

# A NEW REFINEMENT TO A FAMILIAR TECHNOLOGY—TIME-OF-FLIGHT EDM IN A TOTAL STATION

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## ABSTRACT

Optical total stations have been in common use for almost a quarter century. With few exceptions, their EDM systems have been of the phase resolving type, requiring the use of a retroreflector. The recently introduced Trimble 5600 with DR200<sup>+</sup> EDM (originally released as the Geodimeter System 600S DR200<sup>+</sup>) represents a significant upgrade to the capabilities heretofore available in optical total stations. Its EDM utilizes time-of-flight technology enabling reflectorless distance measurements to points of interest. Whether it is a safety issue, measuring an impossible-to-reach point, or simply a procedure that rapidly speeds up the work of surveying—reflectorless EDM technology puts awesome capabilities, flexibility and accuracy in the modern surveyor's hands. Unlike the commonly used handheld reflectorless measuring devices, this instrument delivers unsurpassed measurement speed, range and accuracy in the most demanding of field situations. In this paper the theory of time-of-flight measurement is discussed and compared, and contrasted with the phase resolving EDMs. A description of the integration of the EDM in its total station package and the opportunities it offers for improving surveying performance are presented.

## BIOGRAPHY

Joseph V. R. Paiva, is director of business development for the Engineering & Construction Division of Trimble. His previous assignments at Trimble have included senior scientist and technical advisor for Land Survey research and development and vice president and general manager of the Land Survey group. Previously, Paiva was vice president and a founder of Sokkia Technology, Inc., where he guided the development of GPS- and software-based products for surveying, mapping, measurement and positioning. He has also held senior technical management positions in The Lietz Co. and Sokkia Co. Ltd., of Tokyo, Japan. Dr. Paiva was also a professor of civil engineering at the University of Missouri-Columbia, and a partner in a surveying/civil engineering consulting firm. He is a Registered Professional Engineer (PE), Registered Professional Surveyor (PS), and has more than 25 years experience in civil engineering, surveying and mapping.

## INTRODUCTION

Optical total stations have been in common use for almost a quarter century. With few exceptions, their EDM systems have been of the phase resolving type, requiring the use of a retroreflector. Phase resolving EDMs generally require retroreflectors to be positioned at the point being measured. The introduction of a class of instruments that do not require retroreflectors has been hailed as an advancement for many types of work the surveyor does. For safety reasons, the ability to survey without reflectors the surfaces of traveled roadways, building and rock faces and objects previously only accessible to a rod person by means of ascending or descending using ladders, ropes or even cranes has been well received. Even when safety is not involved there are many surveying situations where the complete inaccessibility of a point has made it necessary to survey using triangulation before reflectorless technology became available. Sometimes, reflectorless total stations just reduce the work spent in reaching routine points to be surveyed. Whether it is a safety issue, measuring an impossible-to-reach point, or simply a procedure that rapidly speeds up the work of surveying—reflectorless EDM technology puts awesome capabilities, flexibility and accuracy in the modern surveyor's hands.

The recently introduced Trimble 5600 200<sup>+</sup> shares many features with other reflectorless total stations available today. It also has several features that are unique. This paper discusses both to present to the user a complete picture of its potential. Speed, accuracy and measurement range are the instrument's strongest points. Elements of the theory of design underpinning these characteristics are especially emphasized in the discussion.

The 5600 DR200<sup>+</sup> represents a significant upgrade to the capabilities heretofore available in optical total stations. Its EDM utilizes time-of-flight technology enabling reflectorless distance measurements to points of interest. Unlike the commonly used handheld reflectorless measuring devices, this instrument delivers unsurpassed measurement speed, range and accuracy in the most demanding of field situations. In this paper the theory of time-of-flight measurement is discussed and compared, and contrasted with the phase resolving EDMs. A description of the integration of the EDM in its total station package and the opportunities it offers for improving surveying performance are presented.

## EDM MEASUREMENT TECHNIQUES

Two techniques for measuring distances with light waves are commonly used. By far the most common is phase resolving technology. Time-of-flight technology is the other. The latter has not been used to a large degree in surveying instruments until recently.

### **Phase Resolving Technology**

Many surveyors with phase resolving technology EDMs commonly refer to the measurement technique as akin to measuring how long it takes light transmitted from the surveying instrument to be returned to the instrument and then applying the speed of light to determine the distance. This, however, is an incorrect perception. The emitted light is modulated so as to create a pattern. The received pattern (after reflection) is compared with the emitted pattern to resolve the distance. In effect the EDM measures how much the received pattern must be "shifted" to

exactly match the emitted pattern. A high signal to noise ratio, to enable precise measurement of the phase shift, is obtained by using a retroreflector to get a high strength signal in the surveying instrument's receiver. The signal is balanced with an attenuator to match it with the optimum signal strength required by the receiver to measure the phase with high precision. To measure a distance with high accuracy, a short modulated wavelength must be used. This, however, makes resolution of distances typically measured by surveyors ambiguous. This ambiguity is resolved by changing the modulation, to allow longer wavelengths. Generally, the distance measurement made with the longer wavelengths has coarser precision, but the ambiguity in the measurement is removed. The final result is a combination of the unambiguous coarse measurement(s) and the fine measurement.

### **Time-of-Flight Technology**

Pulsed or time-of-flight EDM systems do indeed measure the time taken by a pulse of light to be emitted, reflected and received by the receiver of the system. This basic principle has been used in many of the handheld laser "guns" used to get rapid reflectorless measurements of low precision. Sophisticated signal processing techniques and other statistical analysis of repeated measurements allow measurement accuracies approaching that of phase resolving technology, but with much faster measurement times and measurement ranges to reflectors as well as reflectorless targets.

## TRIMBLE 5600 DR+ EDM TECHNOLOGY

In general, the measurement technology emits rapid, but short (on the order of 40 4.5 ns pulses per second, spaced to generate about 25KHz for the Trimble 5600). Even though this laser energy is classified as Laser Class I, the peak power of 12W (as compared to a few tens of mW for phase resolving EDMs) enables direct reflection to be strong enough to be detected. These reflected pulses are still on the order of one-millionth of the emitted pulses. Once detected by avalanche photodiodes, special signal processing techniques are used to make the returned energy useful enough to make measurements on to determine the range to the sighted target.

**Initial Measurement Phase:** The first pulses fired by the 5600 are analyzed by the on-board software to determine whether the returned energy is of the level indicating that the measurement is to a prism. If so, the processes to further attenuate the received pulses are started to condition them to the level required for the most accurate measurements on the returned waveforms. If no prism is detected the software then analyzes the received data for multiple targets. As this system is reflectorless, there is always the possibility that there will be returned energy from other surfaces than the intended targets.

In general, the software can detect multiple targets that are separated along the axis of the measuring beam by distances greater than about 0.65m. This corresponds to about half of the 4.5 ns pulse length of 1.3m.

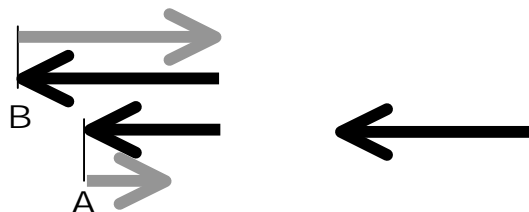




Figure 1: Reflected Pulse Interference; Targets Close to Each Other Axially

Figure 2: Discrete Reflected Pulses; Targets Separated by More Than Pulse Length

In Fig. 1, two targets, A and B are shown separated by less than the pulse length. The dark pulses shown moving right to left are emitted. The grey pulses shown moving left to right are reflected. It can be seen that the pulse reflected from the closer target A will interfere with the pulse reflected from B. When the targets are separated by more than the pulse length as in Figure 2, it can be seen that such interference does not occur. It should be apparent from inspection that the separation between A and B at which interference is likely to happen is at one-half of the pulse length.



Figure 3: Trimble 5600 DR<sup>+</sup>  
(Robotic version shown)

Resolving the Distance: The distance is resolved using more than one signal processing technique. One of them relies on the analyzing the shape of the emitted pulse and the reflected pulse. Both are analyzed to identify discrete points for comparison to make the determination of the elapsed time of travel. Unlike the figures above, it should be noted that seldom will a reflected pulse have the same or even similar waveform of the emitted pulse. Thus finding a one-to-one comparison point for evaluating time of flight is one of the most sophisticated aspects of the signal processing technology of the 5600.

This analysis is done by making measurements at several dozen points on the emitted and reflected waveforms and determining the shape of each before committing to fiducial points (there may be more than one in each fitted waveform) to make the timing decision.

A further technique for making the measurement is even more basic and necessary before the waveforms can be analyzed. This is the process of integrating the measurements being made at the average rate of 25KHz approximately to develop a strong indication of the pulse. The noise in the system is sufficiently high that a single pulse would result in no possibility of making a measurement. It is only with thousands that it is possible to cause the reflected pulses to “rise” out of the noise.

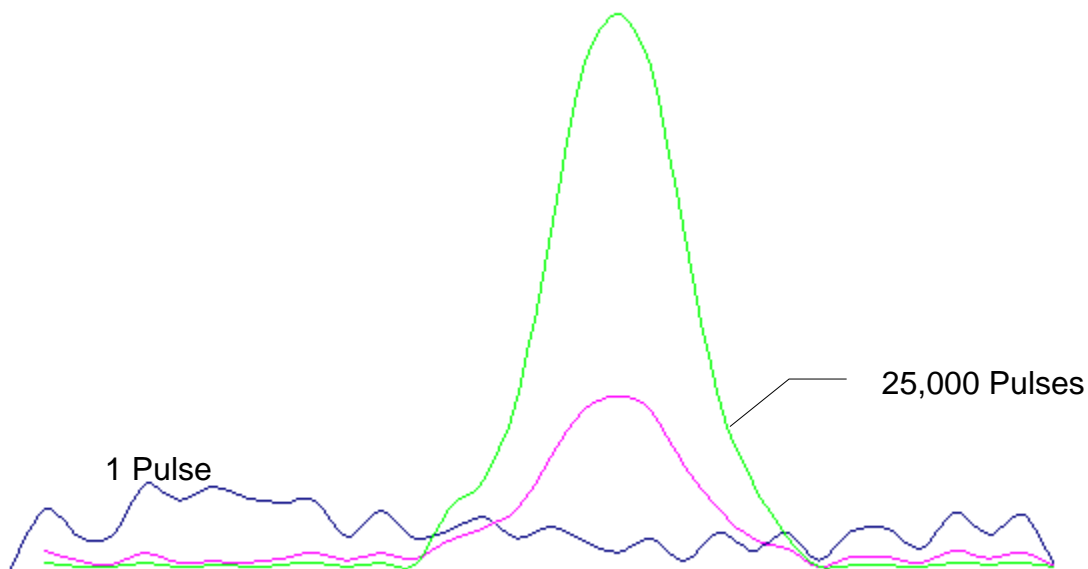


Figure 4: Integration of the Measurements to Make the Pulse Detectable

These are the most important of the techniques that not only yield a viable measurement, but they make the speed, accuracy and range of the 5600 feasible.

## OPPORTUNITIES

Reflectorless ranging has been used in a wide variety of applications, generally in the form of the handheld laser guns. Finally, accuracies on the order of 3mm when measuring under 200m *and* reflectorless range of over 200m to surfaces the equivalent of Kodak Grey (18% reflectivity) and 600m to the equivalent of Kodak White (90% reflectivity) are possible. Where reflectorless measurement have heretofore been for the purposes of determining rock volumes and configurations of open pit mine surfaces, it is now possible to use it in situations where precise construction stakeout, precision mapping and detailed as-built drawings need to be compiled.

Mapping the complexities of compound surfaces, especially when the servo-driven capabilities of the instrument are used and automated monitoring of soil and rock faces susceptible to instability are further examples of new applications with reflectorless measurement that are now feasible.