EELECTROMAGNETIC DISTANCE MEASUREMENT (EDM)

The EDM equipments which are commonly used in land surveying are mainly *electronic* or *microwave systems* and *electro-optical instruments*. These operate on the principle that a transmitter at the master station sends modulated continuous carrier wave to a receiver at the remote station from which it is returned). The instruments measure slope distance D between transmitter and receiver. It is done by modulating the continuous carrier wave at different frequencies and then measuring the phase difference at the master between the outgoing and incoming signals. This introduces an element of double distance is introduced. The expression for the distance D traversed by the wave is

$$2D = n\lambda + \frac{\phi}{2\pi}\lambda + k$$

where

ϕ = the measured phase difference,

λ = the modulated wavelength,

n = the number of complete wavelength contained within the double distance (an unknown), and

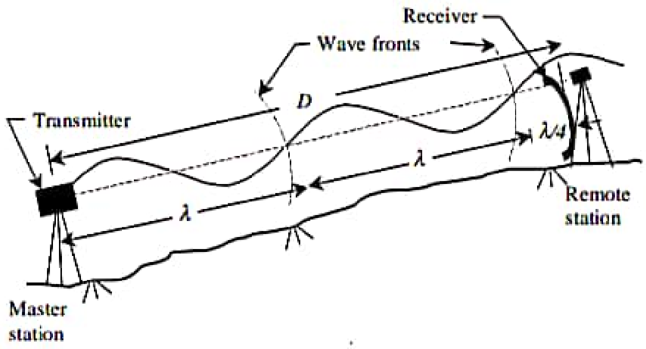
k = a constant.

To evaluate n, different modulated frequencies are deployed and the phase difference of the various outgoing and measuring signals are compared.

If c_0 is the velocity of light in vacuum and f is the frequency, we have

$$\lambda = \frac{c_0}{nf}$$

where n is the refractive index ratio of the medium through which the wave passes. Its value depends upon air temperature, atmospheric pressure, vapour pressure and relative humidity. The velocity of light c_0 in vacuum is taken as 3×10^8 m/s.



The infrared based EDM equipments fall with: ie electro-optical group. Nowadays, most local survey and setting out for engineering works are being carried out using these EDM's. The infrared EDM has a passive reflector, using a retrodioptive prism to reflect the transmitted infrared wave to the master. The distances of 1-3 km can be measured with an accuracy of ± 5 mm. Many of these instruments have microprocessors to produce horizontal distance, difference in elevation, etc.

Over long ranges (up to 100 km with an accuracy of ± 50 mm) electronic or microwave instruments are generally used. The remote instrument needs an operator acting to the instructions from the master at the other end of the line. The signal is transmitted from the master station, received by the remote station and retransmitted to the master station.

Measurement of Distance from Phase Difference

The difference of the phase angle of the reflected signal and the phase angle of the transmitted signal is the *phase difference*. Thus, if ϕ_1 and ϕ_2 are the phase angles of the transmitted and reflected signals, respectively, then the phase angle difference is

$$\Delta\phi = \phi_2 - \phi_1$$

The phase difference is usually expressed as a fraction of the wavelength (λ). For example,

$\Delta\phi$	0°	90°	180°	270°	360°
Wavelength	0	$\lambda/4$	$\lambda/2$	$3\lambda/4$	λ

Fig. 2.13 shows a line *AB*. The wave is transmitted from the master at *A* towards the reflector at *B* and is reflected back by the reflector and received back by the master at *A*. From *A* to *B* the wave completes 2 cycles and 1/4 cycles. Thus if at *A* phase angle is 0° and at *B* it is 90° then

$$\Delta\phi = 90^\circ = \frac{\lambda}{4}$$

and the distance between *A* and *B* is

$$D = 2\lambda + \frac{\lambda}{4}$$

Again from *B* to *A*, the wave completes 2 cycles and 1/4 cycles. Thus if ϕ_1 is 90° at *B* and ϕ_2 is 180° at *A*, then

$$D\phi = 90^\circ = \frac{\lambda}{4}$$

and the distance between *A* and *B* is

$$D = 2\lambda + \frac{\lambda}{4}$$

The phase difference between the wave at A when transmitted and when received back is 180°, i.e., $\lambda/2$ and the number of complete cycles is 4. Thus

$$2D = 4\lambda + \frac{\lambda}{2}$$

$$D = \frac{1}{2}\left(4\lambda + \frac{\lambda}{2}\right)$$

The above expression in a general form can be written as

$$D = \frac{1}{2}(n\lambda + \Delta\lambda)$$

where

n = the number of complete cycles of the wave in traveling from A to B and back from B to A, and

Δl = the fraction of wavelength traveled by the wave from A to B and back from B to A.

The value of $\Delta\lambda$ depends upon the phase difference of the wave transmitted and that received back at the master. It is measured as phase angle (ϕ) at A by an electrical phase detector built in the master unit at A. Obviously,

$$\Delta\lambda = \left(\frac{\Delta\phi}{360^\circ}\right)\lambda$$

where

$\Delta\phi$ = the phase difference

$= \phi_2 - \phi_1$

In Eq n is an unknown and thus the value of D cannot be determined. In EDM instruments the frequency can be increased in multiples of 10 and the phase difference for each frequency is determined separately. The distance is calculated by evaluating the values of n solving the following simultaneous equations for each frequency.

$$D = \frac{1}{2}(n_1\lambda_1 + \Delta\lambda_1)$$

$$D = \frac{1}{2}(n_2\lambda_2 + \Delta\lambda_2)$$

$$D = \frac{1}{2}(n_3\lambda_3 + \Delta\lambda_3)$$

For more accurate results, three or more frequencies are used and the resulting equations are solved.

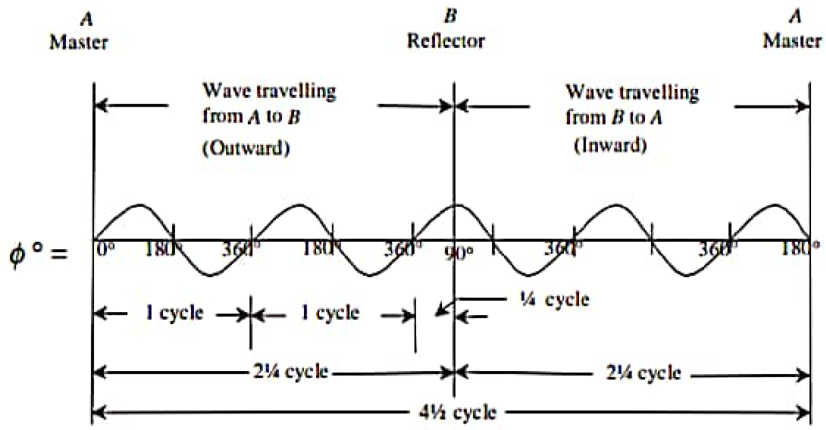
Let us take an example to explain the determination of n_1, n_2, n_3, etc. To measure a distance three frequencies f_1, f_2, and f_3 were used in the instrument and phase differences $\Delta\lambda_1$, $\Delta\lambda_2$, and $\Delta\lambda_3$ were measured. The f_2 frequency is $\frac{9}{10}f_1$ and the f_3 frequency is $\frac{99}{100}f_1$. The wavelength of f_1 is 10 m.

We know that $$\lambda \propto \frac{1}{f}$$

therefore, $$\frac{\lambda_1}{\lambda_2} = \frac{f_2}{f_1}$$

$$\lambda_2 = \frac{f_1}{f_2}\lambda_1 = \frac{f_1}{\frac{9}{10}f_1} \times 10$$

$$= \frac{100}{9} = 11.111 \text{ m.}$$



Similarly, $$\lambda_3 = \frac{f_1}{\frac{99}{100}f_1} \times 10 = \frac{1000}{99} = 10.101 \text{ m.}$$

Let the wavelength of the frequency $(f_1 - f_2)$ be λ' and that of $(f_1 - f_3)$ be λ'', then

$$\lambda' = \frac{f_1\lambda_1}{(f_1 - f_2)} = \frac{f_1\lambda_1}{\frac{f_1}{10}} = 10\lambda_1 = 10 \times 10 = 100 \text{ m}$$

$$\lambda'' = \frac{f_1\lambda_1}{(f_1 - f_3)} = \frac{f_1\lambda_1}{\frac{f_1}{100}} = 100\lambda_1 = 100 \times 10 = 1000 \text{ m.}$$

Since one single wave of frequency $(f_1 - f_2)$ has length of 100 m, λ_1 being 10 m and λ_2 being 11.111 m, the f_1 frequency wave has complete 10 wavelengths and the f_2 frequency wave has complete 9 wavelengths within a distance of 100 m.

To any point within the 100 m length, or stage, the phase of the $(f_1 - f_2)$ frequency wave is equal to the difference in the phases of the other two waves. For example, at the 50 m point the phase of f_1 is $(10/2) \times 2\pi = 10\pi$ whilst that of f_2 is $(9/2) \times 2\pi = 9\pi$, giving a difference of

$10\pi - 9\pi = \pi$, which is the phase of the $(f_1 - f_2)$ frequency. This relationship allows distance to be measured within 100 m. This statement applies as well when we consider a distance of 1000 m. Within distance of 500 m, the f_1 wave has phase of $(100/2) \times 2\pi = 100\pi$, the f_3 wave has $(99/2) \times 2\pi = 99\pi$, and the $(f_1 - f_3)$ wave has phase of $100\pi - 99\pi = \pi$. If in a similar manner further frequencies are applied, the measurement can be extended to a distance of 10,000 m, etc., without any ambiguity.

The term *fine* frequency can be assigned to f_1 which appear in all the frequency difference values, i.e. $(f_1 - f_2)$ whilst the other frequencies needed to make up the stages, or measurements of distance 100 m, 1000 m, etc., are termed as *coarse* frequencies. The f_1 phase difference measured at the master station covers the length for 0 m to 10 m. The electronics involved in modern EDM instruments automatically takes care of the whole procedure.

On inspection of Fig. 2.14, it will be seen that two important facts arise:

(a) When $\Delta\lambda_1 < \Delta\lambda_2$, $n_1 = n_2 + 1$ $\quad (n_1 = 7,\ n_2 = 6)$

(b) When $\Delta\lambda_1 > \Delta\lambda_2$, $n_1 = n_2$ $\quad (n_1 = 5,\ n_2 = 5)$

These facts are important when evaluating overall phase differences.

Now for we get

$$n_1\lambda_1 + \Delta\lambda_1 = n_2\lambda_2 + \Delta\lambda_2$$

$$n_1\lambda_1 + \Delta\lambda_1 = (n_1 - 1)\lambda_2 + \Delta\lambda_2$$

From Eq. (3.43) the value of n_1 can be determined.