UTAH PEACE OFFICER STANDARDS AND TRAINING

RADAR/LIDAR

PRINCIPLES, THEORY, AND APPLICATION OF MODERN POLICE RADAR AND LIDAR

Utah Peace Officer Standards and Training Police Traffic RADAR and LIDAR

Acknowledgements:

For several years there has been a need across the state of Utah for a RADAR/LIDAR program that all agencies access for reference and review.

In 2012 a RADAR/LIDAR executive committee was formed from various agencies from around the State of Utah. This committee worked hard to build a RADAR/LIDAR manual, training slides and curriculum for all officers to reference and review.

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Chapter 1: Speed Problem

<u>Chapter Objectives</u>:

- Discuss how speed has historically related to motor vehicle crashes
- Describe how increased speed relates to motor vehicle crashes in terms of:
    - Perception and Reaction
    - Braking Distance
    - Total Stopping Distance
- Apply basic math formulas to demonstrate the relationship between higher speeds and crashes

<u>Speed and Crashes</u>

Many young drivers, excited to have their license and the keys to a car, have driven beyond the posted speed limit or beyond what is reasonable and prudent for the road conditions. Many older drivers, confident in their abilities, have driven faster than the legal speed limit. The vast majority of these drivers do not immediately crash their vehicles. In fact, it is probably safe to say that most drivers who speed do not always crash simply because they are traveling faster than what the laws allow. If this were the case, the penalties for speeding would be much more severe.

However, common sense says that, while not all drivers who speed crash, a speeding driver is more likely to crash than a non-speeding driver. The adage says that “Speed Kills,” but is this supported by data?

The Utah Highway Safety Office collects and compiles crash data for all roads in Utah. Over the last ten years, there were 543,620 motor vehicle collisions. Statistically, these collisions were subdivided into non-injury or property damage crashes, injury crashes, and fatal crashes. Of all collisions, 90,137 or 16.6% involved a speeding driver. However, over the last ten years, 42.3% of all fatalities involved a speeding driver and 66.1% of all fatalities occurred on roadways where the posted speed limit was 50 mph or greater. Studies show that a 5% increase in average speed leads to a 10% increase in injury crashes and a 20% increase in fatal crashes.

In this chapter, we will look at several simple math problems that will illustrate how increasing speed will increase the chance for a collision and the severity of that collision.

Basic Order of Math Rules

In order to correctly calculate any math problem, a specific order must be followed in completing each step of the problem. Failure to follow the proper order will yield incorrect results and erroneous answers. Someone once coined the phrase "Please Excuse My Dear Aunt Sally" as an acronym for the proper order. The first letter of each word coincides with the order in which sections of the math problem should be solved.

- **P**lease = **P**arentheses
- **E**xcuse = **E**xponents
- **M**y **D**ear = **M**ultiplication & **D**ivision
- **A**unt **S**ally = **A**ddition & **S**ubtraction

Parenthesis

First, portions of the problem which are enclosed in parentheses should be solved before moving on to other sections. For example, the equation below should yield a total of 18.

$$4 + 2 \quad \times 3$$

The portion in parentheses is solved first.

$$(4 + 2)$$

The answer from the parentheses (6) is multiplied by 3, which yields the total of 18.

$$6 \quad \times 3 = 18$$

However, the same problem if the 2 and 3 are multiplied first and the 4 is added second, then the final answer would be 10.

Parentheses, also called brackets, come in various different shapes and sizes and are always found in pairs. ( ), { }, and [ ] are common examples. You may encounter a math problem that has more than one set of parentheses. In this case, one set of parentheses will always surround another. For example, in the problem listed below, the inner parentheses, ( ) are surrounded by the outer parentheses, { }.

$$\{4 + 6 \times \quad 2 + 5 \quad - 3\}$$

To correctly solve equations with multiple pairs of parentheses, start with the innermost set of parentheses, solve the problem found within, and work your way outward.

Exponents

Second, when working through a math problem, exponents should be solved next. If there are no parentheses in a math problem, start with the exponents. Exponents are the numbers slightly above and to the right of another, like a superscript. In the problem $6^2 + 9$, the number 2 is an exponent. In this case, the exponent indicates the number 6 should be multiplied by itself. This is commonly called "squaring" a number. Another way to write the same problem would be $6 \times 6 + 9$. There is no limit to the value of an exponent. $6^{5,000,000}$ means that the number six should by multiplied by itself 5,000,000 (five million) times. For the math in this manual, the highest exponent will be the number two.

Multiplication & Division

Third, all values which are multiplied and divided should be solved after exponents and parentheses. If there are no parentheses or exponents, start with multiplication and division. There are several ways in a math problem to write "multiply" or "divide." For simplicity and consistency, all math problems in this manual will use "$\times$" for multiply and "$/$" for divide. The divide symbol may be written as a diagonal line or a horizontal line, separating the numerator (top set of numbers) and the denominator (bottom set of numbers).

Addition & Subtraction

Fourth, solve for the addition and subtraction in the math problem.

Speed & Velocity

The terms Speed and Velocity are often used interchangeably, though they do not mean the same thing. This course will mirror many of the principles, terms, and formulas taught in the Basic Crash Investigation course. Speed always refers to measurements made in miles per hour (mph). Velocity always refers to measurements made in feet per second (fps). It is important to know how to convert one to the other.

The following formulas are two simple ways to convert back and forth between speed and velocity.

$$\text{Speed} = \text{Velocity} / 1.47$$

$$\text{Velocity} = \text{Speed} \times 1.47$$

To understand the conversion factor, consider the following. First, there are 5,280 feet in a mile. Second, there are 60 minutes in an hour and each minute is made up of 60 seconds, yielding 3,600 seconds in an hour. Taking the total number of feet in a mile (5,280) and divide it by the total number of seconds in an hour (3,600), the result is 1.4666666, with the number 6 repeating infinitely. To simplify, the number is rounded to 1.47.

***Problem*:** If Mr. Jones is traveling at 40 mph, what is his velocity?

In this problem, Mr. Jones is traveling at 40 mph and the question asks what his velocity would be at that speed. By using the formula:

$$\text{Velocity} = Speed \times 1.47$$

we simply replace the word “Speed” with 40 mph, so the problem now reads:

$$\text{Velocity} = 40 \times 1.47$$

Solving for 40 x 1.47 on a calculator yields 58.8. Remembering that velocity is always measured in feet per second, the answer is 58.8 fps.

Perception & Reaction – How does it relate?

The term perception means the amount of time it takes a normal person to perceive a hazard. Perception means to see the hazard, recognize it for what it is, and determine to avoid the hazard. The standard perception time will be set at 0.75 seconds. Obviously, an impaired or distracted driver will likely take longer than 0.75 seconds to perceive a hazard. On the other hand, an alert, attentive driver in good physical and mental condition may take less than 0.75 seconds to perceive a hazard. However, the 0.75 seconds is a good standard to use. Perceiving the hazard means visually seeing it, recognizing that it presents a danger, and determining that some course of action must be taken to avoid the hazard. In real life, a driver may choose to steer around a hazard to avoid a collision. For simplicity, the only course of action used by drivers in this manual will be to apply brakes and stop the vehicle, staying within their travel lane.

A driver will travel a known distance as they perceive a hazard. Consider a driver who is traveling in a 20 mph in a school zone versus a driver who is traveling 75 mph on the interstate. While both have the same Perception Time of 0.75 seconds, the driver on the interstate will travel further in that 0.75 seconds than the driver in the school zone. The formula to calculate the perception distance is

$$Perception\ Distance = 0.75 \times Velocity$$

The term reaction means the amount of time it takes a normal person to react to that hazard and will be set at 0.75 seconds. Reacting to the hazard means that the driver has decided on a course of action and makes the physical motions to implement that course. For simplicity, the only course of action used by drivers in this manual will be taking their foot off the gas and applying the brakes in a panic stop. Much the same as perceiving a hazard, an impaired or distracted driver will clearly take longer than the 0.75 seconds to react to the hazard while an attentive driver may take less than .075 seconds to react

A driver will still travel a known distance as they react to a hazard. Consider a driver who is traveling in a 20 mph in a school zone versus a driver who is traveling 75 mph on the interstate. While both have the same reaction time of 0.75 seconds, the driver on the interstate will travel further in that 0.75 seconds than the driver in the school zone. The formula to calculate the reaction distance is

$$Reaction\ Distance\ =\ 0.75\ \times\ Velocity$$

If we negate the effects of engine braking and assume that the brake is applied in a panic stop, the vehicle can be assumed to be traveling at a constant speed as the driver perceives and reacts to the hazard. Then, as soon as the brakes are applied, the full stopping power of the vehicle is in force as it skids to a stop. With this in mind, there is no speed loss until all four wheels of the vehicle are locked and skidding. Therefore, the perception and reaction times can be combined into 1.5 seconds. This is the total amount of time it takes for the driver to perceive and react to any hazard in the roadway. The formula to calculate the total distance a driver travels as they perceive and react is

$$Perception\ \&\ Reaction\ Distance\ =\ 1.5\ \times\ Velocity$$

Remember that the distance resulting from this formula will always be measured in feet.

Problem: What is the perception / reaction distance for Mr. Jones traveling at 40 mph?

In the previous section, we calculated that when Mr. Jones was traveling 40 mph, he was traveling 58.8 feet per second. Taking that value, we can replace the word “Velocity” with 58.8.

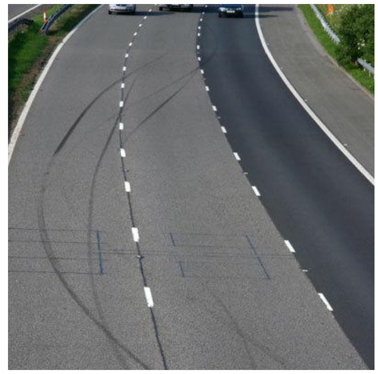
$$Perception\ \&\ Reaction\ Distance\ =\ 1.5\ \times\ Velocity$$
$$Perception\ \&\ Reaction\ Distance\ =\ 1.5\ \times\ 58.8$$

The problem now can be solved by simply entering the numbers into a calculator. The final answer is 88.2. Remembering that Mr. Jones was traveling at 58.8 feet per second and the time he traveled was measured in seconds, the final answer is measured in feet, or 88.2 feet.

While 1.5 seconds may seem like a significant amount of time to simply perceive and react, consider the last time you were at a stop light at the end of a long line of cars. When the light turned green and the first driver perceived and reacted and went through the intersection. The second driver perceived and reacted to the first driver going and started through the intersection. Then the third driver perceived and reacted and so on. The pattern continued until you started to move forward. By this point, you noticed that the light has already turned red. Why the delay? It is simply due to the perception and reaction time for each of the drivers in the line.

Braking Distance – Skidding to a stop

Once the driver has decided to stop the vehicle, there is a certain amount of distance they will travel before their vehicle comes to a stop. This distance is determined by two main factors: the speed at which the vehicle is traveling and the drag factor for the roadway. Obviously, the faster a vehicle is traveling, the longer it will take to skid to a stop while slower vehicles take a shorter distance to skid to a stop. Nearly everyone has seen the long skid marks on a stretch of interstate highway and thought "Wow! They must have been going fast!" Similarly, most drivers have been traveling at a lower speed, applied the brakes hard, and felt their vehicle come to an almost immediate stop with little to no skidding. Since we're all familiar with how speed affects braking distance, what then is the "drag factor" and how does it affect braking distance?



Drag factor is also known as the coefficient of friction and both terms can be used interchangeably. Simply put, the drag factor is the stopping ability of the road surface. Some people call it the "stickiness" or "abrasiveness" of a road. Roadways with a high drag factor have a high stopping ability while roadways with a low drag factor have a low stopping ability.

Pavement Type	Drag Factor Range
Dry Asphalt/Cement	.60 - .80
Wet Asphalt/Cement	.45 - .70
Ice, Loose snow	.10 - .25
Packed snow	.30 - .55

Consider a newly paved concrete surface and imagine scuffing your shoe across that surface. New concrete has a relatively high drag factor. Your shoe would stop fairly quickly and you would feet a significant resistance to the movement of your foot. Consider an icy surface and imagine scuffing your shoe across that surface. Ice has a relatively low drag factor. Your shoe would slide fairly easily across the icy surface and you would feel little, if any, resistance. The concrete surface, with its high drag factor, had a much greater stopping ability than the icy surface, with its low drag factor.

In most formulas and in this manual, the letter "f" is used to represent drag factor. In this manual, you will not be asked to calculate any drag factors. The value will be given to you in each problem. It is important to note that for this portion of the calculations, the braking distance formula requires the speed of the vehicle in question. Perception & Reaction Distance will use velocity; Braking Distance will use speed.

To calculate the distance traveled by a vehicle as it skids to a stop, we will use the formula

$$d = \frac{Speed^2}{(30 \times f)}$$

The letter "d" equals the total distance, measured in feet, the vehicle travels as it skids to a stop. The speed is squared (multiplied by itself). The number 30 is a constant (number that is always used in the formula and never changes). The letter "f " is the drag factor for that roadway and will be given to you with the question.

Problem: What is the braking distance for Mr. Jones traveling at 40 mph on a roadway with a drag factor of 0.65?

$$d = \frac{Speed^2}{(30 \times f)}$$

First, as shown above, take the known values from the word problem and substitute them for the corresponding unknowns (speed &f) in the formula.

$$d = \frac{40^2}{(30 \times 0.65)}$$

Following the rules of the order of math, first solve for the items in parentheses.

$$d = \frac{40^2}{19.5}$$

Second, solve for the exponents.

$$d = \frac{1600}{19.5}$$

Finally, solve for multiplication and/or division.

$$d = 82.05$$

Total Stopping Distance

Total stopping distance is the simplest to calculate, assuming the calculations for Perception & Reaction Distance and for Braking Distance were done correctly. Simply use the formula

$$Total\ Stopping\ Distance = Perception\ \&\ Reaction\ Distance\ +\ Braking\ Distance$$

In the case with Mr. Jones, his Perception & Reaction Distance was 88.2 feet and his Braking Distance was 82.05 feet.

$$Total\ Stopping\ Distance = Perception\ \&\ Reaction\ Distance\ +\ Braking\ Distance$$
$$Total\ Stopping\ Distance = 88.2\ +\ 82.05$$
$$Total\ Stopping\ Distance = 170.25$$

Speeding in a Residential Zone – Is It a Problem?

Now, we'll work through a series of problems that deal with the Total Stopping Distance in a residential zone. First, we'll calculate the total stopping distance for a vehicle traveling at the posted limit of 25 mph. Next, we'll calculate the same distance for a vehicle traveling 35 mph, 10 over the posted limit. Finally, we'll consider the total stopping distance for a vehicle traveling 45 mph, 20 over the posted speed limit. Unfortunately, it is not uncommon to find drivers traveling at these speeds in residential zones. For ease of reading, all the problems are on their own page in this manual.

Problem #1: Mr. Jones is traveling in a residential zone with a posted speed limit of 25 mph. A young boy runs out into the road directly in front of Mr. Jones' car, 90 feet away. The drag factor for the road is 0.65. At **<u>25 mph</u>**, can Mr. Jones stop in time?

Problem #1, Step 1: Convert Mr. Jones' speed (25 mph) to velocity.

$$\text{Velocity} = \text{Speed} \times 1.47$$
$$\text{Velocity} = 25 \times 1.47$$
$$\text{Velocity} = 36.75$$

Problem #1, Step 1 Answer: 36.75 fps

Problem #1, Step 2: Solve for the Perception & Reaction Distance for Mr. Jones at 25 mph.

$$Perception \,\&\, Reaction\ Distance = 1.5 \times Velocity$$
$$Perception \,\&\, Reaction\ Distance = 1.5 \times 36.75$$
$$Perception \,\&\, Reaction\ Distance = 55.13$$

Problem #1, Step 2 Answer: 55.13 fps

Problem #1, Step 3: Solve for the Braking Distance for Mr. Jones at 25 mph.

$$d = \frac{Speed^2}{(30 \times f)}$$

$$d = \frac{25^2}{(30 \times 0.65)}$$

$$d = \frac{25^2}{19.5}$$

$$d = \frac{625}{19.5}$$

$$d = 32.05$$

Problem #1, Step 3 Answer: 32.05 feet

Problem #1, Step 4: Solve for the Total Stopping Distance for Mr. Jones at 25 mph.

$$Total\ Stopping\ Distance = Perception \,\&\, Reaction\ Distance + Braking\ Distance$$
$$Total\ Stopping\ Distance = 55.13 + 32.05$$
$$Total\ Stopping\ Distance = 87.63$$

Problem #1, Step 4 Answer: 87.63 feet. Mr. Jones can stop prior to hitting the child.

Problem #2: Mr. Jones is traveling in a residential zone with a posted speed limit of 25 mph. A young boy runs out into the road directly in front of Mr. Jones' car, 90 feet away. The drag factor for the road is 0.65. At **<u>35 mph</u>**, can Mr. Jones stop in time?

Problem #2, Step 1: Convert Mr. Jones' speed (35 mph) to velocity.

$$\text{Velocity} = \text{Speed} \times 1.47$$
$$\text{Velocity} = 35 \times 1.47$$
$$\text{Velocity} = 51.45$$

Problem #2, Step 1 Answer: 51.45 fps

Problem #2, Step 2: Solve for the Perception & Reaction Distance for Mr. Jones at 35 mph.

$$Perception\ \&\ Reaction\ Distance = 1.5 \times Velocity$$
$$Perception\ \&\ Reaction\ Distance = 1.5 \times 51.45$$
$$Perception\ \&\ Reaction\ Distance = 77.18$$

Problem #2, Step 2 Answer: 77.18 feet.
Note: At this point, Mr. Jones has less than 13 feet to stop his car.

Problem #2, Step 3: Solve for the Braking Distance for Mr. Jones at 35 mph.

$$d = \frac{Speed^2}{(30 \times f)}$$

$$d = \frac{35^2}{(30 \times 0.65)}$$

$$d = \frac{35^2}{19.5}$$

$$d = \frac{1225}{19.5}$$

$$d = 62.82$$

Problem #2, Step 3 Answer: 62.82 feet

Problem #2, Step 4: Solve for the Total Stopping Distance for Mr. Jones at 35 mph.

$$Total\ Stopping\ Distance = Perception\ \&\ Reaction\ Distance + Braking\ Distance$$
$$Total\ Stopping\ Distance = 77.18 + 62.82$$
$$Total\ Stopping\ Distance = 140$$

Problem #2, Step 4 Answer: 140 feet. Mr. Jones cannot stop prior to hitting the child.

Problem #3: Mr. Jones is traveling in a residential zone with a posted speed limit of 25 mph. A young boy runs out into the road directly in front of Mr. Jones' car, 90 feet away. The drag factor for the road is 0.65. At **<u>45 mph</u>**, can Mr. Jones stop in time?

Problem #3, Step 1: Convert Mr. Jones' speed (45 mph) to velocity.

$$\text{Velocity} = \text{Speed} \times 1.47$$
$$\text{Velocity} = 45 \times 1.47$$
$$\text{Velocity} = 66.15$$

Problem #3, Step 1 Answer: 66.15 fps

Problem #3, Step 2: Solve for the Perception & Reaction Distance for Mr. Jones at 45 mph.

$$Perception\ \&\ Reaction\ Distance = 1.5 \times Velocity$$
$$Perception\ \&\ Reaction\ Distance = 1.5 \times 66.15$$
$$Perception\ \&\ Reaction\ Distance = 99.23$$

Problem #3, Step 2 Answer: 99.23 feet.

Note: By the time Mr. Jones has started braking, he has already hit the child. This means the child was struck at 45 mph.

Problem #3, Step 3: Solve for the Braking Distance for Mr. Jones at 45 mph.

$$d = \frac{Speed^2}{(30 \times f)}$$

$$d = \frac{45^2}{(30 \times 0.65)}$$

$$d = \frac{45^2}{19.5}$$

$$d = \frac{2025}{19.5}$$

$$d = 103.85$$

Problem #3, Step 3 Answer: 103.85 feet

Problem #3, Step 4: Solve for the Total Stopping Distance for Mr. Jones at 45 mph.

$$Total\ Stopping\ Distance = Perception\ \&\ Reaction\ Distance + Braking\ Distance$$
$$Total\ Stopping\ Distance = 99.23 + 103.85$$
$$Total\ Stopping\ Distance = 203.08$$

Problem #3, Step 4 Answer: 203.08 feet. Mr. Jones cannot stop prior to hitting the child. The child will likely be killed by the impact.

Speeding on the Highways – Is It a Problem?

Next, we'll work through a series of problems that deal with the Total Stopping Distance in a highway with the speed limit of 65 mph. First, we'll calculate the total stopping distance for a vehicle traveling at the posted limit of 65 mph. Next, we'll calculate the same distance for a vehicle traveling 80 mph, 15 over the posted limit. Finally, we'll consider the total stopping distance for a vehicle traveling 95 mph, 30 over the posted speed limit. Again, for ease of reading, all the problems are on their own page in this manual.

Problem #4: Mr. Jones is traveling in on the freeway with a posted speed limit of 65 mph. Two vehicles are involved in a collision, directly in front of Mr. Jones' car, 365 feet away. The drag factor for the road is 0.65. At **65 mph**, can Mr. Jones stop in time?

Problem #4, Step 1: Convert Mr. Jones' speed (65 mph) to velocity.

$$\text{Velocity} = \text{Speed} \times 1.47$$
$$\text{Velocity} = 65 \times 1.47$$
$$\text{Velocity} = 95.55$$

Problem #4, Step 1 Answer: 95.55 fps

Problem #4, Step 2: Solve for the Perception & Reaction Distance for Mr. Jones at 65 mph.

$$Perception \,\&\, Reaction\ Distance = 1.5 \times Velocity$$
$$Perception \,\&\, Reaction\ Distance = 1.5 \times 95.55$$
$$Perception \,\&\, Reaction\ Distance = 143.33$$

Problem #4, Step 2 Answer: 143.33 fps

Problem #4, Step 3: Solve for the Braking Distance for Mr. Jones at 65 mph.

$$d = \frac{Speed^2}{(30 \times f)}$$

$$d = \frac{65^2}{(30 \times 0.65)}$$

$$d = \frac{65^2}{19.5}$$

$$d = \frac{4225}{19.5}$$

$$d = 216.67$$

Problem #4, Step 3 Answer: 216.67 feet

Problem #4, Step 4: Solve for the Total Stopping Distance for Mr. Jones at 65 mph.

$$Total\ Stopping\ Distance = Perception \,\&\, Reaction\ Distance + Braking\ Distance$$
$$Total\ Stopping\ Distance = 143.33 + 216.67$$
$$Total\ Stopping\ Distance = 360$$

Problem #4, Step 4 Answer: 360 feet. Mr. Jones can stop prior to hitting the stopped cars, with 5 feet to spare.

Problem #5: Mr. Jones is traveling in on the freeway with a posted speed limit of 65 mph. Two vehicles are involved in a collision, directly in front of Mr. Jones' car, 365 feet away. The drag factor for the road is 0.65. At **80 mph**, can Mr. Jones stop in time?

Problem #5, Step 1: Convert Mr. Jones' speed (80 mph) to velocity.

$$\text{Velocity} = \text{Speed} \times 1.47$$
$$\text{Velocity} = 80 \times 1.47$$
$$\text{Velocity} = 117.6$$

Problem #5, Step 1 Answer: 117.6 fps

Problem #5, Step 2: Solve for the Perception & Reaction Distance for Mr. Jones at 80 mph.

$$Perception \;\&\; Reaction\ Distance = 1.5 \times Velocity$$
$$Perception \;\&\; Reaction\ Distance = 1.5 \times 117.6$$
$$Perception \;\&\; Reaction\ Distance = 176.4$$

Problem #5, Step 2 Answer: 176.4 feet.

Problem #5, Step 3: Solve for the Braking Distance for Mr. Jones at 80 mph.

$$d = \frac{Speed^2}{(30 \times f)}$$
$$d = \frac{80^2}{(30 \times 0.65)}$$
$$d = \frac{80^2}{19.5}$$
$$d = \frac{6400}{19.5}$$
$$d = 328.21$$

Problem #5, Step 3 Answer: 328.21 feet

Problem #5, Step 4: Solve for the Total Stopping Distance for Mr. Jones at 80 mph.

$$Total\ Stopping\ Distance = Perception \;\&\; Reaction\ Distance + Braking\ Distance$$
$$Total\ Stopping\ Distance = 117.6 + 328.21$$
$$Total\ Stopping\ Distance = 504.61$$

Problem #5, Step 4 Answer: 504.61 feet. Mr. Jones cannot stop prior to hitting the stopped cars.

Problem #6: Mr. Jones is traveling in on the freeway with a posted speed limit of 65 mph. Two vehicles are involved in a collision, directly in front of Mr. Jones' car, 365 feet away. The drag factor for the road is 0.65. At **<u>95 mph</u>**, can Mr. Jones stop in time?

Problem #6, Step 1: Convert Mr. Jones' speed (95 mph) to velocity.

$$\text{Velocity} = \text{Speed} \times 1.47$$
$$\text{Velocity} = 95 \times 1.47$$
$$\text{Velocity} = 139.65$$

Problem #6, Step 1 Answer: 139.65 fps

Problem #6, Step 2: Solve for the Perception & Reaction Distance for Mr. Jones at 95 mph.

$$Perception \,\&\, Reaction\ Distance = 1.5 \times Velocity$$
$$Perception \,\&\, Reaction\ Distance = 1.5 \times 139.65$$
$$Perception \,\&\, Reaction\ Distance = 209.48$$

Problem #6, Step 2 Answer: 209.48 feet.

Problem #6, Step 3: Solve for the Braking Distance for Mr. Jones at 95 mph.

$$d = \frac{Speed^2}{(30 \times f)}$$

$$d = \frac{95^2}{(30 \times 0.65)}$$

$$d = \frac{95^2}{19.5}$$

$$d = \frac{9025}{19.5}$$

$$d = 462.82$$

Problem #6, Step 3 Answer: 462.82 feet
Note: the Braking Distance is greater than the original available stopping distance.

Problem #6, Step 4: Solve for the Total Stopping Distance for Mr. Jones at 95 mph.

$$Total\ Stopping\ Distance = Perception \,\&\, Reaction\ Distance + Braking\ Distance$$
$$Total\ Stopping\ Distance = 209.48 + 462.82$$
$$Total\ Stopping\ Distance = 672.30$$

Problem #6, Step 4 Answer: 672.30 feet. Mr. Jones cannot stop prior to hitting the cars. It is likely that someone in the cars will either be killed or severely injured by Mr. Jones' collision with their cars

Chapter 2: Speed Laws

Chapter Objectives:

- Identify the difference between basic and absolute speed limits
- Become familiar with the relevant statutes and laws in Utah
- Define how Utah speed limits are established by statute
- Define voluntary compliance and identify how it relates to effective enforcement
- Identify legal requirements for law enforcement officers regarding the speed limit

Speed limits arose in the early 20th Century in response to increased injuries and fatalities due to the increasing popularity of the automobile. Federal, state and local jurisdictions realized they had a vested interest in regulating traffic speeds. Over the years, the tools and sophistication of enforcement techniques have improved dramatically. However, the laws have changed very little from their original versions. In Utah, there are two major types of speed laws that establish the speed limit:

1) The basic or prima facie speed limit.
2) The absolute speed limit.

Basic Speed Limit (41-6a-601):

The basic or prima facie speed limit is laid out in the Utah traffic code in 41-6a-601: ""A person may not operate a vehicle at a speed greater than is reasonable and prudent under the existing conditions, giving regard to the actual and potential hazards then existing." The code section specifically lists several hazards that must be considered: 1) approaching intersections or railroad crossings, 2) approaching or negotiating curves, 3) approaching a hillcrest, 4) traveling on any narrow or winding roadway 5) other hazards such as pedestrians, traffic, weather, and highway conditions.

The primary difference between this statute and the absolute speed limit is that the basic speed limit is typically not posted. It is not the speed limit signs that most motorists recognize. Additionally, the basic speed limit is typically lower than the posted speed limit. Because the language of this statute specifically mentions actual and potential hazards, this law relies heavily on the typical actions of reasonable people. Actual or potential hazards can certainly make a 'reasonable' speed far lower than the posted speed limit. One common example might be crashes that occur on snowy or icy roads. These weather conditions on a road that has a posted speed limit of 55 miles per hour would clearly make traveling at the posted limit inadvisable.

In addition to the general language regarding reasonable speeds given the hazards, this statute also establishes speed limits in unincorporated areas or other areas where an absolute speed limit is not posted. These limits are:

- 20 miles per hour in a reduced speed school zone as defined in Section 41-6a-303
- 25 miles per hour in any urban district
- 55 miles per hour in other locations

The above speeds are considered by statute to be reasonable in areas where other absolute speed limits have not been established. Most law enforcement, in colloquial terms, cite this code section with the description, "speed too fast for the existing conditions."

When law enforcement determine that a motorist has violated this code section, it is important to note the hazards, conditions and factors that led the officer to believe that the speed was unsafe or unreasonable. Unlike absolute speed limits, there is not often a specific number that is unlawful under this code section. For example, an officer, in their citation notes, might note standing snow, slush or ice, the fact that a violator lost control of the vehicle, the prevailing traffic speeds compared to the violator's speed, the speeds possible in the officer's patrol vehicle and so forth.

Absolute Speed Limits (41-6a-602[1] & 41-6a-603[1]):

The above code sections grant to the Utah Department of Transportation and municipalities the authority to establish absolute speed limits on each highway and roadway under their jurisdiction. By using the methods explained below, UDOT and municipal authorities can mandate a 'safe and reasonable' speed that cannot be exceeded, regardless of road conditions or hazards. Once a speed limit is established and clearly posted, exceeding that speed limit becomes, by definition, 'unreasonable'. The absolute speed limit is what most consider as the 'speed limit'. This is the law that results in posted speed limit signs.

These absolute speed limits are similar to the 'per se' statute found in Utah DUI law in that neither law relies on performance deficiencies or actual danger to the public. Exceeding the number established by the governmental authority is, by itself, an illegal action. For example, a person driving a high-performance vehicle with speed-rated tires may be perfectly safe to operate at 75 miles per hour on a road where the absolute speed limit is posted as 65 mph. Many, many motorists exceed the absolute speed limit on a regular basis with little to no adverse consequences. The fact that the speed exceeded the posted, absolute speed limit, however, renders the actions unlawful.

How Speed Limits Are Established:

The Utah Legislature has given both UDOT and municipalities wide discretion in establishing absolute speed limits, but such limits must be imposed based on hard data relating to the safety of the motoring public. UDOT policy 06C-25 describes the procedures used for conducting a 'speed zone study'. Speed limits are not established arbitrarily.

A 'speed zone study' is primarily based on the '85th percentile'. Traffic engineers will go to a location where speed limits either will be established or changed. They will measure the speeds of all traffic during time frames where crashes and other factors do not interrupt the normal flow. Speed limits are typically established at the speed at or below which 85% of the traffic is traveling. For example, if UDOT establishes a speed limit of 45 mph on a roadway, it typically means that 85% of all traffic on that road is traveling 45 mph or lower.

Additionally, UDOT will not, without exigency, establish a speed limit more than 5 mph below the 85th percentile. If such an action is taken, it will usually be with mitigating factors such as:

1. Road surface characteristics, shoulder condition, grade, alignment, and sight distance.
2. Roadside development and culture, and roadside friction.
3. Safe speeds for curves or hazardous locations within the zone.
4. Pedestrian activity, parking practices, and other traffic.
5. Reported crash experience for the most recent three-year period.

(http://www.udot.utah.gov/main/uconowner.gf?n=10468406714475616)

If such factors justify the drop of a speed limit below the 85th percentile, UDOT is required by their policy to conduct follow-up speed zone studies within 6-12 months.

According to UCA 41-6a-602(2), UDOT may also regulate speed limits on roadways under its jurisdiction with regard to:

1. Time of day
2. Highway construction
3. Type of vehicle
4. Weather conditions
5. 'other highway safety factors'

By utilizing these procedures, speed limits are established which are conducive to the flow of traffic, incorporate the vast majority of already existing speeds and help to ensure that speeds on the roadway do not vary greatly.

Voluntary Compliance:

'Voluntary compliance', for the purposes of this program, is defined as: **"*The willful or deliberate obedience to any law without direct police intervention.*"** In other words, 'voluntary compliance' describes the behavior of the vast majority of the motoring public. Most people obey most of the traffic laws most of the time.

Law enforcement officers are charged not only with apprehending violators of the law, but to attempt to increase voluntary compliance, as well. A marked patrol car can by itself encourage compliance. For example, some county agencies often park a marked patrol car in their jurisdiction with a mannequin in the driver seat. Officer presence can often induce compliance. There are other instances where voluntary compliance is observed:

- Staying to the right of a double yellow line on a rural highway
- Proceeding through an intersection on a green light as opposed to stopping to verify cross traffic has stopped for their red light

As seen in Chapter 1: The Speed Problem, effective enforcement can have a demonstrable effect on prevailing vehicle speeds and this directly correlates to a reduction in speed-related crashes, injuries and deaths. The minimum requirements for effective enforcement are difficult to define. In heavily populated areas, effective enforcement by means of saturation patrols and number of violators cited is nearly impossible. The number of available officers is simply dwarfed by both the traffic and calls-for-service volume.

Additionally, effective enforcement includes more than just bodies in uniform making traffic stops. Every time a violator passes a marked patrol unit and is not stopped, the seriousness of the speed laws is diminished in the public eye. The motoring public is emboldened to future violations, as well. While the state may never have the number of bodies in uniform required, every violator stopped will be seen by dozens, if not hundreds, of other motorists. Simply taking action on one person may change the behavior, however slight, of many more.

Public perception of enforcement also plays a large part in voluntary compliance. If enforcement efforts are concentrated on revenue rather than education and public safety, the reaction to such efforts will largely be negative. Remember: the goal of speed limits and enforcement of those limits is to reduce property damage, injury and death on the state's roadways and to increase public safety. Voluntary compliance is one of the most important ways to accomplish this goal. Any enforcement that reduces voluntary compliance will, in the end, be counterproductive.

Police Officers and The Speed Limit:

***PLEASE NOTE*: Nothing in this section should be construed to absolve a law enforcement officer of their responsibility to adhere to their departmental policy. State statute alone is discussed below and does not supersede departmental policy should that policy contain stricter guidelines than herein listed.**

Utah Code 41-6a-212 explains the privileges and responsibilities of the operators of emergency vehicles. Two subsections will be specifically addressed here: 41-6a-212(3)(b), and 41-6a-212(6).

41-6a-212(3)(b) states: "An operator of an authorized emergency vehicle may exceed the maximum speed limit when engaged in normal patrolling activities with the purpose of identifying and apprehending violators." Amended in 2008, this section codifies into law the privilege of emergency vehicle operators to exceed the posted speed limits in limited circumstances. However, when on-duty and operating under this statute, <u>all</u> law enforcement should be keenly aware that, as always, they are under public scrutiny.

This section does NOT apply to off-duty use of a marked patrol unit nor to a law enforcement officer operating a personal vehicle or other departmental vehicle that does not meet the criteria to qualify as an emergency vehicle, as outlined in statute.

41-6a-212(6) is counterpoised with the above and states: "The privileges granted under this section do not relieve the operator of an authorized emergency vehicle of the duty to act as a reasonably prudent emergency vehicle operator in like circumstances." From this, it is clear that 3(b) is not a blanket protection for law enforcement. Excessive speed under 3(b) will always be scrutinized by the public and courts alike through the lens of "reasonable prudence". Referring back to Chapter 1, consider the stopping distances on a normal roadway at the speeds below:

1. 65 mph: 358 ft
2. 85 mph: 554 ft
3. 100 mph: 729 ft
4. 130 mph (governor limit on Ford Crown Victoria): 1145 ft
5. 150 mph (governor limit on Dodge Charger): 1473 ft

As we can see, driving at the vehicle's limit for the Ford Crown Victoria takes an extra 787 ft to stop than traveling at the freeway speed limit of 65 mph. This equates to two and a half football fields or 0.15 miles. This increases to 1115 ft *extra* that is needed to stop if traveling at the Dodge Charger's maximum speed. That equates to 3 ¾ football fields or just under a quarter mile *extra* that is needed to stop the vehicle than had it been traveling at the freeway speed limit of 65 mph. Consider these examples when determining whether your own emergency response meets the criterion of reasonableness.

In recent years, the public has become increasingly less likely to tolerate excessive speed or reckless driving by law enforcement. Many high-profile cases recently have involved the death or serious injury of innocent by-standers. Aside from the obvious tragedy whenever death or injury to innocent parties is involved, these cases have ruined the careers of otherwise good officers. The most egregious cases have also led to the criminal prosecution of the officers for negligent homicide or like statutes in other states. In many of these cases, the officers were operating outside the scope of their departmental policy. As always, law enforcement officers should understand that their departmental policy may be stricter than state law in this area and many legal protections are unavailable to them should they exceed policy. **<u>Always follow department policy!</u>**

Chapter 3: Non Radar Enforcement of Speed Limits

Chapter Objectives

- Define pacing enforcement of speed laws
- Identify pacing limitations
- Identify the specific requirements for effective pacing for enforcement
- Define time/distance enforcement of speed laws
- Identify time/distance limitations
- Identify the specific requirements for effective time/distance enforcement

Pacing:

Pacing is defined as following a vehicle to determine its speed. The officer must maintain a constant distance from the target vehicle. The officer measures the target vehicle speed by using the patrol vehicle's speedometer. The officer must ensure a complete tracking history by following the target vehicle for a reasonable distance. The officer should take note of the patrol speed and determine whether the target vehicle is in excess of the speed limit.

There are multiple techniques to ensure proper pacing is observed by the officer. To ensure that you are following at a relative distance, the officer can measure the change in following distance utilizing stationary objects such as light poles and bridges. An officer can determine the distance between the target vehicle and the patrol vehicle when they pass a stationary object. For example: A motorist passes a bridge and the officer times how long it takes the patrol vehicle to pass the same location. Performing this a second time will tell the officer whether the distance between the two vehicles is increasing, decreasing or staying the same.

Another technique the officer can use is to set the patrol speed at a lower rate than the target vehicle. When the target vehicle is visibly pulling away from the patrol vehicle the officer knows that the target is traveling faster. The officer would then cite the driver for the known speed of the patrol vehicle.

One issue that may cause pacing to be less effective is that the target vehicle may see the officer and slow down before an appropriate tracking history is established. Tracking history will be discussed in greater detail in chapters 7 and 8.

Verify The Patrol Vehicle’s Speedometer:

The officer should ensure that the speedometer in the patrol vehicle is accurate. This can be done by utilizing several different techniques:

- Using a known distance and time calculation, the use of a stopwatch would be employed to verify accuracy
    - The patrol vehicle’s speedometer may be verified by the officer. The officer should start a stopwatch at the beginning of a measured mile and then stop the stopwatch at the end of the measured mile. The officer should then calculate the actual speed by using the following mathematical formula: Speed (in mph) = 1 mile x 3600/Time (measured in seconds). The officer should then record the date, time, VIN, elapsed time, distance traveled, the actual speed vs. the indicated speed and the person who performed the test for verification. This test should be repeated and recorded to verify the results.
- GPS
- Radar/Lidar

Time/Distance Calculations

An officer can determine a target vehicle’s speed by utilizing a time distance calculation. This is accomplished by measuring the time it takes a vehicle to travel a known distance. The officer can then use the following mathematical formula:

- **Speed = Distance/Time/1.47**

The distance is measured in feet and the time in seconds. The officer should ensure that a large enough distance is used in order to obtain a proper result. It is recommended that the officer use 600 feet or more for greater speeds (freeway speeds). It is acceptable to use a shorter distances for slower speeds (such as 300 feet for speeds of approximately 30 mph).

Time/Distance enforcement requires some preparation of the enforcement area by the officer. This type of enforcement can be done individually or by multiple officers working an enforcement area together.

Time / Distance:
Speed Chart for 30 MPH Zone

SPEED ENFORCEMENT CHART				DISTANCE = 300 FEET			
SPEED LIMIT = 30 MPH				SPEED = DISTANCE / TIME / 1.47			
Time (sec)	Speed (mph)	Time (sec)	Speed (mph)	Time (sec)	Speed (mph)	Time (sec)	Speed (mph)
6.0	34.1	5.0	40.9	4.0	51.1	3.0	68.2
5.9	34.7	4.9	41.7	3.9	52.4	2.9	70.5
5.8	35.3	4.8	42.6	3.8	53.8	2.8	73.1
5.7	35.9	4.7	43.5	3.7	55.3	2.7	75.8
5.6	36.5	4.6	44.5	3.6	56.8	2.6	78.7
5.5	37.2	4.5	45.5	3.5	58.4	2.5	81.8
5.4	37.9	4.4	46.5	3.4	60.2	2.4	85.2
5.3	38.6	4.3	47.6	3.3	62.0	2.3	88.9
5.2	39.3	4.2	48.7	3.2	63.9	2.2	93.0
5.1	40.1	4.1	49.9	3.1	66.0	2.1	97.4

Speed Chart: Officers conducting enforcement using time/distance calculations should create a speed chart for specific speeds. Officers should measure a known distance on the roadway. Officers need to be aware that a distance error may occur based on the angle of observation. The officer should select an observation area which enables the officer to observe traffic passing both the start and stop point of the known distance. The officer must be able to safely enter the roadway and stop the violator or the officer must be able to accurately identify the violator and relay the information to assisting officers. The assisting officers will be in a location which allows for a safe traffic stop. The observing officer should be in a location, which allows him to witness the traffic stop and verify the violator's vehicle. The officer stopping the target vehicle should make note of the observing officer and the information relating to the stop.

Potential Problems Associated with Time/Distance Enforcement

Some of the problems associated with time/distance calculations are inaccurate measured distances, an inaccurate stop watch and measured time. There is also the potential for human error such as: did the officer measure the same point on the vehicle for start and stop points. These problems can be avoided by the enforcing officer by paying attention to detail and ensuring all measurements are accurate and the stopwatch is verified. Violators may also witness the officer in the area and slow down prior to traveling through the measured known distance area.

Measuring Accurate Distances

The officer can ensure the most accurate measurements by utilizing a Laser or Steel Measuring tape. Cloth measuring tapes tend to stretch and shrink over time. Small wheel Roll-O-Meters can bounce and skip which may cause free spinning and an inaccurate measurement. The large wheel Roll-O-Meter may have the same problems but are somewhat more stable.

Certify Your Tape Measure(if necessary): Officers may also certify their tape measure at the Department of Agriculture's weights and measures program. It is located at 350 North Redwood Road in Salt Lake City, Utah 84114. The phone number is 801-538-7100. The officer can compare their tape measure to a known standard at three or four known distances. The officer should then record the time, date and the name of the person who performed the certification.

Measuring Accurate Time

Officers may verify their stop watch by calling the Universal Time Clock or Atomic Clock, located in Boulder, Colorado. It measures the vibration of a Cesium Atom, which vibrates 9.2 billion times per second. The clock is so accurate that it will not gain or loose one second in 60 million years. It can be accessed by going to www.autotime.com or www.nist.time.gov. Officers can also call 1-303-499-7111 for coordinated universal time.

Verify Your Stopwatch: Officers may call the atomic clock voice recording and start the stopwatch at the tone. Note the time and wait approximately 20 minutes then call the atomic clock voice recording, stop the stopwatch at the tone, and note the time. Compare the difference between the stopwatch and the atomic clock. The officer should record the time and date of the verification.

Chapter 4: Radar History and Basics

Chapter Objectives:

- Understand history of radar
- Define Radar and radar development
- Discuss Doppler principle
    - Define Doppler principle
- Relative motion
- Discuss wavelength and frequency
- Discuss how a Radar wave interacts with the environment
    - Reflective
    - Refractive
    - Absorption

Radar History

Radar began with the man who came up with the concept for the physics principle that radar operates on: Christian Johann Doppler, an Austrian physicist and astronomer who wrote a paper on the determination of motion using the frequency of light in the study of the movement of stars.

His discovery in 1842 was dubbed the Doppler Principle, the concept defining how radar determines speed. Of course there were no radars in that time, but his principles created the foundation for radar development many years later.

By the 1930s, scientists had noticed when ships passed between radio transmitters some of the signal reflected back to the source. A team of scientists headed by Sir Robert Alexander Watson-Watt developed the first radar in 1935 utilizing this discovery and building on what was later defined as the Doppler Principle.

An example of the Doppler Principle can be demonstrated by means of a train whistle. As the train approaches from a distance, the whistle tone sounds higher. When the train is nearest to the observer's position, the tone is normal. As the train travels away from the observer, the whistle tone sounds lower. The train whistle is an example of the Doppler Principle using sound waves.

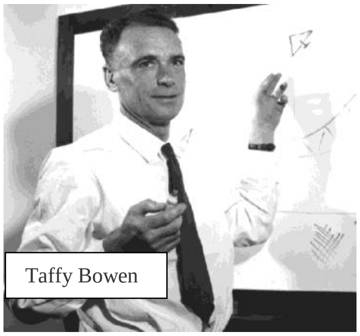
In light of the threat posed by Nazi Germany, Great Britain built a series of 21 radar towers 90 miles from London along the coast facing France and Germany.

In 1940 the Nazis started a series of bombing raids on England. They knew that an invasion would only be successful if they could establish air superiority. At the time the Luftwaffe had 2,400 planes while the British only had about 600.

Chain Home Network Tower

However, the 21 radar towers called the Chain Home Network gave the British a decided advantage. The radar would alert the British of an incoming attack 100 miles before the Nazi planes reached the coast. This allowed the British to get their citizens to shelters and scramble fighters, giving them an edge.

Also in 1940, British scientist Taffy Bowen traveled to the United States with design plans for radar. In the United States he joined with US scientists at the campus of MIT in Cambridge, Massachusetts, where they established the Radiation Laboratory, or RAD-LAB. The lab worked closely with the military on over 100 different radar projects. The United States Military supplied test sites for the radar field experiments since they had not yet entered the war.



Taffy Bowen

In 1941 that changed. On December 7th, 1941 an Army radar site detected 353 planes approaching Hawaii. The information was passed up the chain of command but not acted on, resulting in the devastating attack on Pearl Harbor, forever changing not only the US's position on the war, but their position on radar intelligence as well.

Throughout the war, many different applications of radar were introduced. Air-to-ground radar was developed and placed in aircraft. Ship-borne radar was developed as well. Both of these technologies aided in the winning of the war. After the war, Winston Churchill noted that the atomic bomb may have ended the war, but radar won the war.

From 1945 to 1950, radar took off in many directions. The United States Military developed radars with better range, capable of making determinations of the size and weight of a target. One of the major accomplishments was the military coupling radars with a computer to track objects and correlate information.

Astronomers use radar to measure the speed and movement of planets by detecting and measuring the difference between the transmitted and received radio wave frequencies. Radar is no more than a specialized radio transmitting and receiving device operating at an extremely high frequency and utilizing a directional antenna. Hence the term Radar – RADIO DETECTION AND RANGING.

Types of Radar

Radar can be classified into two types:

- Pulse Radar
- Continuous-Wave Radar

Pulse Radar sends out signals in powerful bursts or pulses (for example: a strobe flashlight). Pulse radar determines distance by measuring the time it takes a radar wave to reach an object and return to the transmitter and then divides that time by two (distance to target). All radio waves travel at the speed of light. This known constant plus time is used to determine distance. Speed of an object can also be determined by continual tracking of that object. Pulse radar is utilized in the aviation industry. The pulse wave principle is utilized with light waves in the operation of Lidar, to be discussed later in Chapter 10.

Continuous-Wave Radar sends out continuous signals rather than short bursts. This is the type of wave utilized by police traffic radar.

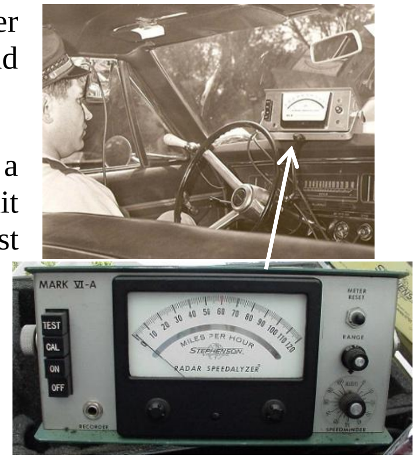
The main advantage of continuous wave radar is that energy is not pulsed so these are much simpler to manufacture and operate. Continuous wave radar maximizes the total power on a target because the transmitter is broadcasting continuously. Continuous wave radar detects only the rate of relative motion (speed) between an object reflecting the radio waves and the antenna, it cannot determine direction. In other words, traffic radar detects motion/speed only, not direction.

All traffic radar devices emit non-ionizing radiation in the region of the electromagnetic spectrum referred to as microwave radiation. The early traffic radar devices were designed to operate at 10.525 gigahertz (GHz), in which the electromagnetic energy wave oscillates at a frequency of 10.525 billion cycles per second. In accordance with nomenclature developed by engineers for the microwave portion of the electromagnetic energy spectrum, these devices also came to be known as X-band radars.

In 1975, a second traffic radar frequency was introduced that uses the higher frequency of 24.15 GHz, which lies in the portion of the spectrum known as K-band. In the 1990's a third frequency of traffic radar was introduced that operates at about 35 GHz (33.4 - 36.00), in what is known as the Ka-band.

The very early traffic radar devices were large, cumbersome, and suitable only for stationary use, i.e., the speed-measuring device had to be stationary itself to obtain an accurate indication of the speed of oncoming vehicles. In the early 1970's the use of radar speed-measuring devices increased rapidly. It was during this period that large numbers of police officers began to have radar units at their disposal for common, and in many cases, almost daily use.

Police radar began as an analog system using a needle rather than a digital readout. Digital technology was not far behind though, and along with it came moving radar.



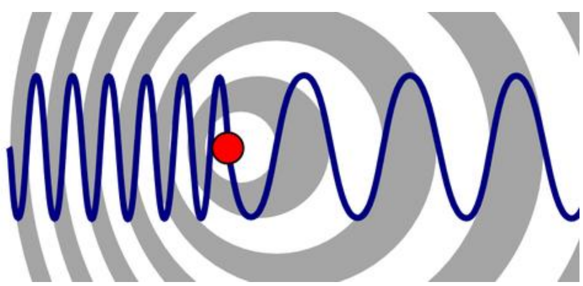
Traffic radar units have been produced in two basic types, a one-piece unit designed for hand-held use, and a two-piece unit designed for a fixed mount. Hand-held units were first introduced in the late 1970's. A few hand-held models have been designed for optional fixed mount use, although most models produced were exclusively designed and used for either hand-held or fixed mount operation. Both types have been and are widely used since the introduction of hand-held models in the late seventies, with the large majority of units having been the two-piece units. The two-piece units consist of an antenna and a separate electronics component that contains the controls and the display panel. Normally, the electronics (display) component is mounted on the dashboard or among instruments beside the officer in the patrol vehicle. The antenna can be mounted in various locations, and has been used with mounts on the front dashboard, the rear dashboard (at the rear windshield behind the seat), or with a bracket on one of the side windows, which can hold the antenna inside or outside, facing forward or back. In some cases, two antennas are used in the same vehicle (usually one front and one back dashboard mount) with a switch provided to choose one or the other antenna at a given time.

In the 1970's radar units became available that could operate in either a stationary mode, or a moving mode. Stationary mode radars had to be used by an officer in a fixed position, but moving mode radars could correctly adjust for the motion of the patrol vehicle while determining the speed of the target or vehicles coming toward the patrol vehicle. Moving mode radars use have always been used with a fixed mounted radar. The determination of which mode to use was entirely a matter of choice of the officer and was usually a function of the standard operating procedure of the law enforcement agency or traffic control unit of that agency.

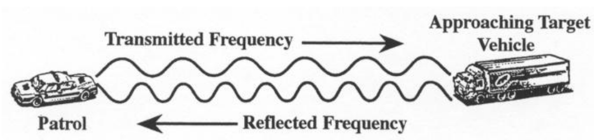
Doppler Principle

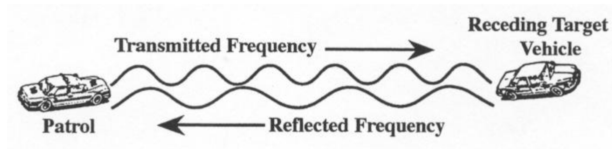
Traffic radar devices operate in a Doppler mode, meaning it determines a frequency shift in the reflected signal. This principle of measuring relative motion between the transmitter and the receiver is known as the Doppler Effect or Doppler Principle.

Wikipedia defines the Doppler Effect as: *"The change in frequency of a wave for an observer moving relative to the source of the wave. It is commonly heard when a vehicle sounding a siren or horn approaches, passes, and recedes from an observer. The received frequency is higher (compared to the emitted frequency) during the approach, it is identical at the instant of passing by, and it is lower during the recession."*



In other words, the Doppler principle or the **Doppler shift is the difference between the transmitted and the received frequency.** This shift emits an audible sound. The audible sound is higher for a faster moving vehicle and lower for a slower moving vehicle. Doppler audio assists the radar operator in the verification of a target or other anomalies, to be discussed later in chapters 7 and 8.





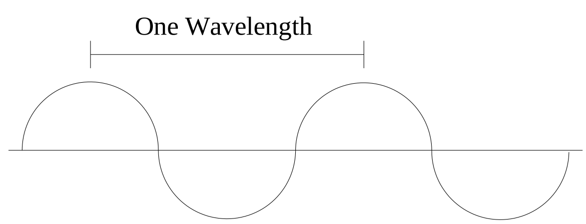
Relative Motion

For Radar to operate the operator needs to understand Relative Motion. Relative Motion is the changing distance in relation to the speed between two objects. For Example:

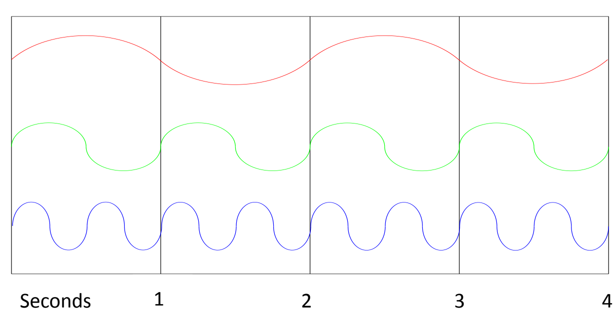
- The radar is stationary and the object reflecting the signal is moving
  - Exception – If the object is moving in a circle around the radar then there is no relative motion
- The radar is moving and the object reflecting the signal is stationary
- The radar and the object reflecting the signal are both moving but in opposite directions
- The radar and the object reflecting the signal are both moving in the same direction but at different speeds
- Both moving but at an angle to each other
- ***There is no relative motion when the radar and the object reflecting the signal are moving the same direction at the same speed***

Wavelengths & Frequency

A wave is a term for a form of energy transmitted through a medium such as air, water or space. One wave is measured from one point of the cycle to the next equivalent point in the same direction as the first. The length of the wave varies with the frequency at which they are transmitted. The higher the frequency the shorter or smaller the wave will be. For example:



- AM radio waves – one wave is 950 feet long
- Police radio wave – one wave is 6 feet long
- Radar wave –
  - 1" long (X band)
  - 1/2" (K band)
  - 1/4" (KA band)



The frequency is simply the number of cycles or waves that pass a point in one second. Frequencies are determined at the point of transmission or at the point of reception and are usually expressed as cycles per second (CPS). As the cycles per second increases corresponding units of measurement called kilo, mega, giga, and tera are used. The chart below indicates the increasing frequency or cycles with its corresponding designation.

Cycles per second	**Number**	**Designation**	**Abbreviation**	
0-100	Hundreds	Hertz	HZ	
1000	Thousands	Kilohertz	KHz	
1,000,000	Millions	Megahertz	MHz	
1,000,000,000	Billions	Gigahertz	GHz	Police Radar
1,000,000,000,000	Trillions	Tereahertz	THz	Police Lidar

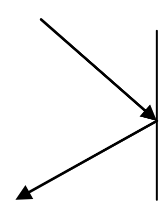
If we remember that all radio waves travel at the speed of light, 186,282.4 MPS or 670,616,640 miles per hour, then it will only take .00000203 (203 hundred millionths) of a second for a radar wave to reach a vehicle 2000 feet away and return to the radar unit.

Now that we understand the radio wave, the transmitted signal and the Doppler principle, let's analyze what occurs when a transmitted radar wave strikes an object. A signal reflected off of a stationary object will return at the same frequency. Since there is no frequency shift the radar will determine there is no motion. A radar signal reflected off of an approaching vehicle will be compressed. The returned frequency will now be higher than the transmitted frequency. On the inverse, a receding vehicle or a vehicle moving away from the transmitter will be stretched resulting in a return frequency lower than the transmitted frequency.

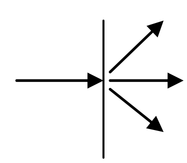
Radar & the Environment

Let's discuss how radar or radio wave interacts with the environment. Generally speaking, radio waves will continue indefinitely unless they are reflected, refracted or absorbed. Understanding how radio waves interact with the environment is important to the effective operation of police traffic radar.

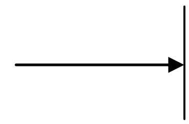
- Reflection – Radio waves bounce off of an object. Merriam-Webster defines reflection as the return of light or sound waves from a surface. Think about shooting a laser pointer at a mirror. The reflection of the laser light is proportional to the angle to which it strikes the mirror. If I shoot the laser light straight at the mirror it will come right back at me. If I point the laser light at the mirror at an angle the laser light will bounce off the mirror in direct relationship the angle of approach.



- Refraction – Radio waves break apart when going through a medium which neither reflects nor absorbs the signal. When this occurs, the radio signal cannot return to the transmitter. An example of refraction is when light passes through a prism or a crack in a windshield. The light is distorted or diffused into different angles.



- Absorption – Radio waves strike an object and neither reflect or refract the signal. This occurs when the radio waves strike an object such as a mountain, tree, or other stationary object and do not allow the wave to return to the transmitter.



Most material will affect the radio wave with a combination of one to all three of the aforementioned environmental interaction anomalies.

Doppler Principle Demonstrations:

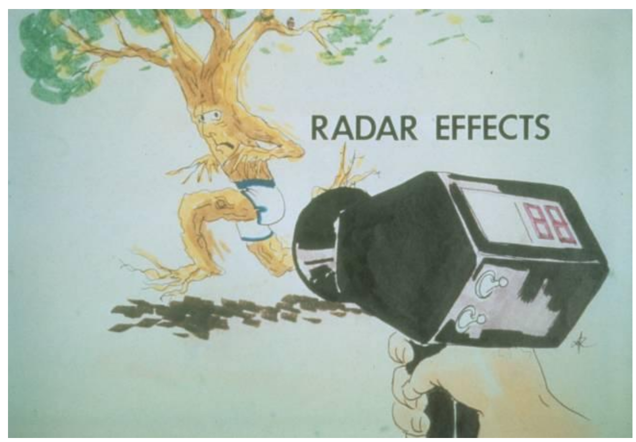
http://www.youtube.com/watch?v=JX_A99Bq9AI
http://www.youtube.com/watch?v=ZPJyYaXhuv4&feature=related
http://www.youtube.com/watch?v=imoxDcn2Sgo
http://www.youtube.com/watch?v=yWIMWqkcRDU&feature=related
http://www.youtube.com/watch?v=a3RfULw7aAY&feature=related

Chapter 5: Radar Effects and Interference

Chapter Objectives:

- Define three categories of radar interference and give examples of each:
  - Mechanical
  - Electrical or Frequency
  - Operational
  - Harmonic
- Identify how to prevent or correct each type of interference
- Identify legal and operational limitations of radar detectors and jammers

Introduction:



Many current radar critics attempt to illustrate the unreliability and inaccuracy of the devices by demonstrating situations in which traffic radar units are apparently clocking trees at 88 mph and houses at 28 mph. Obviously, what has been encountered is not a speeding tree or a moving house. This phenomenon is really an example of radar effects.

Radar effects are those things of an electrical, mechanical, or operational nature that may cause erroneous speed indications on the radar device's readout. Even though numerous radar effects will be identified, not all effects will be encountered. All radar effects are somewhat circumstantial in nature.

It is important for an operator of traffic radar to understand radar effects and the procedures for the avoidance or elimination of these effects. With that understanding will come the reduction of potential error.

Radar Interference can be divided into three main categories which will be explored in-depth below:

- External Mechanical Interference
- Electrical or Radio Frequency Interference (RFI)
- Operational Interference
- Harmonic

External Mechanical Interference:

Radar is designed to detect and register objects in motion. The environment in which traffic radar is used is full of objects in motion or potential sources of external mechanical interference. Things such as large rotating signs and rooftop air-conditioning units are sources of potential interference. However, using tracking history and Doppler audio will prevent this potential interference from becoming a problem.

RFI (Radio Frequency Interference):

Our environment today is full of radio signals being generated by a wide variety of electronic devices. This random RFI is another potential interference source. Most modern radar units have antennae to detect and inhibit operation when RFI is present. Should the operator receive an RFI warning, the following could possibly be the cause:

- Other radios capable of transmitting near the device (police, CB, business and possibly cell phones or Wi-Fi devices)
- High-voltage power lines
- Some streetlights (mercury vapor, neon and other lights can emit radio waves)

To eliminate RFI issues, move the radar unit away from the potential source of RFI. RFI should be rare with modern radar systems.

Operational Interference:

Pulsating Signal Amplitude:

Characteristics:

This effect only occurs in the moving mode of operation. Most modern radars have eliminated this as a possibility due to digital signal processing. When a radar signal encounters an irregular surface having a consistent pattern, such as a chain link fence, the signal, which is returned, may be interpreted as a multiple, irregular Doppler shift. If this situation occurs, an erroneous speed-reading may be displayed.

Avoidance/Elimination

Doppler audio is an effective tool in the identification of this effect. The Doppler audio will not be strong, clear and crisp. Careful observation of the environment will assist in the identification of this effect. Use proper tracking history techniques.

Feedback Effect (Panning Effect):

Characteristics:

This effect is only possible with a two-piece radar unit. When the radar antenna is pointed at or across the counting unit, an erroneous reading occurs. This results in a swamping of the counting unit with its own signal. The resulting reading is usually high. In order for this to occur, improper mounting or operating procedures would have to be used.

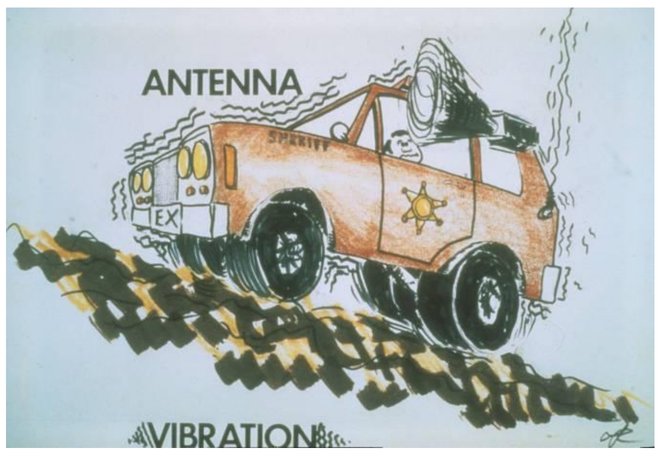
Avoidance/Elimination

In order to fix this error, use approved mounting procedures. Do not point the antenna across the counting unit. Keep the antenna and counting unit separated as far as is possible. Use proper tracking history.

Antenna Vibration Effect:

Characteristics:

The radar is unable to distinguish whether the radar or the target is moving. If the radar antenna is vibrated sufficiently by a rough road or other factors, an erroneous speed-reading may result.



Avoidance/Elimination

Mount the radar antenna securely. Avoid unsuitable locations. Use proper tracking history.

Dented or Damaged Radar/Antennae:

Characteristics:

Dented or damaged radar/antennae may result in a distortion of the beam.

Avoidance/Elimination

Have damaged or dented radar/antennae repaired or replaced.

Windshield Obstruction:

Characteristics:

A dirty or obstructed windshield may reduce range. A radar signal may be distorted by a damaged or obstructed windshield.

Avoidance/Elimination

Keep the windshield clean and free of obstructions. Aim the radar antenna properly (straight ahead or behind and slightly down). Use proper tracking history.

Weather and Terrain:

Characteristics:

Terrain **-** Radar signals will not pass through most solid objects, including tree foliage. Make certain the path between the radar and target vehicle is unobstructed. A glass window is a partial reflector of radar. Therefore, some reduction in range will be experienced when aiming through patrol vehicle windows.

Precipitation **–** Rain/snow absorbs and scatters the radar signal. This reduces the range and increases the possibility of obtaining readings from the speed of the raindrops/snowflakes.

Avoidance/Elimination

Avoid using radar during periods of adverse weather.

Heat Build-up:

Characteristics:

Excessive heat may cause components to change value by causing the frequency to drift. Excessive heat or cold may cause damage.

Avoidance/Elimination

Shield counting units/displays to avoid heat build-up. Maintain a moderate temperature. If a radar unit has become excessively hot or cold, allow the environment to attain a comfortable temperature for at least 15 minutes prior to using the device.

Panning/Scanning:

Characteristics:

Spurious speed-readings are possible if the antenna of stationary mode radar is moved in a sweeping or panning motion. Erroneous speed-readings are also possible when moving radar sweeps the terrain while the vehicle completes a U-turn.

Avoidance/Elimination

The radar antenna should always be properly mounted (straight ahead or back and slightly down). Change patrol speed 5/20 setting to 20. When stationary radar operation is being conducted, the radar antenna should remain as motionless as possible. Disregard all moving radar readings obtained while in the process of any turning movement. Use proper tracking history.

Batching Effect:

Characteristics:

This effect only occurs with moving mode radar. If a radar device does not update low and high Doppler simultaneously, and a change in patrol speed occurs, an erroneous target speed-reading may be displayed. Batching effect only occurs if the patrol vehicle changes speed while using moving radar. Not all radar devices are susceptible to batching. This will only be found in older radars. The ability to process multiple signals at once and digital signal processing has all but eliminated this effect.

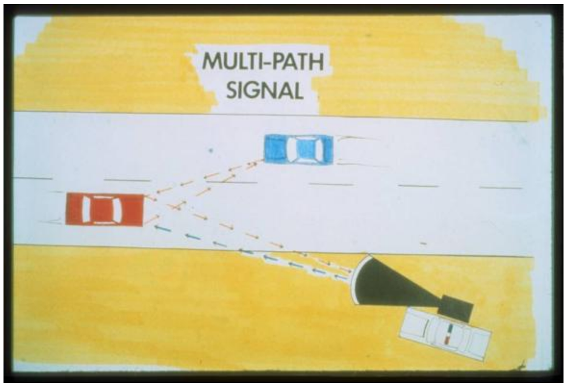
Avoidance/Elimination

Always maintain a constant speed when checking traffic with moving radar. Use proper tracking history.

Multi-Path Signal Effect:

Characteristics:

This effect occurs when the radar signal reflects off the target, strikes another vehicle, and bounces off the target a second time before returning to the radar unit. This is easily recognized by the rapid shift in the audio tone and the unusually high target speed-reading created by the multiple Doppler shifts that have occurred.



Avoidance/Elimination

Use the Doppler audio and proper tracking history.

Window Tint:

Characteristics:

Some window tints have metallic flakes or other conductive materials. Vehicles with this tint may encounter greatly reduced range or operability if the beam is transmitted through these windows.

Avoidance/Elimination

Mount the antenna away from window tint if possible.

Harmonic Interference:

Characteristics:

Pulsating Signal - This effect is found in older radars and occurs when patrolling near an object with a continuous, repeating pattern such as a fence.

Multi-Path Signal - Occurs when the radar beam bounces off several objects before returning to the antenna. This results in a short-lived signal.

Patrol Speed Capture - Occurs when the radar detects the Low Doppler and also captures another part of the radar beam which bounces off a stationary object as the High Doppler. This effect only occurs when there are no other vehicles present.

Avoidance/Elimination

Doppler audio is an effective tool in the identification of this effect. The Doppler audio will not be strong, clear and crisp. Careful observation of the environment will assist in the identification of this effect. Keep the radar antennae pointed straight ahead and pointed slightly down. Use proper tracking history techniques.

Radar/Lidar Detectors:

Claim to:

- Detect radar signals
- Display a visual and sound an audio alert

In reality:

- Effectiveness depends on radar constantly transmitting
- Many false signals in different areas
- Due to perception/reaction time, if an officer is actively running radar and using proper tracking history techniques, when the detector goes off, it is only an indicator to the driver that he/she will be getting pulled over.

Radar detectors are legal in Utah in personal vehicles. However, they are **illegal in all commercial vehicles**. A commercial vehicle is defined in UCA 41-1a-102:

> *(11) "Commercial vehicle" means a motor vehicle, trailer, or semitrailer used or maintained for the transportation of persons or property that operates:*
> *(a) as a carrier for hire, compensation, or profit; or*
> *(b) as a carrier to transport the vehicle owner's goods or property in furtherance of the owner's commercial enterprise.*

The driver of a commercial vehicle who has an operating radar detector or has a commercial vehicle equipped with a radar detector should be cited under Federal Motor Carriers Safety Regulations 392.71(a) which states:

> *No Driver shall use a radar detector in a commercial motor vehicle, or operate a commercial motor vehicle that is equipped with or contains a radar detector.*

Radar Jammers:

Claim to:

- Detect the radar frequency
- Send a rotating, Doppler shifted signal back to the radar unit
- Scramble the radar unit by making hundreds of various speed signals appear at the same time

In reality:

- The signal they transmit is so weak; the effective range is only a few feet.
- They look cool.
- They give the speeder a false sense of security, making them easier to ticket and more dangerous.

Radar Jammers are illegal in the United States. This is due to the fact that the Federal Communications Commission (FCC) has restricted the police radar channels to police use only. In the FCC rules and regulation manual Part 90.20, paragraph "F", subsection #4 it states in part:

> ***(4) A licensee of a radio station in this service may operate radio units for the purpose of determining distance, direction, speed, or position by means of a radiolocation device on any frequency available for radiolocation purposes without additional authorization from the Commission, provided type accepted equipment or equipment authorized pursuant to § 90.203(b)(4) and (b)(5) of this part is used, and all other rule provisions are satisfied.***

What it means is basically all the radar users are covered as long as the stations that they use for day to day communications are properly licensed. All the police radio channels are covered. **Radar jammers are illegal in all vehicle under Utah law: 41-6a-609.**

Chapter 6: The Radar Beam

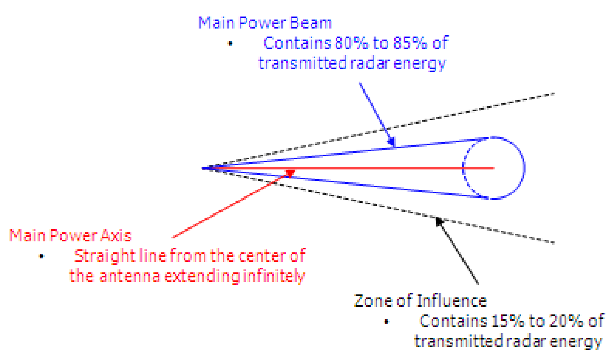
Chapter Objectives:

- Learning the areas of the radar beam
- Understanding the zone of influence
- How to determine the radar beam width
- What reflects a radar signal
- Understanding lines of equal sensitivity
- Understanding the inverse square law
- Understanding contour Lines of Equal Sensitivity
- Beam Range Sensitivity
- Range Control Techniques

Introduction to the Radar Beam:

A similar example of a radar beam is the light source emitted from a flashlight, i.e. conical in shape and different areas of power or illumination. The energy from a radar beam also extends outward indefinitely until it is reflected, refracted, or absorbed.

Main Power Beam - The main power beam contains 80% to 85% of the transmitted energy, between 18 degrees and 12 degrees in width. The 18 degrees to 12 degree beam width is known as the **Main Power Beam.** The main power beam surrounds the main power beam axis.



Main Power Beam Axis: The main power beam axis can be compared to a straight line that extends directly out of the transmitting antenna. The beam axis is surrounded like a traffic cone by the main power beam that contains the 80% to 85% of the transmitted energy. The main power beam extends to greater size or circumference as it extends outward. You can find the width of a radar beam by locating the **half power points** in the radar beam. The width of a radar beam is defined by the Federal Communications Commission as where the half power points are located in the radar beam.

The Half Power Point: This is defined as the location where the energy of the radar beam has dropped by 50% in relationship to the main power beam axis.

Main Beam Width: This is determined by measuring the signal strength along the main power axis and then perpendicular from the axis until the signal strength is dropped to half of that strength measured at the main axis. This measurement is done several times and at various points along the axis until an outline of the beam is determined at the half-power point. Each manufacturer of radar devices publishes the actual degree of beam angle for each unit. Generally speaking, police traffic radar utilizes main power beam widths of between 18 degrees and 12 degrees.

Zone of Influence: The remaining 15% to 20% of the transmitted energy or the radar beam is found outside the width of the main power beam and is referred to as the zone of influence. Since the zone of influence contains 15% to 20% of the radar's initial energy, there is definitely enough energy to reflect a frequency and therefore register a vehicle or object outside the main power beam.

Determining a Beam Width:

Trigonometric functions are essential when working with radar beams. When you calculate a beam that is conical in nature, you are essentially working with a "right" triangle. A radar beam divided in half is construed as a right triangle. A right triangle contains one angle of 90 degrees. It is important to understand the three sides of this right triangle in order to determine the width of a beam at any given distance. The three sides of a right triangle are the hypotenuse, adjacent, and opposite. Using trigonometric functions with a mathematical formula will help you determine the width of a beam. It is important to consider that calculating beam widths are always approximates. There is not a clear and exact point where the edge of the beam begins and ends.

Case law has stated that the officer must articulate that a vehicle was within the radar beam at the time of the reading. Because of this, officers must be able to estimate beam width and distance to the target vehicle. Estimating beam width is accomplished by using the Beam Width Formula below.

Beam Width Formula: The beam width of the main power beam in feet, at varying distances from the transmitter is:

BW = 2 X D X Tan (1/2 angle)

Plug the following information into the formula and then follow the rules of mathematics.

BW = Beam Width

D= Distance along the main axis

½ angle = ½ the beam angle for the radar device

<u>Target Reflectivity:</u>

Understanding how objects react with the radar beam will help the operator understand the signal that is showing on his display. The difference in an object of shape, size and composition in relationship to other objects can help identify the correct target.

Size – The relationship of the front area of an object (semi truck vs. passenger car vs. motorcycle) will return a signal in relation to the size of the object. **Remember** to always consider the **inverse square law** (distance/power return of object).

> ***Inverse Square Law:*** *The inverse square law states that the decrease in strength of a radar signal is inversely proportional to the square of the change in distance from the antenna. Energy twice as far from the source is spread over four times the area, hence one-fourth the intensity. According to the inverse square law if two vehicles of equal size, shape and composition and are both located on the main power axis of the radar beam, the closest vehicle will reflect the most radar signal.*

Shape – The more flat surface area of an object, the more radar signal is reflected directly back towards the antenna. The more angled the surface area of an object the greater possibility that the signal will be reflected back at an angle to the antenna. No vehicle is completely blind to radar. All vehicles have radiators, headlights, front license plates, etc.

Composition – Radar beams are largely absorbed by materials which are non-metallic. Vehicles which utilize fiberglass for fenders and bumpers do not reflect the radar beam nearly as well as vehicles with steel fenders and bumpers.

Lines of Equal Sensitivity: A radar beam contains an infinite number of conical shaped lines of energy which are equal in sensitivity. If two identical vehicles are located an equal distance from the main power axis, the returned signal would be equal for both vehicles.

Contour Lines of Equal Sensitivity: This rule states that the strongest reflected signal is determined by the location of the target vehicle to the main power beam. Contour lines of equal sensitivity when imagined appear as cigar shaped areas of sensitivity within the radar beam. To better understand contour lines of equal sensitivity it is helpful to review all beam reflection rules (inverse square rule, lines of equal sensitivity, size, shape and composition).

If two similar vehicles are positioned so that one is located directly along the main power axis and the other is located at the edge or the radar beam, the vehicle located on the main power axis will reflect the stronger signal.

A vehicle with equal size will reflect the radar beam with equal strength when located upon a single contour line of equal sensitivity. In other words, a target that is located on the main power axis will reflect a radar beam of equal strength to a much **closer** vehicle located perpendicular to the main power axis or on the contour line of equal sensitivity.

Therefore, it is possible for the radar to display a target vehicle speed for a vehicle which is further from the radar if one vehicle is further away, but on the main power axis and a second vehicle is traveling closer, but is further off the main power axis and outside the contour lines of equal sensitivity.

Beam Range – Sensitivity:

As mentioned earlier, the radar beam extends outwards indefinitely until it is reflected, refracted or absorbed. In reality the beam range as referred to is that distance where the radar signal may be reflected from an object and then accurately received by the radar antenna. All radar manufacturers specify the range of their devices within these specifications. The range of the radar will also vary considerably due to several conditions: Atmospheric conditions (rain, snow and fog), terrain (hills, curves, fences and buildings), heavy traffic, etc.

Most radars have a sensitivity adjustment top control the beam range. Radar operators must understand that excessive range may, in fact, hamper the ability to obtain a valid reading.

Most radars also contain **automatic gain circuitry** which increases the sensitivity of the radar if there is not a strong reflected signal within the main power beam. This circuitry will also decrease in sensitivity when there are many strong reflected signals, as would be the case in heavy traffic. Automatic gain circuitry prevents a radar unit in heavy traffic from selecting a large target vehicle which is much greater in distance than a closer, smaller target vehicle.

Range Control Techniques:

There are three range control techniques:

1. **Sensitivity control functions** – These functions can be turned down to decrease the sensitivity of the radar. Remember, a reduction in sensitivity does not change the transmitting power and the reduction in sensitivity is equal across all spectrums of reflected signals.
2. **Tilting the antenna downward** – This will change or move the main power beam and the zone of influence.
3. **Use of the environment** – Terrain such as hills and curves will reduce the effective range of the radar. The radar beam continues in a straight path and cannot bend around curves or over hills. Police traffic radar is basically a line of sight speed measuring device.

Chapter 7: Stationary Radar Operation and the Cosine Effect

Chapter Objectives:

- Identify proper procedure for stationary radar operation
- Describe proper tracking history and why it is necessary
- Identify limitations in each of the three phases of stationary radar operation
- Define 'Doppler audio' and explain why it is useful
- Define the cosine effect and identify the effect it has on police traffic radar and lidar

Stationary Radar and Tracking History:

As seen in earlier chapters, while police traffic radar has made significant technological advances to limit the effects of interference and reduce the number of erroneous readings, they can and do still occur. In addition, target identification is an ongoing challenge. The radar cannot determine direction or distance to the target vehicle, and it cannot otherwise alert the operator as to which vehicle's speed is displayed in the target window. In heavy traffic, there could potentially be hundreds, if not thousands, of vehicles in the radar's beam at any one time. Despite digital signal processing, direction sensing capability, multiple antennas and automatic gain circuitry, the operator must still employ common sense and reliable techniques in order to properly identify the violator's vehicle and write reliable and trustworthy citations.

In addition to limiting the range of the radar beam as seen in Chapter 6, the primary way that an officer has to identify the correct vehicle is the tracking history. By using the following system of checks in every enforcement action, the radar operator can be reasonably certain that the speed reading obtained did, in fact, come from the vehicle stopped for the violation. Unfortunately, even when consistently using these techniques, there will be many instances where the operator is unable to determine with certainty which vehicle is the target vehicle in the radar. As such, **when there is any doubt regarding which vehicle is the target, TAKE NO ACTION.**

A good tracking history consists of the following:

V - Visual Estimation
A - Audio Tone
R - Radar Confirmation

The acronym 'VAR', or 'VARS' for moving radar (see Chapter 8), will help the operator remember the procedure for proper tracking history. A full and complete tracking history should be completed for every speed violation written using radar. If possible, multiple readings on both antennas (if so equipped) and notes on changes in speed, braking and other behavior should be noted, as well, even after the vehicle has passed the patrol unit. For each speed violation, the operator should ask themselves the following: "Is it likely that the vehicle I am observing would return the strongest radar signal?"

Visual Estimation:

The 'V' in the 'VAR' acronym stands for 'visual estimation'. An officer must be able to visually estimate and note a number of factors:

1) Vehicle speed
2) Vehicle distance
3) Vehicle position within the radar beam
4) Surrounding traffic conditions/types
5) Possible sources of interference

Visually Estimating Vehicle Speed:

In order to pass this course, students must be able to visually estimate the speed of vehicles within 5 mph of their actual speed as verified by time/distance, radar or lidar. While it sounds daunting, most people have an intuitive ability to estimate speeds. A child can watch approaching vehicles and accurately gauge whether or not it is safe to cross the street. All motorists must estimate the speed of approaching traffic in order to safely negotiate turns and merges. Numbers or mile-per-hour values are not typically associated with these estimates, but they are, in fact, speed estimates. With practice and guidance, officers simply refine this innate skill and gain the ability to assign miles-per-hour values to their estimates.

While there are many possible cues an officer might use to estimate speed, there are really only two reliable indicators: 1) increase or decrease in relative size over time and 2) distance covered over time (usually measured mentally, without the aid of a clock). Using other indicators can be problematic. For instance, if an officer notes a vehicle rapidly passing all other traffic, it is possible that traffic is slower than normal due to some other circumstance. Rapidly passing other traffic can be a reliable indicator that a vehicle is the one displayed in a radar's 'fast' window (if so equipped), but is unreliable as a visual estimation of a speed value. Optical illusions such as observing traffic rounding a curve can also alter an officer's perception of vehicle speed.

There really is no satisfactory formula or 'rule of thumb' for visually estimating speeds. It is a skill that simply takes experience and time. However, some suggestions are offered here.

- Utilize rudimentary time/distance techniques while observing traffic. For instance, delineator posts in Utah on flat, straight roadways are typically placed every 1/10th of a mile, or every 528 feet. (Note that this spacing changes on curves and ramps.) If an officer counts approximately 5 seconds for a vehicle to travel between one delineator post and the next, that vehicle is traveling approximately 70 mph:
    - (528 feet / 5 seconds = 105 fps ➡ 105/ 1.47 = 71 mph)
- In problem areas within an officer's jurisdiction, they might set up a patrol area and mentally estimate speeds by watching traffic pass between two landmarks (signposts, driveways, trees, etc.). By verifying these estimations with radar or lidar, visual estimations in specific areas of enforcement can be tightened.
- Comparing simultaneous traffic speeds between freeways and frontage roads can also give an officer a better idea of what urban/residential speeds 'look like' versus freeway speeds.

During the practical portion of this basic course, students are encouraged to get as much practice visually estimating the speeds of vehicles as possible, while verifying their estimations with the tools provided (radar, lidar and time/distance). Consistent practice is also necessary.

Visually Estimating Distance:

In order to help identify the target, radar operators must also visually estimate the distance to the target or suspected target vehicle. Remember: the distance from the antenna and the distance to the main power axis are two primary factors in determining which vehicle is the target vehicle. Also, operators must be prepared to explain how they know a particular vehicle was within the width of the radar beam at the time a reading was obtained (*Michigan v. Ferency, 1984*).

Once again, the surest way to develop this skill is simply practice and time. However, many of the same techniques above can be modified to assist the operator in estimating distances:

- **Delineator posts on flat, straight roadways are usually 528 feet apart.** This can give a reliable estimation of distance. For example, if an officer notes a radar reading while the apparent target vehicle is at least two delineator posts distant, the operator can be reasonably certain that the vehicle is at least 1000 feet away.
- **The average modern sedan is approximately 12-14 feet long.** This is also, mentally, a readily available 'yard stick' to the officer. For example, in the moving mode, estimating that a suspected target vehicle is 4 car lengths behind or ahead of the patrol vehicle, the operator can be reasonably certain that the vehicle is approximately 50 feet away.
- Likewise for distance from the main power axis, **most travel lanes are 12-15 feet wide**. By counting the number of lanes, the operator can get an idea of how 'offset' a vehicle is compared to the main power axis.

- In urban or residential areas, **most grid layouts in Utah have 8 city blocks to one mile**. This means that one city block is approximately 660 feet long and there are 2 city blocks in ¼ mile. This also provides a good unit to estimate distance and can readily be converted to a distance in feet or miles.
- In areas where such 'standardized' references are unavailable, the officer can measure the distance between landmarks using either a GPS unit, lidar distance function or the odometer on the patrol vehicle. These pre-measured landmarks can then aid the officer in estimating distances.

Visually Estimating the Vehicle Position in the Radar Beam:

As seen in earlier chapters, *in <u>most</u> circumstances*, the vehicle closest to the antenna and closest to the main power axis will be the target when size, shape or composition is not an issue. During the 'V' section of the tracking history, officers should also note the vehicle's position in the beam relative to other vehicles. A typical note seen in speed citations is: "the suspect vehicle was directly behind the patrol vehicle, closest to the rear antenna and within the main power axis." Keep in mind always the rule of thumb: "Would I expect this vehicle to return the strongest radar signal?"

Visual Notation of Surrounding Traffic and Possible Sources of Interference:

The last thing an officer must do visually is to note the severity and type of traffic at the time of the stop, and to note any possible sources of interference. Many uniform citations have specific areas for notation of 'light', 'moderate' or 'heavy' traffic. It is also advantageous for an operator to note, for instance, the presence of large vehicles. A motorcycle adjacent to a large tractor/trailer will likely <u>never</u> be the target vehicle, no matter how close the motorcycle gets. Noting the presence of the large vehicle can help an officer explain the lack of Doppler audio or why the vehicle never gave a reading as the 'target'.

Any power lines, weather conditions, traffic lights or other possible sources of interference should also be noted.

<u>Audio Tone</u>:

Most modern radar units are equipped with a feature known as 'Doppler audio'. **Doppler audio is a sound emitted by the radar to assist the operator in the identification of the target vehicle.** Only the target vehicle will have Doppler audio associated with it. There will be no tone for the vehicle in the 'fast' window, if the radar is so equipped.

The audio tone's pitch will normally be proportional to the relative speed of the target vehicle. Faster vehicles or larger relative speeds will produce a higher pitch and slower vehicles or lower relative speed will produce a lower pitch. Also, if a target changes speed while the tone is present, the pitch of the tone should match the change in speed. For example, if an operator is tracking a vehicle, hears the Doppler audio, and then sees the front bumper drop indicating hard braking, the Doppler audio pitch should lower in conjunction with the change in speed. In this way, operators can use Doppler audio to verify target vehicles and complete tracking histories without taking their eyes off the suspect vehicle.

Doppler audio tones are also dependent on the return signal strength. A weak return signal will ordinarily result in a scratchy, intermittent, static-filled or low-volume audio signal. A strong return signal, however, will result in a consistent, clear or higher-volume audio signal. This can also be useful during target identification. For instance, if an operator is watching a close, compact vehicle and the Doppler audio is scratchy or intermittent, the operator might look beyond the close vehicle to see if there is another vehicle causing the target reading. In so doing, the operator might see a distant tractor/trailer that is the more likely target vehicle. Additionally, most erroneous readings such as patrol speed capture and multi-path signal effect will not produce any Doppler audio. A radar reading without <u>any</u> audio, therefore, can alert the operator that there might be interference or some other issue.

Weak Doppler audio signals might be caused by a number of factors. For instance, if a vehicle is close to the antenna but offset by several lanes, it is likely returning radar energy from the 'zone of influence' (see Chapter 6) rather than the main power beam. Distance will also cause poor Doppler audio. As a vehicle approaches, the Doppler audio is likely to get stronger and clearer corresponding to a stronger return signal.

Used in conjunction with visual estimations of speed, distance and position in the radar beam, Doppler audio is a great tool for the operator in identifying a target vehicle. A typical tracking history up to this point might go as follows: "Tan passenger car in the #2 lane rounded the corner at an apparent high rate of speed. Visual estimate of speed was 60 mph in a 40 mph zone. Estimated distance of 700 feet. Surrounding traffic was light, wooded area, no power lines or street lights. Line of sight was uninterrupted. One other red sports car present, much closer to the patrol vehicle. Doppler audio was strong, but likely corresponded to the closer vehicle. Once the red vehicle passed the patrol car, the Doppler audio became scratchy and intermittent. The tan passenger car was now the closest to the rear antenna and was crossing the beam's axis. As the tan car approached, the Doppler audio became strong and clear. Visual estimation of speed was steady at 60 mph."

<u>Radar Confirmation</u>:

The last step in a complete tracking history is to verify the visual estimate of speed with the radar. Contrary to popular belief, speed citations in Utah are not radar or lidar citations. They are visual estimations of speed confirmed with radar or lidar. After an officer has successfully completed the visual and audio steps of the tracking history, the officer can then look at the radar and match the target speed displayed with their visual estimations. If the reading is significantly different than the visual estimation, it is possible that either the estimation was off or that the speed displayed does not correspond to the vehicle tracked. If there is any doubt as to the true speed of the vehicle, no enforcement action should be taken.

Continuing the example above, the tracking history may continue. "Radar reading at this point was 62 mph. The tan car was the only vehicle in the rear beam at this point. As the vehicle came within approximately 250 feet, the bumper dipped noticeably indicating braking. The speed slowed and visual estimate changed to approximately 35 mph in a 40 mph zone. The Doppler audio lowered in pitch at the same time. Radar reading changed to 39 mph in the target window. Radar was switched to front antenna as the vehicle passed the patrol car and a reading on the front antenna of 38 mph was obtained. The tan vehicle was one of approximately a dozen in the front beam, was the closest by 500 feet and was entering the beam's main power axis. Traffic stop initiated."

Stationary Radar Errors and the Cosine Effect:

As was seen earlier, modern radars are still susceptible to several problems that the operator must be aware of and mitigate as much as they can (refer to Chapter 5 for a review of these errors).

The Cosine Effect:

One stationary radar effect that is the result of the sheer physics involved is the '**Cosine Effect'**. This effect will be present in all radar and lidar measurements. Radar and lidar, both, have one inherent limitation that cannot be overcome with the current technology. Both technologies can accurately measure speed, but **can only measure the relative speed between the target and the observer.** In other words, radar and lidar measure **how fast a target vehicle is closing on or moving away from the patrol vehicle, not the vehicle's true, straight-line speed**. The relative speed of a target vehicle toward or away from the observer will never be the same as what is displayed on a speedometer unless the target is moving directly toward or directly away from the observer. In practice, this never happens. For the purposes of this program, the 'Cosine Effect' is defined as:

- **The difference between the speed relative to the observer and the target's true, straight-line speed as a result of an observation angle.**

It is critical to note that in stationary radar, the Cosine Effect will always result in a target speed on the radar that is *lower* than the vehicle's true speed. In other words, the Cosine Effect in stationary radar is always in the violator's favor. This can be seen intuitively. If someone observes a moving object at an angle, the observed object will always be traveling faster in a straight line than it will be toward or away from the observer. The shortest (and therefore *fastest*) path between two points is a straight line. Any relative speed that occurs off of that straight line will be slower than the true speed.

Compounding the advantage to the violator, most radars ‘truncate’, or round down, any decimal readings. This means that, for example, if a radar calculates a target speed of 84.99 mph, it will display 84 mph. It ignores completely anything after the decimal point. Both of these factors combine to produce consistently conservative speed measurements that give the benefit of the doubt to the violator.

Understanding the Cosine Effect Mathematically:

Although the officer will never be able to measure or demonstrate the following thought experiments in reality on any speed citation, understanding the concept is critical to understanding how radar and lidar function. In practical application, officers can observe the Cosine Effect on their radar not by doing the math, but by watching the target speed drop as the angle of observation to their target increases. Assuming the vantage point is good and the vehicle does not brake or slow due to the officer’s presence, all radar readings will drop as the angle of observation increases. At angles less than 5°, the Cosine Effect will be so minimal as to be negligible and easily ignored by the operator. Greater than 5°, however, the operators must understand that the target speed displayed could be significantly lower than the target’s true speed.

Mathematically, the Cosine Effect can be shown using simplified trigonometry. Indeed, the term ‘cosine’ is a trigonometric function related to the relationships between the angles and side lengths of right triangles. Specifically, ‘cosine’ refers to the ratio or relationship between the hypotenuse of a right triangle and the adjacent side. When the angle and adjacent side lengths are known, a simple formula can tell us what relative speed the radar will measure versus the true, straight-line speed of the target:

$$\mathbf{IS = TS \bullet Cos(\theta)}$$

Where:

IS = Indicated Speed (speed shown on the radar or relative speed between target/patrol car)

TS = True Speed of the target (straight-line speed or speed shown on target’s speedometer)

θ = The angle of observation/angle from main power axis to the target in degrees

Using this formula, one can see the Cosine Effect become more severe as the angle increases. The following examples use a constant target True Speed of 60 mph. Using the above formula for 0°, 5°, 15°, 30°, 45° and finally 90°, the students will see the relationship between the True Speed and the Indicated Speed as a function of the observation angle.

Example 1 (θ = 0°):

True Speed: 60 MPH

IS = TS • Cos(θ)

IS = 60 • Cos(0)

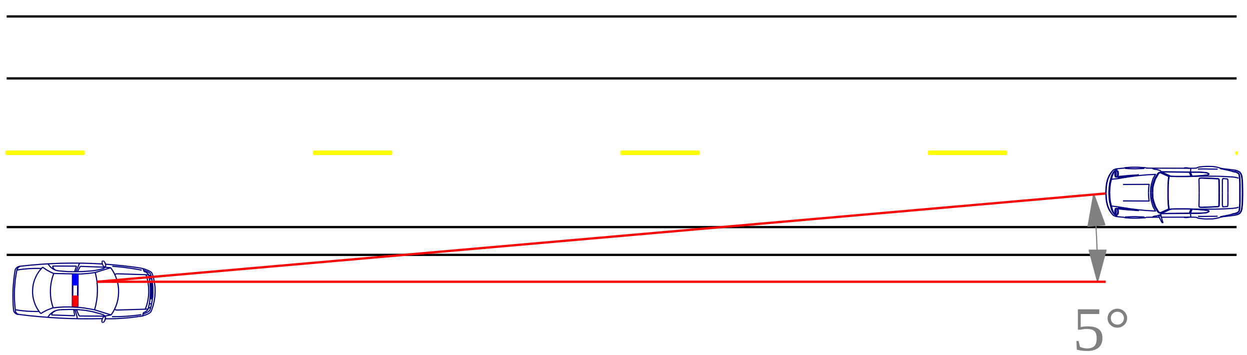
*Counterintuitively, the cosine of 0 = 1, not 0

IS = 60 • 1

IS = 60 MPH

In this example, we see the math in a scenario which would hopefully never occur. This example shows mathematically that when conditions are perfect, the radar will show the true speed, but not higher than the true speed.

Example 2 (θ = 5°):



True Speed: 60 MPH

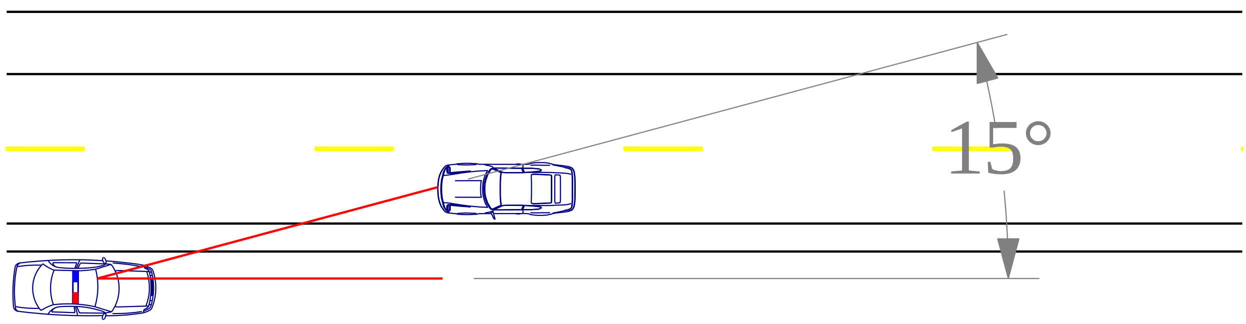
IS = TS • Cos(θ)

IS = 60 • Cos(5)

IS = 60 • 0.9962

IS = 59 MPH (truncated from 59.77 mph)

Example 3 (θ = 15°):



True Speed: 60 MPH

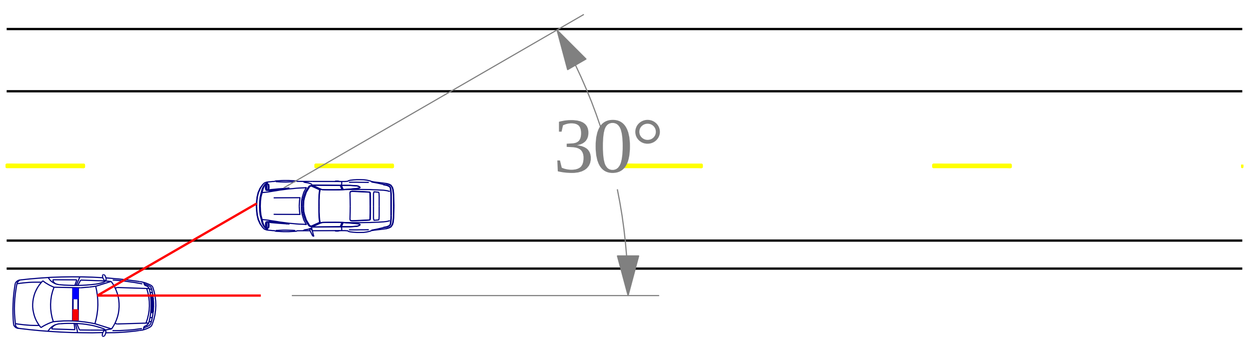
IS = TS • Cos(θ)

IS = 60 • Cos(15)

IS = 60 • 0.9659

IS = 57 mph (truncated from 57.96 mph)

Example 4 (θ = 30°):



True Speed: 60 mph

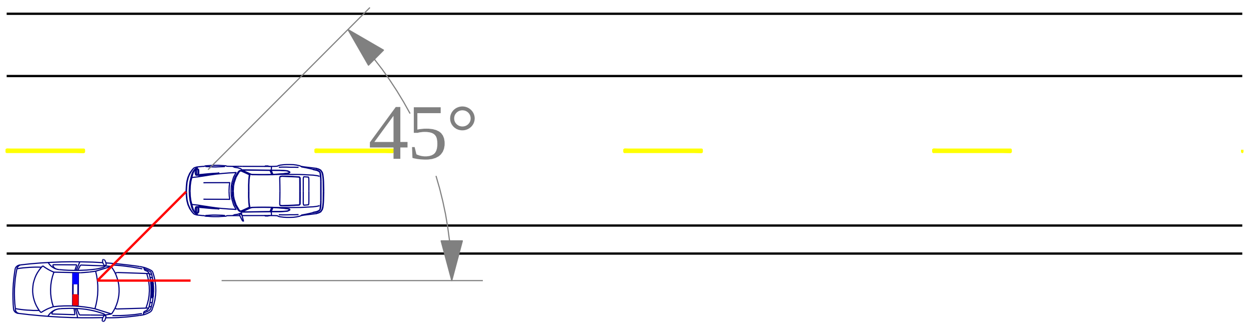
IS = TS • Cos(θ)

IS = 60 • Cos (30)

IS = 60 • 0.866

IS = 51 mph (truncated from 51.96)

Example 5 (θ = 45°):



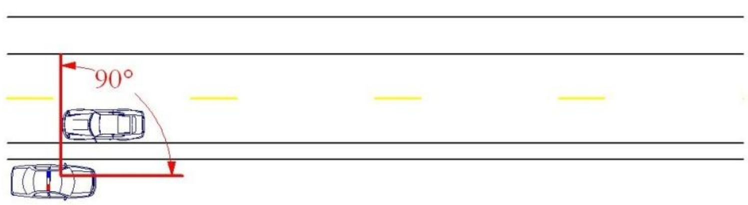
IS = TS • Cos(θ)

IS = 60 • Cos(45)

IS = 60 • 0.7071

IS = 42 mph (truncated from 42.43 mph)

Example 6 (θ = 90°):



IS = TS • Cos(θ)

IS = 60 • Cos(90)

IS = 60 • 0

IS = 0

From Example 6, we can see the Cosine Effect intuitively, again. If the target vehicle is directly adjacent to the patrol vehicle, the relative speed between them will be exactly 0. The target will not be moving toward, nor moving away from the observer, even though the true, straight-line speed has never changed from 60 mph.

Conclusion:

Effective speed enforcement using radar in the stationary mode requires the operator to complete a full tracking history, positively identify the target vehicle using that history and understand the possible limitation on the radar unit.

Consistently utilizing the 'VAR' method of tracking history will greatly reduce the chance of stopping the wrong vehicle. Practicing visual estimation techniques outside the classroom is critical. Doppler audio can aid the operator in identifying the target in a number of different ways. Operators should always ask themselves if the vehicle they're observing is likely to be the one returning the strongest Doppler shift.

By understanding both truncation and the Cosine Effect, operators can gain confidence that any tickets they write using stationary radar likely underestimate the violator's speed.

Chapter References:

1. UDOT Standard Drawing, GW 10.
URL: http://www.udot.utah.gov/main/uconowner.gf?n=5679945180118894992
2. Kustom DGE User's Manual
3. Kustom Eagle II User's Manual

Chapter 8: Moving Radar Operation and Potential Errors

Chapter Objectives:

- Identify proper procedure for moving radar operation
- Describe proper tracking history and why it is necessary
- Define 'Doppler audio' and explain why it is useful
- Define the double-cosine effect and identify the effect it can have on police traffic radar
- Define other common moving radar errors, such as shadowing & low-speed combining

Moving Radar and Tracking History:

Similar to what was discussed in the previous chapter on Stationary Radar, target identification can also be a challenge when operating a radar unit in moving mode. The radar unit cannot determine the angle or distance to the target vehicle, nor can it otherwise indicate to the operator which vehicle's speed is displayed in the target window. In heavy traffic, there could potentially be hundreds, if not thousands, of vehicles in the radar's beam at any moment. Despite digital signal processing, direction sensing capability, multiple antennas and automatic gain circuitry, the operator must employ common sense and reliable techniques in order to properly identify which vehicle is shown on the radar's display.

In Chapter 7, Stationary Radar, the concept of a tracking history was introduced. Tracking history should also be employed when using a radar unit in moving mode. By using the following system of checks in every speed-enforcement stop, the radar operator can be reasonably certain that the speed reading obtained did in fact come from the vehicle stopped for the violation. Unfortunately, even when consistently using these techniques, there will be many instances where the operator is unable to determine with certainty which vehicle is the target vehicle in the radar. As such, **when there is any doubt regarding which vehicle is the target, TAKE NO ACTION.**

A good tracking history with a radar unit in moving mode consists of the following:

V - Visual Estimation
A - Audio Tone
R - Radar Confirmation
S - Speedometer Check

The acronym 'VARS' will help the operator remember the procedure for proper tracking history. A full and complete tracking history should be completed for every speed violation written using radar. If possible, multiple readings on both antennas (if so equipped) and notes on changes in speed, braking and other behavior should be noted, as well, even after the vehicle has passed the patrol unit.

<u>Visual Estimation</u>:

The 'V' in the 'VARS' acronym stands for 'visual estimation.' An officer must be able to visually estimate and note a number of factors:

1) Vehicle speed
2) Vehicle distance
3) Vehicle position within the radar beam
4) Surrounding traffic conditions/types
5) Possible sources of interference

Visually Estimating Vehicle Speed:

In order to pass this course, students must be able to visually estimate the speed of vehicles within 5 mph of their actual speed as verified by time/distance, radar or lidar. While it sounds daunting, most people have an intuitive ability to estimate speeds. A child can watch approaching vehicles and accurately gauge whether or not it is safe to cross the street. All motorists must estimate the speed of approaching traffic in order to safely negotiate turns and merges. Numbers or mile-per-hour values are not typically associated with these estimates, but they are, in fact, speed estimates. With practice and guidance, officers simply refine this innate skill and gain the ability to assign miles-per-hour values to their visual estimates.

While there are many possible cues an officer might use to estimate speed, there are really only two reliable indicators: 1) increase or decrease in relative size over time and 2) distance covered over time (usually measured mentally, without the aid of a clock). Using other indicators can be problematic. For instance, if an officer notes one vehicle rapidly passing all other traffic, it is possible that the other traffic is traveling slower than the posted speed limit due to some unusual circumstance. Auditory cues, such as high engine RPM, may simply indicate a lower than normal gear setting. Visual cues, such as bouncing suspension or unusual lean in a curve, might simply indicate faulty equipment. Optical illusions such as observing traffic rounding a curve can also alter an officer's perception of vehicle speed.

There really is no satisfactory formula or 'rule of thumb' for visually estimating speeds. It is a skill that simply takes experience and time. However, some suggestions are offered here.

- Utilize rudimentary time/distance techniques while observing traffic. For instance, delineator posts in Utah on flat, straight roadways are typically placed every $1/10^{th}$ of a mile, or every 528 feet. (Note that this spacing changes on curves and ramps.) If an officer counts approximately 5 seconds for a vehicle to travel between one delineator post and the next, that vehicle is traveling approximately 70 mph
  - (528 feet / 5 seconds = 105 fps ➡ 105/ 1.47 = 71 mph)
- In problem areas within an officer's jurisdiction, they might set up a patrol area and mentally estimate speeds by watching traffic pass between two landmarks (signposts, driveways, trees, etc.). By verifying these estimations with radar or lidar, visual estimations in specific areas of enforcement can be tightened.
- Comparing simultaneous traffic speeds between freeways and frontage roads can also give an officer a better idea of what urban/residential speeds 'look like' versus freeway speeds.

During the practical portion of this basic course, students are encouraged to get as much practice visually estimating the speeds of vehicles as possible, while verifying their estimations with the tools provided (radar, lidar and time/distance). Consistent practice is also necessary.

Visually Estimating Vehicle's Distance:

In order to help identify the target vehicle, radar operators must also visually estimate the distance to the target vehicle. Remember: both the distance from the antenna and the distance to the main power axis are two primary factors in determining which vehicle will return the strongest radar signal and appear on the "main target" window of the display. The other factors are the size, shape, and composition of the target vehicle and other surrounding vehicles.

Once again, the surest way to develop this skill is simply practice and time. However, many of the same techniques above can be modified to assist the operator in estimating distances:

- **Delineator posts on flat, straight roadways are usually 528 feet apart.** This can give a reliable estimation of distance. For example, if an officer notes a radar reading while the apparent target vehicle is at least two delineator posts distant, the operator can be reasonably certain that the vehicle is at least 1000 feet away.
- **The average modern sedan is approximately 12-14 feet long.** This is also, mentally, a readily available 'yard stick' to the officer. For example, in the moving mode, estimating that a suspected target vehicle is 4 car lengths behind or ahead of the patrol vehicle, the operator can be reasonably certain that the vehicle is approximately 50 feet away.
- Likewise for distance from the main power axis, **most travel lanes are 12-15 feet wide**. By counting the number of lanes, the operator can get an idea of how 'offset' a vehicle is compared to the main power axis.

- In urban or residential areas, **most grid layouts in Utah have 8 city blocks to one mile**. This means that one city block is approximately 660 feet long and there are 2 city blocks in ¼ mile. This also provides a good unit to estimate distance and can readily be converted to a distance in feet or miles.
- In areas where such 'standardized' references are unavailable, the officer can measure the distance between landmarks using either a GPS unit, lidar distance function or the odometer on the patrol vehicle. These pre-measured landmarks can then aid the officer in estimating distances.

Radar operators must be prepared to explain how they know a particular vehicle was within the width of the radar beam at the time a reading was obtained (*Michigan v. Ferency, 1984*). In the Stationary Radar chapter, we discussed how to calculate beam width at specific distances. The visual estimation of target distance is key to determining the radar's beam width, which in turn helps establish if the target vehicle was capable of registering on the radar's display.

Visually Estimating the Target Vehicle's Position in the Radar Beam and Expected Radar Signal Strength:

As seen in earlier chapters, *in <u>most</u> circumstances*, the vehicle closest to the antenna and closest to the main power axis will return the strongest signal when size, shape or composition are not an issue. Therefore, officers should note the suspect's vehicle's position in the radar beam relative to other vehicles. Always keep in mind the rule of thumb: "Would I expect this vehicle to return the strongest radar signal and thus appear in the "main target" window on the radar's display?" In a case where the officer expects the target vehicle to return the strongest signal, a typical observation note for a speed citation may be:

> "The suspect vehicle was directly behind the patrol car, closest to the rear antenna and on the main power axis."

If the radar unit is equipped with a "fastest vehicle" setting and the operator does not believe the radar would return the strongest signal, they should look for the speed to register in the "fastest vehicle" window on the radar display. For example, no matter how close the motorcycle gets, when it is adjacent to a large tractor/trailer, it will likely <u>never</u> be the vehicle which returns the strongest signal. A radar operator would expect that the motorcycle in this situation would not appear in the "main target" window in the radar's display, but would rather appear in the "fastest vehicle" window. In this case, a typical observation note for a speed citation may be: "the suspect vehicle (a motorcycle) was in the left lane, passing a row of semi-trucks." Target vehicle size in relation to surrounding traffic should also be recorded in the citation notes. Remember, when dealing with the "fastest vehicle" setting, for most radar units only the strongest signal is translated into a Doppler audio.

Visual Notation of Surrounding Traffic and Possible Sources of Interference:

Regarding visual observations, the last thing an officer must do is to note the quantity and type of traffic and any possible sources of interference at the time the radar reading was obtained. Many citations have specific areas for notation of 'light', 'moderate' or 'heavy' traffic.

Power lines, inclement weather conditions, or other possible sources of interference should also be noted.

Audio Tone:

The "A" in the VARS acronym stands for Audio Tone. Most modern radar units are equipped with a feature known as 'Doppler audio'. **Doppler audio is a sound emitted by the radar to assist the operator in the identification of the target vehicle.** Only the strongest radar signal will have Doppler audio associated with it. There will be no tone for the "fastest vehicle" window, if the radar is so equipped.

The audio tone's pitch will normally be proportional to the relative speed of the target vehicle. Faster vehicles will produce a higher pitch and slower vehicles will produce a lower pitch. When a target vehicle changes speed while the tone is present, the pitch of the tone should match the change in speed. For example, if an operator is tracking a vehicle, hears the Doppler audio, and then sees watches as the vehicle brakes abruptly, the Doppler audio pitch should drop. This way, operators can use Doppler audio to verify target vehicles and complete tracking histories without taking their eyes off the suspect vehicle.

Doppler audio tones are also dependent on the return signal strength. A weak return signal will ordinarily result in a scratchy, intermittent, staticky, or low-volume audio signal. A strong return signal, however, will result in a consistent, clear, or higher-volume audio signal. This can also be useful during target identification. For instance, if an operator is watching a close, compact vehicle and the Doppler audio is scratchy or intermittent, the operator might look beyond the close vehicle to see if there is another vehicle causing the target reading. In so doing, the operator might see a distant tractor/trailer that is the more likely vehicle registering on the radar.

Weak Doppler audio signals might be caused by a number of factors. For instance, if a vehicle is close to the antenna but offset by several lanes, it is likely returning radar energy from the 'zone of influence' (see Chapter 6) rather than the main power beam. Distance will also cause poor Doppler audio. As a vehicle draws closer to the radar antenna, the Doppler audio is likely to get stronger and clearer, corresponding to a stronger return signal.

Used in conjunction with visual estimations of speed, distance, and position in the radar beam, Doppler audio is an excellent tool for the operator in identifying a target vehicle. A typical tracking history up to this point might read as follows:

> "Tan passenger car in the #2 lane rounded the corner at an apparent high rate of speed. Visual estimate of speed was 60 mph in a 40 mph zone. Estimated distance of 700 feet. Surrounding traffic was light, wooded area, no power lines or street lights. Line of sight was uninterrupted. One other red sports car present, much closer to the patrol vehicle. Doppler audio was strong, but likely corresponded to the closer vehicle. Once the red vehicle passed the patrol car, the Doppler audio became scratchy and intermittent. The tan passenger car was now the closest to the rear antenna and was crossing the beam's axis. As the tan car approached, the Doppler audio became strong and clear. Visual estimation of speed was steady at 60 mph."

Radar Confirmation:

The "R" in the VARS acronym stands for Radar Confirmation. This is verifying the visual estimate of speed with the radar's displayed reading. Contrary to popular belief, speed citations in Utah are <u>not</u> radar or lidar citations. They are visual estimations of speed <u>confirmed</u> with radar or lidar. Once an officer has successfully completed the visual and audio steps of the tracking history, the officer can then look at the radar and match the target speed displayed with their visual estimations. If the reading is more than five (5) miles per hour different than the visual estimation, it is possible that either the estimation was off or that the speed displayed on the radar does not correspond to the vehicle the officer was tracking. If there is <u>any</u> doubt as to the true speed of the vehicle, no enforcement action should be taken.

Continuing the example above, the tracking history notes may read:

> "Radar reading at this point was 62 mph. The tan car was the only vehicle in the rear beam at this point. As the vehicle came within approximately 250 feet, the front bumper dipped noticeably, indicating braking. The speed slowed and visual estimate changed to approximately 35 mph in a 40 mph zone. The Doppler audio lowered in pitch at the same time. Radar reading changed to 39 mph in the target window. Radar was switched to front antenna as the vehicle passed the patrol car and a reading on the front antenna of 38 mph was obtained. The tan vehicle was one of approximately a dozen in the front beam, was the closest by 500 feet and was entering the beam's main power axis. Traffic stop initiated."

Speedometer Check:

Finally, the “S” in the VARS acronym stands for Speedometer Check. Here, the radar operator verifies the patrol car’s speedometer with the radar’s patrol speed reading. Any major discrepancy between the two will result in an erroneous reading in the target vehicle windows on the radar display. In these cases, no enforcement action should be taken until the problems with the indicated patrol speed have been corrected. Ways to resolve common patrol speed problems will be treated later in this chapter.

Chapter 3, Non-radar Enforcement of Speed Limits, explained how to determine the accuracy of a patrol car’s speedometer. While the speedometer should ideally display the exact speed, it may be unrealistic to expect 100% accuracy. As long as the officer is aware of a minor variance between the patrol car’s true speed and the speedometer’s indicated speed, it should not be an issue for a proper tracking history.

For example, suppose an officer has determined that when he is traveling 58 mph according to his speedometer, his true speed is 60 mph. When he completes the “S” or speedometer check portion of VARS as he is patrolling at 60 mph, he should expect that radar’s patrol speed should read 62 mph. The two mile variance between his true speed and speedometer indicated speed is already accounted for.

However, suppose that same officer is traveling at 60 mph by his speedometer yet the radar’s patrol speed window shows he is traveling at 40 mph. This much larger discrepancy is neither expected nor acceptable. In this case, the officer should not take enforcement action, but should attempt to identify the cause and resolve the problem with the indicated patrol speed.

Moving Radar Speed Calculation:

The radar uses a three-step process when in moving mode to determine the speed of a target vehicle.

1. The radar unit determines the patrol car’s speed. This value is known as Low Doppler.
2. The radar unit determines the relative speed between the patrol car and the target vehicle. This value is known as the High Doppler.
3. The radar either adds the Low Doppler to the High Doppler or subtracts the Low Doppler from the High Doppler to determine the target speed. Adding or subtracting is dependent upon target direction and position.

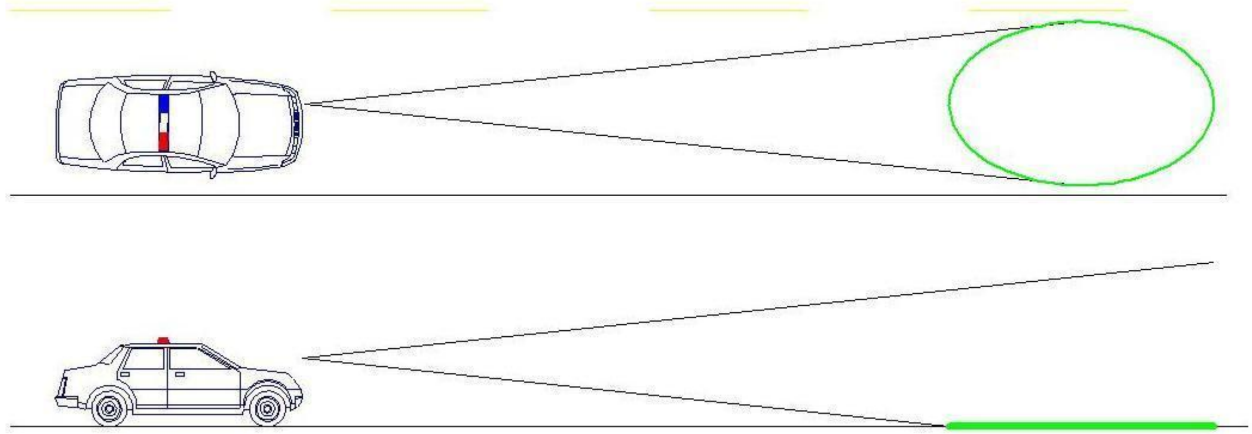
Patrol Speed or Low Doppler

As discussed in Chapter 6, The Radar Beam, the transmitted radar beam is conical in shape and extends infinitely into space until it is reflected, refracted, or absorbed. As this conical beam is transmitted, a portion of it impacts the ground a certain distance in front of the patrol car. If the radar antenna is mounted on the front dash or windshield of a patrol car approximately four feet above the ground and is perfectly level, it is fairly simple to calculate the point at which the transmitted radar energy impacts the ground. Using the formula **BW = 2 X D X Tan (1/2 angle)** presented in Chapter 6 and simple algebra, the point at which the radar beam from a 12 degree radar unit impacts the ground is about 38 feet in front of the radar antenna.

Police radar uses the Doppler Principle to measure relative speed between the target and the patrol car. Since the patrol car is in motion when the radar is used in moving mode and the ground is a stationary object, there is relative motion between the two. When the radar beam impacts the ground approximately 38 feet in front of the patrol car, a portion of the radar signal is reflected back towards the radar antenna. Given the relative motion between the ground and the patrol car, the radar signal that returns to the antenna is Doppler shifted. Based on the amount of Doppler shift, the radar calculates the relative motion between the patrol car and the ground. This information is translated into the patrol speed, displayed on the radar's display in miles per hour. Due to the close proximity of this portion of the ground to the radar antenna, the radar energy strikes the ground and returns to the antenna in a fraction of a second. Normally, this is the first signal which returns to the radar antenna. The portion of the ground impacted by the radar beam is called the "Hot Spot."

Whenever the patrol car uses the front antenna, the radar signal returning from the "Hot Spot" is always compressed and returned at a higher frequency. This is because the radar antenna is moving towards the "Hot Spot." Whenever the patrol car uses the rear antenna, the returning radar signal is always stretched and returned at a lower frequency. This is because the radar antenna is moving away from the "Hot Spot."

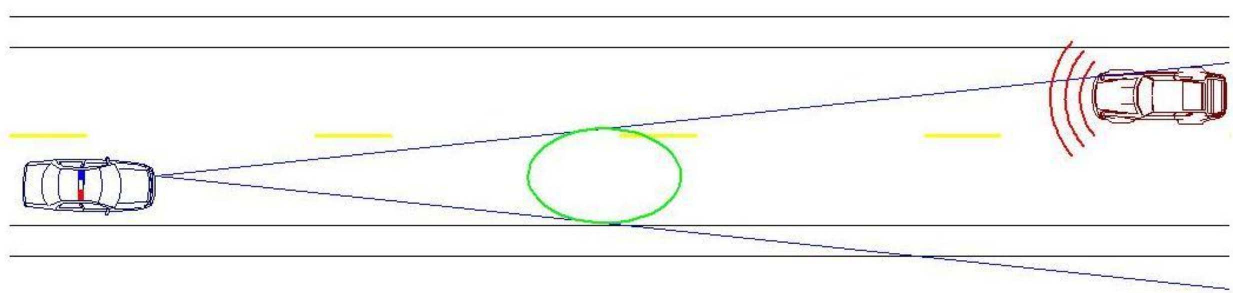
Below is a basic representation of the radar beam transmitting from the antenna and impacting the ground on the "Hot Spot," highlighted as a green oval and a green line.



Relative Speed or High Doppler

As the radar beam continues past the “Hot Spot,” another portion of the radar beam will impact the target vehicle. If the target vehicle is in motion, the radar energy is Doppler shifted at a different rate than the Doppler shift from the ground. The amount of Doppler shift is measured and the radar calculates the relative motion or relative speed between the target vehicle and the patrol car in miles per hour. This is termed the High Doppler.

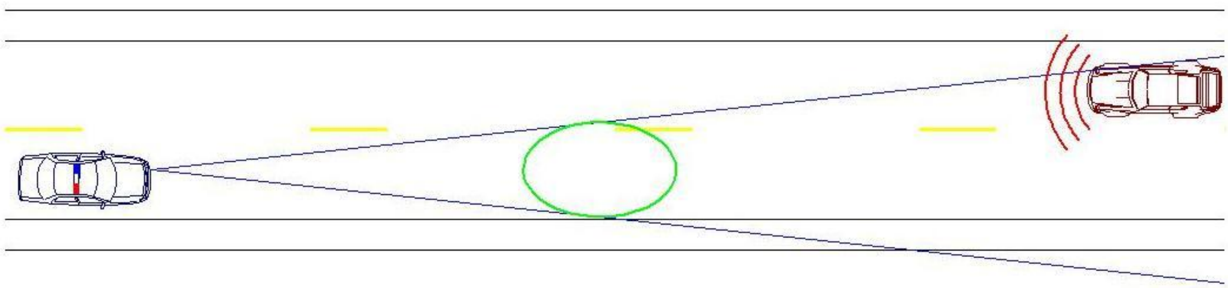
Below is a basic representation of the radar beam transmitting from the antenna and impacting the target vehicle, shown as the red waves in front of the car on the right.



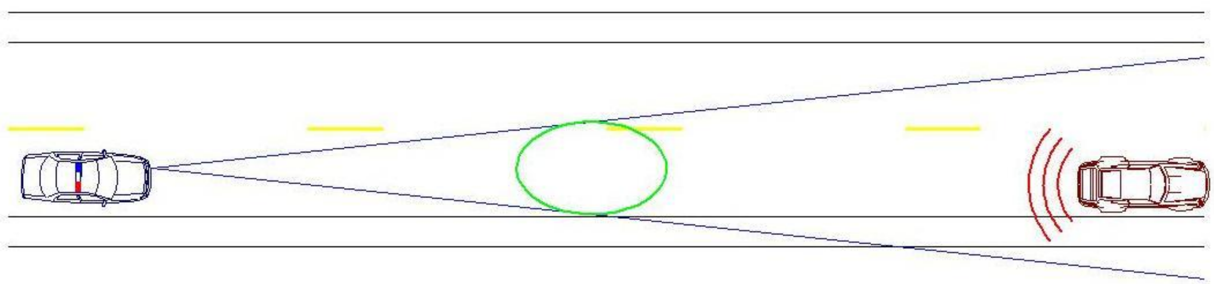
Note that the “Hot Spot” is significantly closer to the patrol car than the target vehicle. For this reason, it takes a less time for the radar energy to travel from the antenna to the “Hot Spot,” impact the ground, and return to the antenna than it takes for the radar energy to travel to the target vehicle, impact, and return to the antenna. The radar counting unit relies on this difference to determine which Doppler shifted signal is the Low Doppler and which is the High Doppler.

Final Target Speed Calculation

Once the radar has determined both the Low and High Dopplers, it adds or subtracts the values depending upon the target location (front or rear antenna) and direction (closing upon or moving away from the patrol car).



In the diagram directly above, suppose the Low Doppler value was 60, which would mean the patrol car would be moving at 60 mph. Suppose the High Doppler value was 140, which would mean the relative speed between the two vehicles would be 140 mph. In this instance, since the two vehicles are moving towards each other, the Low Doppler would be subtracted from the High Doppler (140 – 60), resulting in a target speed of 80 mph. This would be displayed on the radar in the target window.



In the diagram directly above, suppose the Low Doppler value was 60, which would mean the patrol car would be moving at 60 mph. Suppose the High Doppler value was 20, which would mean the relative speed between the two vehicles would be 20 mph. If the target vehicle were traveling faster than the patrol car, the target would be moving away from the patrol car. In this instance, the Low Doppler would be added to the High Doppler (60 + 20), resulting in a target speed of 80 mph. This would be displayed on the radar in the target window. The radar would determine that the target vehicle was traveling faster due to the stretched, lower frequency Doppler shift returning from the target vehicle.

However, using the same diagram, if the target vehicle were traveling slower than the patrol car, the distance between the two would be decreasing and the patrol car would be gaining on the target vehicle. The Doppler shift returning from the target vehicle would be compressed and a higher frequency. In this case, the High Doppler value of 20 would be subtracted from the Low Doppler value of 60 (60 – 20), resulting in a target speed display of 40 mph.

<u>Moving Radar Errors</u>:

The previous chapter, Stationary Radar, explained how the Cosine Effect and radar truncation (rounding down) will always result in a displayed speed that is lower than the target vehicle's true speed. This is not the case with moving radar. With both the Double-Cosine Effect and Shadowing errors, it is possible for the radar to display a target speed which is erroneously faster than what the target is actually traveling. However, proper adherence to the VARS acronym should prevent the officer from making an improper speed enforcement stop.

The Double-Cosine Effect:

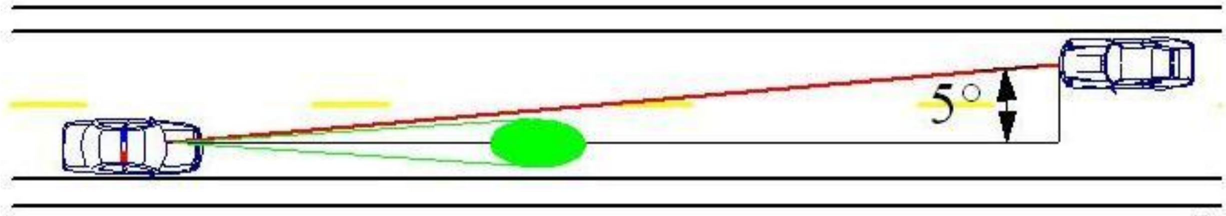
In moving mode, both the Low Doppler and High Doppler can be subject to the Cosine Effect. When both are affected, it is termed the Double-Cosine Effect. This is particularly problematic to law enforcement officers since it can result in a radar-displayed speed which is higher than what the target is actually traveling. To minimize the potential for this error, the radar operator should ensure that both the front antenna and rear antenna are in-line with the patrol car (pointed straight ahead or straight behind) and **<u>not</u>** angled off to the side. The antennas should also be tilted slightly down towards the ground to better capture the Low Doppler.

What follows are a series of examples that illustrate how the Low and High Doppler are affected by the Cosine and Double-Cosine Effects. In all the examples, the patrol car is traveling at 60 mph and using the front antenna. The target vehicle is approaching from the opposite direction and is traveling at 75 mph. In these examples, the Low Doppler value is subtracted from the High Doppler value to yield the target vehicle speed. To calculate the amount of error resulting from the Double-Cosine Effect, follow these four steps:

1. Calculate the relative speed between the target and patrol car
2. Adjust the relative speed for any cosine error. This number becomes the High Doppler.
3. Adjust the patrol speed for any cosine error. This number becomes the Low Doppler.
4. Subtract the Low Doppler from the High Doppler to obtain the indicated target speed shown on the radar display.

The Double-Cosine Effect – High Doppler Error:

<u>Example #1</u>



In Example #1, the patrol car's front radar antenna is pointed straight ahead and the resulting angle between the "Hot Spot" and the radar antenna is zero degrees (0°). The target vehicle is approaching at an angle of five degrees (5°). The patrol car is traveling at 60 mph and the target vehicle is traveling at 75 mph.

1. *Calculate the relative speed between the target and patrol car*
   If the patrol car is traveling at 60 mph and the target vehicle is traveling towards the patrol car at 75 mph, then the two speeds are added.

$$Patrol\ Speed + Target\ Speed = Relative\ Speed$$
$$60 + 75 = 135$$

2. *Adjust the relative speed for any cosine error. This number becomes the High Doppler.*
   If the two vehicles are approaching at a five degree (5°) angle, then the relative speed is adjusted for a five degree (5°) cosine error.

$$Adjusted\ Relative\ Speed = Relative\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Relative\ Speed = 135\ \times Cos\ 5$$
$$Adjusted\ Relative\ Speed = 135\ \times 0.996$$
$$Adjusted\ Relative\ Speed = 134.48$$
$$High\ Doppler = 134$$

3. *Adjust the patrol speed for any cosine error. This number becomes the Low Doppler.*
   Since the front radar antenna is pointed straight ahead (and tilted slightly down to better capture the Low Doppler), the resulting angle is zero degrees (0°).

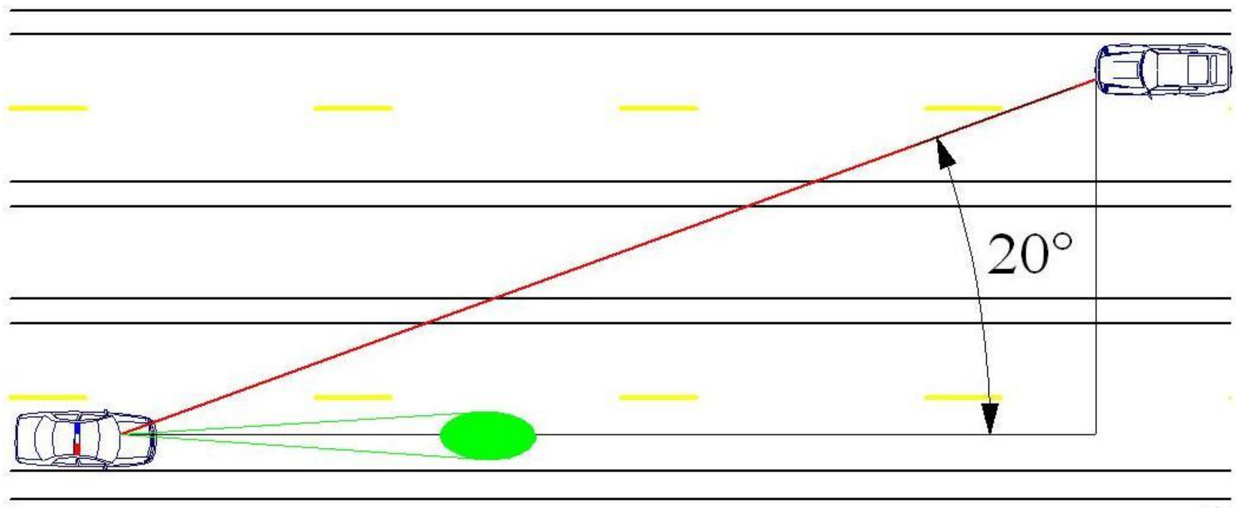
$$Adjusted\ Patrol\ Speed = Patrol\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Patrol\ Speed = 60\ \times Cos\ 0$$
$$Adjusted\ Patrol\ Speed = 60\ \times 1$$
$$Adjusted\ Patrol\ Speed = 60$$
$$Low\ Doppler = 60$$

4. *Subtract the Low Doppler from the High Doppler to obtain the indicated target speed shown on the radar display.*

$$Indicated\ Target\ Speed = High\ Doppler - Low\ Doppler$$
$$Indicated\ Target\ Speed = 134 - 60$$
$$Indicated\ Target\ Speed = 74\ mph$$

Therefore, the radar would register that the target vehicle is traveling 74 mph. This is one (1) mph slower than what the target vehicle is actually traveling.

Example #2



In Example #2, the patrol car's front radar antenna is pointed straight ahead and the resulting angle between the "Hot Spot" and the radar antenna is zero degrees (0°). The target vehicle is approaching at an angle of 20 degrees (20°). The patrol car is traveling at 60 mph and the target vehicle is traveling at 75 mph.

1. *Calculate the relative speed between the target and patrol car*
   If the patrol car is traveling at 60 mph and the target vehicle is traveling towards the patrol car at 75 mph, then the two speeds are added.

$$Patrol\ Speed + Target\ Speed = Relative\ Speed$$
$$60 + 75 = 135$$

2. *Adjust the relative speed for any cosine error. This number becomes the High Doppler.*
   If the two vehicles are approaching at a 20 degree (20°) angle, then the relative speed is adjusted for a 20 degree (20°) cosine error.

$$Adjusted\ Relative\ Speed = Relative\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Relative\ Speed = 135\ \times Cos\ 20$$

$$Adjusted\ Relative\ Speed = 135\ \times 0.939$$
$$Adjusted\ Relative\ Speed = 126.85$$
$$High\ Doppler = 126$$

3. *Adjust the patrol speed for any cosine error. This number becomes the Low Doppler.*
   Since the front radar antenna is pointed straight ahead (and tilted slightly down to better capture the Low Doppler), the resulting angle is zero degrees (0°).

$$Adjusted\ Patrol\ Speed = Patrol\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Patrol\ Speed = 60\ \times Cos\ 0$$
$$Adjusted\ Patrol\ Speed = 60\ \times 1$$
$$Adjusted\ Patrol\ Speed = 60$$
$$Low\ Doppler = 60$$

4. *Subtract the Low Doppler from the High Doppler to obtain the indicated target speed shown on the radar display.*

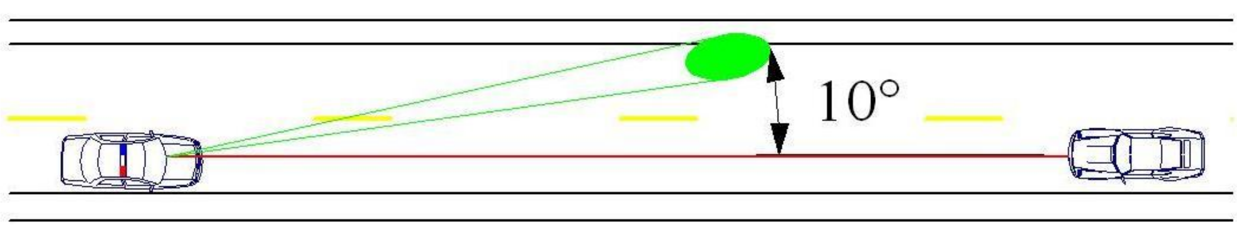
$$Indicated\ Target\ Speed = High\ Doppler - Low\ Doppler$$
$$Indicated\ Target\ Speed = 126 - 60$$
$$Indicated\ Target\ Speed = 66\ mph$$

Therefore, the radar would register that the target vehicle is traveling 66 mph. This is nine (9) mph slower than what the target vehicle is actually traveling.

In both Examples #1 and #2, the indicated target speed is less than what the target is actually traveling. As long as the radar antenna is properly mounted and directed (straight ahead or behind and pointed slightly downward), all moving radar readings should be lower than what the target is actually traveling.

The Double-Cosine Effect – Low Doppler Error:

<u>Example #3</u>



In Example #3, the patrol car's front radar antenna is pointed at a slight angle, resulting in the "Hot Spot" registering off to the side at a 10 degree (10°) angle. The target vehicle is approaching head-on at an angle of zero degrees (0°). The patrol car is traveling at 60 mph and the target vehicle is traveling at 75 mph. (Clearly, should this be a real-life example, the primary concern would be to avoid a head-on collision. However, for demonstrative purposes, this example simply shows the dangers of a Low Doppler cosine error.)

1. *Calculate the relative speed between the target and patrol car*
   If the patrol car is traveling at 60 mph and the target vehicle is traveling towards the patrol car at 75 mph, then the two speeds are added.

$$Patrol\ Speed + Target\ Speed = Relative\ Speed$$
$$60 + 75 = 135$$

2. *Adjust the relative speed for any cosine error. This number becomes the High Doppler.*
   If the two vehicles are approaching at a zero degree (0°) angle, then the relative speed is adjusted for a zero degree (0°) cosine error.

$$Adjusted\ Relative\ Speed = Relative\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Relative\ Speed = 135\ \times Cos\ 0$$
$$Adjusted\ Relative\ Speed = 135\ \times 1$$
$$Adjusted\ Relative\ Speed = 135$$
$$High\ Doppler = 135$$

3. *Adjust the patrol speed for any cosine error. This number becomes the Low Doppler.*
   Since the front radar antenna is angled slightly off to the side, the resulting angle is ten degrees (10°).

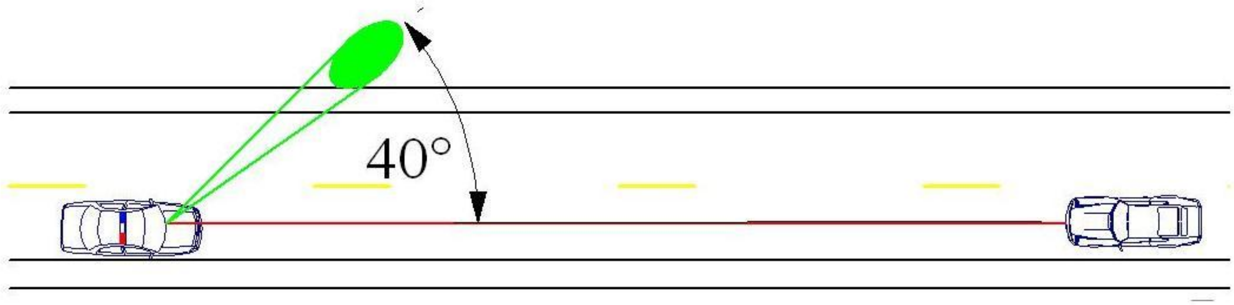
$$Adjusted\ Patrol\ Speed = Patrol\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Patrol\ Speed = 60\ \times Cos\ 10$$
$$Adjusted\ Patrol\ Speed = 60\ \times 0.984$$
$$Adjusted\ Patrol\ Speed = 59.08$$
$$Low\ Doppler = 59$$

4. *Subtract the Low Doppler from the High Doppler to obtain the indicated target speed shown on the radar display.*

$$Indicated\ Target\ Speed = High\ Doppler - Low\ Doppler$$
$$Indicated\ Target\ Speed = 135 - 59$$
$$Indicated\ Target\ Speed = 76\ mph$$

Therefore, the radar would register that the target vehicle is traveling 76 mph. This is one (1) mph faster than what the target vehicle is actually traveling.

Example #4



In Example #4, the patrol car's front radar antenna is pointed at a significant angle, resulting in the "Hot Spot" registering off to the side at a 40 degree (40°) angle. The target vehicle is approaching head-on at an angle of zero degrees (0°). The patrol car is traveling at 60 mph and the target vehicle is traveling at 75 mph. (Clearly, should this be a real-life example, the primary concern would be to avoid a head-on collision. However, for demonstrative purposes, this example simply shows the dangers of a Low Doppler cosine error.)

1. *Calculate the relative speed between the target and patrol car*
   If the patrol car is traveling at 60 mph and the target vehicle is traveling towards the patrol car at 75 mph, then the two speeds are added.

$$Patrol\ Speed + Target\ Speed = Relative\ Speed$$
$$60 + 75 = 135$$

2. *Adjust the relative speed for any cosine error. This number becomes the High Doppler.*
   If the two vehicles are approaching at a zero degree (0°) angle, then the relative speed is adjusted for a zero degree (0°) cosine error.

$$Adjusted\ Relative\ Speed = Relative\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Relative\ Speed = 135\ \times Cos\ 0$$
$$Adjusted\ Relative\ Speed = 135\ \times 1$$
$$Adjusted\ Relative\ Speed = 135$$
$$High\ Doppler = 135$$

3. *Adjust the patrol speed for any cosine error. This number becomes the Low Doppler.*
   Since the front radar antenna is angled slightly off to the side, the resulting angle is 40 degrees (40°).

$$Adjusted\ Patrol\ Speed = Patrol\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Patrol\ Speed = 60\ \times Cos\ 40$$
$$Adjusted\ Patrol\ Speed = 60\ \times 0.766$$

$$Adjusted\ Patrol\ Speed = 45.96$$
$$Low\ Doppler = 45$$

4. *Subtract the Low Doppler from the High Doppler to obtain the indicated target speed shown on the radar display.*

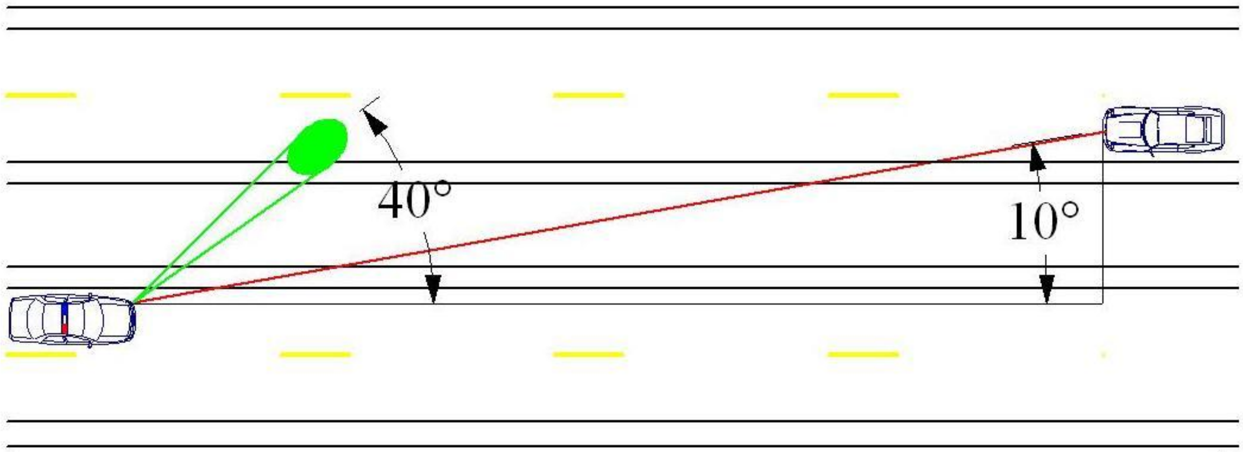
$$Indicated\ Target\ Speed = High\ Doppler - Low\ Doppler$$
$$Indicated\ Target\ Speed = 135 - 45$$
$$Indicated\ Target\ Speed = 90\ mph$$

Therefore, the radar would register that the target vehicle is traveling 90 mph. This is 15 mph faster than what the target vehicle is actually traveling.

In both Examples #3 and #4, the indicated target speed is greater than what the target is actually traveling. With the radar antenna angled off to the side even slightly, the resulting Low Doppler reading is less than what the patrol car's true speed. It is important to note that every mile per hour that "goes missing" from the patrol car's speed (Low Doppler reading) is added to the target vehicle's speed. In Example #3, the Low Doppler reading was one mile per hour less than the patrol car's true speed, resulting in a target speed one mile per hour faster than the target's true speed. Example #4, the Low Doppler reading was 15 miles per hour less than the patrol car's true speed, resulting in a target speed 15 miles per hour faster than the target's true speed.

The Double-Cosine Effect – High and Low Doppler Error:

<u>Example #5</u>



In Example #5, the patrol car's front radar antenna is pointed at a significant angle, resulting in the "Hot Spot" registering off to the side at a 40 degree (40°) angle. The target vehicle is approaching head-on at an angle of 10 degrees (10°). The patrol car is traveling at 60 mph and the target vehicle is traveling at 75 mph.

1. *Calculate the relative speed between the target and patrol car*
   If the patrol car is traveling at 60 mph and the target vehicle is traveling towards the patrol car at 75 mph, then the two speeds are added.

$$Patrol\ Speed + Target\ Speed = Relative\ Speed$$
$$60 + 75 = 135$$

2. *Adjust the relative speed for any cosine error. This number becomes the High Doppler.*
   If the two vehicles are approaching at a ten degree (10°) angle, then the relative speed is adjusted for a ten degree (10°) cosine error.

$$Adjusted\ Relative\ Speed = Relative\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Relative\ Speed = 135\ \times Cos\ 10$$
$$Adjusted\ Relative\ Speed = 135\ \times 0.984$$
$$Adjusted\ Relative\ Speed = 132.94$$
$$High\ Doppler = 132$$

3. *Adjust the patrol speed for any cosine error. This number becomes the Low Doppler.*
   Since the front radar antenna is angled slightly off to the side, the resulting angle is 40 degrees (40°).

$$Adjusted\ Patrol\ Speed = Patrol\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Patrol\ Speed = 60\ \times Cos\ 40$$
$$Adjusted\ Patrol\ Speed = 60\ \times 0.766$$
$$Adjusted\ Patrol\ Speed = 45.96$$
$$Low\ Doppler = 45$$

4. *Subtract the Low Doppler from the High Doppler to obtain the indicated target speed shown on the radar display.*

$$Indicated\ Target\ Speed = High\ Doppler - Low\ Doppler$$
$$Indicated\ Target\ Speed = 132 - 45$$
$$Indicated\ Target\ Speed = 87\ mph$$

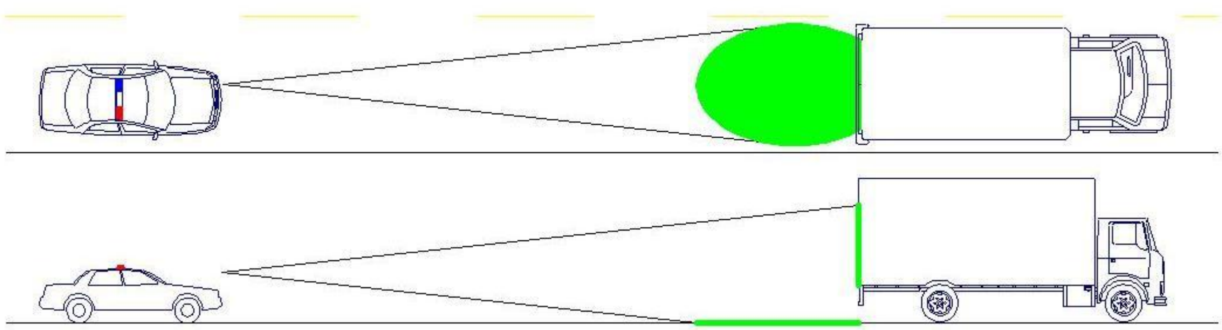
Therefore, the radar would register that the target vehicle is traveling 87 mph. This is 12 mph faster than what the target vehicle is actually traveling.

Examples #5 is more of a real life example of the dangers of twisting or angling the radar antenna off to one side. Though the Low Doppler error is slightly mitigated by the High Doppler error, the resulting radar reading is inaccurate and unreliable. Again, the indicated target speed is greater than what the target is actually traveling, resulting from the “lost” Low Doppler value being transferred to the target vehicle.

Through proper application of the acronym VARS, an officer would never make a speed enforcement stop in this situation. Using example #5, suppose the officer made a visual estimation (**V** in VARS) at about 70 mph for the target vehicle. When the officer activates the radar unit, the Doppler audio is clear and strong (**A** in VARS). When the officer looks at the radar, he noticed the radar display (**R** in VARS), he notices the radar reading is 17 mph off from the visual estimation. Finally, he checks the patrol speedometer against the radar indicated patrol speed (**S** in VARS), and notices the radar shows a patrol speed at 45 mph while his speedometer shows a patrol speed at 60 mph, a 15 mph discrepancy between the two. At that point, the officer disregards the radar reading and likely stops on the side of the road to readjust the mounting on the front radar antenna. It should be pointed straight ahead and tilted slightly down to better capture the true Low Doppler.

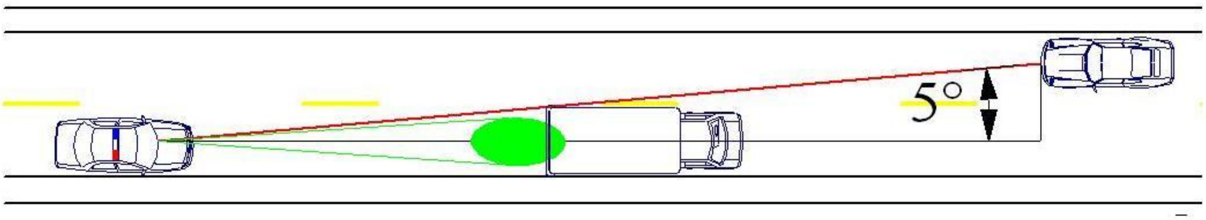
Shadowing Error:

Shadowing is the result of the radar unit using a large, slow moving vehicle to calculate the Low Doppler. With a minimal relative speed between the slow moving vehicle and the patrol car, the resultant Low Doppler reading is inaccurately lower than the patrol car’s true speed.



The above diagrams illustrate how traffic in front of the patrol car can interfere with the “Hot Spot.” In the top diagram, it appears that only a small portion of the “Hot Spot” is on the rear of the truck. However, considering the fact that the main power axis runs through the center of the radar beam, it would impact directly on the back of the truck. Therefore, the rear of the truck would reflect a much stronger signal than the road surface and it is highly likely that the radar would interpret this as the Low Doppler.

Example #6



In Example #6, the patrol car's front radar antenna is pointed straight ahead and the "Hot Spot" is on the back of the box truck directly in front of the patrol car. The target vehicle is approaching head-on at an angle of five degrees (5°). The patrol car is traveling at 60 mph, the box truck is traveling at 45 mph, and the target vehicle is traveling at 60 mph.

1. *Calculate the relative speed between the target and patrol car*
   If the patrol car is traveling at 60 mph and the target vehicle is traveling towards the patrol car at 60 mph, then the two speeds are added.

$$Patrol\ Speed + Target\ Speed = Relative\ Speed$$
$$60 + 60 = 120$$

2. *Adjust the relative speed for any cosine error. This number becomes the High Doppler.*
   If the two vehicles are approaching at a five degree (5°) angle, then the relative speed is adjusted for a five degree (5°) cosine error.

$$Adjusted\ Relative\ Speed = Relative\ Speed\ \times Cos\ \theta$$
$$Adjusted\ Relative\ Speed = 120\ \times Cos\ 5$$
$$Adjusted\ Relative\ Speed = 120\ \times 0.996$$
$$Adjusted\ Relative\ Speed = 119.54$$
$$High\ Doppler = 119$$

3. *Adjust the patrol speed for any Shadowing Error by determining the relative speed between the box truck and the patrol car. This number becomes the Low Doppler.*
   Since the patrol car is gaining on the box truck, the box truck's speed is subtracted from the patrol car's speed.

$$Adjusted\ Patrol\ Speed = Patrol\ Speed - Box\ Truck\ Speed$$
$$Adjusted\ Patrol\ Speed = 60 - 45$$
$$Adjusted\ Patrol\ Speed = 15$$

4. *Subtract the Low Doppler from the High Doppler to obtain the indicated target speed shown on the radar display.*

$$Indicated\ Target\ Speed = High\ Doppler - Low\ Doppler$$
$$Indicated\ Target\ Speed = 119 - 15$$
$$Indicated\ Target\ Speed = 114\ mph$$

Therefore, the radar would register that the target vehicle is traveling 114 mph. This is 54 mph faster than what the target vehicle is actually traveling.

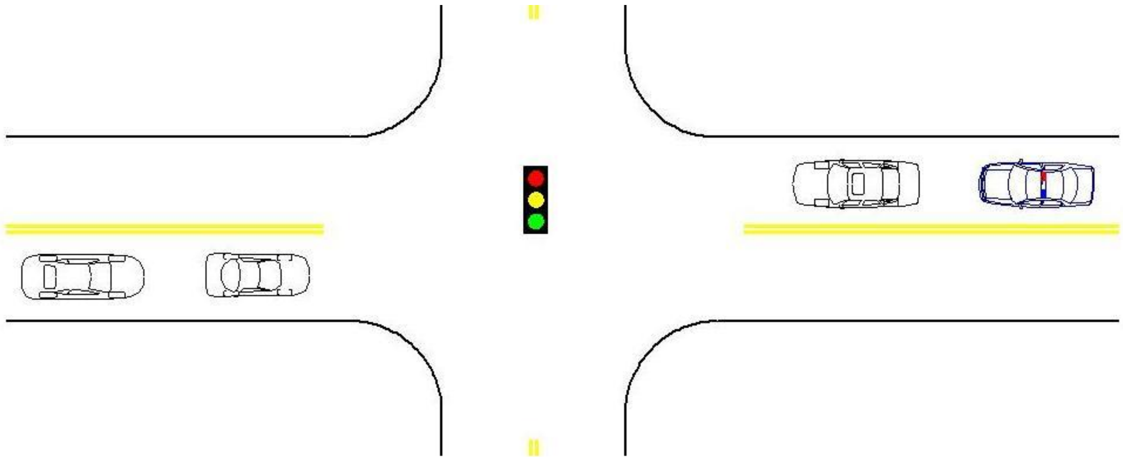
Through proper application of the acronym VARS, an officer would never make a speed enforcement stop in this situation. Using example #6, suppose the officer made a visual estimation (**V** in VARS) at about 65 mph for the target vehicle. When the officer activates the radar unit, the Doppler audio is clear and strong (**A** in VARS). However, the officer notes the pitch seems unusually high for a vehicle traveling at about 65 mph. When the officer looks at the radar, he noticed the radar display (**R** in VARS), he notices the radar reading is 54 mph off from the visual estimation. Finally, he checks the patrol speedometer against the radar indicated patrol speed (**S** in VARS), and notices the radar shows the patrol speed at 15 mph, while his speedometer shows the patrol speed at 15 mph, 45 mph discrepancy between the two. At that point, the officer recognizes he has a Shadowing Error.

In order to resolve the Shadowing Error the officer must do two things. First, he must move to a point where the “Hot Spot” is well away from the box truck and back onto the roadway in front of his patrol car. He can slow down and increase his following distance, change lanes, or pass the box truck. Second, the officer must cycle the radar to “reset” the Low Doppler. Some radar units will do this automatically while others require a manual reset. To perform a manual reset, the officer can power the radar unit off and then on again, press the Patrol Speed Blank button, switch from moving to stationary mode and back again, switch from front antenna to rear antenna and back again, or activate and then release the Hold feature, temporarily pausing the transmission of radar energy. The officer should then check and ensure that the speedometer matches the radar unit’s indicated patrol speed.

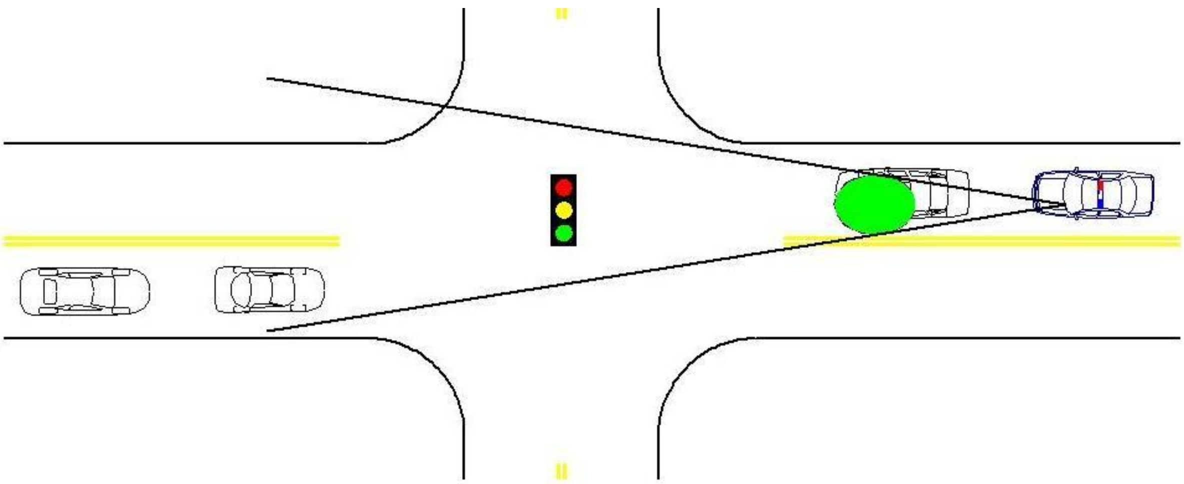
Low Speed Combining:

Low Speed Combining Error is similar to a Shadowing Error in that it involves a situation where the “Hot Spot” is not reading off the ground in front of the patrol car but rather off a vehicle in front of the patrol car. Low Speed Combining generally occurs at low speeds, in stop-and-go traffic, or when traffic is just beginning to flow at an intersection.

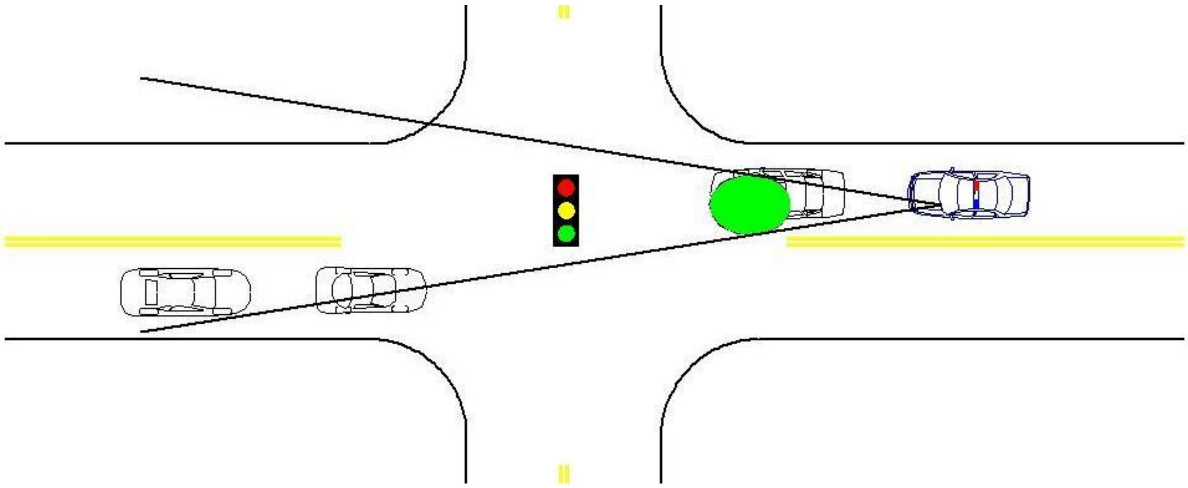
What follows are a series of four diagrams which illustrate how Low Speed Combining occurs. The diagram immediately below shows traffic stopped at a traffic light with a patrol car on the right side of the diagram, directly behind another vehicle.



As shown below, should the officer activate the radar antenna, the “Hot Spot” would appear on the rear of the vehicle in front of him and would not strike the ground.

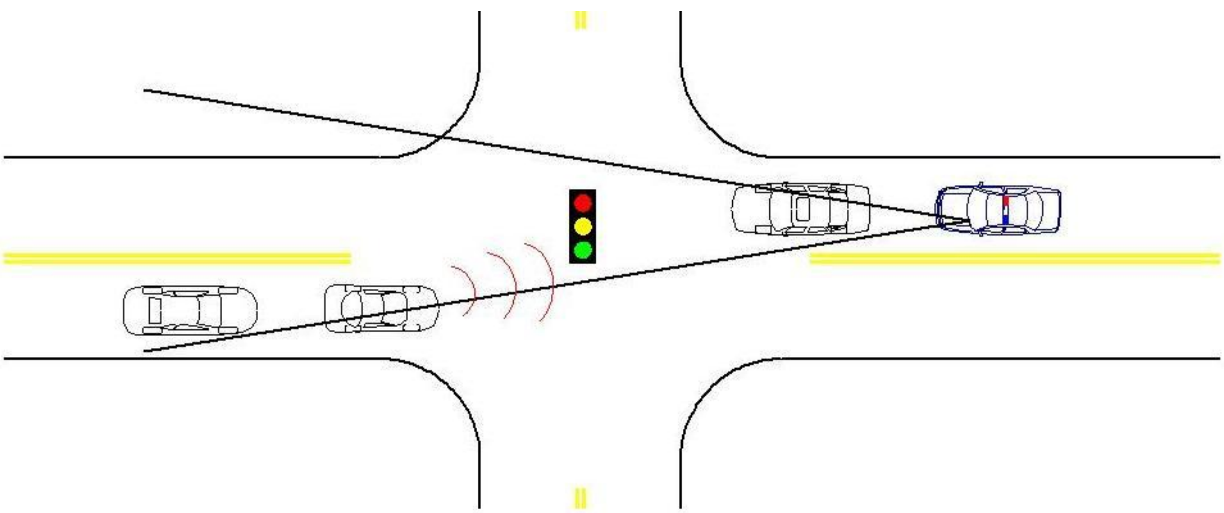


As the light turns green and traffic begins to flow, the relative distance between the patrol car and the vehicle in front of it remain fairly constant, as shown below.



Therefore, the relative speed between the patrol car and the vehicle in front of it is close to zero. With no relative speed between the two vehicles, there is no Doppler shift in the radar signal returning from the "Hot Spot" area. With no Doppler shift, the radar does not register the return signal.

As the radar beam continues outward, it strikes the vehicles approaching from the opposite direction, as shown below.



This is the first radar signal that returns to the radar antenna and, as the first signal, is interpreted by the radar to be the Patrol Speed. Given that the signal is Doppler shifted to the amount of both the patrol car's speed and the target's speed, their combined speeds appear in the Patrol Speed window of the radar unit's display. From this combination, we have the term, Low Speed Combining. Likely the first indicator would be the absence of a target speed in the radar unit's display, but the speedometer check (**S** in VARS) would also clearly indicate a problem with the radar reading.

Resolving the Low Speed Combining Error is nearly identical to resolving the Shadowing error. First, the officer must move to a point where the "Hot Spot" is well away from the vehicle in front of him and back onto the roadway in front of his patrol car. He can slow down and increase his following distance, change lanes, or pass the vehicle in front. Second, the officer must cycle the radar to "reset" the Low Doppler. Some radar units will do this automatically while others require a manual reset. To perform a manual reset, the officer can power the radar unit off and then on again, press the Patrol Speed Blank button, switch from moving to stationary mode and back again, switch from front antenna to rear antenna and back again, or activate and then release the Hold feature, temporarily pausing the transmission of radar energy. The officer should then check and ensure that the speedometer matches the radar unit's indicated patrol speed.

Weather Related Errors:

The radar unit relies upon the Low Doppler to accurately calculate the target speed when the radar is being used in moving mode. Anything that interferes with the Low Doppler signal will inhibit the radar unit's operating capability. The following conditions have the potential of interfering with the Low Doppler:

- Falling snow
- Rain
- Sleet
- Standing water
- Ice or snow-packed roads
- Rain, snow, or other obstructions on the windshield

To correct weather related errors, move to an area where the radar can receive a good Low Doppler signal. In all reality, in heavy inclement weather, most police officer will be obligated to handle a large volume of crashes and will have little time for speed enforcement.

Conclusion:

Effective speed enforcement using radar in the moving mode requires the operator to complete a full tracking history, positively identify the target vehicle using that history and understand the possible limitation on the radar unit. Consistently utilizing the 'VARS' method of tracking history will greatly reduce the chance of stopping the wrong vehicle or stopping a vehicle with an erroneous radar reading.

Chapter References:

4. UDOT Standard Drawing, GW 10.

URL: http://www.udot.utah.gov/main/uconowner.gf?n=567994518011894992

5. Kustom DGE User's Manual
6. Stalker DSR 2x Operator's Manual
7. Kustom Eagle II User's Manual

Chapter 9: Radar Maintenance, Installation and Testing

Chapter Objectives:

- Know the components of the radar
- Understand proper mounting/installation procedures
- Know interference sources and remedies
- Understand testing procedures for checking the accuracy of the radar

Most available radar systems consist of a dash-mounted display unit and a counting unit that can be mounted with the display unit, or separately using a remote cable option.

One or two antenna units, and a wireless or wired remote control unit. The radar system is powered from the 12-volt, vehicle power system using a power cable from the counting unit.

Each system component should be installed in a location that provides good operator visibility and convenience, but does not obscure the road or interfere with air bag operation.

Display/Counting Unit - To mount the combined display/counting units; connect the power cable (if cable is not hard wired to the unit) to the power jack on the back of the counting unit. Plug the front and/or rear antenna cables into the back of the counting unit. If using only one antenna, plug it into the desired (front or rear) jack. After attaching the mounting bracket to the selected mounting surface with Velcro or screws, insert the combined display/counting unit into the mount and secure with thumbscrews into the threaded holes located on each side of the counting unit.

Display Unit - To mount the display unit only, separate the counting unit from the display unit by unscrewing the two screws on the back panel. Connect the remote mount cable (if applicable), to the connector on the back of the display unit.

Attach the display unit to the mounting bracket using one thumbscrew on each side or attach directly to the dash. After mounting, make sure the display will not dislodge during high-speed maneuvers.

Counting Unit - To mount the counting unit separately from the display unit, select an out-of-the-way mounting location, such as under the dash or inside the console. Connect the power cable to the power jack located on the back of the counting unit (if applicable).

Plug the front and/or rear antenna cables into the back of the counting unit. If using only one antenna, plug it into the desired jack. Connect the remote mount cable to the connector on the front of the counting unit. Secure the mounting bracket on the counting unit to a suitable mounting surface with Velcro or screws. Install the counting unit into the bracket.

Antenna Unit - Before proceeding with the final installation, check the intended mounting locations for fan interference on both antennas. See the section on fan interference. Find a suitable location and attach the antenna mounting bracket to the selected mounting surface. Attach the antenna unit to the bracket. Connect the antenna cable to the antenna. Repeat these steps for the second antenna, if desired.

INTERFERENCE SOURCES AND REMEDIES

A variety of sources, both natural and man-made, can cause misleading indications or poor performance. The operator should note the symptoms described below, and take steps to avoid the problem, or ignore the misleading indications.

Vehicle Ignition Noise – Today's radar systems are typically designed to operate by simply plugging the supplied power cord into the vehicle's cigarette plug. Although rare, an extremely noisy vehicle electrical system may cause erratic operation. If this condition occurs, first eliminate possible causes such as a faulty vehicle battery or alternator. If the problem persists, it is recommended that a two conductor shielded cable be run directly from the vehicle battery to the cigarette lighter plug. This should eliminate any problems from vehicle electrical noise.

Fan Noise - Fan noise is a common Doppler radar problem when aiming the antenna through a window from inside the patrol vehicle. A small amount of the radar beam is reflected off the glass back into the vehicle. This may allow the radar to pick up fan noise from within the patrol vehicle. The problem is not a problem with the radar, but with the location of the radar's antenna. Doppler radar is designed to detect moving or vibrating objects; therefore, it may detect any moving or vibrating surfaces inside the patrol vehicle, such as the fan or a dashboard that is vibrating from the fan. Fan interference can be verified by turning off or changing the speed of the fan.

Most fans generate speeds of 30 mph or less. As a result, fan noise is normally only a problem when operating in stationary mode or when operating in moving mode with patrol speeds less than 30 mph.

To eliminate fan noise, try the following steps in order:

1. Find a location (by moving the antenna) inside the vehicle that is free of fan noise; such as a corner of the dash away from the fan. The lower left side of the dash is a recommended location.

2. Insure that the antenna beam is not deflected back into the vehicle by anything in its path such as wipers, window trim, or anything mounted on the dash. Do not mount the counting/display unit or antenna/power cables in front of the antenna on the dash.

3. Locate the antenna as close to the inside glass as possible (preferably less than 1/2 inch).

4. Turn the fan off while operating the radar in stationary mode or moving mode with patrol speed under 30 mph.

Power Supply - A low voltage condition from the vehicle's electrical system may cause the radar unit to indicate a low voltage condition and will inhibit speed readings. If the vehicle battery and charging system is functioning properly, the low voltage may be due to a loose or bad connection. Check all power plugs and connections.

No Power - If the radar does not have power, check the fuse in the power cable.

Unscrew the silver tip on the end of the cigarette plug and remove the fuse. If the fuse is blown, replace with a new fuse and test the radar.

If the power cable fuse is okay, check the fuse in the vehicle's fuse block or console fuse block that provides the power to the cigarette lighter or power cord supplying power to the radar unit.

If the fuse is okay, place the radar in a different vehicle or try a different radar in your vehicle.

TESTING

In order to ensure compliance with FCC rules, meet legal requirements for admissibility of radar speed measurements, and verify full operating performance, the following test procedures are recommended. If the unit fails any of the tests, it should be removed from service until the cause of the problem is corrected.

Periodic Calibration –It is recommended that the radar system be certified to meet the manufacturers' specifications in accordance with your departments' policies. Current Utah DPS recommendation is that radar/lidar units be tested by a qualified technician every three (3) years. The following performance characteristics should also be verified on a regular basis:

1. Unit indicates correct speed (± 1 mph) when reading a target of known speed.

2. Unit detects targets of good reflectivity over unobstructed, flat terrain at distances of 1/2 mile, or more, when set for highest sensitivity.

There are three tests that should be conducted at the beginning, end, and periodically throughout the shift. Those tests will be discussed in detail but are summarized as:

1. Light segment check
2. Internal circuitry check
3. Known speed check (tested against the patrol speedometer)

The following should be conducted once during the shift:

4. Tuning fork check –
    a. Front and Rear Antennas:
        i. Stationary Mode
        ii. Moving Mode

Power-On Self-Test - Each time a radar unit is powered on, an automatic self-test is performed to verify that the unit functions. The display illuminates all segments during the self-test. Check to make sure all segments illuminate properly. If a light segment is not functioning, do not use the radar and remove it from service. If an internal problem is detected, the radar system will indicate some type of failure has occurred. Check the manual for specific failure codes to help diagnose the problem if applicable.

A self-test can be performed at any time by pressing the TEST key. This performs a diagnostic check on the unit. Since some radar systems may only test the currently selected antenna, it may be necessary to perform this test twice -- once with the front antenna selected, and once with the rear antenna selected. After the system confirms that the self-test was successful, the radar may then enter “fork mode” that is used for the tuning fork tests (see tuning fork test section).

Tuning Fork Testing

The radar system may need to be put into a fork testing mode in order for the fork to be displayed by the radar system. This is especially true on systems with DSP (direction sensing).

Stationary mode

Two (2) tuning forks are supplied with a moving radar system, and a single fork with stationary radar. The tuning forks are labeled with the speed and band or frequency they are designed for. Make sure you have the appropriate forks for your radar system. DO NOT trade forks between radar units.

To perform the tuning fork test: press the moving/stationary key (moving radar systems) and select the stationary mode. Press the antenna key to select the front antenna, then press the transmit (xmit) key to enter transmit mode. If required, press the self test key and wait for the fork test indicator to show the system is in fork test mode.

Strike the tuning fork against a hard, nonmetallic surface, such as the heel of a shoe. Quickly hold the tuning fork approximately two (2) inches in front of the antenna, with the narrow edge of the fork facing the antenna. The target window should indicate the speed indicated on the fork +/- 1 mph

Repeat the above test with the second fork if applicable.

Select the rear antenna, if equipped, and repeat the tuning fork test.

The tuning fork test should be performed on each antenna. Some departments perform this test both before and after each citation, or before and after each shift. Check your department policy.

Moving mode – Opposite

Press the moving/stationary key and select the moving opposite mode. Press the antenna key to select the front antenna, and press the transmit (xmit) key to enter transmit mode. If required, press the self test key and wait for the fork test indicator to show the system is in fork test mode.

Strike both tuning forks against a hard nonmetallic surface, such as the heel of a shoe. Quickly hold the lower speed fork approximately two (2) inches in front of the antenna, with the narrow edge of the fork facing the antenna. The patrol window should indicate the fork +/- 1mph. Now move the higher speed fork in front of the antenna with the narrow edge facing the antenna. The target window should register the *difference* between the two fork speeds ± 2 mph.

Select the rear antenna, if equipped, and repeat the tuning fork test.

The tuning fork test should be performed on each antenna. Some departments perform this test both before and after each citation, or before and after each shift. Check your department policy.

Moving mode – Same Direction

Press the moving/stationary key and select the moving opposite mode. Press the antenna key to select the front antenna, and press the transmit (xmit) key to enter transmit mode. If required, press the self test key and wait for the fork test indicator to show the system is in fork test mode.

Strike both tuning forks against a hard nonmetallic surface, such as the heel of a shoe. Quickly hold the higher speed fork approximately two (2) inches in front of the antenna, with the narrow edge of the fork facing the antenna. The patrol window should indicate the fork +/- 1mph. Now move the lower speed fork in front of the antenna with the narrow edge facing the antenna. The target window should register the *sum* of the two fork speeds ± 2 mph.

Select the rear antenna, if equipped, and repeat the tuning fork tests.

The tuning fork test should be performed on each antenna. Some departments perform this test both before and after each citation, or before and after each shift. Check your department policy.

Directional Target Moving-Vehicle Test

A directional moving vehicle test can be performed as an additional check of performance and accuracy. To perform the moving vehicle test: select the front antenna, and the press the transmit (xmit) key to enter transmit mode. During this test you will need to repeatedly press the MOV/STA key to switch between stationary closing mode (SC) and stationary away mode (SA).

While driving a patrol vehicle, with an accurately calibrated speedometer, aim the front antenna down an empty highway directly in front of the vehicle. While moving, alternately switch between SC mode and SA mode. As you alternate between the two directional modes, verify that SC mode always shows an accurate approaching ground speed in the target window while SA mode always shows no speed in the target window. While in stationary closing (SC) mode, the moving roadway appears as an approaching target to the radar and will be seen in the target window but will not be seen when the radar is in the stationary away (SA) mode. If your radar system is equipped with a rear antenna, repeat the above tests with the rear antenna selected.

The speed indicated by your radar system should match the speedometer indication within a small error (depending on speedometer accuracy). This simple test verifies both accurate speed measurement and proper direction sensing operation. This test is optional and is not a substitute for the tuning fork test, but is a good overall indication of proper operation of the unit.

TROUBLESHOOTING:

Radar will not power on:

Make sure all cables are mated correctly with their connectors (including the main power cord!). Check the vehicle cigarette-plug connector for dirty contacts. Check for a blown fuse in the console or vehicle fuse box and cigarette-plug.

Low or no speaker volume:

Press the key on the remote control to adjust the volume. Aud 1 (lowest level) to Aud 4 (highest level).

Radar has short range:

Set range (sensitivity) control to maximum (longest range). Note: Opposite direction mode and same direction mode sensitivity settings may need to be set independently.

Radar suffers from patrol speed shadowing:

If the patrol window indicates an incorrect patrol speed, the “PS blank” or other patrol blank key, blanks the patrol speed window and acquires a new patrol speed.

Change the low-end patrol speed from 5 mph to 20 mph (if applicable), thus preventing patrol speed tracking below 20 mph. It is not possible to allow patrol speed tracking below 20 mph and to eliminate patrol speed shadowing simultaneously.

Radar will not lock onto patrol speeds below 20 mph:

Change the low-end patrol speed from 20 mph to 5 mph. The radar will now be susceptible to patrol speed "shadowing," which can be easily corrected by pressing the PS blank key.

Radar has trouble maintaining patrol speed:

Mount the antenna higher above the dash and/or point antenna slightly down toward the ground. Make sure the wipers are not in the radar beam path. Make sure the windshield does not have paint/mask around the perimeter.

Radar picks up vehicle fan and reads 5 to 30 mph in stationary mode:

Check for proper aiming of antenna. Make sure that the paint/mask or metallic objects are not deflecting the radar beam down into defroster vents. If so, raise antenna above obstruction.

Radar displays Low Voltage icon:

Make sure the cigarette-plug is securely installed and the contacts are clean.

Radar flashes Hot in display:

The radar is overheating. Move radar out of direct sun. Do not leave radar operating in a closed vehicle.

Chapter 10: Lidar

Chapter Objectives:

- Define Laser and Lidar
- Identify how Lidar calculates speed and distance
- Calculate Lidar beam width
- Identify maintenance and testing requirements for Lidar units
- Identify the limitations of Lidar units

Laser

Laser is defined as **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. Laser light travels at the speed of light, which is a constant and does not change. Light travels at 186,282 miles per second, which equals 670 million miles per hour. Each wavelength is measured in one billionth of a meter, known as nanometers.

History of the Laser

In 1917, Albert Einstein theorized that a single frequency of light could be produced, which would not spread out over a great distance. In 1960, Theodore Maiman developed the first working laser using a ruby crystal. The first Lidar unit for police use was patented in 1989 by Laser Technology Inc.

Lidar

Lidar is defined as **L**ight **D**etection **A**nd **R**anging. The Lidar utilizes laser light to measure speed and distance. The Lidar sends out a pulse of laser light, which is reflected and returns to the Lidar unit.

Calculating Distance Using Police Lidar

The Lidar sends out a pulse of laser light which is reflected off of the object or vehicle. The laser returns to the Lidar unit, which measures the time of flight and divides this number by 2 (time the light travels to and from the object). The Lidar unit then calculates the distance using the speed of light as a constant. **Distance=Speed of Light X Time of Flight.**

Calculating Speed Using Police Lidar

The Lidar unit sends out a continuous series of pulses while the trigger is being depressed. The Lidar calculates the change in distance as the vehicle is moving toward or away from the unit. The Lidar calculates speed by measuring the change in distance over change in time.

General Use and Instructions

The use of the Lidar can only be done while in the stationary mode. In the stationary mode target a specific vehicle and make a visual estimation of the vehicle's speed. Aim the Lidar at the font of the vehicle, preferably a reflective surface such as the front license plate or headlamps. Depress the trigger for 3 to 5 seconds to obtain a good reading and tracking history. Confirm that the reading on the Lidar unit is consistent with your visual estimation of speed.

Lidar Beam Width

The laser will expand as it travels and will grow larger the further away the target is from the Lidar unit. The Lidar beam width is measured in milliradians, which is a fraction of a single degree. Stalker and Kustom Signals Lidars have beam widths of 3.0 milliradians, which is approximately 0.1719 degrees.

It is important to understand that the beam width of a Lidar unit will expand as the target distance becomes greater. Beam widths can be calculated by using the following mathematical formula: **Beam Width= 2 X Distance X Tan (degree/2)**

Example 1: How wide is a 0.1719 degree laser beam at 1500 feet from the Lidar unit?

BW= 2 X 1500 X Tan (0.1719/2)

BW= 3000 X Tan (0.0859)

BW= 4.5 feet

This means that at 1500 feet from the target the beam width is 4.5 feet.

Example 2: How wide is a 0.1719 degree laser beam at 5000 feet from the Lidar unit?

BW= 2 X 5000 X Tan (0.1719/2)

BW= 10,000 X Tan (0.0859)

BW= 15 feet

This means that at 5000 feet from the target the beam width is 15 feet.

Lidar Testing:

Daily Testing

Daily testing of Lidar units should consist of Internal Circuitry Check, Sight Alignment Check and a Known Distance Check.

Internal Circuitry Test: The Lidar will have a manual test button or will automatically perform an internal circuitry test when powered on. The Lidar unit will normally indicate a passing check by beeping or displaying "Pass" on the electronic display.

Known Distance Check: The operator should measure 2 known distances greater than 100 feet (ie 120' and 150'). (It is recommended that a permanent range be marked at the operators department or division). Put the Lidar into Distance Mode, then hold the Lidar Unit level at the start end of the range and aim it at the marker on the opposite end of the range. Check the Lidar unit and confirm that the distance matches the known distance (pre measured) at each point on the range.

Sight Alignment Check: The operator should put the Lidar into distance mode. Hold the Lidar vertical, aim the Lidar at a narrow object, preferably one with a solid object behind it (ie a light pole in front of a fence). Depress the trigger then pan the Lidar beam across the solid object and then the narrow object. The distance should change as the Lidar sight crosses the narrow object. The greater the distance to the object the more accurate the test will be. Rotate the Lidar horizontally and repeat the test. This test ensures that the Lidar sight is aligned with the laser beam. If there is any discrepancy, remove the Lidar from service and have it repaired by a qualified technician.

Weekly Testing

Known Speed Test: It is recommended that Lidar operators conduct a known speed test on a weekly basis. The known speed test can be conducted either with one person or two. With two officers, have Officer (A) drive toward or away from the officer with the Lidar unit (Officer B). Officer (A) should drive at a known and constant speed while Officer (B) obtains a reading. Officer (B) should then verify that the Lidar reading matches the known speed. With one officer, travel at a known and constant speed. Aim the Lidar at a large, reflective, stationary object directly in front of the patrol vehicle. The operator should verify that the Lidar reading matches the known speed.

Certification Checks

Each Lidar unit needs to be checked and certified every 3 years by a qualified technician. The technician will provide paperwork assuring that the unit is operating properly at the time of the certification. If the Lidar unit is used by multiple officers, consider storing the certification paperwork in a central location where all operators have access.

Lidar Errors and Limitations

Possible Errors: Although the Lidar units are very reliable and easy to use they are still subject to potential problems. The Lidar operator needs to be familiar with and be able to identify and correct any potential errors. The Lidar is subject to the Cosine Error and Truncation, but will only display a lower speed then the target vehicle's actual speed. Lidar units are subject to RFI although most are equipped with RFI detectors. One of the potential errors may occur when the operator moves the Lidar beam up and down the sloped hood of the target vehicle. This can create a higher reading than the target vehicle is actually traveling. This is known as Lidar sweep error and is easily corrected by using the Lidar unit with a stable platform.

Lidar Limitations: Because the Lidar unit relies on the reflection of light the construction of the target may affect the operator's ability to obtain a reading. The Lidar reflects better off of white or light colored vehicles and gives the unit a greater range. However, the Lidar reflects less off of black and dark colored vehicles causing less of a range for a speed reading to be obtained. Fabric covers on the front of vehicles may also decrease the Lidar's effective range. One other limitation to the use of Lidar is that it can only be used in the stationary mode.

Chapter 12: Case Law and Court Preparation

Chapter Objectives:

- Identify and gain familiarity with case law governing the use of speed detection devices in Utah.
- Identify common defenses used in court.
- Identify good practices for note-taking and citation completion.
- Understand and identify the materials and certifications required for court.

Speed Detection Case Law:

Since the introduction of speed detection devices in the mid-20th Century, there have been a great number of court cases challenging their scientific principles of operation, the techniques used in their operation, the accuracy of their calibrations and readings, and the operator's training and competency to use the devices. Over the course of the last 50 or so years, these cases have molded law enforcement's use and employment of these devices. A student's understanding of these cases is crucial to understanding both how court cases involving speed violations will proceed, and also to understand why the training has evolved the way it has. This course and the officer's required actions when employing the devices are a direct result of this body of case law.

The first important case regarding speed detection devices was a case out of New Jersey in **1955: State v. Dantonio**. This was one of the first cases where appellate decisions were made regarding the efficacy of police traffic radar. The ruling itself cites several other prior cases, going back to 1953, but this case was the first to state clearly that 1) radar was a scientifically reliable method for measuring speed, 2) that a few hours' training was sufficient to train an operator in the appropriate usage of the device and 3) that operators/officers need not be electrical engineers or experts in the field of radar. At this point, the case law was sufficiently rigorous to allow the widespread use of police traffic radar and also for law enforcement agencies to be reasonably sure of the acceptance of such readings in courts.

Following is an incomplete list of cases and their citations of court decisions regarding radar:

- *Everight v. City of Little Rock*, 326 S.W.2d 796 (Ark. 1959)
    - Court took judicial notice of the reliability of radar
- *State v. Graham*, 322 S.W.2d 188 (Mo. App. 1959)
    - Court took judicial notice of radar's ability to measure speed.

- *State v. Tomanelli*, 216 A.2d 625 (Conn. 1966)
    - Court applied the Frye test to the Doppler principle, police traffic radar and upheld the tuning fork as a reliable accuracy test.
- *Honeycutt v. Commonwealth*, 408 S.W.2d 421 (Ky, 1966)
    - This case held that a properly constructed and operated radar is capable of accurately measuring speed. It reaffirmed the reliability of the tuning fork as an accurate calibration check, stated that operators require only a few hours instruction and that operators need not understand the scientific principles behind radar nor explain the inner workings. Finally, this case established the 'lead vehicle theory' which was abolished with State v. Ferency. This theory held that the closest vehicle was the one that would return the most radar energy and thereby be the target. As this course has shown, this theory is erroneous and was abolished.
- *State v. Gerdes,* 191 N.W.2d 428 (MN, 1971)
    - The Supreme Court of Minnesota stated that an internal-only calibration check was inadequate and some form of external check must be done to ensure the reliability of the radar.
- *State v. Hanson*, 270 N.W.2d 212 (WI, 1978)
    - This case addressed moving radar specifically and established that moving radar enforcement must include a separate verification of patrol speed ('S' in the current program's 'VARS' or some similar method).
- *Michigan v. Ferency*, 351 N.W.2d 225 (MI, 1984)
    - This case established the seven guidelines for moving radar operation, which reaffirmed State v. Hanson and has helped shaped the Radar/Lidar program in Utah. So far as radar is concerned, this is one of most important cases.

The Seven Guidelines for Moving Radar Operation (Michigan v. Ferency, 1984):

1. The officer must have adequate training and experience.
2. The radar must be in proper working condition and installed properly at the time of citation.
3. The radar must be used in an area with minimum distortion and/or interference.
4. The patrol speed (Low Doppler) is displayed on the radar and independently verified by speedometer.
5. The officer must test the radar unit at the beginning and end of the shift.
6. The officer must be able to establish that the target vehicle was within the beam width at the time the radar reading was obtained. (Lead vehicle theory dismissed)
7. A qualified technician must perform a periodic check and certification of the radar.

The following is an incomplete list of cases and their citations for court decisions regarding <u>lidar</u>:

- *State v. Abeskaron*, 740 A.2d 690 (N.J. Super. A.D. 1999)
    - This appellate court decision in New Jersey was one of the first cases where lidar was found, based on prior *Frye*-type hearings, to be scientifically reliable and not 'new or novel' technology.
- *People v. Canulli*, 792 N.E.2d 438 (Ill. App. Ct. 2003)
    - This case, as in the last case, is one where the court found that lidar technology was new and novel enough to require *Frye* hearings to establish the reliability of the devices.
- *State v. Wiliamson*, 166 P.3d 387 (ID, 2007)
    - While this case is much more recent and does not address *Frye* or the requirements of new and novel technology, the court does adopt a very similar procedure for acceptance of laser evidence to that found in radar case law. The foundation must be laid that: "the officer was qualified to operate the device, that the unit was properly maintained, and that it was used correctly."
- *Hall v. State*, 225 S.W.3d 524, 536 (Tex. Crim. App. 2007)
    - This Texas case is another where case law on lidar was scant enough that the appeals courts found that *Frye* hearings were necessary to establish lidar's reliability in measuring speed.

In the case of lidar, the history of the case law is less clear cut. Even in the short list above, there are two cases ruling one way, and two cases ruling another. Although there is no Utah-specific binding case law on the subject, the courts have been generally accepting of both technologies so long as the proper procedures (such as those found in *Hanson*, *Ferency* and *Wiliamson*) are followed. These include accuracy and reliability checks by the operators, proper tracking history, visual estimations and independent patrol speed verification in the case of moving radar.

The case law and history of these technologies' uses in law enforcement can help the student also understand why the program and training has evolved to its current state. Generally speaking, the seven guidelines for moving radar, VARS and the daily/periodic checks of the equipment are sufficient to allow the admissibility of radar/lidar evidence in Utah courts. However, court preparation and knowing what to expect when a speed citation goes to trial are also essential to the operator.

FCC LEGAL REQUIREMENTS

The Federal Communications Commission requires that an operating license be obtained by the user of the equipment. In the case of local government agencies already licensed under part 90 in the Public Safety Radio Service, ***the requirement for a separate authorization for radar speed detection devices was eliminated, effective February 1, 1983, and licensees may operate speed detection devices as part of their base/mobile communications systems***.

Common Defenses and Challenges to Speed Citations:

Because of the reliability and robustness of both radar and lidar when used properly, defense challenges to speed citations are narrowed to primarily two areas: 1) whether or not the device was functioning properly and operated correctly and 2) which vehicle was responsible for the reading obtained. In lidar, the second challenge is largely eliminated so long as the officer properly checked sight alignment prior to use.

The case law above very clearly shows that courts will not accept as inherently reliable any radar or lidar reading when the unit has not been checked for accuracy or was not operated correctly. If the officer failed to check the device prior to use in writing citations, it is likely that the radar or lidar reading would be inadmissible. If the officer failed to complete a tracking history for radar or failed to visually estimate speeds and distances, it is possible that the reading would not be allowed.

If the officer's operator certification has lapsed, it is possible that their knowledge base is sufficiently degraded that their operation of the devices could be sub-par. More importantly, though, a valid certification is required to operate radar and lidar. Law enforcement does not allow citizens to operate vehicles with lapsed licenses, and the same standards apply. Likewise, the failure of an officer to provide the calibration certificates for both the radar/lidar, tuning forks and other hardware can result in dismissed citations.

With radar specifically, the most common defense challenge is the allegation that a vehicle other than the defendant's was responsible for the reading reported on the radar. Especially in heavy traffic, it is possible to have hundreds of vehicle within a radar beam at the same time. Improper or incomplete target identification or failure to complete tracking histories can raise doubt about which vehicle actually was the target vehicle.

Lidar does not have the difficulties in court with target identification unless the sight alignment checks were neglected or faulty. However, lidar citations still can be and still are regularly challenged.

While most traffic stops for speed are considered 'routine', they are still regularly challenged. In many cases, these challenges are frivolous and attempt to shirk responsibility for a violation by finding fault in the details. However, there are certainly cases where an officer can make mistakes. In the interest of fairness and justice, every citizen is entitled to the assurance and knowledge that an officer is capable, confident and professional. Proper speed enforcement is essential not only simply to avoid court, but to ensure the image of law enforcement as impartial and professional is upheld. Consider the following tips when conducting speed enforcement and assume that every person stopped for speeding will challenge the citation.

Preparing for Court Before the Traffic Stop:

The radar/lidar operator's best court preparation comes not from preparing immediately before trial, but before a traffic stop is even initiated. Keeping in mind the need to be thorough and detail-oriented even on the last traffic stop of the day is the best practice not only to guard against writing erroneous citations, but also ensures that the right of the state's citizens to due process is preserved.

The first step to ensuring successful eventual prosecution is making sure that all the daily and periodic checks have been completed according to departmental policy. Recall from Chapters 10 and 11 that these checks should be completed both before and after the shift, and periodically during the shift. This is the recommended testing schedule, but departmental policy may differ from this. Always follow departmental policy.

Next, completion of VAR(S) and thorough note taking prior to the stop will help the officer not only explain the certainty of the violation, but will allow for more complete court preparation should the violation go to trial. Take notes on every phase of the tracking history. Visually, note not only the estimation of speed and distance, but also surrounding traffic and weather conditions, obstructions, possible sources of interference, lane position and any violator behaviors such as sudden slowing, evasive actions or other unusual actions. Note the strength, pitch and any changes in the Doppler audio tone. Note the initial radar reading, any change in reading corresponding to visual changes in speed, apparently cosine effects as the target passes, and attempt to get multiple radar readings on multiple antennas. For lidar enforcement, note the distances at which the vehicle was first and last measured. Note any impediments to line of sight that would interrupt the laser. And for moving radar, ensure to note that the patrol speed displayed matched a speedometer, patrol GPS unit or other secondary confirmation.

Preparing for Court During the Traffic Stop:

During the stop, violator statements and admissions can provide useful information for a future judge or jury. Many cooperative violators nonetheless attempt to excuse their actions with explanations. "I was late for work/the airport/to pick up my children, etc." This information helps to corroborate that they were exceeding the speed limit. In addition, many otherwise cooperative violators may admit to speeding, but not to the degree alleged by the officer. These statements can also establish the fact that the violator was speeding, if not the severity.

Conversely, perhaps the sincerity and detailed explanations of surrounding traffic behavior or other circumstances could convince an officer that there was an error in judgment. Careful notes and consideration to driver statements could help dispel suspicion of speeding or other alleged traffic violations. The inclusion of possibly exculpatory evidence in a citation can both help set the driver's mind at ease on scene and demonstrate ethical and honest conduct to a future trier of fact.

Materials Required for Court Appearance, a 'Court Portfolio':

Court preparation for speeding violations requires certain documents and materials be present to ensure that the radar or lidar reading can be considered reliable. The following materials should be brought to court and preferably reviewed prior to appearance.

- The officer's radar/lidar operator certification. This document is often the first demanded by attorneys or defendants. It is also one of the simplest pieces of missing evidence that could convince a court to dismiss a citation outright. Remember: citizens cannot operate a vehicle legally without a valid driver's license and the same applies to law enforcement.
- Certificates and documentation for the hardware used. For radars, this should include certificates for the counting unit, both antennas (if so equipped), and one certificate for each tuning fork. For lidars, typically one certificate is provided. Some departments may require equipment to be signed out on a log. If so, attempt to bring a copy of the log to prove that a particular device was used and in the officer's possession that day. Some officers go so far as to bring in the tuning forks themselves, although this is not typically required.
- The daily shift log required by most departments should also show that a radar/lidar unit was checked before and after the shift. Bring a copy of the duty log to court. In addition to proving that the radar/lidar was checked, it can also corroborate times and locations. Many computerized logging systems have the capability to log GPS coordinates or otherwise fill in location fields, thereby eliminating argument over where the violation or stop actually occurred.
- If pacing was used, it is important to have some documentation on the method used to verify patrol speed. Simply testifying that one's patrol car has 'Certified Calibration' stamped under the speedometer is insufficient. If GPS was used in conjunction to verify the speedometer measurement, note so on the citation. If the officer has independently verified the calibration on the patrol speedometer, any documentation on this fact should be brought to court.
- If time/distance was used, it is important to bring calibration verification for the distance measurement device (cloth tape, lidar distance function, roll-o-tape, etc.), the stopwatch or timing device and log of activity for the enforcement shift.

Preparing for Court and Demeanor in Court

When appearing in court it is important officers follow courtroom demeanor and procedures.
The following guidelines should be followed when testifying in a court of law:

- Look like a professional; uniform, grooming, language, and personal demeanor
- Be prepared, review your field notes and video prior to appearing in court
- Review your notes for the case in advance
- Arrive for court early

- Be prepared to answer technical questions regarding beam width, cosine effect, double cosine effect, etc.
- Articulate the facts; know what you are talking about
- Don't argue with a prosecutor, defense attorney or the judge
- Do not display emotions such as anger and arrogance. These are not traits of a professional
- Answer only the required question. Many times when testifying, people expound on their answers, sometimes opening holes in the case and other lines of questioning for the defense
- Don't attempt to answer a question if you don't know the answer
- Keep your answers brief. Listen to all the questions carefully
- Accept the court's ruling regardless of the outcome.

If you lose, learn from the experience and make yourself and your case stronger in the future. If you win, learn what you did right and continue doing the right thing. Always re-evaluate, just because you did it right and won this time doesn't mean you will win the next time.

Practical Note Taking Exercise:

You are running Radar on I-15 at 1400 hours. You observe a small red compact passenger car in the number #1 lane passing a suburban and several other larger vehicles. You visually observe the red car traveling at 85 mph in a 65 mph zone. Unfortunately the suburban and the other vehicles are taking the strongest signal and you only confirm the red car at 80 mph in the fastest window of the radar display. You decide to pull into traffic and stop the red car. You move into position, activate your overhead police lights. The vehicle pulls over to the left shoulder and stops.

You approach the vehicle and ask the driver for his registration, insurance, and driver license. The driver gives you the requested information. You ask the driver "how fast he was traveling" he says he doesn't remember, however he doesn't believe he was speeding.

The driver is cooperative. What would you cite him for? Write the notes on a piece of paper as you would on the citation notes.

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