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# Introduction to Electronic Surveying Equipment

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## Engineering Aid Basics

**“Chapter 4, Electronic Surveying Equipment”**
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# Chapter 4

# Electronic Surveying Equipment

## Topics

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## Overview

This chapter is intended to supplement what you learned in the previous discussion and introduces the basic principles and uses of other types of electronic surveying equipment.

Material presented here about electronic distance-measuring equipment, electronic positioning systems, laser equipment, and global positioning systems (GPS) equipment is general in nature and is not meant to replace the manufacturer's operations handbook. This updated equipment is being used by Engineering Aid's at this time and you will be expected to know how to operate each piece of equipment.

## Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the purpose, functions, components, and use of the electronic distance-measuring equipment.
2. Describe the electronic positioning systems.
3. Describe the purpose, use, and considerations of laser equipment

## Prerequisites

None

This course map shows all of the chapters in Engineering Aid Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

# 1.0.0 ELECTRONIC DISTANCE-MEASURING (EDM) EQUIPMENT

When electronically determining the straight-line distance (horizontal or slope) between two points or stations, the equipment used (1) sends an electronic impulse of known velocity or rate of speed, and (2) measures the time it takes for the impulse to travel the length of the interval between the points. Then, by using the equation distance = rate x time, the length of the interval is determined.

Two types of electronic distance meters (EDMs) are commonly used. They are the electromagnetic (microwave) instruments and the electro-optical (light wave) instruments. This section discusses the basic principles of the operation and use of both types of instruments. To learn more about EDM principles, read publications such as *Surveying Theory and Practice* by Davis, Foote, Anderson, and Mikhail.

## 1.1.0 Electromagnetic (Microwave) EDM Instruments

The first generation of electromagnetic equipment was very precise for measuring long distances; however, it was too bulky and heavy for the practicing surveyor's needs. Over the years, with improvements in technology electromagnetic EDMs have become smaller and more portable, and are being equipped with direct readout capability.

To use them, two identical and interchangeable instruments are set up at both ends of the line that needs measuring (*Figure 4-1*). The line must be unobstructed but need not be intervisible. This means observations in fog or during other unfavorable weather conditions are possible.

**Figure 4-1 – An electromagnetic distance-measuring instrument.**

As illustrated in *Figure 4-2*, the sending (master) instrument transmits a series of modulated radio waves to the receiving (remote) instrument. The remote instrument interprets the signals and sends them back to the master unit, which measures the time required for the radio waves to make the round trip. The distance is computed based on the velocity of the radio waves. Because velocity is affected by atmospheric conditions, corrections for temperature and barometric pressure must be applied according to the operating instructions provided with the equipment.

**Figure 4-2 – Electromagnetic distance measuring equipment in use.**

## 1.2.0 Electro-Optical (Light Wave) EDM Instruments

Electro-optical EDMs use the velocity of light waves to determine the distance between two points. The earliest of these instruments, the Geodimeter, was developed during the same decade as the electromagnetic EDMs. *Figure 4-3* shows an example of a Geodimeter. Like the electromagnetic instruments, the first generation of electro-optical instruments was heavy, bulky, and not well suited to the needs of the practicing surveyor; however, through later development, modern electro-optical EDMs became smaller, lighter, and easier to use, and required less power.

Modern short-range instruments have ranges from 0.3 miles to 3 miles. Longer range instruments, using coherent laser light, have ranges from 50 feet to 36 miles.

To use an electro-optical EDM, the instrument is set up at one end of the line being measured and a reflector at the other end of the line. As with the electromagnetic EDM, the line must be free of obstacles. However, unlike using the electromagnetic device,

**Figure 4-3 – An electro-optical distance measuring instrument (Geodimeter).**

the stations at both ends of the line must also be intervisible. After setup, the EDM sends a modulated beam of light to the reflector, which returns the light pulse back to the EDM. When the instrument receives the reflected light flash, it converts the readings into linear distance between the EDM and the reflector with corrections made for atmospheric conditions.

## 1.3.0 Direction of EDM Measured Lines

As previously mentioned, an EDM transmitter by itself is useful for determining only the length of a line. With some of the older EDM models, distance and direction are determined by separate setups of an EDM and a theodolite over the same station. With more recent EDM systems, the EDM transmitter is mounted on the theodolite or is built into the theodolite.

## 1.4.0 Reduction of Slope Distance

As you learned in EA Basic, to reduce the slope distance of a line to horizontal distance, either the vertical angle of the line measured from the instrument or the difference in elevation between the ends of the line must be known. With this information you can use the equations found in Chapter 13 of the EA Basic to reduce the slope distance. Using the chaining or transit-tape operations makes the calculations relatively simple. However, when the same equations are applied to EDM operations, the procedures are frequently a little more complicated. The methods of slope reduction discussed in this chapter should be used only for slope distances that are less than 2 miles in length or for observed vertical angles that are less than 5 degrees. For a discussion of slope reduction when distances of over 2 miles or vertical angles greater than 5 degrees are encountered, consult commercial publications, such as *Surveying Theory and Practice* by Davis, Foote, Anderson, and Mikhail.

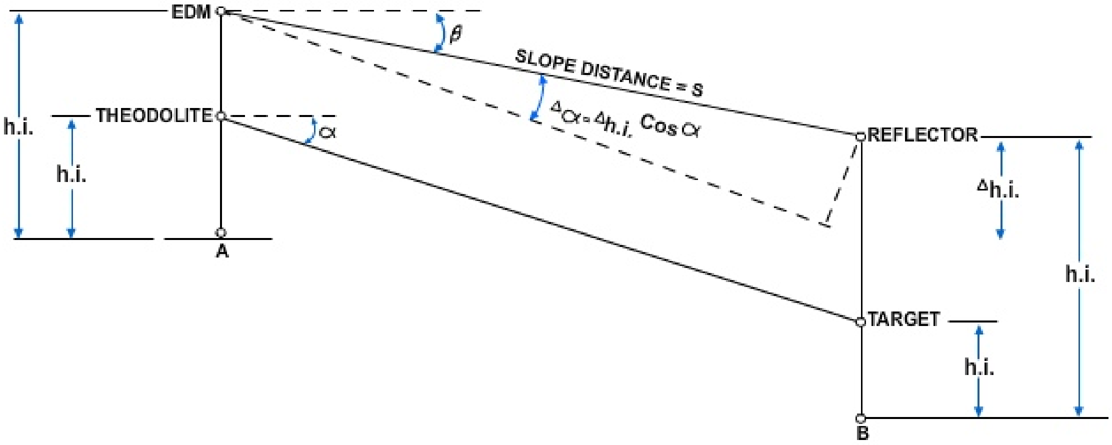

**Figure 4-4 – Slope reduction using vertical angle and slope distance.**

### 1.4.1 Slope Reduction Using the Vertical Angle

When the slope distance and the vertical angle are obtained from separate setups of an EDM and a theodolite, additional information is required for reducing the slope distance. This information includes the heights above the ground (*h.i.)* of the EDM transmitter and the reflector or remote unit, the *h.i.* of the theodolite, and *the h.i.* of the target. You must consider these differing heights of the equipment in your computations since they result in a correction that must be applied to the observed vertical angle before the slope distance can be reduced.

*Figure 4-4* illustrates the situation in which the slope distance and vertical angle are obtained from separate setups of an EDM and a theodolite. In *Figure 4-4* the EDM transmitter, reflector, theodolite, and target are each shown at their respective *h.i.* above the ground. Angle $\alpha$ is the observed vertical angle and $\Delta_\alpha$ is the correction that must be calculated to determine the corrected vertical angle, ß, of the measured line. To reduce the slope distance, *s,* you must make an adjustment for the differing heights of the equipment. This adjusted difference in instrument heights ($A_{h.i.}$) is calculated as follows:

$$\Delta_h = (h.i.\ reflector - h.i.\ target)$$

$$- (h.i.\ EDM - h.i.\ theodolite).$$

With $\Delta_{h.i.}$ known, now solve for $\Delta_\alpha$ which is needed to determine the corrected vertical angle. You can determine it as follows:

$$\Delta_a = \frac{\Delta_{h.i.} \cos a}{s \times \left(4.848 \times 10^{-6}\right)}$$

Now, solve for corrected vertical angle, ß, by using the formula

$$ß = \alpha + \Delta_\alpha$$

**NOTE**

The sign of $\Delta_{h.i.}$ is a function of the sign of the difference in *h.i.,* which can be positive or negative. You should exercise care in calculating ß so as to reflect the proper sign of α, Δ and $\Delta_{\alpha}$.

Finally, you can reduce the slope distance, *s,* to the horizontal distance, *H,* by using the following equation:

$$H = s \cos ß$$

To understand how the above equations are used in practice, consider the following example. Assume the slope distance, *s,* from stations *A* to *B* (corrected for meteorological conditions and EDM system constants) is 2,762.55 feet. The EDM transmitter is 5.52 feet above the ground, and the reflector is 6.00 feet above the ground. The observed vertical angle is 4°30'00". The theodolite and target are 5.22 feet and 5.40 feet above the ground, respectively. To calculate the horizontal distance and solve the problem, proceed as follows:

$$\Delta_{h.i.} = (6.00 - 5.40) - (5.52 - 5.22) = 0.30\text{ft.}$$

$$\Delta_{\alpha =} (.030\cos - 4°30'30')$$

$$[(2{,}762.55)\ (4.848 \times 10^{-6})] = 22.33''$$

$$ß = -4°30'00'' + 0°00'22.33'' = -4°29'37.67''$$

$$H = 2{,}762.55 \cos -4°29'37.67'' = 2{,}754.04\text{ft.}$$

The above example is typical of situations in which the slope distance and the vertical angle are observed using separate setups of an EDM and a theodolite over the same station. Several models of the modern electro-optical systems, however, have the EDM transmitter built into the theodolite. In this way, the vertical angle and the slope distance can be observed simultaneously. In some of these models, there is a vertical offset between the electrical center of the transmitter and the optical center of the theodolite. Also, the height of the EDM reflector may not be at the same height as the target used to observe the vertical angle. For these conditions, you need to consider these vertical offsets in the manner described above.

### 1.4.2 Slope Reduction Using the Difference in Elevation Between End Points

Refer to *Figure 4-5* to see how to reduce a slope distance using the difference in elevation between two stations. In *Figure 4-5*, the EDM transmitter is located at station *A* and has an *h.i.* equal to *AD.* The reflector at station *B* has an *h.i.* equal to *BE.* The ground elevations at *A* and *B* are known, and the difference between these elevations is designated $\Delta_{A\text{-}B}$. To reduce the slope distance, *s,* you first determine the difference in elevation between *D* and *E.* This can be done using the following equation:

$$\Delta_{DE} = \Delta_{A\text{-}B} - AD + BE$$

In other words, $\Delta_{DE} = \Delta_{A\text{-}B}$ – *h.i.* of EDM + *h.i.* of reflector.

Now, looking again at *Figure 4-5*, see that *CDE* is a right triangle; therefore, since the slope distance was observed and recorded using the EDM, and having calculated $\Delta_{DE}$, you can determine the horizontal distance, *CD,* simply by using the Pythagorean theorem.

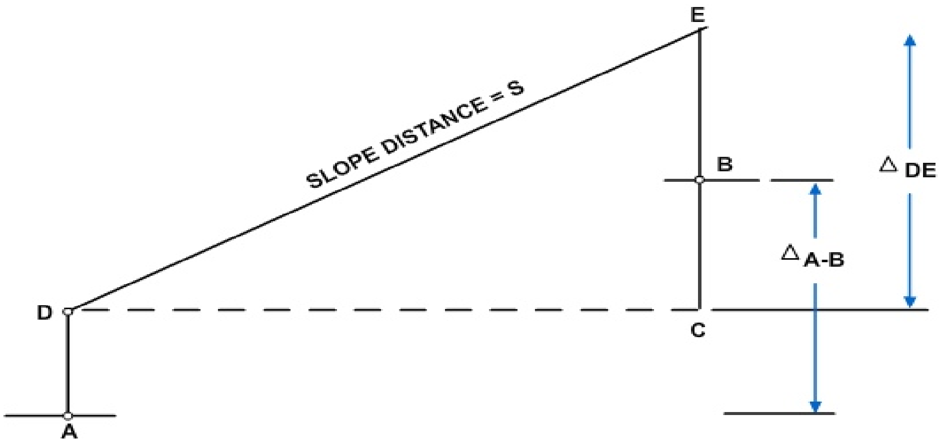

**Figure 4-5 – Slope reduction using difference in elevation.**

# 2.0.0 ELECTRONIC POSITIONING SYSTEMS

Three classes of modern positioning systems are used to determine positions on the surface of the earth. Two of the classes are the initial positioning systems and the Doppler positioning systems. The initial positioning systems require experience with navigational systems on board aircraft, and the Doppler systems deal with signals received from satellites. Both systems are beyond the scope of this chapter. However, the Doppler positioning system is briefly discussed at the EA Basic level. The third class of positioning systems is electronic positioning systems.

Electronic positioning systems consist of specially designed short-to-medium range EDMs that are attached to, or built into, a theodolite and can be used to determine distances and directions from a single setup of the instrument. Although many different electronic positioning systems are manufactured, each individual instrument is classed into one of three general groups as follows:

1. **Combined theodolite and EDM.** Instruments within this group consist of an optical-reading repeating or direction theodolite with an attached EDM transmitter that can be removed for independent use of the theodolite.
2. **Computerized theodolite and EDM.** The instruments in this group are similar to those within the combined theodolite and EDM group but have built-in electronic computers.
3. **Electronic tachometers.** The equipment in this integrated, digitized, electronic system consists of a digitized theodolite, microprocessor, and EDM transmitter incorporated into one instrument. The instruments in this group also can be equipped with solid-state memory and magnetic tape or punched paper-tape storage units for storage of data.

The above systems can be applied to nearly any type of surveying that is discussed in this or the EA Basic. However, for the normal day-to-day work performed by an EA surveyor, there is little need for these types of instruments since most of the surveys require lower-order precision. When its use is justified, an electronic tachometer is available to augment equipment for the Naval Mobile Construction Battalions. The equipment consists of an electronic digitized theodolite, an EDM unit, a microprocessor, a keyboard and display register, and a data storage unit. By inputting certain controlling data, such as temperature and atmospheric pressure that the built-in atmospheric correction system needs, and by proper manipulation of the instrument controls, the operator can obtain horizontal angles, vertical angles, slope distances, horizontal distances, relative elevation, and coordinates of an unknown point. The data obtained is displayed by a liquid crystal display that can be transmitted and stored in a separate data collector. Complete operating instructions are provided with the tachometer.

# 3.0.0 LASER EQUIPMENT

Laser light is of a single color, where light waves are in step with each other, and the light beam spreads only slightly as the distance from the light generator to the target increases. These characteristics make the laser useful for surveying equipment used in various types of construction layout. Although a wide variety of special-purpose laser instruments exists, most have been designed for construction layout and are classified into two general groups as follows:

1. **Single-beam laser alignment instruments.** These instruments project a single beam of light that is visible on targets under all lighting conditions. Included in this group are laser-equipped theodolites and transits, and lasers used for alignment of pipes, drains, and tunneling equipment.
2. **Rotating laser levels.** These are instruments where the laser beam is rotated by rapidly spinning optics to provide a reference plane in space over open areas.

## 3.1.0 Single-Beam Laser Alignment Instruments

A typical single-beam laser alignment instrument is mounted on a transit-like framework with horizontal and vertical motions, a spirit level that is parallel to the axis of the laser, and both vertical and horizontal circles. A telescope is attached to the laser housing to allow the operator to sight the location of the transmitted laser spot. A separate fanning lens allows the laser beam to be converted to a horizontal or vertical line instead of a spot.

## 3.2.0 Rotating Laser Level

A self-leveling, rotating laser is shown in *Figure 4-6*. In this instrument, the laser unit is mounted vertically on a platform containing two orthogonally mounted sensors that act like spirit levels and deviate from center when the platform is not level. The amount of deviation is detected electronically, and the consequent electrical impulses drive servomotors that automatically level the base and make the axis of the laser vertical. The laser beam is emitted at an angle 90 degrees to the axis of the laser by an optical train, and the optics rotate to form a horizontal reference plane. This device also can be side-mounted so the axis of the laser is in a horizontal position, and a vertical plane can be formed by the rotating beam. An electronic sensing device, parallel to the axis of the laser, allows self-plumbing of the rotating beam. The instrument is self-leveling and self-plumbing within a range of 8 degrees. Beyond 8 degrees, it will not operate. This is a safety feature. The tolerance specified for the position of the reference plane with respect to true level or true vertical is 20 seconds of arc. Thus, in a distance of 330 feet, a deviation of 0.03 feet is possible.

Figure 4-6 – Rotating laser level

### 3.2.1 Laser Rod

A laser rod equipped with a laser detector (*Figure 4-7*) contains a sliding battery-powered sensor on the front face of the rod. When within 0.45 feet above or below the rotating laser beam, this sensor locks onto the beam and emits a beep that indicates that a reading should be taken. The operator then reads the rod directly to the nearest 0.01 feet.

The sensor has two modes, the lock mode and the float mode. In lock mode the sensor seeks the beam and then locks onto it, giving a beep to alert the operator to read the scale. The float mode enables the sensor to fix on the laser beam and continue reading the beam, as the rod is moved up and down. The lock mode is used for normal leveling and for determination of elevation or position. The float mode is useful when forms or stakes must be adjusted.

**Figure 4-7 Laser level rod equipped with a laser detector.**

### 3.2.2 Uses and Advantages of the Laser Plane

Some uses and advantages of the laser plane include the following:

1. The laser plane replaces the horizontal line of sight of the engineer's level, and the laser beam replaces a string line.
2. The operation of setting a grade stake to a given elevation is the same as using an engineer's level, except that there is no need for instructions from the operator of the instrument.
3. It is not necessary to have an operator stationed at the instrument to indicate when to get on line or obtain a rod reading.
4. When a laser target is properly attached to a machine used in operations, such as grading, paving, and tunneling, the operator of the machine can stay on the proper alignment and grade (*Figure 4-8*).

**Figure 4-8 – Grading machine controlled by laser level and laser detector.**

5. The laser level shuts off when the laser beam deflects from horizontal.
6. It increases the number of rod readings, as each rodman can set elevations without waiting for the instrumentman, thereby increasing the area of survey within a given time frame.

## 4.0.0 GLOBAL POSITIONING SYSTEM EQUIPMENT

The standard equipment used today consists of the Trimble® S6 Total Station combined with the Trimble® Integrated Survey Rover (ISR). This system gives you the most advanced MagDrive technology for increased speed. When the Total Station is teamed with the Robotic technology of the Trimble® Integrated Survey Rover (ISR) and GNSS/GPS system you have the latest in fast, accurate surveying. For detailed operating instructions you should consult the Trimble® User's Manual for all systems mentioned here.

## 4.1.0 Trimble® S6 Total Station

The Trimble® S6 Total Station (*Figure 4*-9) is set up using a tripod as discussed in EA Basic, Chapter 17. When this system is upgraded to Autolock™ technology semi-robotic operation is enabled with measuring and recording taking place at the total station. The S6 series of instruments seeks out the active remote measuring target (RMT), lock to it, and follows it during movement between points. There are no fine adjustments needed, no focusing, and surveying can be accomplished in any conditions including darkness. The instrument will locate the target in any situation. In most cases the Autolock™ feature makes it possible to stake out and gather survey data as fast as the rodman can move. Robotic operation offers the same advantages as Autolock™ but allows you to work on your own. Robotic measuring offers more than manpower savings, it also gives higher quality measurements. All the control initiation and registering takes place at the measuring point where any errors or discrepancies are quickly identified. The long range direct reflex EDM system (DR 200+) option on the S6 series allows you to measure up to 600 meters against a white object and 200 meters against Kodak Grey which is the international standard to determine the range of reflectorless total stations. The range using a single prism of 5.5 kilometers. When the DR 200+ is combined with robotic operation you effectiveness and speed improves significantly.

**Figure 4-9 — Trimble® S6 Total Station.**

## 4.2.0 Trimble® Integrated Survey Rover

The Trimble® Integrated Survey Rover (ISR) combines Global Positioning System (GPS) and optical data collection on the rover pole (*Figure 4-10*). The system was designed to be used in conjunction with a Trimble® Total Station such as the Trimble® S6 and a GNSS/GPS survey system such as the Trimble® R8 shown on the rover pole. When the total station is used for surveying areas where clear lines of sight is not possible due to obstructions or severe elevation changes, then GPS is the solution. With this system you can switch between techniques and all data can be stored using the alpha/numeric control unit at either the Total Station or on the rover pole itself. The Trimble® R8 is equipped with R-Track technology which is already capable of receiving L2C signals that are part of GPS modernization.

### 4.2.1 Integrated Control Using a Total Station and Post-processed GPS

The following is an example of integrated control using a total station and post-processed GPS. Using the Trimble® S6 Total Station establish a local control network and then the Trimble® R8 to connect the local control network to geodetic control using the following steps:

**Figure 4-10 – Trimble® 5800 RTK Rover with ACU and Trimble® R8 GNSS/GPS.**

1. Set up the backsight prism and attach the Trimble® GPS receiver/antenna on top (*Figure 4-10*).
2. Wirelessly connect the Trimble® ACU to the GPS receiver and start a postprocessed survey. With the Trimble® R8 just select the data logging botton to start logging data.
3. Set-up the Trimble® S6 on the instrument point and perform the station setup, using the Trimble® ACU. Measure rounds to the backsight point and foresight point(s) or measure topographic points.
4. End the conventional survey and postprocessed survey at this point.
5. When back at the office where your Terramodel programs are located, download all data into the desired program. Postprocess the data with coordinated base station data. Perform a combined network adjustment using the established base station control.

The next example is using theTrimble® Integrated Survey Rover. This is the ultimate integrated surveying setup which fully integrates a Trimble® S6 Total Station and Trimble® R8 GPS system. This combines robotic operation with a multi-channel, multi-frequency global navigation satellite system (GNSS) receiver, antenna and data-link radio combined in one compact unit. This system is best utilized in areas with overhead obstructions and then using the GPS in open areas or when line of sight is temporarily obstructed. When the total station line-of-sight is obstructed, quickly changing to GPS to measure a few points is always going to be much faster than establishment of a new instrument point, moving the total station, and then performing a new total station setup. By use of this method the total station can also be placed in the most suitable location for line-of-sight operation, independent of any overhead obstructions.

You are increasing efficiency at establishing control by measuring points with either technology, or both. GPS measurements can be easily transformed to ground control, or coordinates can be established to provide the orientation for total station measurements. You will have improved data integrity by measuring points with both technologies for truly independent verification and confirmation of survey accuracy.

By operating both technologies independently you are saving time and the survey can be completed in a timely manner. The survey data can be easily combined in the field or back at the office using the Terramodel software program.