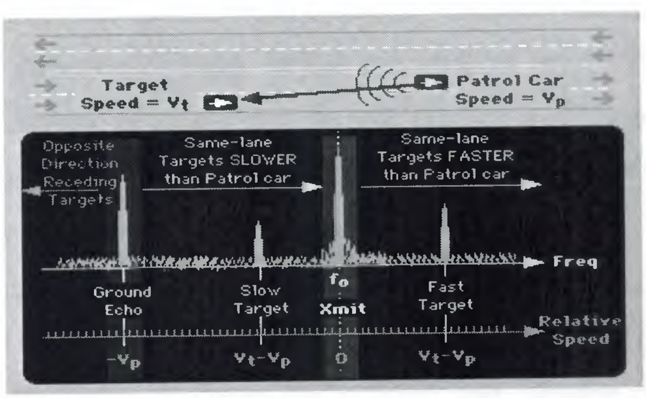


Figure 2.7 Moving mode spectrum same direction (lane) target rear antenna.

Target relative speed to radar is $v_r = v_t - v_p$, so:

$$v_t = v_r + v_p \quad (2.8)$$

Note that receding (opposite direction) targets have a negative speed (compared to same-lane targets), this type of radar can (if built-in) distinguish between same-lane targets and opposite direction targets.

2.9 Doppler Effect

The Doppler effect, named after Christian Andreas Doppler, is the apparent change in frequency or wavelength of a wave that is perceived by an observer moving relative to the source of the waves. For waves, such as sound waves, that propagate in a wave medium, the velocity of the observer and the source are reckoned relative to the medium in which the waves are transmitted Doppler Effect, change in the wavelength (or frequency) of energy in the form of waves, e.g., sound or light, as a result of motion of either the source or the receiver of the waves; the effect is named for the Austrian scientist

Christian Doppler, who demonstrated the effect for sound, if the source of the waves and the receiver are approaching each other (because of the motion of either or both), the frequency of the waves will increase and the wavelength will be shortened—sounds will become higher pitched and light Will appear bluer, if the sender and receiver are moving apart, sounds will become lower pitched and light will appear redder. A common example is the sudden drop in the pitch of a train whistle as the train passes a stationary listener. The Doppler effect in reflected radio waves is employed in radar to sense the velocity of the object under surveillance. In astronomy, the Doppler effect for light is used to measure the velocity (and indirectly distance) and rotation of stars and galaxies along the direction of sight. In the spectrum of nearly every star there are wavelengths, characteristic of atoms that lie near but not quite coincident to the same wavelengths as measured in the laboratory. The small deviations or shifts are generally due to the relative motion of the celestial object and the earth.

Both blue shifts and red shifts are observed for various objects, indicating relative motion both toward and away from the earth. Such shifts have been used to measure the orbital velocity of the earth, to detect binary stars and variable stars, and to detect rotation of other galaxies, the Doppler Effect is responsible for the red shifts of distant galaxies, and also of quasars, and thus provides the best evidence for the expansion of the universe, as described by Hubble's law. In addition to observations of visible light, the Doppler effect for radio waves is utilized by astronomers to determine the velocities of dust clouds in the spiral arms of the Milky Way galaxy, these observations provided the first direct proof that our own galaxy is rotating.

The Doppler shift in radar pulses reflected from the surfaces of Venus and Mercury have been analyzed to obtain new values for their periods of rotation about their axes.

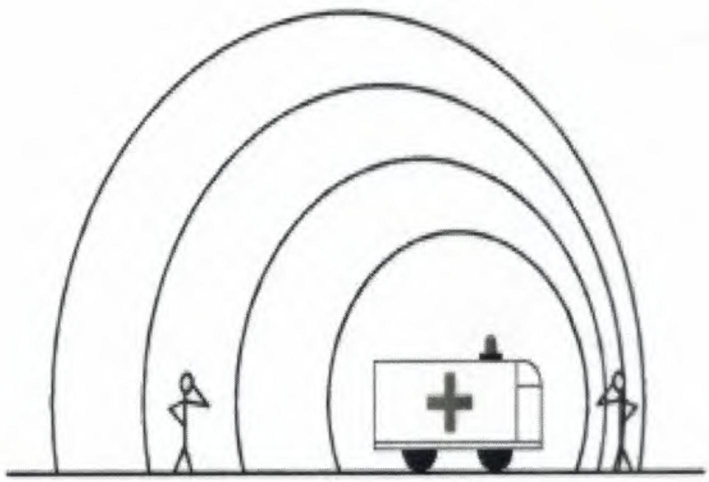


Figure 2.8 Sound waves emanating from an ambulance moving to the right, the perceived frequency is higher on the right, and lower on the left.

The total Doppler effect may therefore result from either motion of the source or motion of the observer. Each of these effects is analyzed separately. For waves which do not require a medium (such as light or gravity in Special Relativity) only the relative difference in velocity between the observer and the source needs to be considered, Doppler first proposed the effect in 1842 in the monograph (On the colored light of the binary star and other stars). The hypothesis was tested for sound waves by the Dutch scientist Christoph Hendrik Diederik Buys Ballot in 1845. He confirmed that the sound's pitch was higher as the sound source approached him, and lower as the sound source receded from him. Hippolyte Fizeau discovered independently the same phenomenon on electromagnetic waves in 1848 (in France, the effect is sometimes called "effete Doppler-Fizeau"). It is important to realize that the frequency of the sounds that the source emits does not actually change. To understand what happens, consider the following analogy. Someone throws one ball every second in your direction. Assume that balls travel with constant velocity.

If the thrower is stationary, you will receive one ball every second. However, if he is moving towards you, you will receive balls more frequently than that because there will be less spacing between the balls. The converse is true if the person is moving away from you. So it is actually the wavelength, which is affected; as a consequence, the perceived frequency is also affected.

If the moving source is emitting waves through a medium with an actual frequency f_0, then an observer stationary relative to the medium detects waves with a frequency f given by:

$$f = f_0\left(\frac{v}{v + v_{s,r}}\right) \tag{2.9}$$

where v denotes the speed of the waves in the medium and $v_{s,r}$ denotes the speed of the source with respect to the medium (negative if moving towards the observer, positive if moving away), radial to the observer.

A similar analysis for a moving observer and a stationary source yields the observed frequency (the observer's velocity being represented as v_0):

$$f = f_0\left(1 + \frac{v_0}{v}\right) \tag{2.10}$$

These can be generalized into a single vector equation. Take the coordinate system to be at rest with respect to the medium, whose speed of sound is c .

There is a source s moving with velocity v_s and emitting waves with frequency f_s . And a detector r moving with velocity v_t , where the unit vector from s to r is n i.e.

$$r_T - r_S = n\left|r_T - r_S\right| \tag{2.11}$$

Then the frequency f_r at the detector is found from:

$$\frac{f_r}{f_s} = \frac{1 - n v_r / c}{1 - n v_s / c} \tag{2.12}$$

If $v_s \langle\langle c$, then the change in frequency depends mostly on the relative velocity of the source and detector.

$$\frac{f_t}{f_s} \approx 1 - n \cdot \frac{(v_t - v_s)}{c} \tag{2.13}$$

The first attempt to extend Doppler's analysis to light waves was soon made by Foveae, in fact, light waves do not require a medium to propagate and the correct understanding of the Doppler effect for light requires the use of the Special Theory of Relativity.

2.10 Application of Doppler Radar

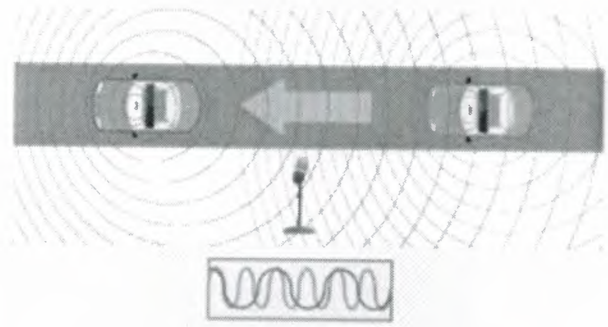


Figure 2.9 Records moving police.

A stationary microphone records moving police sirens at different pitches depending on their relative direction.

2.11 Daily Use of Doppler Effect

The siren on a passing emergency vehicle will start out higher than its stationary pitch, slide down as it passes, and continue lower than its stationary pitch as it recedes from the observer.

Astronomer John Dobson explained the effect thus," The reason the siren slides is because it doesn't hit you." In other words, if the siren approached you directly, the pitch would remain constant (as $v_{s,r}$ is only the radial component) until the vehicle hit you, and then immediately jump to a new lower pitch. The difference between the higher pitch and rest pitch would be the same as the lower pitch and rest pitch. Because the vehicle passes by you, the radial velocity does not remain constant, but instead varies as a function of the angle between your line of sight and the siren's velocity:

$$v_{s,t} \cos \theta \tag{2.14}$$

where v_s denotes the velocity of the object (source of waves) with respect to the medium, and θ is the angle between the object's forward velocity and the line of sight from the object to the observer.

2.11.1 Doppler Radar And Astronomy

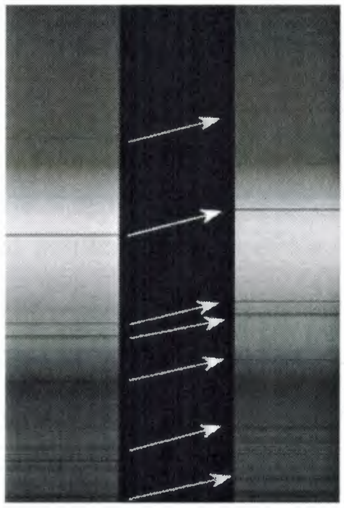


Figure 2.10 Red shift of spectral lines in the optical spectrum of a super cluster of distant galaxies (right), as compared to that of the Sun (left).

The Doppler effect for electromagnetic waves such as light is of great use in astronomy, and results in either a so-called red shift or blue shift. It has been used to measure the speed at which stars and galaxies are approaching to, or receding from us, i.e. The radial velocity, this is used to detect that an apparently single star is, in fact, a close binary and even to measure the speed of rotation of stars and galaxies. The use of the Doppler effect for light in astronomy depends on the fact that the spectra of stars are not continuous. They show absorption lines at well defined frequencies that are correlated with the energies required to excite electrons in various elements from one level to another. The Doppler effect is recognizable in the fact that the absorption lines are not always at the frequencies that are obtained from the spectrum of a stationary light source. Since blue light has a higher frequency than red light, the spectral lines from an approaching astronomical light source show a blue shift and those of receding sources show a red shift. Among the nearby stars, the largest radial velocities with respect to the Sun are +308 km/s (BD-15°4041, also known as LHS 52, 81.7 light-years away) and -260 km/s (Woolly 9722, also known as Wolf 1106 and LHS 64, 78.2 light-years away). Positive radial velocity means the star is receding from the Sun, negative that it is approaching, the red shift effect that shows remote galaxies seem to be moving away from us is not caused by the Doppler effect, although many laymen believe it is. This effect is caused by the expansion of the universe, which is subtly different, and can be used to estimate the age of the universe (see red shift and Hubble's Law).

2.11.2 Doppler Effect Used In Temperature Measurement

Another use of the Doppler effect, which is found mostly in astronomy, is the estimation of the temperature of a gas, which is emitting a spectral line. Due to the thermal motion of the gas, each emitter can be slightly red or blue shifted, and the net effect is a broadening of the line, this line shape is called a Doppler profile and the width of the line is proportional to the square root of the temperature of the gas, allowing the Doppler-broadened line to be used to measure the temperature of the emitting gas.

2.11.3 Doppler Effect Used In Traffic Police Radar

The Doppler effect is also used in some forms of radar to measure the velocity of detected objects. A radar beam is fired at a moving target - a car, for example, as radar is often used by police to detect speeding motorists - as it recedes from the radar source. Each successive wave has to travel further to reach the car, before being reflected and re-detected near the source.

As each wave has to move further, the gap between each wave increases, increasing the wavelength. In some situations, the radar beam is fired at the moving car as it approaches, in which case each successive wave travels a lesser distance, decreasing the wavelength. In either situation, calculations from the Doppler effect accurately determine the car's velocity, the Proximity fuse which was developed during World War II also relies on Doppler radar.

2.11.4 Doppler Effect Used In Medical imaging

An echocardiogram can within certain limits produce accurate assessment of the direction of blood flow and the velocity of blood and cardiac tissue at any arbitrary point using the Doppler effect. One of the limitations is that the ultrasound beam should be as parallel to the blood flow as possible. Velocity measurements allows assessment of cardiac valve areas and function, any abnormal communications between the left and right side of the heart, any leaking of blood through the valves (alveolar regurgitation),

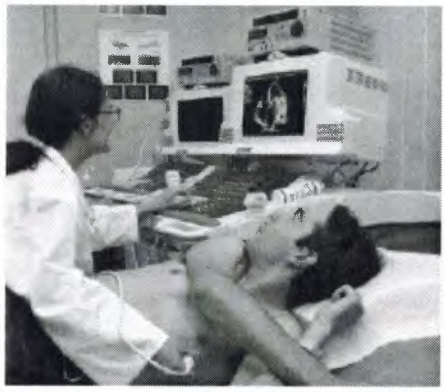


Figure 2.11 Doppler ultrasound of blood flow through the heart.

The calculations of the cardiac output. Contrast enhanced ultrasound using gas-filled micro bubble contrast media can be used to improve velocity or other flow-related medical measurements; however, "Doppler" has become synonymous with "velocity measurement" in medical imaging. But in many cases it is not the frequency shift (Doppler shift) of the received signal that is measured, but the phase shift (when the received signal arrives), velocity measurements of blood flow is also used in other fields of medical ultrasonography, such as obstetric ultrasonography and neurology.

2.11.5 Doppler Effect Used In Flow measurement

Instruments such as the laser Doppler velocimeter (LDV) and Acoustic Doppler Velocimeter (ADV) have been developed to measure velocities in a fluid flow. The LDV and ADV emit a light or acoustic beam, and measure the Doppler shift in wavelengths of reflections from particles moving with the flow. This technique allows non-intrusive flow measurements, at high precision and high frequency.

2.12 Relativistic Doppler Effect

In physics, the relativistic Doppler effect is change in the observed frequency of light due to the relative motion of source and observer when taking into account the Special Theory of Relativity. In general, the change in frequency measured by a stationary observer of a wave emitted by a moving source can be obtained by:

$$f_0 = \frac{f_s}{(1-\beta\cos\theta)\gamma} \tag{2.15}$$

where f_0 denotes the frequency observed, and f_s the frequency of source.

Frequency of source equal to velocity in the line of sight ($v_{parallel}$) divided by the speed of light (c). γ denotes Lorenz factor due to the total velocity of the object (not just in the line of sight)

For the classical Doppler effect arrangement when the observer and the source are receding from each other and there is no perpendicular movement, the equation reduces to:

$$f_0 = f_s\sqrt{\frac{1+\alpha}{1-\alpha}} \tag{2.16}$$

where $\alpha = v/c$

and v denotes the relative velocity, positive when object and observer are moving away And (c) the speed of light.

In the Special Theory of Relativity, space and time are not absolute, and a speed is something like a rotation in space-time, so that someone traveling at a different speed has a different point of view regarding which sets of points are simultaneous (at the same time point) or at the same point of space. The speed of light is a special, limiting sort of rotation. In some ways it is like an infinite quantity (using the arcane function, where rapidity θ is $\theta \equiv \arctan h\left(\frac{v}{c}\right)$, which is interpreted as a constant in ordinary measurement. Since adding anything to infinity (in the special cases where this can be defined to make sense) is still infinity, the speed of a photon of light from a source that is moving towards or away from the observer is not affected by that relative motion this is counter-intuitive if space and time are assumed to be absolute. Thinking of a speed as a sort of rotation (given the name rapidity to avoid confusion with other types of rotation) can help. However, while the speed of a photon does not change, a change of speed by the observer does correspond to a sort of rotation in which the time and space axes are different.

An application of the Lorenz transformation shows that the effect is that the frequency, and therefore energy, of the photons is affected: photons from any approaching source are increased in energy and photons from a receding source are reduced in energy: this is more intuitively satisfying, it is similar to the change in kinetic energy of an object due to the thing or person throwing it moving relative to the observer, This is the relativistic Doppler effect.

You can never "run alongside" a photon: this does not seem too unreasonable; but, what seems less reasonable, when assuming absolute time (and space), is that no matter how fast you chase a photon it is always moving away from you at exactly the same speed; but you do have the consolation that the photon appears to have less energy the faster you chase it; but it will never quite have zero energy. Again, thinking of a speed as a sort of rotation can help. In this article the term light is intended to mean any electromagnetic radiation, which is a particle that has no rest mass and which must always travel at the speed of light (when in a vacuum).

2.13 Doppler Shifting on Earth

When you see a cop by the roadside writing somebody a speeding ticket, or hear the clamor of a fire truck going by, you're probably not sparing much thought for the expansion of the universe, or even the rotation of the Galaxy. but in fact, all these things are connected. The policeman using his or her radar or laser speed gun to enforce a traffic law is using the same physical principle that scientists use to study the rotation and motion of stars, the distance to the edge of the Milky Way galaxy, and even learn important things about our entire universe.

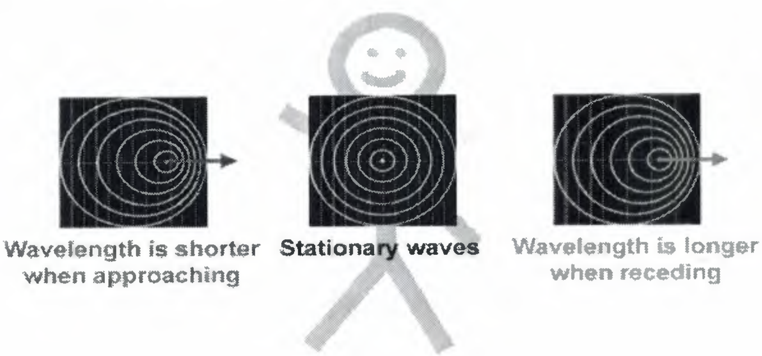


Figure2.12 This physical principle is called the Doppler shift.

When the fire truck passes, the sound of its siren changes, the sound waves emitted by the approaching fire truck are pushed closer together by its motion, so the notes seem to have a higher frequency than they'd have if you and the fire truck. Were both parked In the same way, the sound waves from a receding fire truck are appearing to have a lower frequency, the cop waiting by the roadside with his speed gun uses the same physical effect; he bounces a radar wave off your car and measures the frequency of the reflected wave. The frequency will be higher the faster you're going. Better not be going too fast, because the policeman can measure your speed to a fraction of a mile per hour using this method - probably more accurately than your speedometer, in fact.

Johann Christian Doppler (1803-1853) first demonstrated the effect using sound waves. But we see a similar effect with light waves. On Earth the effect is so tiny that we normally don't notice it. But when we study the stars, we can get a lot of mileage out of the Doppler effect.

2.14 Red Shifts, Blue Shifts

Stars emit light. Using a prism or a diffraction grating, we can spread this light out into a spectrum, if we look at the spectrum of the Sun or any other star, we see not only the rainbow of colors from red, orange and yellow through to violet, but also a distinctive pattern of dark lines. At certain wavelengths, light will be absorbed by chemical elements like hydrogen, helium, calcium, and iron; these wavelengths are based on atomic physics and can be measured extremely accurately in a laboratory on Earth. If a star is moving towards us, the whole pattern of the spectrum gets shifted to shorter wavelengths, i.e. towards the blue end of the spectrum, this is a blue shift, and we can measure it very accurately by comparing the apparent wavelengths of the spectral lines with the known laboratory wavelengths. If the star is receding, the pattern moves to longer, redder wavelengths, and this is a red shift. "Blue shifts come, and red shifts go, and that's pretty much everything you need to know.

$$v = cx \text{ (wavelength shift) / (wavelength).} \qquad (2.17)$$

where v denotes the relative velocity (speed) of the star, c denotes the velocity of light, and {wavelength} the known wavelength of the line as measured in the laboratory.

We can use this equation until the relative speed becomes a significant fraction of the speed of light and then it's back to Einstein's Theory of Relativity, for a more detailed formula.

Extremely careful measurements of nearby stars can determine their relative speeds with a precision as small as 10 meters per second. Analyzing a large number of nearby stars shows that our Sun and its neighbors orbit the distant center of our Milky Way galaxy with a velocity of 250 km/sec. We're about 26,000 light years from the center of the Galaxy, and so it'll take 220 million years for us to complete an orbit, we can also tell that the stars nearer the center of the Galaxy rotate faster, so we're being 'passed' by those stars nearer the center, and 'overtaking' those stars that orbit further from the center of the Galaxy; this is the differential rotation of the Galaxy. But that's not all, there are many more things we can learn using the Doppler Shift, and here is a summary of just a few: We can measure the masses of binary stars, by detecting the velocity changes as they orbit around their common center of gravity, and combining these velocities with the period of the orbit. In the same way, we can look for evidence of massive planets in orbit around other stars, by searching for the small velocity changes in the central stars caused by their unseen planetary companions; this is not an easy thing to do.

Certain types of stars known as Cepheid variables have atmospheres that swell and shrink periodically. Using the Doppler technique, we can tell that such a star's surface may be moving at speeds up to 50 km/sec. As the period of the pulsation is related to the average brightness of the star, we can tell roughly how far away the star is by combining its apparent brightness with its pulsation period. So the Doppler effect can help us determine distances as well as speeds, we can detect the rotation of the Sun easily enough by following the positions of sunspots, but the spectrum of the light from various regions of the Sun also shows this rotation. The equator at the Sun's east limb is approaching us at 2 km/sec, and the west limb is retreating from us at the same speed, when we look at the spectra of other galaxies and map their velocities, we find that on average, all galaxies are speeding away from each other, with very high red shifts. (There are exceptions, where galaxies are close enough to be drawn together by their gravities.)

The Doppler Shift tells us that the universe as a whole is expanding. What's more, galaxies at greater distances ('higher red shifts') are speeding away more quickly -- just as you'd expect in the aftermath of a giant explosion: the Big Bang. And finally, it now looks as if the expansion of the universe is accelerating and so on; out to the edges of the Universe'Behind' the stars and galaxies and clusters of galaxies, scientists can detect the cosmic background radiation left over after the Big Bang. This radiation has a temperature just three degrees above Absolute Zero red shifted into the radio portion of the electromagnetic spectrum. So, using one simple physical phenomenon the Doppler Shift that you can hear for yourself on any city street scientists can make discoveries about the speeds, masses and behavior of stars as close as our Sun or as distant as other galaxies, and study the properties of those galaxies to find out the structure of the Universe.

2.15 Doppler Frequency Shift For Doppler Radar

The WSR-88D radar uses a wavelength of ~10.5 cm and has the transmission frequency of $\approx 2.85\times10^{9}$ Hz. If a target has a radial motion of 50 knots, the Doppler frequency shift would be

-2*-25ms*-1 / 0.105m =476 Hz. (2.18)

476 Hz is approximately 0.00002% of the transmission frequency. This is too small to be measured by the antenna.

Instead the Doppler radar uses a Pulse-to-Pulse Phase Change to determine target radial velocity

2.16 Pulse-Pair Processing

Initial phase information about each transmitted pulse must be known.

As a target changes radial position between two successive pulses, the phase of the returned signal will change from pulse to pulse.

If a target moves to the radar beam or remains stationary, the phase of the returned signal will not change from pulse to pulse.

1. Pulse Repetition Frequencies and Time
2. Principles of Meteorological Doppler radar
3. Pulse Repetition Frequency/Time

PRF and PRT determine the maximum target range (R max) and maximum Doppler velocity (V max) that can be accurately measured.

2.17 Pulse-Doppler

Pulse-Doppler is a radar system that functions by sending short pulses of radio energy and simultaneously listens for the echo from objects using the same antenna. He time delay between pulse transmission and echo reception gives the range to an object. Pulse-Doppler radar uses the Doppler shift principle to determine the relative velocity of objects.

2.18 The Doppler Dilemma

V max and R max both depend on PRF

R max inversely related

V max directly related

No single PRF maximizes both R max and V max!!!

2.19 Backscattered Energy

Definition: Energy from the radar's pulse that is reflected or backscattered toward the radar by the target.

The degree or amount of "backscatter" is determined by targets:

1) Size (radar cross-section)

2) Shape (round, oblate, flat, etc.)

3) State (liquid, frozen, mixed, dry, wet)

4) Concentration (# of particles per unit volume)

2.20 Frequency shift

In the physical sciences and in telecommunication, the term frequency shift has the following meanings:

1) Any change in frequency

2) A Doppler shift

3) Any change in the frequency of a radio transmitter or oscillator. (Note: In the radio regime, frequency shift is also called rf shift.)

Frequency-shift telegraphy

In facsimile, a frequency modulation system where one frequency represents picture black and another frequency represents picture white. Frequencies between these two limits may represent shades of gray

An intentional frequency change used for modulation purposes

CHAPTER 3
TRAFFIC POLICE RADAR

3.1 Overview

Traffic police radars are remote sensors that emit electromagnetic waves (radio, microwave, or light) in order to measure reflections for detection purposes (presence, location, motion, etc.)

3.2 Police Radar

Radar speed detectors bounce microwave radiation off of moving vehicles and detect the reflected waves. These waves are shifted in frequency by the Doppler Effect, and the beat frequency between the directed and reflected waves provides a measure of the vehicle speed.

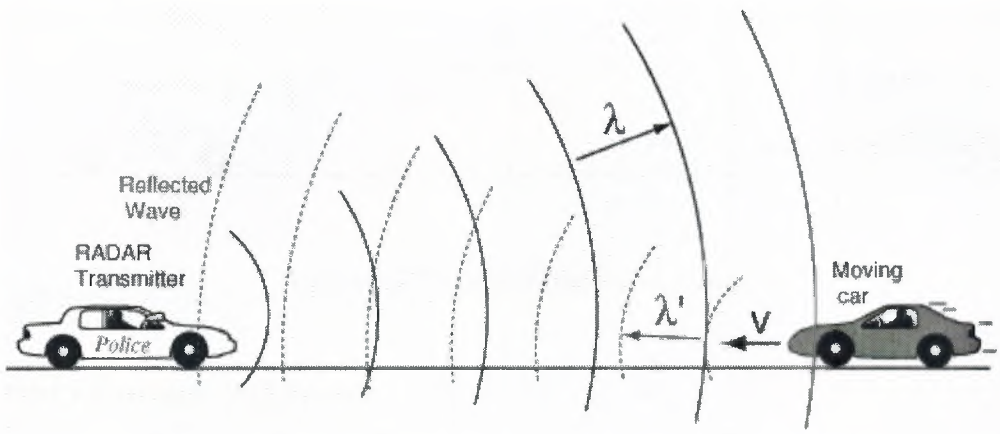


Figure 3.1 Transmitted radar wave.

3.3 Doppler Shift, Moving Target

The Doppler shift for relatively low velocity sources such as those encountered by police radar can be obtained by:

$$\frac{\Delta f}{f} = \frac{Vs}{c} \tag{3.1}$$

But in this case there are two shifts: one because the wave incident on the moving car is Doppler shifted and an additional shift because the reflection is from a moving object. The frequency shift of the reflected wave received at the source of the wave is

$$\frac{\Delta f}{f} = \frac{2Vt\arg et}{c} \tag{3.2}$$

This shift is detected by measuring the beat frequency with the transmitted wave.

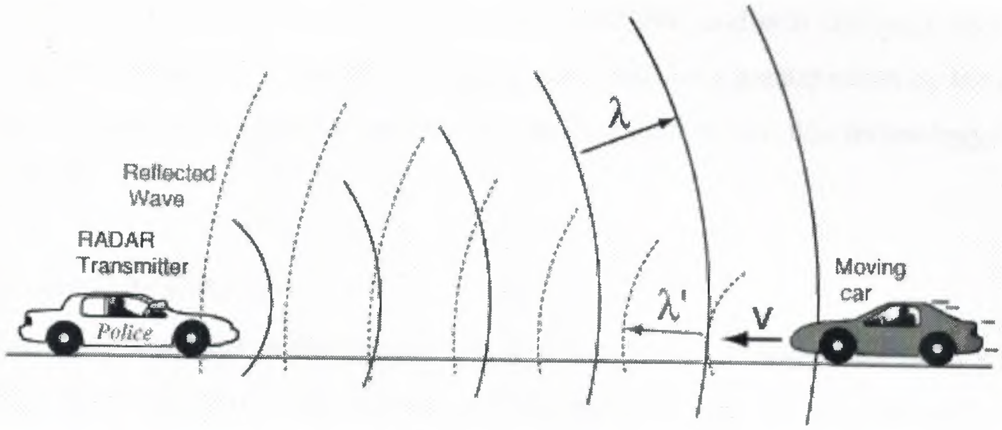


Figure 3.2 Transmitted radar wave.

3.4 Beat Frequency and Speed

The beat frequency between a microwave transmitted signal and a reflected signal off a moving object is

$$f`reflected - f`transmitted = \Delta f = \frac{2Vt\arg et}{c} f \tag{3.3}$$

Where the target velocity is taken as positive if the target approaching the transmitter, police radar uses this method for measurement of auto speed.

3.5 The Problems with Police Radar

Reprinted with permission from the brochure Blind Trust, blind Trust is a publication of the non-profit organization radar (Radio Association Defending Airwave Rights, Inc.).

3.5.1 Traffic Radar Reliability

The use of traffic police radar is so widespread that we naturally assume the technology is reliable. After all, if there were questions about radar's accuracy, would the courts process speeding violations with such assembly-line efficiency?

We tend to take the answer to this question on faith. That may be unfortunate, because radar makes mistakes, Lots of them. Some experts estimate that 10-20 percent of all radar-backed speeding tickets are issued in error; and in the case of radar that is operated from a moving police vehicle the number of bad tickets may be as high as 30 percent! .This Brochure [a print version of this info. is available from radar] is intended to familiarize the reader with some of the most common radar errors. Our Hope is that more people will realize that traffic radar is not infallible, and will challenge speeding tickets they know they don't deserve. The end result will be a greater effort by the radar industry to build better products and by law enforcement to use this technology more responsibly.

3.5.2 Two Kinds of Radar

To understand how radar makes mistakes, it is first necessary to know how radar works. Basically, there are two kinds of radar traffic radar, and rotating antenna radar. The latter group includes weather, airport, military and other types of commercial radar. By contrast, traffic police radar uses a stationary single antenna that points in a single direction; does not transmit a modulated signal; and does not use a cathode ray screen to display information. All radar works by transmitting a microwave beam on a specific frequency. Targets that are struck by the beam reflect microwave energy to the antenna; a computer analyzes any changes in frequency and displays this information. Military commercial types of radar use a sweeping, modulated beam which provides details about an objects' shape, speed, and direction for the operator. By contrast, the stationary beam and digital readout of police traffic radar yield only one piece of information: how fast a target is approaching or receding from the radar. Traffic police radar doesn't tell its operator which object it is measuring or the direction that the object is traveling, limitations that compel manufacturers to build in certain electronic compromises.

3.5.3 Radar Gone Bad

In early 1979, a Miami television station showed viewers a radar gun clocking a palm tree at 86 mph and a house at 28 mph, in the first instance, the reading was caused by panning the radar antenna and in the second, the radar unit was measuring the fan motor in the patrol car, the TV report prompted a court case that brought radar errors national attention. A year later the National Bureau of Standards tested the six most popular police radar models, finding that all produced false speed-readings in the presence of CB or police radios. Each of the two-piece units produced panning errors like the one that caught the Miami house apparently moving at 28 mph.

All of the moving radar units were subject to "shadowing," causing some of the patrol car's speed to be added to that of the target vehicle (Federal Register, Vol. 46, No. 5, Jan. 8, 1981). When the International Association of Chiefs of Police tested 24 radar models in 1983 and '84, the results showed that nearly all of the units were affected by temperature variation, five failed accuracy tests, four had unacceptably wide beam widths and three tended to provide inaccurate readings due to nearby police or CB radios.

Federal performance standards were proposed but never adopted during the Reagan administration. Instead, radar manufacturers promised to police their own ranks. From out perspective, things haven't improved. Police radar is as error prone today as ever, particularly with the widespread use of radar in the instant-on mode. And the effectiveness of the manufacturers' self-policing policy came to light recently (3/89) when it was revealed that one radar maker sold thousands of units bearing fraudulent federal communications commission certification. Some of radar's shortcomings are readily apparent, beam Width is one. Think of a radar beam as a cone - narrow at the radar antenna and widening as it heads for the horizon. Even the narrowest of radar beams - 11 degrees - is 38 feet wide when 200 feet down the road and 57 feet wide at 300 feet away.

Some radar units transmit a beam as wide as 24 degrees, by the time a radar beam is several hundred feet from a patrol car, and the microwaves are blanketing an area as wide as an expressway, now picture that expressway full of cars and trucks, and remember that traffic radar can't tell its operator which vehicle it is monitoring, or whether the target is approaching or traveling away from the police car. You quickly understand how great the potential is for misidentification. Let's throw in another twist or two, even though police radar is based on the Doppler Principle, most units do not interpret the Doppler shift it self, rather, they process the frequency of the signal and use its analog to represent target speeds. Known as phase-lock loop, or PPL, this processing can lock onto the wrong target, double or triple low speed-readings, or produce "ghost" readings. Other types of common radar errors are:

3.5.3.1 Radio or Microwave Interference

Can come in a variety of forms, both natural and man-made, but they have one thing in common - they produce a false or incorrect reading on the radar unit's display. Common sources of electromagnetic interference include airport radar; microwave transmissions; transmissions of CB, ham, VHF/UHF, and cellular two-way radio/ telephones, including police and business radios; faulty sparkplug wires; mercury vapor and neon lights; high-tension power lines; and high voltage power substations, the radio energy from these sources can overload or confuse the sensitive circuits in a radar gun.

3.5.3.2 Mechanical Interference

Is any moving object, other than the target vehicle, that can produce false or incorrect radar reading. The most common sources are vibrating or rotating signs near the roadway; fan blades moving inside or outside the patrol car (air conditioner, heater, defroster or engine fan); Another moving vehicle that reflects radar waves better than the target vehicle; and multiple targets in the main radar beam causing multiple reflections of nearly equal strength and making the display read, high, low, or completely blank.

3.5.3.3 Multi-Path Beam Cancellation

Occurs when the radar signal returning directly to the radar gun from the target vehicle is canceled by a secondary reflected signal. This cancellation can occur while the target remains in plain view of the operator. The display may blank or suddenly switch to another vehicle beside or behind the original target until the cancellation ceases.

3.5.3.4 Panning

Occurs when the radar beam past accidentally sweeps the counting/computing unit. This can happen only to a two-piece radar unit. The radio energy from the antenna portion overloads or confuses the counting/computing circuitry.

3.5.3.5 Shadowing

Is a problem that occurs only with moving radar, and plagues all moving radar. The radar locks onto a large moving object in front of the patrol car instead of the passing terrain and computes the difference in speeds between the two vehicles as lower than the actual patrol speed. Consequently, the radar adds the remainder of the patrol speed to the target's speed, producing an erroneously high reading.

3.5.3.6 Batching

Is caused by time lags in the computing of speeds by some types of moving radar. If the patrol car rapidly accelerates or decelerates while measuring target speeds, the display can read higher or lower than the actual speed.

3.5.3.7 Stationary Cosine Error

Is a problem, which occurs when the radar unit is not taking its readings from vehicles that are directly ahead of or behind the police vehicle - there is an angle between the radar unit and its target, and it is the cosine of this angle (remember your high school trigonometry?) that determines the magnitude of the error. With stationary radar, the greater the angle between the radar and the roadway, the lower the indicated speed. This error does not become significant until the angle to the roadway exceeds 10 degrees. Fortunately, with stationary radar, the cosine error is in favor of the motorist.

3.5.3.8 Moving Cosine Errors

Can result in readings that are either higher or lower than the target's actual speed. More often, the erroneous reading is not in the motorist's favor. The moving radar can lock onto a large object to the side of the roadway instead of the ground and, due to the cosine error, compute a lower-than-actual speed for the patrol car. The remainder of the patrol speed is added to the target's speed. Similarly, if the radar is not carefully aligned within 10 degrees of the patrol car's direction of travel, it will compute a lower-than-actual patrol speed. Again, the remainder is added to the target speed.

On the other hand, if moving radar is used to measure across a wide median, as on an interstate highway, the large angle can cause a lower-than-actual target speed to be displayed, assuming the patrol speed is correctly computed.

3.5.3.9 Multiple Bounce Errors

Sometimes happen when there are multiple moving targets within the main beam, causing several reflected of near-equal strengths but varying frequencies to arrive at the radar gun's antenna. Depending on the gun, the display may switch from one speed reading to another, it may show a combination of the reflections, or it may blank out. Overpasses on freeways are commonly the source of multiple bounce errors. The error observed most often is a double bounce, which causes the patrol car's speed to be indicated in both the target display and the patrol display.

Sometimes the overpass bounce will involve a large, slower-moving vehicle near that patrol car, causing the target speed to be displayed as the speed of the patrol plus that of the slower vehicle. In another multiple bounce case, the signal can be reflected more than once, by two moving objects, and the total Doppler shift will be displayed as a higher- than-actual speed.

3.5.3.10 Terrain Error

Takes place when hilly or curved roadways affect radar's ability to process information. When the patrol car is at the crest of a hill, it is very easy for radar to overshoot the nearest vehicle and instead take a reading from a vehicle on the next hill. Because traffic radar is "direction blind," differences in reflectivity may cause instant-on readings to display the speed of a receding vehicle rather than of an approaching vehicle. So that vehicle "on the next hill" need not even be traveling the same direction as the supposed target vehicle.

3.6 Pulse Problems

The careful, well-trained operator can spot many of these radar errors when they occur, by constantly monitoring traffic speeds, he will notice the oddball reading or the onset of some other problem, this ongoing record of vehicle speeds and possible sources of interference is known as a traffic or tracking history. With no traffic or tracking history, it is difficult for the operator to know which vehicle produced a particular speed-reading, or whether there is some sort of interference present. When radar is used in the instant-on mode - short bursts of one or two seconds duration - the potential is great for these errors being misinterpreted as actual speed-readings. Particularly troublesome are problems involving target identification, and the first three types of errors mentioned above (radio or microwave interference, mechanical interference and multi-path cancellation). One Pennsylvania driver tells of following an Ohio Highway Patrol car on a rolling interstate highway. Each time the police cruiser neared the top of a hill, the trooper would flip on his radar (setting off the Pennsylvanian's radar detector), after cresting the hill and taking a brief reading of whatever was on the other side, the officer would shut off his radar again. This went on for several miles," the driver explained, "until the police car did a U-turn in the median, presumably to get trolling in the opposite direction." As we pointed out earlier, instant-on radar has only one purpose - to try to confound radar detector users, but the drawbacks are many. In addition to increasing the likelihood that radar errors will go unnoticed, instant-on radar also defeats one of radar's most useful features.

Studies have shown that highly visible police patrols are most effective when it comes to encouraging drivers to obey traffic laws; radar and radar detectors increase the "visibility" of a patrol car, slowing traffic over a wider area. But despite such evidence, instant-on radar is growing in popularity; too many officers see radar detectors as a threat to their authority, rather than an ally in helping encourage motorists to obey the rules of the road.

3.7 Wavelengths, Speed and Frequency

A radar unit transmits radio signals, the same kind of radio signal transmitted by any radio station, CB radio, or TV station. Radio signals go out in waves, like the waves on a pond surface that has been disturbed. The waves radiate out in a continuous series, so many per second, and will continue to go on forever unless they are absorbed, reflected or refracted by another object in the path. If reflected, they bounce back in the direction they came from. Back to the transmitting unit. As stated before, radio signals, or radar signals, go out in waves, a series of peaks and valleys. The distance from the beginning of a peak to the bottom of a wave is one wavelength. A wavelength is a measurable distance. An X band wave measures 1 1/5 inches long while K band has a wavelength of 1/2 inch. Compared to other types of radio transmissions, radar waves are very short.

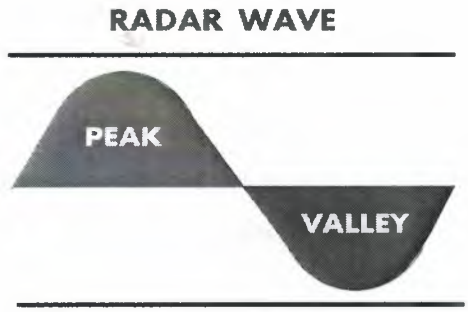


Figure 3.3 The radar wave.

The wave shown in figure 3.3 is the same wave that transmitted from a radio or television transmitter. A traffic radar beam may transmit as many as 36 billion waves per second. The waves are continuous as long as the radar is transmitting and will travel on forever unless absorbed, reflected or refracted. Because traffic radar uses very little power, the waves can be absorbed easily by particles in the atmosphere. This limits the operational range of traffic radar. If the object they bounce off is moving towards or away from the transmitter, then the object's motion changes the signal, the wavelength and frequency are changed. The receiving part of the radar gun detects this change, calculates it and displays the change in miles per hour.

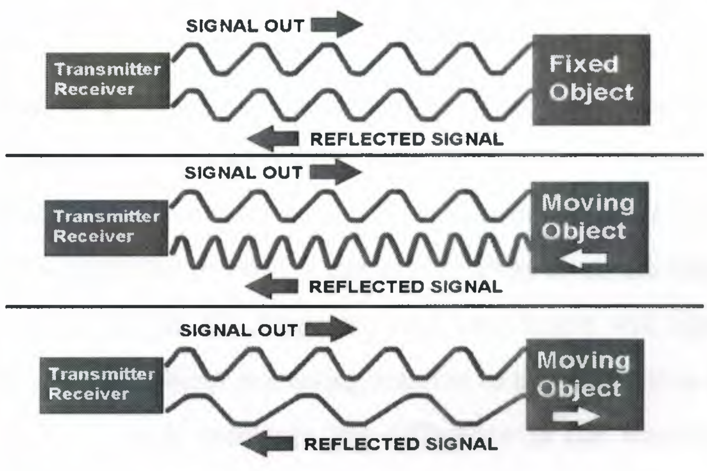


Figure 3.4 The top image shows radar signal going out and reflecting with no change in the wavelength. The radar unit would read a target speed of 0 mph.

The second image shows a radar return with the object moving towards the radar. The radar display will show the speed of the object due to the increase in the frequency (rate) of return of the waves; more waves coming back in a set time frame than were sent out. The last image shows how the waves would change if the object were moving away, a lower rate (frequency) of return, and fewer waves coming back in a given time frame.

The number of waves sent out in one second is called the frequency. Frequency is controlled by the transmitting unit. Radar operates in extremely high frequencies, in the microwave or gigahertz band, way above the AM and FM radio bands. Two frequencies assigned to traffic radar are X band and K band. X band radar is assigned 10.525 GHz. (10,525,000,000 waves per second) and K band operates at 24.15 GHz. (24,150,000,000 waves per second). X and K band radars are the ones the motorist is most likely to encounter. The FCC also permits burglar-alarm motion sensors and supermarket door openers to operate in this frequency. X band radar was first commonly used in the 1960's. K-band has been around since the 70's. When the FCC authorized police use of another microwave band, the Ka-band in 1982 (radar gun makers did not produce the radar guns to use it until 1989), the frequency available for clocking speeds jumped to a wide band, from 34.20 to 35.20 GHz. In 1992 this was expanded again to a bandwidth of 33.40 to 36.00 GHz. Radar operating in this range is called wide-band radar. All radio signals travel at one speed, the speed of light, which is 186,000 miles per second. This never changes. If a radar signal is sent out on a certain frequency with a certain wavelength, it will continue on at that frequency and wavelength unless it hits something. If it is reflected by a stationary object, then it will bounce back at the same speed and frequency and the wavelength will be the same.

The traffic radar readout will display 0 miles per hour because the object is not moving. But if it is reflected off an object that is moving towards or away from the radar unit, it will come back at the same speed but the frequency and wavelength will change. The readout will indicate the speed the object is moving relative to the receiver in miles per hour. The receiver on the radar unit measures the difference in the wavelength and frequency received compared to what was sent out. If the moving object is coming towards the radar, then the wavelength will be shorter, it is compressed, and the frequency must be higher, more waves in a given distance. If it is going away, the wavelength will be longer, it extends and the frequency must be lower. The speed of the signal never changes, just the wavelength and frequency. The scientific principle, on which radar works, as described above, is called the Doppler Principle. It is named after the discoverer Christian Johann Doppler, an Austrian physicist. The Doppler Principle states "When there is relative motion between two objects, one of which is emitting energy in waves, the frequency of the energy wavelength will be changed because of the relative motion." The key words here are "relative motion". Relative motion is a change in distance between two objects over a period of time. But not all moving objects are moving relative to each other. A group of passengers on a jet plane traveling along at 300 m.p.h. have no relative motion between themselves, they are all moving along together at 300 m.p.h. and the relative distance between them is not changing. But there is relative motion between them and the friends they left behind at the airport.

Two cars going along a highway, both at 65 M.P.H., in the same direction, have no relative motion between them. But there is relative motion between them and the police car parked on the side. There is also relative motion between them and the oncoming traffic. It is this motion that radar detects; the relative motion between the radar unit and a target vehicle.

Traffic radar works in two modes, stationary, when the radar unit is not moving, and moving mode, both the radar unit and the target vehicle are moving. It is almost impossible for stationary radar to provide a strong audio Doppler tone in error. Of the two modes, stationary radar is the easiest to use. Moving mode is most often used by highway patrols on high-speed roads and requires greater care to target the right vehicle. If a radar gun is set to the stationary mode and the patrol vehicle is moving, the radar will pick up the relative motion of the car over the earth and display the patrol vehicle's speed. Should another vehicle approach, it will calculate the closing speed between the two cars and display that. For instance, if the patrol vehicle is going along at 30 M.P.H., and another car is approaching from ahead at 40 M.P.H., and then the radar display will read 70 M.P.H. (30 + 40 = 70).

The mode of most radar guns can be changed by the operator just by pressing a button. The radar guns have indicator lights to show which mode they are in. In stationary mode, only one speed, a target speed is displayed; the patrol speed display window will always be blank. Both stationary and moving mode radar sends out one signal but moving radar reads two returns. One is called the low Doppler shift. The low Doppler shift is a return from the surrounding terrain, the speed the patrol car is moving relative to the earth. The other return is the high Doppler shift, the speed of a target vehicle.

The radar computer reads the low Doppler shift and then reads the high Doppler shift. The high Doppler shift is the relative closing speed between the two cars. If the patrol is going along at 55 M.P.H. and the approaching car is traveling at 75 M.P.H., then the closing speed is 130m.p.h. The radar's computer subtracts the low Doppler shift from the high Doppler shift and displays this as the approaching vehicle speed (130 - 55 = 75). So far,so good. There is a unique possibility for error when using moving radar. The audio Doppler tone will only reflect the approaching vehicles computed speed, not the patrol vehicle speed. The patrol speed is displayed but without a tone. If for any reason, such as outside interference or equipment failure, the patrol speed-reading on the radar is lower than the actual patrol speed, then the residual speed computed from the closing rate will be given to the approaching vehicle. For example, a patrol car is traveling along at 55 M.P.H. but the low Doppler shift on the radar unit is reading 25 M.P.H. as a patrol speed because there is a large truck going 30 M.P.H. in front of the patrol car. The back end of the truck is reflecting a strong low Doppler shift. The radar unit is reading the closing speed of the patrol car on the truck going in the same direction in front. (55 - 30 = 25). From the opposite direction comes a car, traveling at 60 m.p.h. Since the radar unit "thinks" it is moving over the earth at 25 M.P.H., and is closing on the approaching car at 115 m.p.h., then it shows the speed of the approaching vehicle as 90 M.P.H. (115 - 25 = 90). This is 30 M.P.H. over the actual speed of the target vehicle.

The only way for the officer to avoid writing an undeserved citation in this situation is to check the radar displayed patrol speed against the patrol car's speedometer. They must match whenever moving mode radar is being used. Another phenomena associated with moving radar is batching. Batching occurs when the patrol car speeds up or slows down suddenly. The radar unit cannot keep up with the sudden changes in speed using the low Doppler shift. This will cause momentary speed-readings inconsistent with the vehicle's actual speed. Radar operators are taught to maintain roughly even speeds when running moving radar. Sudden shifts in speed from a vehicle being tracked on the high Doppler shift will not cause this type of error. Some radar units have two transmitter heads, one pointing to the front and one to the rear. Either one can be operated in a stationary or moving mode as explained earlier. The one in the front operates in the standard moving radar mode; it calculates the closing speed of the two vehicles and subtracts the patrol vehicle speed. The one in the rear does it a little differently. A car, coming up behind a patrol car, must be closing on the patrol, which is going faster. As it enters the radar's operational beam, the radar's computer uses readings from both transmitter heads to determine the target speed. The front transmitter is used to determine the patrol vehicle speed while the rear transmitter reads the closing speed of the target vehicle behind. If a patrol vehicle is traveling at 30 M.P.H., and is being approached from behind by another car going 60 M.P.H., then the car from behind is closing on the patrol car at 30 m.p.h. The radar's computer adds the two speeds and displays the result as the speed of the closing vehicle (30 + 30 = 60). It is difficult to estimate the speed of a car approaching from the rear using your rear-view mirrors but this must be done for the officer to issue a citation in this scenario.

The mode of the radar, moving checking vehicles coming from behind, moving checking vehicles approaching from the front or stationary is selected by the radar operator using a series of buttons on the radar unit. The officer must know which mode the radar is in at all times. Radar, due to the wide fan pattern of the radar beam, is not lane selective on multi-lane roads. The operator cannot pick out a target vehicle when there is another vehicle going in the same direction in the immediate vicinity of the target. To a certain extent, two vehicles going in opposite directions can also affect the returns. If the operator claims his radar is lane selective, then he is not competent to operate traffic radar and any citations he issues are questionable.

3.8 Low Speed Doppler Shift

For many low velocity applications such as Doppler velocity measurement, the general form of the Doppler shift is unnecessarily complex. The general Doppler frequency expression

$$v = \frac{v_0\sqrt{1-\beta}}{(1-\beta)} \tag{3.4}$$

where $\beta = v_s/c$

Can be expanded by the binomial expansion and only the first two terms of the expansion used,when expressed in terms of the frequency shift, this becomes :

$$v \approx v_* \frac{1-\beta/2}{1-\beta} \tag{3.5}$$

3.9 Radar detectors

Recall that when a radar beam is transmitted, it goes out in a fan pattern and will go on forever unless it hits something. The operational range of a radar beam is about one-half mile. Radar receivers require a fairly strong signal to produce a reading. Radar detectors will pick up a very weak signal, far away from the radar gun, parts that are too faint for the radar receiver to analyze. Basically, a radar detector is an extremely sensitive radar receiver, when it receives a radar signal, it buzzes or lights up to alert the driver. The driver is supposed to slow down in time to avoid a citation. Great in theory, lousy in reality.

The first problem with radar detectors is sensitivity. They tend to give out false warnings. Radio signals can be sent out from burglar alarm motion detectors, radio station transmitters, and even automatic door openers. They all use high frequency radio to detect motion and some infringe into the radar bands. Radar detectors, being necessarily sensitive to work at all, often give out false warnings because of these types of transmitters. With the production of Ka band radar guns, operating within a very wide band, the work of radar detectors became much more difficult. To provide a warning, they have to search a very large area of the radar frequency spectrum, this slows their response time down as they try to tune out possibly false signals. To add to the confusion, radar gun makers now have a large area in which to tune their radar guns. All radar units have a "hold transmission" switch. Sometimes this is called "instant on radar" or "pulsed radar". Both terms are misnomers. The unit is powered up but no signal is being sent out, as long as no signal is going out, there is nothing for the radar detector to detect. An officer, sitting on the side of a road, simply waits until he has a vehicle in sight and well within his radar operational range. If you are not paying attention, you won't see him. Then he hits the switch and starts getting speed readings in milliseconds. Let's assume you are going along at 75 M.P.H. in a 55 M.P.H. zone. The police have radar set-up but with the "hold transmission" button set. No signal is going out; your radar detector is quiet. The radar operator sees you in his range visually estimates your speed and turns on the radar gun. You radar detector starts screaming wildly and you hit the brakes. Too late. The officer got your highest speed reading as soon as he turned on the radar gun. Then he tracked your speed down from 75 to a more sedate 50, all the while watching the nose of your car dive as it decelerated While he was watching you madly trying to slow down, he was getting speed readings equal to your deceleration, Just a little more confirmation that he has the right car with the very high initial speed reading. Another way the police thwart radar detectors is to use terrain to their advantage. If a radar unit is set up on the far side of a hill, facing up the hill, the extraneous radar signal, the part radar detectors depend on to give early warnings, will be absorbed by the earth or head off into space, once your car crests the hill approaching the radar unit, you are being tracked. Now your radar detector will start sounding off. About 30 seconds too late.

Some radar detectors boast of the ability to locate radar to the side. This is of absolutely no value. Radar only detects relative motion, either coming in or going away. If a car is going along perpendicular to a radar unit, then there is very little relative movement. The only readings the radar would display would be extremely low. This is called Cosine Error, a function of geometry. For the most accurate readings, radar must be within 10 degrees of the travel path of the target vehicle. The farther off to the side of the road, the greater the angle, the greater the angle, the more the closing speed decreases and a radar reading below the target's true speed is presented in the display. Cosine Error always works in the motorist's favor.

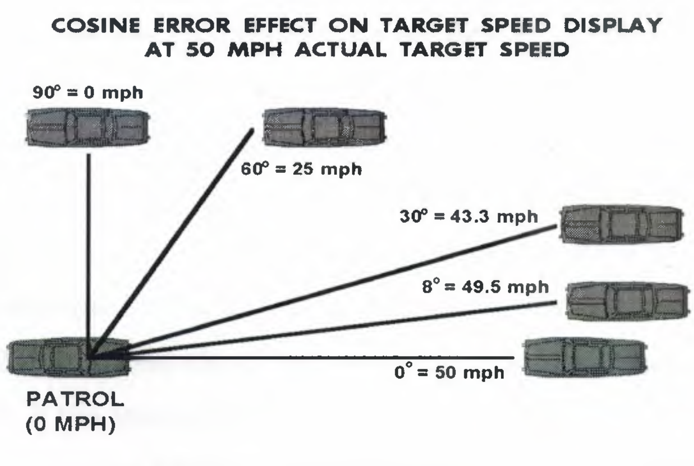


Figure 3.5 The effect of Cosine Error.

This is derived from the mathematical "Law of Sins," in trigonometry. Cosine Error always works against the motorist and favors the police, never even mention Cosine Error in court. It only works against you by proving your actual speed was higher than the radar's display. If you like to drive fast and purchased a radar detector to give you ample warning of the presence of traffic radar, then be prepared to pay extra for fines and increased insurance rates. You are going to get caught. The author has yet to see any radar detector manufacturer provide a guarantee that offers to pay the fine of anyone caught speeding on radar while using one of these devices. And don't forget the increase in insurance rates that go along with speeding tickets. They cannot get around the fact that traffic radar operates under some very basic laws of physics and this is what governs their actual performance. More than one police officer has found amusement in annoying drivers with radar detectors. Many detectors mount high on the windshield with small flashing lights.

These lights can be seen out the back window at night. Imagine your frustration when your radar detector keeps going off intermittently with no police in sight, what's going on? Look in your rear-view mirror and see if there is a patrol car back there.The officer just might be following you while turning his radar on and off watching the lights through your rear window, radar detectors are illegal to operate in some states. There is a "radar detector" in use by the police in those states. Radar detector detectors work because all electronic devices emit radio frequencies when in use. Radar detector detectors scan for emissions in certain bands from these devices. There is probably a "radar detector" on the market. A few other ways people have tried to defeat radar includes hanging chains from the car's body so they drag on the ground. The theory is this grounds out the car and the radar signals are directed to the ground and not back towards the radar unit. This does not work. Radar does not "energize" a car body; it is merely reflected like light from a mirror. Placing foil in the hubcaps will do nothing more than cause the wheels to go out of balance and give you a rough ride, frantically honking the horn has been put forth as a means to defeat radar. This is done under the mistaken impression that the rapid oscillation of the horn's speaker will interfere with the radar signal. No. Not even close. The oscillation is so small, and the horn so buried under sheet metal, it has absolutely no affected. Except to get the attention of the police officer as you go by. Radar hammers are sometimes advertised. These devices are sold in kit form, not as complete, ready-to-install units and for a very good reason. They are illegal to sell or operate without a license from the Federal Communications Commission because they are radio transmitters.

Radar manufacturers have licenses for the units they sell; individual licenses are not required for each operator. The FCC will not issue you a license for a traffic radar jammed but they will be happy to take your application fee before denying your request. Radar hammers are supposed to transmit a signal on the same frequency and wavelength as the radar gun pointing at you. The signal sent out by the jammed either causes a blank display on the police unit or a lower speed reading, of course, this assumes your jammed matches the exact frequency of the police unit and with all the radar bands now available, this would be a neat trick.

There are often repeated stories of someone having built a traffic radar jammed that will cause a radar gun to instantly burn out, Pure fairy tale, the signal strength required to cause a circuit burn out from an outside transmission would be so strong every electronic device within a 5 mile radius of the jammed would begin to glow. No automotive electrical system could possibly produce this much power.

Some police traffic radar units even have a jamming indicator/locator so they can track you down, confiscate the jammed and take the matter to federal court. This can be much more serious, and costly, than a speeding ticket. Should they decide not to prosecute, do you really think they are going to give that expensive piece of contraband back to you, a few states have specifically outlawed the possession of radar hammers in vehicles. Tests conducted by various auto enthusiast magazines have consistently shown radar hammers do not provide the protection from police radar they claim. They are all made by very small electronics firms, hobbyists really, usually in a backyard garage. To top it all off, they are expensive. Sometimes as much as $2000 for a basic kit with a few critical parts missing that you have to track down and install yourself. By not providing a complete unit, the manufacturer can skirt federal laws regarding the licensing of radio transmitters. Once you use it, you have no protection from prosecution.

3.10 Doppler Expression Expansion

To get a simplified expression for the Doppler frequency expression, the square root in the expression:

$$v = \frac{v_* \sqrt{1-\beta}}{(1-\beta)} \tag{3.6}$$

Can be expanded using the binomial expansion as

$$(1-\frac{v}{c}) = 1 - \frac{1}{2}\frac{v}{c} - \frac{1}{8}\frac{v}{c} + ... \tag{3.7}$$

For low speeds where v << c, the first two terms give a good approximation of the Doppler shift:

$$\frac{v - v_*}{v_*} = \frac{\Delta v}{v_*} \approx \frac{v_s}{c} \tag{3.8}$$

Low velocity Doppler shift expression

3.11 Lasers, Timing Devices and Other ways

Laser timing devices have become the latest addition to the traffic speed enforcement arsenal. "Laser radar" is a misnomer as there is no radar in the laser devices. Laser timing devices, also known as Lieder, use light instead of radio signals. The basis is a little different from radar in that lasers send out pulses of light and measures the time it takes for the reflection to return. Laser timing devices, unlike radar, have not received judicial notice and it is possible to challenge laser devices on operating principles. This means the state would have to bring in experts to support their case. Be warned, however, that any discussion of the physics of lasers and how they work is going to be extremely technical with very intense math. Since lasers are still fairly new in traffic enforcement, there are major differences in the way each unit works. Lieder have a very narrow beam compared to radar. At 1000 feet, the beam is less than four feet wide. Lieder can pick out a single vehicle from a group of cars as long as there are no vehicles in a straight line between the Lieder transmitter and the reflecting surface.

To run Lieder, the operator must have a visual line of sight to the targeted vehicle. Any reflective surface on the target vehicle is sufficient for a Lieder return although operators are instructed to aim for the front license plate. Lasers are routinely used by land surveyors to measure distances, but they are not shooting at moving targets when they do this and the targets are reflectors designed for such work. Aiming is the biggest problem with lasers in traffic work. Like a rifle.

Its requires careful aim to get the right target reading long enough for the unit to calculate a speed. This is not easy when the targets are moving at highway speed. And lasers may have three beams instead of one to get an average over a larger area than a single beam would produce. This can also result in errors if any other vehicles are in the vicinity of the target vehicle. At present, Lieder is restricted to the stationary mode. it cannot be run from a moving vehicle. It is typically used in the "wolf pack" scenario where one officer runs the Lieder while several others up the road pull over vehicles he has identified. The identification process includes make, color, type and sometimes model of the targeted vehicle, most often, the officer running the Lieder can see which vehicles his cohort are pulling over and provides confirmation via radio when he sees they have the right one. Lieder are not subject to radio interference because it does not use radio signals. It is subject to failures in inclement weather but very few departments would risk destroying an expensive laser unit in the rain.

Laser detectors are on the market but they have no value in reality. Laser beams are detectable, in the same way the sound of a guillotine is detectable to the condemned, he hears it just before his head is lopped off. Lasers do not emit a broad, fan type beam over great distances. The laser is not turned on until the operator has a target vehicle in sight so there is nothing for a laser detector to detect until it is too late. Lieder, like radar, can give readings almost instantly, car and Driver Magazine reported in their November 1993 issue that the use of powerful lights may reduce, and sometimes defeat, liar's effectiveness and buy time for drivers to slow down after their lieder detectors go off. Every state has laws on how bright and how many lights you can have on the front of your car. What's allowed, typically no more than 300 candlepower total, is far below that required to defeat police lasers. Lasers could be jammed if your car was equipped with extremely powerful lights covered with an infrared band filter. All lights produce some infrared light, but this filter blocks all-light except that in the 904 nanometer range, which is that of police laser.

The FCC does not govern lighting so laser hammers are legal from this aspect. By sending out an infrared light similar to that of the laser gun, the receiving diode in the laser gun can't make a determination between reflected laser guns light and "jamming" light from the car, the laser gun would not get a reading.

This would be a practical solution if the power requirements for lights bright enough to have any effect would not burn out your car's electrical system. Covering the headlights with the filter has several problems, it is illegal because by law you cannot drive with the headlights covered, and standard headlights will not produce nearly a strong enough jamming light and the filters just might melt from the heat of the lamps. Of course, you could always tow around a small diesel generator to power a few 1000 watt lamps with the appropriate heat shields and filters, a car can be made to be less visible, but not invisible, to lasers. Cover all the reflective surfaces, headlights, taillights, windows and chrome, with light refracting covers and paint the entire body with flat, not glossy, black paint. Do not apply wax. If you have been clocked with a laser, defend on operator training, qualification, vehicle identification and the tracking history checklist, there are two other ways commonly used to detect speeding vehicles; airborne officers and pacing. Pacing requires the patrol officer to get behind a car and travel along with it for a sufficient distance to determine cruising speed; Police vehicles should have calibrated speedometers. Just because the automaker put a placard on the dash saying the speedometer was calibrated does not mean it will remain that way forever. It is a mechanical device subject to wear and tear. Speedometers need to be calibrated regularly. It is not hard to calibrate a speedometer; a radar unit in stationary mode can be used. A card indicating when the speedometer was calibrated, who did it and how it was done should be in the patrol car at all times, any differences between the speedometer speed indications and the calibration device speed readings should be noted in not more than 10 M.P.H. increments.

A speedometer can be off by several miles per hour and still be accurate as long as this difference is taken into account, Police vehicles are subject to hard use, sudden accelerations and decelerations. A speedometer is controlled by a series of small cogs in the speedometer head, the part you see on the dash, connected by a cable to the transmission. Any wear or damage to the cogs or cable can put the speedometer off true. Changes in tire or wheel rim size from the original manufacturer's specifications can also cause a change in accuracy. To achieve a good speed-reading while pacing, a steady speed must be achieved for some distance. Sudden bursts of speed can cause speedometers to show a momentary high speed that does not accurately reflect the actual speed achieved.

A pacing distance of 1/10th mile at a relatively steady speed is generally considered sufficient, airborne officers watch traffic from a light aircraft flying along a highway. Painted on the road are white bars, ground markers, spaced at specific distances. The officer in the aircraft starts a stopwatch when a car crosses the first of a series of bars then stops it when the same car crosses the next in the series, a quick check of a timing sheet shows that if it took a car 10 seconds to travel the one-quarter mile between the two bars, then it is traveling at 90 M.P.H. He radios to another officer on the ground some distance ahead of the offending vehicle and then watches to make sure he stops the right one. The police tend to calibrate those stopwatches regularly. If you go to court to challenge this type of ticket, the prosecution must present both officers to testify, one other type of timing device in very limited use is Vassar. Vassar is a trade name for a simple, visual, stopwatch arrangement that is entirely dependent unpins the officer's observations. The officer starts a stopwatch when a vehicle passes a reference point and stops it when the vehicle reaches another reference point, the time it takes to pass between the two points is used to calculate your speed. Vassar can be challenged on the basis of where the officer was located when he made the observations, how accurately he measured the distance between the two reference points and that the distance between the two points was sufficient to comp [sensate for any errors in timing.

It is important that the two reference points be clearly visible to the officer, they have to be physical objects for the target vehicle to pass by at the beginning and end of the timing phase. There are even more timing devices in use including electric eyes or air hoses spaced across a road. Both of these arrangements are connected to a timer that measures the time it takes a car to break two sequential beams or hoses. They are in extremely limited use. How to defend against a ticket received in this situation would depend upon the device.

CONCLUSION

Radar is an acronym for radio detection and ranging. radar technology has been used for purposes ranging from warfare to weather predictions to catching speeders on the highways. Radar detection devices emit and receive radio waves to determine the distance from the source to the object by measuring the time it takes for the echo of the wave to return.

Specifically, weather radar measures the direction and the speed of moving objects, such as precipitation, and has the capacity to measure the velocity of the particles in order to determine the rate at which the particles are falling.

Weather radar is a certain type of radar known as Doppler radar, named because of the Doppler effect which recognizes that the frequency shift of waves bounced off of an object is related to the object's velocity towards or away from the observer (the common example of this effect is the change in pitch of a train whistle as it moves past an observer).

Traffic Police radars are remote sensors that emit electromagnetic waves (radio, microwave, or light) in order to measure reflections for detection purposes (presence, location, motion, etc.)

Traffic police radar has disadvantages and proplems like reability proplems, radio or microwave interface, mechenical interface, stationary and moving cosine error, ect…

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