ABSTRACT

MURPHY, JAMES SMITH. Electronics Based Innovation In A Niche Market: Distances Measured By The Speed Of Light (Under the direction of Dr. Ross Bassett)

The purpose of this study is to document the development of an accurate, affordable, reliable machine to perform the relatively long distance measurements routinely made by land surveyors. Prior to the development of the technology, surveyors used a variety of contact instruments for measurement: ropes, rods, poles, chains and steel tapes. The difficulty of obtaining results on long measurements by contact devices led innovators of the Eighteenth and Nineteenth centuries to develop alternate non-contact methods of measuring: subtense bar, stadia wires and triangulation, all of which came with their own inadequacies. In 1951, Erik Bergstrand, a physicist with the Swedish Geographical Survey Office culminated thirteen years of research by bringing an electronic distance meter which measured distances based on the speed of light to the market. Research efforts undertaken during and after World War II in applied electronics and wave propagation led to the maser, which allowed South Africans Harry Baumann and T. L. Wadley to develop and market a device using the microwave spectrum to measure. Maser research was the progenitor of the laser, which led to the discovery of the lasing properties of a Gallium Arsenide diode emitting light in the infrared spectrum. Advances in transistors and integrated circuit technology introduced the simplification and miniaturization to electronic distance measuring that would transform the once novel instrument into a commodity product.

This thesis explores that transition primarily through the words of those who used these instruments on a daily basis, from the pioneers in the geodetic community who

measured between mountain peaks down to the practicing land surveyor who made his living surveying farms and marking out lots in new subdivisions.

ELECTRONICS BASED INNOVATION IN A NICHE MARKET: DISTANCES MEASURED BY THE SPEED OF LIGHT

by
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BIOGRAPHY

The author, James Smith Murphy, was born in Roxboro, North Carolina to Clyde and Nina Murphy on September 8, 1950. He obtained a Bachelor of Arts degree in Political Science from North Carolina State University in 1999. He obtained his first professional licensure in North Carolina in 1978 and has subsequently been licensed as a Professional Land Surveyor in eight additional eastern states.

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INTRODUCTION

A panoply of literature has examined and documented the impact of technology on society, much of it relating to computers. Over twenty years ago, *Time* magazine named the computer as Man of the Year, and few would disagree that it continues to make sweeping changes in everyday life. The computer was never envisioned to perform the many tasks it has simplified today. Notwithstanding the contribution of Charles Babbage, the first operational computing machine was ENIAC. It was not built to perform word processing or database management. It was built during wartime to solve complex trajectory equations. Concurrently, significant research was underway on methods to propagate radio waves that could provide more secure communications systems and enhance radar capabilities. These massive efforts would continue and intensify as the hot war went cold. The inventions and innovations in one area would unlock a door in another completely diverse area, occasionally allowing a monumental breakthrough to solve an obscure problem in a niche market.

Whatever happened between Mr. Franklin's experiment with kite and keys in a thunderstorm and the designs of Mr. Edison and Mr. Westinghouse that made an inexpensive source of energy available to every home, electricity and technology have been partnered. Whether Tesla or Marconi first developed radio waves is irrelevant; that they were developed and harnessed is significant.[1] The properties exhibited by radio waves and tiny electrons had captured the hearts of militaries around the world. Radio

[1] Marconi Wireless Telegraph Corporation of America v. United States, 320 US 1 (1943).

waves are the building blocks for radar. Electrons permit machines to make rapid calculations and decisions based on preconceived rules, among other things.

It is those other things that this thesis examines, offshoots of larger technological advances that synthesize to create a marvel that can radically change an entire profession. From ENIAC through EDVAC to UNIVAC, from vacuum tubes to transistors to printed circuits to integrated chips, from neon bulbs to nixie tubes to LEDs to liquid crystal displays, electronic devices have gotten faster, cheaper and smaller. Technologies developed for a single purpose have found a plethora of tangential but unintended uses.

Joan Lisa Bromberg cited two trends that informed the rapid growth of electronics research after 1950: a tremendous increase in the funds available for research and development, and a growing market for electronics.[2] After enormous spending to develop radar and communications systems during World War II, the Korean conflict caused the military budget to increase from $13 billion to $50 billion. Cold War shivers centered on the fear of Communist world domination, assuring a steady supply of tax dollars to perform the research that would make faster, smaller and more lethal weaponry. Sputnik, visible in those October night skies in 1957, was a chilling reminder that the Russians were not only a viable and capable antagonist, but had already won the race to space.

Underneath that canopy is a tiny cadre of people engaged in the peaceful task of measuring the earth. Government sources disclose 51,490 people employed in the occupation of surveying in 2003.[3] Surveyors comprise only 0.04% of a workforce

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[2] Joan Lisa Bromberg, *The Laser in America* (Cambridge: The MIT Press, 1991), 1.

[3] Table A-1. National employment and wage data from the Occupational Employment Statistics survey by occupation, May 2003, available from http://www.bls.gov/news.release/ocwage.t01.htm accessed 2 November 2004.

estimated at 130 million by the U. S. Department of the Census. There are actually more legislators than surveyors in the United States. It may be safe to conclude that the market for products needed by surveyors is not overstated by application of the term ‘niche’.

This small cohort’s greatest benefit from the largesse of taxpayer funded research came in the form of an affordable, accurate and lightweight machine that generated substantial increases in productivity and professional work quality. At first, though, it was large, somewhat inefficient, relatively expensive, complicated to operate and served but a single purpose. This thesis chronicles the development of electronic distance measuring equipment through the words of those who experienced first-hand the excitement and pleasure of realizing that very soon, the steel tape would be seen only in museum exhibits.

Since ancient times, societies have needed to make precise measurements of distances for any number of reasons. Inscriptions on the Palermo Stone reflecting daily life in Egypt circa 3000 B.C.E show river-gage readings and “numbering of gold and lands.”[4] Markers set during the time of King Ikhnaton (1375-1378 B.C.E) are extant and have been found to be “…remarkably close…” to current measurements.[5] Chapter 7 of Deuteronomy recounts Moses’ charge to the people of Israel, “Cursed be anyone who moves a neighbor's boundary marker.” Private property ownership is the bedrock of modern capitalist economies, a stark contrast to Marx’s first rule in his manifesto, abolition of property in land.

As long as the markers that delimit boundaries remain in place, there is little to be served by measuring between them. But when a marker is lost or destroyed, it cannot be

[4] R. S. Burnside, “The Evolution of Surveying Instruments,” S*urveying and Mapping* 18, no. 1 (Jan-Mar 1958): 59.
[5] Burnside, 60.

accurately replaced unless its prior location was recorded. Land surveyors are responsible for determining location, and use polar coordinates (direction and distance) to reference positions on the ground.

The devices used for measurement of distance were, until the middle of the last century, contact devices. That is, the instruments had to be handled. From the original Egyptian ropes, the technology progressed through steel link chains, poles that were one quarter chain in length and turned end over end, steel tapes calibrated in chains, steel tapes calibrated in feet and decimal units thereof, and high precision Invar tapes with extremely low coefficients of thermal expansion and modular elasticity.[6]

This thesis will argue that the most profound technological advancement in private practice land surveying since World War II was the introduction of an affordable, accurate non-contact distance measuring instrument. The original machine was named Geodimeter, followed several years later by a similar instrument using a different technology, the Tellurometer. In order to appreciate the value of such instruments, one must have an idea of the skill and knowledge needed to precisely measure overland distances using traditional equipment, i.e., a steel tape. Some understanding of the professionals who use them, and the manner in which they are used, will be helpful.

[6] One chain is sixty six feet, a quarter chain corresponds to sixteen and one half feet.

CHAPTER 1

WHO MEASURES, AND WHY

Surveying texts of the early Twentieth century described three classes of survey: "(1) those for the primary purpose of establishing the boundaries of landed property, (2) those forming the basis of a study for or necessary to the construction of public or private works, and (3) those of large extent and high precision conducted by the government and to some extent by the states."[7]

The distinction between the first two classes described by Davis and Foote is the need of the first group to understand the legal aspects of boundary surveying, an area where the practicing professional is responsible for making quasi-judicial judgments relating to real property ownership lines. The second and third classes merely require technical expertise and an acquired skill in operating instruments. Typically, a practitioner of the first class would be identified as a land surveyor.

Those in the second class are known as topographic surveyors, or survey engineers. Engineering surveyors measure the difference between known points on the surface of the earth, primarily in connection with the design data needed for railroad, highways and airports.[8] A survey engineer is concerned with "…essentially fixing the position of a point in two or three dimensions." This second class contains two sub-groups, those who *locate* and those who *layout*. An understanding of the differences

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[7] Raymond E. Davis and Francis S. Foote, *Surveying Theory and Practice* (New York: McGraw-Hill Book Company, 1940), 2.
[8] *Engineering Survey Manual* (New York: Committee on Engineering Surveying of the Surveying Engineering Division of the American Society of Civil Engineers, 1985), 29.

between *location* and *layout* is necessary to explore how effective electronic distance measurements came to be used.

The third class identified by Davis and Foote are known as geodetic surveyors. Geodesy is loosely understood as that branch of science concerned with measurement of the earth, and as applied to surveying, includes those tasks that require taking the shape of the earth into consideration.

To understand how each of these groups impact average people, consider the situation of a family who elects to build a house. Their first task is to select a location. Whether this is a lot in an existing subdivision, or several acres obtained as a gift from a grandparent, a boundary surveyor will be involved initially to establish or confirm the legal boundaries of the property. It is likely that the surveyor will be required to make a tie between the property corners and a monument established by a government agency in order to establish state plane coordinates for the property. This is a legal requirement in many states if the subject property is within proximity of a published control monument.[9] As the referenced statute reveals, either a Federal or State Agency is responsible for the placement and survey of the monuments. The architect will probably ask for a topographic survey of the property, showing ground contours, roads, sidewalks, water and sewer connections and possibly trees. While performing this study, the surveyor is engaged in what may be termed *location* work. That is, determining the actual location of known features. After the architect has sited the house, the contractor must mark out the location of the proposed house, a task known as *layout*. The methodology of location

[9] See, for example, North Carolina General Statute §47-30 (f) (9): "Where the plat is the result of a survey, one or more corners shall, by a system of azimuths or courses and distances, be accurately tied to and coordinated with a horizontal control monument of some United States or State Agency survey system, such as the North Carolina Geodetic Survey, where the monument is within 2,000 feet of the subject property."

work differs from layout work. The object of interest during location is stationary and easily located. The point needing layout is but one point in a locus of infinite magnitude— a moving target, so to speak. Irrespective of which class the surveyor associates with, a primary task will be measurement of distance.

CHAPTER TWO

CONTACT DISTANCE MEASUREMENTS

Surveying distance measurements are taken along a level line. Slope measurements are inadequate. If the land is subsequently graded, the original slope is lost and a replacement cannot be made with any degree of certainty. In order to achieve a level line over sloping terrain, one end of the measuring tape must be elevated above the ground. Since the point of reference is on the ground, and the tape is above it, an additional device is needed to determine the intersection of the projection of a zenith line and the tape calibrations. This instrument is typically a plumb bob, a brass weight with a pointed end toward the ground, suspended by a string. The surveyor must then ensure that his tape is level and his plumb bob oriented directly above the measuring point on the ground. Using thumb and forefinger, the string is rolled along the tape until the plumb bob tip is directly over the point. At this time, the tape calibrations may be read.

Steel tapes expand and contract with variations in temperature, and unless supported fully throughout (as on a roadway) will sag. In addition, the steel will stretch under the pressure of being supported only on each end. To compensate for fluctuations in temperature, the ambient temperature must be recorded and the taped distance corrected to standard temperature (68° in the United States.) By applying a calibrated spring balance to one end of the tape, adequate tension may be applied to stretch the tape long enough to overcome the errors of the catenary sag. To further complicate matters, the tape may not have been manufactured to an exact length. Comparison to a known baseline is necessary to determine the amount of manufacturing error.

In the 1930s, a field survey party carried a "…transit, 100-ft. steel tape, two range poles, stake bag, stakes, tacks, axe or hammer, two or three plumb bobs, field notebook, chaining pins, and marking crayon."[10] Davis et al. described four classes of survey, class two being used for most boundary survey and road and rail location. "By far the greater number of transit traverses fall in this class."[11] The party would measure the angles to nearest minute and take angle point sightings on range poles plumbed by eye. They would disregard slopes under 2% for measurement, estimate standard pull on the tape and ignore temperature corrections if the ambient temperature were within fifteen degrees of 68 degrees F., the standard. An error of closure of 1 part in 3000 could be expected using this method.

What is an error of closure? Consider this example. Suppose you were in a parking lot, with instructions to walk north 100 feet, east 100 feet, south 100 feet and then west 100 feet. That describes a perfect square, and you should end up exactly where you started. But, if you assume that your wide pace is three feet, and you use the sun and your shadow for direction, there is little chance that after the last leg you will be even close to where you started. The difference between where you started and where you ended up is, to the surveyor, your error. Assume you are very careful and miss by only two feet. You have an error of two feet in a perimeter of four hundred feet, an error of closure of 2/400, or more properly, 1/200.

Error of closure is the standard method for describing the relative precision of a field survey. The numerator is always 1. The denominator varies, with larger numbers meaning better results. More accurate measurements of direction and distance yield a

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[10] Raymond E. Davis, Francis S. Foote and W. H. Rayner, *Elements of Surveying* (New York: McGraw-Hill Book Company, Inc., 1930), 187.
[11] Davis, *Elements,* 199.

better error of closure. In Davis' example, crude techniques yield expected errors of closure of 1/500. The refined techniques specified in the Davis text (higher classes of survey) were expected to yield results approaching 1/10,000.

It should be readily apparent that considerable skill and care is required to precisely measure an overland distance. When the distance must be measured through swampland or mountainous terrain, the inconvenience and burden involved in precise measurement are substantial. For these reasons, early innovators sought non-contact methods of determining distance.

CHAPTER THREE

NON-CONTACT DISTANCE MEASUREMENTS

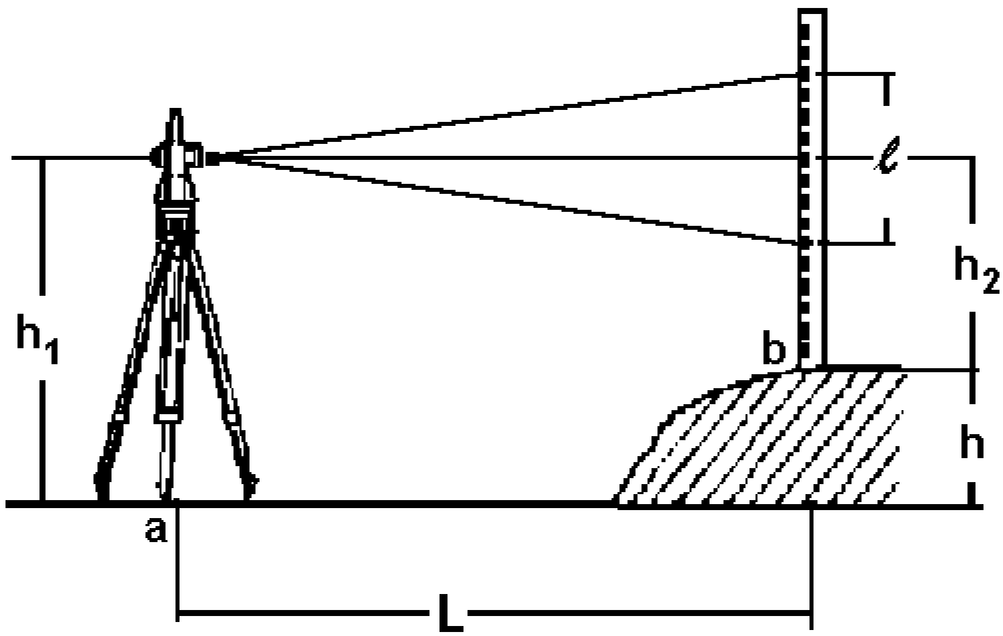

Figure 1. Principles of Stadia Measurement. Source: http://pasture.ecn.purdue.edu/~agen215/stadia.html

Even before Galileo created the first successful telescope, Levi ben Gerson, a Jewish mathematician of the Fourteenth century devised the *baculum,* a calibrated wooden rod was used by Turks, Indians and Arabs to measure distance by observing the extent of the markings that was exposed.[12] Referring to Figure 1, it can be readily seen that as the distance **L** increases, the vertical distance ℓ increases proportionally.

The first optical solution was the introduction of stadia hairs in the reticle of the transit telescope. James Watt, of steam engine fame, is attributed with the first use of

[12] William E. Kreisle, "History of Engineering Surveying," *Journal of Surveying Engineering* 114, no. 3 (August 1988): 107.

stadia during the 1772 survey for the Tarvert and Caledonia canals in England.[13] Fine wires (actually spider web strands) were positioned so that when a calibrated rod was observed at a distance of one hundred feet, exactly one foot of difference was observed between the upper and lower stadia hairs.

Stadia measurements allowed the surveyor to "measure distances with great rapidity but with not very great accuracy."[14] Since the span between wires had to be multiplied by a factor of one hundred, distances determined by stadia were at best within one foot. Ample for some purposes, such as topographic mapping, stadia is wholly inadequate for boundary and control surveying.

The subtense bar was popular in Europe and other parts of the world, but rare in the United States. "Distances are obtained by observation of the horizontal angle subtended by targets fixed on a horizontal bar at a known distance apart of from 2 ft. to 20 ft."[15] It was attached horizontally to a tripod and the angle between targets measured with a precise theodolite. The distance was determined by trigonometric methods. Information relating to the date of either initial use or widespread adoption of the subtense bar remains elusive, although it was used with great success for measuring lengths in rough country during the Great Trigonometrical Survey of India in the Nineteenth century.[16]

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[13] Kreisle, "History," 110.
[14] Charles B. Breed and George L. Hosmer, *The Principles And Practice Of Surveying Volume I Elementary Surveying* (New York: John Wiley & Sons, 1934), 5.
[15] David Clark, *Plane And Geodetic Surveying For Engineers Volume One Plane Surveying*, Third Edition Revised and Enlarged by James Clendinning, (London: Constable & Company Ltd., 1941), 507.
[16] Clark, *Surveying*, 508.

This country's first civilian scientific agency was the Survey of the Coast, established by President Jefferson in 1807.[17] It did not become operational until the 1830s.[18] Later named the Coast and Geodetic Survey, and now the National Geodetic Survey, this agency was responsible for establishing control points throughout the nation. Local surveyors used these control points for myriad purposes, primarily for tying various surveys into a common datum.

Until reliable electromagnetic distance measuring equipment became available, the agency used the principles of triangulation to extend surveys across the continent. Triangulation is a method that uses the mean of redundant observed angles at the vertices of adjacent and overlapping triangles. One very precisely measured baseline distance is needed to begin the chain of triangles, and another precise baseline is required to close the chain and verify results. By using a trigonometric method known as the Law of Sines, once one known side and two angles are known, the other unknowns may be computed. In practice, all of the angles are measured and then each of the three angles adjusted to ensure an internal angle sum of exactly 180 degrees.[19]

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[17] http://www.ngs.noaa.gov/INFO/NGShistory.html accessed 1 November 2004.

[18] Thomas G. Manning, *U. S. Coast Survey vs. Naval Hydrographic Office: A 19th Century Rivalry in Science and Politics* (Tuscaloosa: The University of Alabama Press, 1988), 1.

[19] J. G. Oliver and J. Clendinning, *Principles Of Surveying* Fourth Edition (New York: Van Nostrand Reinhold Company, 1978), 54.

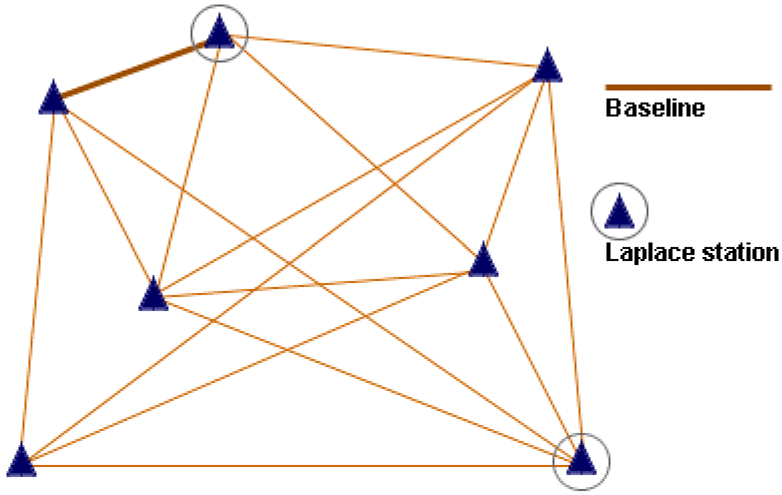

Figure 2. Network of triangles. Source: http://www.sli.unimelb.edu.au/nicole/surveynetworks/02a/notes01.html

Figure 2 shows a simple triangular network used to establish control points by triangulation. The first step is to carefully measure the length of the baseline. A theodolite is centered over the upper circled triangle and redundant angles are measured to all stations that can be observed.

During the spring of 1802, the primary control network of the Great Trigonometrical Survey of India was performed by triangulation.[20] The initial baseline was measured with a one hundred foot steel tape, "supported and tensioned inside five wooden coffers…cleverly slotted onto tripods fitted with elevating screws for leveling."[21] The seven and one half miles of baseline required four hundred individual measurements and required fifty seven days.[22] After one hundred and fifty years of progress, this

[20] John Keay, *The Great Arc: The Dramatic Tale of How India was Mapped and Everest was Named* (New York: HarperCollinsPublishers, 2000), 8.
[21] Keay, *Great Arc,* 30.
[22] Keay, *Great Arc,* 31.

measurement could have been taken in only four hours with a Geodimeter. Twenty five years after that, it could be done in less than a minute.

Six years after the introduction of the Geodimeter, and one year after the Tellurometer came to market, taping methods were still commonly used. R. M Boynton of D. B. Steinman Consulting Engineers described the methods used for a baseline measurement in a paper presented to the American Society of Civil Engineers in February of 1958. Chaining bucks with copper scribe plates were constructed. These bucks are wooden posts set firmly in the ground. They resemble a very short fence post. A copper plate is fastened to the top to permit the surveyor to scribe a thin line with a sharp scribing instrument on the plate. These bucks were placed at 100 meter intervals for use with a 100 meter Lovar tape. The location for the bucks had to be measured first, before the actual precise taping occurs. The baseline was divided into sections, and measured with three different tapes. Temperature and tension readings were taken at each measurement. The line was remeasured, using a different tape for each section. The difference in elevation between each buck was determined by running a "level line" over all the posts to correct the slope measurement to a level measurement. This baseline was slightly over two miles long.[23]

After the baseline was measured, wooden towers called 'signals' were built on the ground and then erected over the points. William McCaslan Scaife, an employee of the United States Coast and Geodetic Survey, maintained a diary doing triangulation work in Alaska during the period 1919 to 1920. On May 13, 1920 he wrote, "Have got the signal about ready to put up. I don't believe a dozen men could have put it up today without

[23] R. M. Boynton, "Precise surveys for Mackinac Bridge," *Surveying and Mapping* 84 no. SU-2 (July 1958): 1716-2.

special equipment. The wind would all but take planks out of our hands and would have if the planks were not held like we were wrestling with them. It was very hard to saw. The wind would get the saw blade and bind it just as if it were nothing. Got my eyes full of sawdust time and again."[24] With his tower finally erected, he began to climb up with his theodolite in an effort to begin measuring angles. On Sunday, May 16, he "Set up over the station and tried to observe, but couldn't see a thing to observe on except Kubegaklin (maybe)." Several different crews from the Coast survey were building and erecting towers in other places for use in the triangulation network. As the work progressed, the men mounted their towers with theodolite and heliotrope.

As its Greek etymology discloses, a heliotrope is an instrument that turned the sun. The signalmen used the mirror in the heliotrope to reflect the sun to other signals (towers) for sighting purposes. The concept of using reflected sunlight came from Carl Frederich Gauss, a German mathematician and astronomer. He was frustrated by the glare of the sun's rays in a church window pane while trying to make observations in Lüneberg. Reflecting on this nuisance, Gauss experimented and devised the heliotrope, which was soon in use around the world. During the Great Trigonometrical Survey of India, Colonel H. Thuillier reported that the heliotropes were visible for ninety to one hundred miles.[25]

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[24] William McCaslan Scaife, Diary. Available from http://www.history.noaa.gov/stories_tales/scaife6.html accessed 28 October 2004.
[25] Silvio A. Bedini, "The Surveyors' Heliotrope: Its Rise and Demise," *The American Surveyor*, Volume 1, No. 6 (November 2004): 44-47.

Figure 3. Heliotrope (1883). Source:
http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=764374

On Saturday, May 29, Scaife wrote, "Got a couple of sets on Kulugakli and Ikolik this morning. About noon Ridge began to show, intermittently, but I got a couple of sets on Ridge and Ikolik. Caught a few glimpses of Ridge this morning, but not enough to observe on. Saw Top pretty good all day, but didn't need him. Now I am practically thru. I have four sets on Kulugakli and Ikolik and four on Ridge and Ikolik, whereas I need only three of each. I took an extra set of each as there was a set of each that I wasn't quite satisfied with, but I think that all are passable. Got a horizon closure within 0.4 second of perfect today, and one within 0.8 second yesterday."[26]

Figure 4. Theodolite (ca. 1820) Source:
http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=762255

[26] Scaife, Diary.

Geodetic survey stations are named. When Scaife writes of Kulugakli and Ridge and Top, he is referencing the names of the signals constructed over other stations in the network. A "set" is a series of redundant angular measurements, usually sixteen turns with the theodolite in the erect face, and another sixteen in the inverted face. An inverted face is when the telescope is upside down. As the sets are taken to all observable signals, the sum of the mean of the individual angles should be 180°. Closing the horizon means to compare the measured sum with the known mathematical sum. Realizing that one second of arc is equivalent to the width of a dime at two miles, closing the horizon within fractions of a second is a remarkable feat.

Figure 5. Bilby Survey Tower (ca. 1945). Source: http://www.photolib.noaa.gov/historic/c&gs/theb2560

The high cost associated with constructing wooden towers led to the United States Coast and Geodetic Survey resorting to traverse methods (that is, measuring distances overland with a steel tape) during the period 1900-1927.[27] By 1927, a Coast and Geodetic chief signalman named Jasper S. Bilby, "…drawing on steel windmill technology used throughout the west, erector set toys, [and] gas pipe towers…" had developed a reusable tower of steel bars and rods held together with bolts.[28] Triangulation returned as the principal method of performing geodetic surveys.

Triangulation methods require the erection of two towers at each position to be observed. One tower supported the instrument, the other supported the operator and his note keeper. With the advent of battery powered lights, observations were taken at night to lighted targets. Clearly, this agency went to a lot of effort to avoid ground measurement methods, a testament to the difficulty of precise contact measurement.

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[27] Joseph F. Dracup, "Geodetic Surveys in the US The Beginning and the next 100 years." Available at www.history.noaa.gov/stories_tales/geodetic5.html accessed 1 November 2004.

[28] Dracup, *Geodetic Surveys.* Available at http://www.history.noaa.gov/stories_tales/geodetic4.html accessed 1 November 2004.

CHAPTER FOUR

GENESIS AND THE EARLY YEARS

The idea that reflected radio waves could be used to determine the position of a remote object was first offered by Nikola Tesla in 1889.[29] By the fall of 1922, the U. S. Naval Research Laboratory successfully "detected a moving ship" by use of reflected radio waves.[30] In 1923, H. Lowy had been experimenting with ground penetrating radar and filed a patent application for an electronic distance measuring instrument.[31] By 1940, with war raging on the European front and the strong probability that the United States would ultimately be involved, Great Britain and the United States collaborated on the development of airborne radar. The top secret Tizard Mission introduced a British development, the cavity magnetron, to the United States in September of 1940. Within a month, government funded research into enhanced radar technology was underway at the Massachusetts Institute of Technology radiation laboratory.[32] The total expenditure during World War II for research, development and procurement of radar equipment was $2.7 billion dollars, eclipsing the $2 billion expended on the Manhattan project.[33]

The end of hostilities resulted in the formal closure of the laboratory on December 31, 1945. New Year's Day of 1946 represented the genesis of the Research Laboratory of Electronics, with the full sponsorship of the United States Office of Scientific Research and Development.

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[29] J. M. Rüeger, *Electronic Distance Measurement* (Berlin: Springer-Verlag, 1990), 1.
[30] http://www.nrl.navy.mil/content.php?P=RADAR.
[31] Rüeger, *Measurement,* 1.
[32] http://rleweb.mit.edu/radlab/radlab.HTM.
[33] Simo Laurila, *Electronic Surveying and Mapping* (Columbus: The Ohio State University Press, 1980), 14.

Despite the accumulation of mental acuity and research dollars available to this group, the first feasible non-contact distance measuring equipment providing the accuracy needed for surveying was the Geodimeter. Its development began in Sweden in 1948 by government geodesist Erik Bergstrand. Bergstrand's primary research efforts involved a refinement of the methods employed by Fizeau, Foucault and Michelson in the late Nineteenth century and early Twentieth century to determine the speed of light.

Scientific curiosity about the speed of light had long existed. In 1688, Galileo attempted to measure the speed by using two shuttered torches on mountains approximately one mile apart. His idea was to have an operator on one mountain open his shutter and start his time measurement. The second operator was to open his shutter immediately upon seeing the first torch, and the first operator ended his timing when he observed the second torch. The experiment yielded no result, as the time interval appeared nonexistent.[34]

Hippolyte Fizeau designed an apparatus in 1849 using a rotating cogwheel to observe the reflection from a mirror 1,000 meters away. Leon Foucault improved on Fizeau's concept by using a rotating mirror, and Albert A. Michelson dedicated his career to refinement of the rotating mirror instrument.[35] In the late Nineteenth century, The Reverend John Kerr developed a device known as the Kerr Cell shutter, capable of shutter speeds approaching 100 nanoseconds. Researchers who followed Michelson would employ the Kerr invention to more closely measure the speed of light.[36]

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[34] Igor D. Novikov, *The River of Time* (Cambridge, UK: Cambridge University Press, 1998), 38.
[35] A.A. Michelson, F.G. Pease, and F. Pearson, "Measurement Of The Velocity Of Light In A Partial Vacuum" *Astrophysical Journal* 82 (1935): 26–61.
[36] Laurila, *Electronic Surveying*, 227.

Bergstrand presented a paper to the International Union of Geodesy and Geophysics in Oslo in 1948 explaining his methods. He employed a light frequency of 8.3 megahertz which produced a wavelength of thirty six meters. The equation he published was $D=K + ((2N-1)/8)*\lambda$, where D is the distance, K is a constant based on the apparatus used, N is a whole number (an integer) and λ is wavelength. His observations provided an estimate of 299,796±2 kilometers per second.[37] Bergstrand announced that AGA Corporation of Stockholm, the largest electronic-optical company in Sweden, intended to manufacture the 'geodimeter' and make it available for sale.

Bergstrand was published again in *Nature* in 1950, reporting that he had successfully measured 20 kilometers between two islands off the Norrland coast and 32 kilometers between two *fjeldtops* in Lapland. The error of closure was found to be 1/450,000.[38]

As previously explained, geodetic surveys are commissioned and performed by governmental agencies. We have seen that geodetic surveyors relied on optical triangulation methods to extend their surveys over great distances. The ability to combine precise distances with the observed angles greatly enhances the ability to use redundant measurements to account for the unavoidable minute errors that are inherent in every measurement. Two factors account for the influence of the geodetic survey community in the development of early electromagnetic distance measuring equipment: applicability and resources.

The original commercial Geodimeter was produced in 1951. The Model 1 was a behemoth, weighing nearly four hundred pounds. The distance computation was derived

[37] E. Bergstrand, "Velocity of Light and Measurement of Distance by High Frequency Light Signalling" *Nature* no. 4139 (February 26, 1949): 338.
[38] Erik Bergstrand, "Velocity of Light" *Nature* no. 4193 (March 11, 1950): 405.

by measuring the phase shift in two different modulation frequencies carried by a 10 gigahertz carrier wave. All electromagnetic waves travel at the speed of light, and the time required for a signal to travel to a terrestrial reflector and return is measured in the billionths of a second. Time could not be measured accurately during this stage of technological development, requiring instead the measurement of phase shifts in the modulated sub-frequencies.

To untangle this technical jargon, recall that there is a direct relationship between the frequency of a wave and the length of the wave. The carrier wave oscillated (vibrated) at ten billion cycles per second (10 gHz). When a lower frequency was combined with the carrier wave, the difference in arrival time of the peak of the carrier wave and the peak of the higher sub-frequency would provide the first rough approximation of the distance. The time difference was visually observed on an instrument known as an oscilloscope. Observations of the difference in the lower sub-frequency wave refined the measurement.

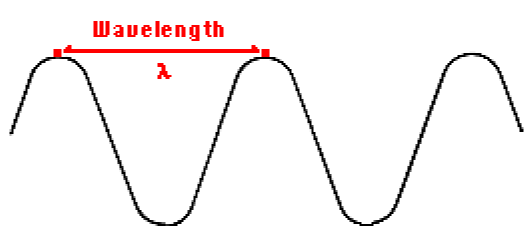

Figure 6. An Electromagnetic Wave. Source: http://imagine.gsfc.nasa.gov/docs/teachers/lessons/roygbiv/roygbiv.html

Very precise crystal oscilloscopes were required to determine the amount of shift of each sub-frequency. The crystals required a thermostatically controlled oven within the unit to maintain the calibration temperature. One source reported that once the equipment was transported and set up, it took ten to fifteen minutes to obtain a measurement in the range of one mile to more than twenty miles.[39] However, quoting Carl Aslakson of the United States Coast and Geodetic Survey, the Smithsonian reported two hours of observation and two hours of computations were required to make a measurement.[40]

Ambient sunlight affected the reflected data which degraded the accuracy of the measurement, making it necessary to take observations only at night. The utility for private sector work was greatly diminished by the inability to measure distances less than several thousand feet, as most private measurements were limited by terrestrial sight occlusions to perhaps several hundred feet.

Figure 7. Geodimeter NASM 2A (1954). Source: http://www.gmat.unsw.edu.au/currentstudents/ug/projects/f_pall/html/e11.html

The early record of reviewing the practicality of these new instruments came primarily from government agencies, the only entities with the financial and labor resources, as well as specificity of applications, to use them. In the mid 1950s, a single long-range Geodimeter cost $25,000.

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[39] J. Gauthier and L. J. O'Brien, "The Geodimeter." *Surveyor's Guide to Electromagnetic Distance Measurement,* ed. J. J. Saastamoinen (Toronto: University of Toronto Press, 1967), 67.
[40] http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=748815.

The Chief topographic engineer for the United States Geological Survey, reporting on the progress in topographic mapping thought that electromagnetic distance measuring equipment was "…not yet economical for topographic mapping control work."[41] John McCall of the Army Map Service offered his analysis of the new equipment: "[T]he continuing development of electromagnetic radiation and instruments will further revolutionize the traditional surveying methods, and the surveyor's tape may become obsolete in the not too distant future."[42] The Supervisory Mathematician for the U.S. Coast and Geodetic Survey expressed his belief that "Geodimeter and Tellurometer are definitely valuable surveying instruments which will play a tremendous part in future geodetic and engineering surveys."[43]

The United States Coast and Geodetic Survey began use of a model 1 Geodimeter in 1953 and acquired a second unit in 1956. During the period 1953 to 1958, they measured eighty four distances, the shortest of which was 0.7 miles and the longest was twenty six miles.[44] Speaking from practical experience, the average private practice surveyor may have measured this many distances in one day, though the distances measured were not nearly as long. From introduction until 1967, less than sixty

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41 Gerald Fitzgerald, "Progress in topographic mapping from 1946 to 1955," *Journal of the Surveying and Mapping Division – Proceedings of the American Society of Civil Engineers* 82, no. SU1 (March 1956): 922-3.
42 John S. McCall, "Distance Measurement with the Geodimeter and Tellurometer," *Journal of the Surveying and Mapping Division – Proceedings of the American Society of Civil Engineers* 83 no SU-2 (November 1957): 1445-6.
43 Austin C. Poling, "The Geodimeter and Tellurometer," *Journal of the Surveying and Mapping Division – Proceedings of the American Society of Civil Engineers* 84 No SU-1 (April 1958): 1617-7.
44 Joseph F. Dracup, *Geodetic Survey 1940 – 1990* http://www.ngs.noaa.gov/PUBS_LIB/geodetic_surveying_1940.html accessed 13 October 2004.

Geodimeters were sold.[45] Transistors did not replace vacuum tubes in the Geodimeter until 1964.[46]

Articles in the professional journals of the time began to appear in the late 1950s. The first review opined that operation is easy. It took just one week of training to learn how to use the instrument.[47] The reviewer stated that no device presently provided the utility and ten centimeter accuracy of the Geodimeter.[48] By the end of 1957, Geodimeter boasted that the instrument was in use in the United States, Canada, Denmark, Indonesia, Japan, Holland and Sweden.[49] With a design directed at the practicing surveyor, and a range of three hundred feet to two miles, the instrument had an estimated cost of three thousand to forty five hundred dollars.[50]

The war effort had resulted in significant advances in aviation and photography, and these technologies had combined to become photogrammetry. This type of mapping uses high quality photographs taken in overlapping flight paths to produce images capable of three-dimensional resolution. By overlapping the photographs, such that one half of the image is visible in each of two frames while the frames are separated by the distance of the differing flight paths, a stereoscopic image causes the photograph to appear three dimensional. This optical trick was nothing new, having been described by

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[45] Marc Cheves, *Geodimeter – The First Name in EDM.* http://www.profsurv.com/ps_scripts/article.idc?id=394 accessed 15 May 2004.
[46] Cheves, *Geodimeter.*
[47] Milton E. Compton, "Distance Measurements, One Million a Second," *Surveying and Mapping* 17 no 1 (January – March 1957): 30.
[48] Compton, "Distance Measurements,", 31-32.
[49] Milton Compton, "Accuracy over Short Distances with the Model 4 Geodimeter," *Surveying and Mapping* 17 no. 4 (October-December 1957): 424.
[50] Compton, "Short Distances", 425.

Wheatstone in 1838.[51] To progress beyond a simple optical illusion, it was necessary to be able to reference visible targets on the photographs to known positions on the ground. This was accomplished by placing large panels on the ground which would be visible in the photography, and then surveying the positions on the ground.

Two types of ground control are used in photogrammetry: basic control and photo control. Basic control is the backbone, measured very carefully and with high precision. Photo control is obtained by lesser precision surveys that begin on basic control, locate the photo panel and then close back on basic control. The basic control is generally adopted from station data published by a Federal or State Geodetic Survey department.[52]

The State of California purchased a Model 3 Geodimeter in September of 1957 for aerial photo control.[53] In just seven months, California had measured two hundred lines with observed errors averaging two tenths of a foot, the worst being a half foot.[54] The department estimated that savings by use of the instrument would be one hundred thousand dollars per year, and touted the Geodimeter as a "…highly practical and unusually dependable tool."[55]

The Chief Surveyor for the Australia Department of the Interior published his experiences with the Geodimeter model NASM4 in 1960. The instrument weighed thirty five pounds and was powered by a Homelite model 15A-115-a gasoline generator. This

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[51]Oliver Wendell Holmes, "The Stereoscope and the Stereograph." *The Atlantic Monthly* 3 (June 1859): 738-48.
[52] Francis H. Moffitt and Edward M. Mikhail, *Photogrammetry Third Edition* (New York: Harper & Row, 1980), 501.
[53] James D. Carter, "Geodimeter Surveying for California Highways," *Surveying and Mapping* 18 no. 4 (Oct-Dec 1958): 438.
[54] Carter, "California Highways", 439.
[55] Carter, "California Highways", 440.

newer model boasted a range of up to three miles with an accuracy of one half inch. Mr. Boyle found that the units "…well adapted for baseline measurement; and precise engineering surveys, such as determination of long bridgespans or dam deformations."[56]

AGA, the manufacturer of the Geodimeter, began advertising in each quarterly issue of the journal of the American Congress on Surveying and Mapping (ACSM). Their advertisements track the progression of innovation in the instruments. Page 25 of the 1959 Volume 1 claimed that the "…cost for the Model 4 is extremely economical and easily returned by savings gained in just a few projects use." In the December 1961 journal, on page 450, the Geodimeter 4-B had an advertised range of fifty feet to eight miles. The ability to measure shorter distances had advanced significantly. In the March 1962 issue, on page 7, Geodimeter introduced a 36 month lease plan: three months down payment and $216.60 per month. The advertisement did not specify if there was a purchase option at the end of the lease term.

With all of the good press and publicity about the Geodimeter, one would expect that it was quite the hot seller. Recalling that the instrument was announced in 1951, much can be drawn from the March 1963 advertisement on page 7 of the ACSM *Journal*: "Several hundred instruments are in daily use all over the country." Twelve years of sales and only hundreds of sales makes one wonder, in retrospect, if AGA had second thoughts about the research and development costs and whether they seriously considered halting production.

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[56] J. Boyle, "Geodimeter NASM4," *Surveying and Mapping* 10 no.1 (Jan-Mar 1950): 49-52.

Figure 8. Tellurometer (1962) Source: http://www.photolib.noaa.gov/corps/corp1403.htm

The competing electromagnetic instrument was the Tellurometer. Although Col. Harry A. Baumann of the South African Trigonometrical Survey is credited with the idea, the actual design for the Tellurometer is attributed to T. L. Wadley of the Telecommunications Research Lab of the South African Council for Scientific Research.[57] The instrument was manufactured and marketed by Tellurometer Pty. Ltd. in Cape Town.

The Tellurometer differed in operation from the Geodimeter in many aspects, primarily weight and size from the perspective of the user. Internally, it operated with microwave carrier frequencies on the order of 3,000 megahertz, whereas the Geodimeter used the visible light spectrum. Unlike the Geodimeter, which operated as a single unit with a massive reflector over the far target, the Tellurometer employed a master/slave relationship with each unit broadcasting and receiving signals from the other. This

[57] Floyd W. Hough, "The Tellurometer – some Uses and Advantages," *Surveying and Mapping*, 17 no. 3 (July-Sep 1957): 282.

relationship required the user to purchase and maintain two of these delicate and sophisticated instruments, significantly increasing the cost. Since the Tellurometer did not use visible light, it was effective during daylight hours. The shortcoming of using microwave frequencies was an aberration known as ground swing, caused by the extremely short waves in the gigahertz spectrum being reflected by the ground or any other surface within the nine degree propagation cone.[58] Sebert, et al. recommended ground clearances of two hundred to three hundred feet for a twenty mile measurement.

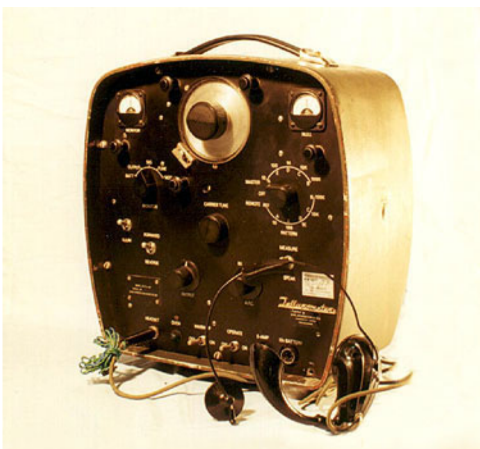

Figure 9. Tellurometer MRA 101 (1962). Source:
http://www.gmat.unsw.edu.au/currentstudents/ug/projects/f_pall/html/e7.html

The Geodimeter could, if necessary, be operated by one person, and only one unit was required, since it bounced visible light off a reflector or mirror that occupied the other end of the line. The Tellurometer, however, required a matched pair: one on the occupied station, another on the remote station, and a skilled operator tending each. This obviously resulted in an increased cost to the user. However, the Tellurometer proved to be popular, one benefit being its ability to operate in daylight conditions. An early review

[58] L. M. Sebert, L. J. O'Brien, M. Mogg, "The Tellurometer," *Surveyor's Guide to Electromagnetic Distance Measurement,* Ed. J. J. Saastamoinen, (Toronto: University of Toronto Press, 1967), 110.

of this instrument appeared in 1957. As with the original Geodimeter reviews, the early information came from the manufacturer and was always laudatory. The 1957 Tellurometer model had a total package weight of eighty five pounds, with training time reported to be a few days. It was listed as having a low relative cost, well within the reach of small surveying organizations.[59]

The Surveys and Mapping Branch of Canada's Department of Mines and Technical Surveys purchased six sets of Tellurometers in 1957, and reported some astounding results. One a single day, working from eleven o'clock in the morning to five in the afternoon, they took seven measurements totaling thirty six and one half miles.[60] Using two sets of Tellurometers, they measured two thousand seven hundred miles in just thirty eight working days.[61] To counter the problems of ground swing and reflectivity, the instruments needed to be above the ground. The Canadian crews realized that instead of placing the entire instrument on towers, they could merely mount the antennae on thirty to forty foot tall masts, an advancement that Tellurometer soon offered as a factory option.[62]

The first evidence found of a private firm using electromagnetic distance measurements came from the firm of Michael Baker, Jr. Inc. The Baker firm, still in existence today, is one of the largest consulting engineering firms in the world. In the early years, Baker introduced photogrammetric services into his company, and soon was performing aerial topographic mapping of vast tracts under government contracts. In the five years between 1952 and 1957, the Baker firm mapped 160,000 square miles for the

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[59] Hough, "Tellurometer", 281.
[60] S. G. Gamble, "Our Experience with the Tellurometer," *Surveying and Mapping* 19, no.1 (1959): 53.
[61] Gamble, "Experience with Tellurometer", 53.
[62] Gamble, "Experience with Tellurometer", 54.

United States Geological Survey.[63] They employed Tellurometer equipment to obtain the ground control needed for their aerial mapping program. The assessment of the equipment suggested that three months of training was necessary, particularly to discern instrument placement to avoid reflective interference. Citing problems with transporting the equipment, Baker concluded that although the costs for ground control surveys were not greatly decreased, the deliverable will be "…more accurate and dependable and will influence highway engineers to accept photogrammetry for more and more uses."[64]

Aerial Control, Inc., a private firm, published their experiences with the Tellurometer in 1959. Their first year was a "period of experimentation, a series of dilemmas and surprises."[65] Aerial Control, like Michael Baker, had sizable contracts with large corporations and the federal government. Among their uses for the Tellurometer was control for location of offshore drill rigs, establishment of baselines for missile ranges, and ground control for the aerial topography of thousands of acres for a new Air Force base. This firm established forty two control points over fifteen thousand acres in six days. Without the Tellurometer, they estimated the task would have required three weeks.[66] In conclusion, author Cocking suggested that electronic distance measuring equipment can meet the joint goals of accuracy and speed if the "…surveyor using this method is able to exercise imagination and resourcefulness."[67] To show the complexity of operating a Tellurometer, an advertisement by that firm in the June 1963 issue of *Surveying and Mapping* revealed some of the original complexity of operation, as well as

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[63] William O. Baker, "The Use of the Tellurometer for Photogrammetric Mapping," *Surveying and Mapping* 19, no. 1 (1959): 51.
[64] Baker, "Use of Tellurometer", 52.
[65] Albert V. Cocking, "A Year with the Tellurometer," *Surveying and Mapping* 19, no. 2 (1959): 233.
[66] Cocking, "A Year", 234.
[67] Cocking, "A Year", 236.

the progress that had been made: "In previous models, the operator took his readings from a circular trace on a graticulated scale [on an oscilloscope face]. In the MRA-3, the measurement is revealed on the instrument panel directly in numerals.[68]

For several years, quick and accurate distance measurement depended on equipment manufactured by foreign nations: Sweden and South Africa. Cold War *realpolitik* demanded that American sources for these instruments be available in the event that Cold turned Hot.

An advertisement appeared on page 15 of *Surveying and Mapping* in March of 1959 introducing the MicroDist, an electromagnetic instrument developed by Cubic Corporation of San Diego, California. In 1958, the United States Army Engineer Research and Development Laboratory (ERDL) asked defense contractor Consolidated Vultee Aircraft (Convair) to design a domestic version of the Tellurometer MRA/1. Cubic Corporation was formed in 1959 by electronic engineers formerly employed by Convair.[69]

Charles B. Hempel, a project engineer with Cubic Corporation published an overview of the American made entry to the world of electromagnetic distance measurement equipment in 1961. By this time, the sales name had changed to ElectroTape due to a name conflict with the Tellurometer Micro-Distancer.[70] Among the virtues of this new device was a total weight of forty nine pounds, an accuracy of one inch and an estimate of training time of two hours. Hempel reported that untrained

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[68] Page 303.
[69] http://americanhistory2.si.edu/surveying/maker.cfm?makerid=8, accessed 11 May 2004. But Cubic Corporation, today still a major defense contractor, dates the company formation as 1951. See http://www.cubic.com/, accessed 11 May 11, 2004.
[70] http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=748453, accessed 22 September 2004.

operators could obtain a measurement in ten to fifteen minutes, and trained operators obtained distances in four minutes.[71] A Cubic Corporation advertisement on page 445 of the December 1961 issue of *Surveying and Mapping* disclosed a cost of $6000 each, with two instruments required for operation. That same issue, on pages 464 and 465, carried the claim of fifteen hundred microwave electronic distance meters in use around world. According to the advertiser (Tellurometer), 95% were Tellurometer. Recall that Geodimeters were not microwave, they were electro-optical, meaning that the market saturation by Cubic in late 1961 was five percent of fifteen hundred, or seventy five units.

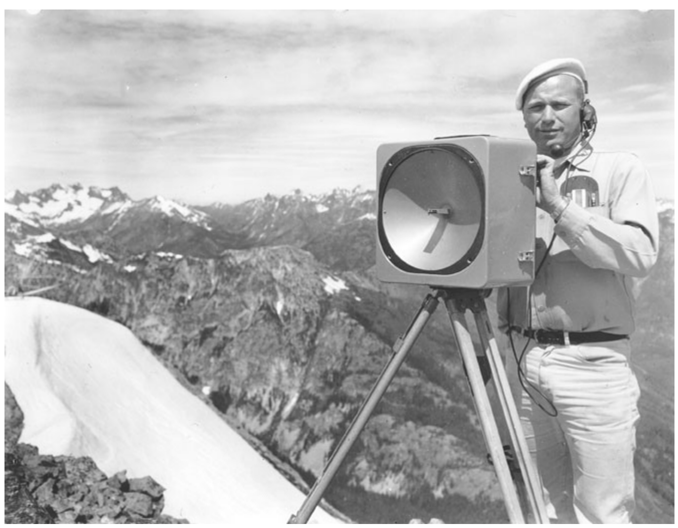

Figure 10. Cubic Electrotape. (1962) Source: http://geography.wr.usgs.gov/outreach/historicPhotos/enlarged/tennant_1962.html

A Cubic ElectroTape Model DM-20 was delivered to the Surveying and Geodesy Division of GIMRADA (Geodesy, Intelligence and Mapping Research and Development

[71] Charles B.Hempel, "Electrotape – A Surveyor's Electronic Eyes," *Surveying and Mapping* 21, no. 1 (1961): 85.

Agency) in November of 1960. A review of the instrument, published by a representative of GIMRADA, found the transistorized unit to be simple to operate.

However, the DM-20 had eight tuning knobs and required the remote auxiliary operator to tune switches on the responder during tuning by the primary operator. Robert Heape, the reviewer, noted that the instrument was less than complete in several respects, but "[t]he contractor has already corrected many of these deficiencies."[72] This reference to a contractor, by a military mapping agency, is reminiscent of the Eisenhower era military-industrial complex. This reinforces the suggestion that substantial public funds contributed to the further refinement of distance measuring equipment.

A Cubic ad for the ElectroTape in the March 1962 issue of *Surveying and Mapping* quoted a program with rents "as low as" one hundred dollars a week for two units. Single instruments were listed for $6040.00 each.[73] No details accompanied the rental price, but the inclusion of the quoted "as low as" suggests that this price was available only for long term rental.

If there was any doubt that industrial espionage and/or reverse engineering was alive and well during this time, one notes with interest that a Cubic Corporation advertisement in the September 1965 issue of *Surveying and Mapping* offered Tellurometer Model MRA-1 units for $495.00 each and Geodimeter Model 4 units for $2450.00 each.[74] Cubic was not a retailer for the overseas companies, and these were not new units.

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[72] Robert E. Heape, Jr., "Electrotape: Electronic Distance-Measuring Equipment," *Surveying and Mapping* 22, no.2 (1962): 265.
[73] P. 23.
[74] P. 480.

This bit of information may be been cause for allegations that the Electrotape violated existing patents owned by the Union of South Africa for the Tellurometer equipment. To resolve the conflict, Cubic and South Africa elected to cross-license their designs.[75]

It would helpful at this step to understand how the prices of this equipment related to the times. The June 1959 issue of *Surveying and Mapping* included a tip-in, or insert, showing fees and salaries broken down by state. In North Carolina, the charge for a three man field crew (chief of crew, transit man, chainman) averaged $10.00 per hour in the metropolitan areas, and $6.00 per hour in the rural hinterlands. The owner of a surveying company reported an average salary of $5.00 per hour, and he paid his chief of crew $2.00 per hour. A transit man received $1.50 per hour, and the lowly chainman's pay averaged $1.00 per hour. The only report found which indicated approximate cost savings using an electronic device was the Aerial Control paper (see footnote 65, supra). Three weeks of work was completed in six days. The cost of a field crew salary, using the reported North Carolina wages, is $4.50 per hour, or $36.00 per eight hour day. Six days of field work resulted in 6 times 36, or $216.00. Three weeks of field work is fifteen days (assuming five days per week), so the salary cost without the equipment would have been 15 times 36, or $540.00. The savings is the difference, or $324.00 for the project. The approximate cost of one Tellurometer in 1959 was $4500.00; two would extend the purchase price to $9000.00. Simple arithmetic shows that twenty eight projects would be required to amortize the initial cost of the equipment, more if training time were a consideration.

[75] http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=748453, accessed 22 September 2004.

The simple arithmetic does not disclose the harsh economic realities behind the math. In the case of Aerial Control's project, setting the control monuments was a tiny portion of the work undertaken. The scope of the project was fifteen thousand acres. Control points that are miles apart and visible only from towers are not suited at all for laying out stakes for line and grade. On-ground traverses must still be run between the long distances to provide the localized control such a project required. Although the Tellurometer did in fact save time and money for the base control, the collateral benefit of localized control provided by a traditional ground traverse was missing. At some point, surveyors used transits and steel tapes to set the local control points so vital for controlling the construction layout. The time required to do this would have been, according to the estimate, three weeks. Under careful scrutiny, it is seen that the Tellurometer did not save anything. It added six days and the cost of the equipment to the task, although the photogrammetric mapping could have been delivered two weeks earlier.

The problem, rapidly becoming evident to many looking at this technology, was the absence of short range capability. Karl Michael Wallace noted, "The greatest deficiency of high accuracy electromagnetic distance measurements seems to be within the range of 0 to 2 miles."[76] By 1965, in reviewing the progression of surveying instrument technology, Paul Blake of the United States Geological Survey reported that "[t]here have been no significant new principles or instruments introduced in the period

[76] Karl Michael Wallace, "Maser Surveying," *Surveying and Mapping* 22, no. 4 (1962): 553.

1962 to 1964."[77] However, there was "…much interest and research in progress to develop [electronic] instruments…for measuring short distances accurately."[78]

[77] Paul Blake, "Survey Instruments and Methods in the United States of America," *Surveying and Mapping* 25, no. 2 (1965): 244.
[78] Blake, "Instruments and Methods," 245.

CHAPTER FIVE

THE 1960S— AN INTERSTICE

Dramatic technological developments of the 1950s and early 1960s began a revolution in electronics that would yield great improvements in non-contact distance measurements. Inventions which were conceived by researchers to fulfill a specific need were soon transmogrified and affected the development in fields far diverse from their seminal purposes.

In 1947, the transistor was developed by Bell Laboratories, a division of AT&T. Bell was seeking a replacement for the vacuum tube and the mechanical relay switch. The hot and power hungry tube was used to handle amplification tasks for their telephone network while the mechanical relay switches selected the proper set of wires needed to connect two telephones. Their invention, the transistor, performed "…many applications, but only two basic functions: switching and modulation— the latter often used to achieve amplification."[79] It seems appropriate that the quest for a replacement for two somewhat large and unreliable devices resulted in the almost serendipitous discovery of a single, efficient replacement for both.

Because they were a regulated public utility, AT&T was restricted from advancing their transistor into uses more inventive than their core business of telecommunications. To comply with federal regulations, they distributed information relating to the transistor to interested companies at minimal cost.[80] Due to their significantly smaller size and

[79] "Bell Labs: More than 50 years of the Transistor" available in PDF from http://www.lucent.com/minds/transistor/ accessed 13 November 2004.
[80] Paul E. Ceruzzi, *A History of Modern Computing* (Cambridge, Ma: The MIT Press, 1998), 65.

minimal power requirements, transistors were the clear replacement for vacuum tubes and rapidly found their way into electronics of all sorts, from radios to radar. The last year that IBM used vacuum tubes in their computers was 1954, but recall that the Geodimeter was not transistorized until ten years later. By 1959, patents had been issued to Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductors for multi-operational circuits. The original moniker of "Micrologic" for these circuits was changed to "Integrated Circuit" by Fairchild.[81] The early integrated circuits were capable of performing specialized operations, one of which involved electronic gates that allowed them not only to count but to make decisions based on binary logic— in other words, compute. The particular circuit design determined what the chip would do under specific circumstances. There was no ability to alter the logic once the circuit was designed and the chip was produced. Noyce would partner with Gordon Moore nine years later to form Intel Corporation, who introduced the programmable microprocessor in November of 1971.[82]

Post-war interest in the propagation of electromagnetic radiation led to the development of the maser in the early 1950s. Maser is an acronym for Microwave Amplification by the Stimulation of Electronic Radiation, and the military-industrial community saw great uses for extremely short wave signals in radar applications. Seeking to take advantage of solid-state technology to make devices that were smaller, more efficient, less expensive, simpler to operate and possessing a wider variety of uses, scientists around the world expanded their research using the new technology. By 1956,

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[81] Ceruzzi, *History,* 179.
[82] Martin Campbell-Kelly and William Aspray, *Computer A History of the Information Machine* (New York: Basic Books, 1996), 237.

several laboratories in the United States that had been experimenting with solid-state technology to generate microwave energy developed a solid-state maser.

Other scientists sought to reduce the wavelength produced by the stimulation methods, leading to an all-out race to produce the laser. Two researchers at Bell Labs, Arthur Schawlow and Charles Townes, filed a patent application for a laser in 1958. Their design was not based on solid-state devices, and there were serious concerns whether radiation in the visible and near visible (infrared) spectrum could actually be produced by the use of semiconductors. Continued investigation showed that the Gallium Arsenide diode would exhibit luminescence when electrically excited, and by 1962, Robert N. Hall of General Electric produced the first GaAs laser on October 9.[83] The GaAs diode became universally known as a light emitting diode, or LED. These were soon in commercial production and would become the source of infrared radiation to power the next generation of electronic distance measuring equipment.

Electronic distance measuring equipment had certainly captured the attention of the geodetic community in this interim. At the 1957 Toronto meeting of the International Association of Geodesy a special study group was established to investigate and evaluate electromagnetic measurements. A symposium was held in Oxford UK in 1965. The papers presented at the conference provide a historical insight into the extent of development during this interim period.[84]

In the exhibit hall, eleven instruments were on display. Five were from exhibitors based in the UK. There were four from Tellurometer and one each from Wild Heerbrugg

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[83] Bromberg, *Laser,* 151.
[84] International Association of Geodesy, *Electromagnetic Distance Measurement A Symposium Held in Oxford Under the Auspices of Special Study Group No. 19, 6-11September 1965,* (Toronto: University of Toronto Press, 1967).

and AGA. The instruments displayed were a Geodimeter Model 6, a Laser Rangefinder from G. & E. Bradley Ltd of London, a Mekometer from Hilger and Watts Ltd of London, three Tellurometers (MRA 4, Model 101 and Model 3), a Wild Distomat DI 50, the E.O.S. Telemeter of C. Z. Scientific in London, an Ordnance Survey Thermistor from the UK Ordnance Survey in Surry, a Gallium Arsenide Modulated Light Source from Tellurometer and an NPL Mekometer II from the National Physical Laboratory in Middlesex.

Of particular interest was the wide geographic dispersion of presenters. Research was underway in Austria, Finland, Great Britain, Poland, the United States and Germany. Efforts to overcome the reflection problems of microwave equipment were being studied in Denmark, Great Britain, Germany, Canada, and the United States. Improvements to the Tellurometer family of microwave devices were discussed by presenters from South Africa and Canada. Sweden, Germany and the UK were represented in the discussion on electro-optical equipment. H. D. Hölscher of the South African National Institute for Telecommunications Research presented a paper outlining their research into the use of GaAs LED technology for EDM purposes.

Two prominent and long-established manufacturers of optical surveying equipment were represented at the symposium. Wild Heerbrugg of Switzerland and Carl Zeiss of Germany had both been engaged in optics and lenses for many years—Zeiss since the middle of the Nineteenth century and Wild since the 1920s. With the exception of subtense bars, neither company was involved in instruments for measurement of distance. Their specialty was angular measurement, and they had established not only a global dealer network but a reputation as the finest surveying instrument makers by the middle of the 1960s. Wild and Zeiss understood that although the geodetic survey market was large, the private practice market was even larger.

In the United States, the European theodolite was gaining wider acceptance and beginning to displace the heavier, less accurate transit instrument. Theodolites were "…manufactured by several European firms with which American companies cannot compete because of wide differences in labor costs," and their use was greatly increasing as the decade of the 1960s ended.[85] They were light, simple to use and, although expensive, afforded increased angular accuracy.[86] Their acceptance by the private practice community made Wild and Zeiss 'household words' in the surveying offices of America.

Wild Heerbrugg, the Swiss optics manufacturer, began experimentation with the Gallium Arsenide diodes in 1963, and collaborated with SERCEL (Societé d'Études, Recherches et Constructions Electroniques) of Nantes, France in 1965 to produce an experimental distance meter capable of measuring over 900 meters by 1966.[87] In 1966, Hewlett Packard developed "breakthrough GaAsP (gallium-arsenide-phosphide) light-emitting diodes."[88] These GaAsP diodes generated a visible red light with very low power needs. GaAsP would become the prevailing technology for the LED displays that provided digital readout for watches, calculators and a plethora of other electronic devices.

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[85] William Horace Rayner and Milton O. Schmidt, *Fundamentals of Surveying* (New York: Van Nostrand—Reinhold Company, 1969), 79.
[86] Jack B. Evert, *Surveying* (New York: John Wiley & Sons, 1979), 52.
[87] http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=748493 accessed 5 October 2004.
[88] http://www.agilent.com/about/newsroom/facts/history.html, accessed 5 October 2004.

In the late 1960s, Carroll and Reed was a very small Canadian firm manufacturing a device used to convert a hand held powered circular saw into a table saw. They were soon joined by Bey Reed's brother Mike, who had a Ph. D. in Optical Engineering and a strong electronics background. Under his direction, Carroll and Reed raised one million dollars in venture capital on the Toronto market and embarked on a mission to produce an electronic distance meter. By 1969 they had developed a breadboard prototype and induced Roger Palmer, a newly graduated electronics engineer, to join their firm. The developers were well aware of the efforts of Wild Heerbrugg and others to develop a system using the infrared portion of the spectrum. While Wild was using multiple modulation frequencies for their phase comparison, the small Canadian company was committed to using a single frequency. They chose 491.6 megahertz, a frequency producing a wavelength of exactly two thousand feet. Palmer called this an unfortunate decision, as they experienced repeated problem with stable signal to noise ratios and incessant phase drift through the processing components.

Very late in the production process a major problem appeared during baseline testing on their test site, an abandoned rail line behind the research offices. The original pilot instruments exhibited a linear variation of up to a tenth of a foot in a measurement of one thousand feet. The developers were frustrated, as the error presented itself differently with different pilot units and different choices of reflectors. The problem was finally traced to variations in the times the LED transmitted its energy, tiny but significant delays that were a function of where on the LED the transmission occurred. Carroll and Reed resolved this problem by the addition of an optical integrating sphere to the LED which blended all the light into a single, stable signal. The addition of the sphere added to the manufacturing cost and more importantly, took six critical months to discover and correct.

In the meantime, Carroll and Reed had arranged for a network of distributors through Europe and North America, and were heavily marketing their new Akkuranger. It is not sound business practice to market a product you cannot deliver, and Carroll and Reed "burned through" their initial startup capital before they could begin serious production and delivery. Approximately thirty units were produced before the employees, who had endured months of no paycheck in the hopes that the effort would succeed, finally abandoned the sinking ship. Carroll and Reed became one more failed business because of undercapitalization.[89]

William A. McLaughlin, Assistant Chief of the Branch of Field Surveys for Rocky Mountain Region of the Topographic Division of the United States Geological Survey, published an article in the April 1970 issue of *The Journal of Surveying and Mapping* explaining that by the time of writing, practically all horizontal control was established by EDM.[90] He confirmed that any model of the Tellurometer later than MRA-1, Electrotape, or Microchain could be used, and models of the Geodimeter later than Model 4 could be used, as long as the distances were determined by measuring from each end of the line (i.e., measure from A to B, then measure from B to A). Older Tellurometers could be used if the reflector station was moved ahead or back by three feet and the distance determined (after adjusting for the shift) was within one third of a foot.[91]

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[89] All information on Carroll and Reed from e-mail between the author and Roger C. Palmer exchanged in October 2004.
[90] William A. McLaughlin, "Map Control by Electronic Surveys," *Journal of the Surveying and Mapping Division – Proceedings of the American Society of Civil Engineers* 96, no.SU1 (April 1970): 81.
[91] McLaughlin, "Map Control," 84.

The Los Angeles Department of Power and Light ran a two hundred fifty six mile transmission line survey in 1966 using a combination of conventional (transit and tape) and electronic equipment. With a Model 6 Geodimeter, Robert Carpenter reported that a five man electronic party completed a forty mile traverse leg, complete with trigonometric levels, in twenty percent less time than a four man conventional party required to survey just twenty miles. The conventional crew did not obtain trig levels.[92] The time savings available with EDM were becoming well known as the decade of the 1960s came to a close.

James G. Donahue of Geneva, Illinois addressed his fellow surveyors at the 1971 Annual Meeting of the American Congress on Surveying and Mapping. Donahue opened his remarks by opining that "[t]he innovation of EDM has been the greatest single advancement to the Land Surveyor in over 4000 years. It has completely revolutionized the practice of Land Surveying from a field of drudgery to a field of wonder and challenge."[93] To support his assertion, Donahue recalled his company's situation in 1964. Needing more work, they decided to purchase an electronic distance meter. After two years of study and comparison, they selected a Geodimeter, basing their purchase on cost, portability, reliability and ease of operation. According to Donahue, they spent $9600.00 for the instrument in 1966. Even after two years of deliberation, after the first few weeks with the new unit the firm wanted to return it to the Swedes. Upon completion of a rather steep learning curve, they "…wouldn't have gone back to the old methods for

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[92] Robert L. Carpenter, "Surveys for the Navajo Power Project's Western Transmission System," *Papers from the 33rd Annual Meeting American Congress on Surveying and Mapping* (March 1973): 126.
[93] James G. Donahue, "A Dream Come True, Electronic Distance Measurement," *Papers from the 31st Annual Meeting American Congress on Surveying and Mapping* (March 1971): 201.

anything."[94] By Donahue's estimate, his firm performed twice the fieldwork at six times the accuracy of conventional methods. Based on his years using electronic instruments, Mr. Donahue named six typical jobs that were ideally suited for an EDM:

1. Boundary surveys of farms from 20 to 200 acres.
2. Subdivision work, but only for setting control points.
3. Right of way surveys for gas lines, telephone cables, etc.
4. Setting columns for large buildings, dams or bridges.
5. Measuring school or city bus routes.
6. Horizontal control for aerial photography.

The Geneva, Illinois firm increased their business five fold in five years, and Mr. Donahue concluded his remarks with a warning. "I really believe that a full time surveyor must get electronic equipment if he is to keep pace with his profession."[95] Many more such warnings were to come.

[94] Donahue, "Dream," 202.
[95] Donahue, "Dream", 204.

CHAPTER SIX

SMALL STEPS AND LARGE LEAPS

In 2004, there are three widely circulated periodicals distributed to nearly all professional surveyors in the United States. These periodicals are free upon request to qualified subscribers. The cost of publication and distribution is borne by advertising revenue. *The American Surveyor* began publication in 2004 as a paid-subscription service, although complimentary copies of the first few issues were widely circulated. It remains to be seen if Cheves Publishing can continue to operate on a paid basis when two competitors continue free circulation. *Professional Surveyor* is published monthly and distributed at no cost in the United States. The September 2004 issue is identified as Vol. 24 No. 9, which would indicate that publication began in 1980. The oldest of the three is *POB Magazine* (POB is a surveyor's acronym for Point of Beginning) which began publication in 1975.[96] The point is, prior to the commencement of publication of *POB*, the only sources of information for new surveying equipment, beyond salesmen and manufacturer's representatives, were professional journals and bound proceedings offered to dues-paying members of either ASCE or ACSM. The advertising in publications by these organizations, as well as evaluations presented at conventions and conferences, provides a valuable timeline for introduction dates of new equipment.

In July of 1969, the world witnessed one small step for man and one giant leap for mankind. Also in that year of momentous achievement, the tiny community of surveyors

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[96] http://www.pobonline.com/FILES/HTML/POB_about_us/0,6671,,00.html accessed 5 October 2004.

gained a major achievement: the introduction of a manageable, affordable electronic distance meter capable of precise results in the short range.

Figure 11. WILD Distomat DI-10 (1969) Source: http://www.sli.unimelb.edu.au/collection/item_details_5.html

Once again, a foreign manufacturer was first on the scene to actually deliver infrared equipment. The WILD DI-10 Distomat arrived in the United States in the fall of 1969. Kenneth E. Reynolds presented a paper in July of 1969 to the ASCE National Meeting of Transportation Engineering.[97] Reynolds was Executive Vice-President of WILD Heerbrugg, the manufacturer of the DI-10.

[97] ASCE is an acronym for the American Society of Civil Engineers.

Subsequently published in the *Journal of the Surveying and Mapping Division* of ASCE, Reynolds suggested that the name Distomat was an acronym for the design considerations of the instrument. Although somewhat sophomoric and strained, the review of his acronym emphasizes the breakthroughs that the Gallium Arsenide Diode devices made: D is designed for complete reliability. The earlier electromagnetic equipment was not completely reliable, as evidenced by advertisements in the ACSM Journal offering replacement parts for the Cubic Corporation Electrotape in just 12 hours. I is for inexpert operators quickly trained. Despite the electromagnetic instrument manufacturers' assertions to the contrary, recall that William O. Baker reported that three months of training were needed to become proficient with the Tellurometer.[98] S represented solid state design, although the other instruments had begun to incorporate semiconductors in the mid 1960s. (The Electrotape being offered in 1960 contained transistors in some of the circuits.[99] The Geodimeter advertisement appearing on page 7 of the March 1965 issue of the ACSM Journal of *Surveying and Mapping* boasted of a fully transistorized unit.) T denoted the ability to turn angles on the WILD T-2 theodolite as well as measure distance. In 1957, William Compton of AGA said, "Existing angle measuring instruments in the surveying parties make it uneconomical to combine accurate angle measurements in the Model 4."[100] O represented "operational immediately," while M suggested a mean square error independent of distance of ± one

[98] Baker, "Use of Tellurometer," 52.
[99] Heape, "Electrotape," 265.
[100] Milton Compton, "Short Distances," *Surveying and Mapping* 17, no. 4 (Oct-Dec 1957): 425.

centimeter. A touted the Distomat's ability to withstand rugged field conditions, including (and this is why the T was there) a temperature range of –13° to 122° F.[101]

Mr. Reynolds, as an executive of WILD Heerbrugg, may have been engaged in a bit of puffery. In the same journal, Raymond Tomlinson of the United States Coast and Geodetic Survey examined the new distance measuring equipment, but came to a different conclusion regarding the training process. He recommended a "…2-day to 3-day training course with the instrument."[102] Tomlinson reported that after setup and aiming, a distance reading could be obtained in about a minute. Another operational anomaly noted by Tomlinson was the requirement to know the length of lines greater than a kilometer within one hundred meters. The readout on the DI-10 showed 95.50m for a line that was 1095.50m in length, requiring the operator to provide the missing hundreds digit. Tomlinson further noted that the distance display would not stabilize for distances greater than one kilometer.[103] In fairness, WILD Heerbrugg specified "up to 1000m" as the measuring range.[104]

The June 1970 issue of *Surveying and Mapping* contained a report by David Rice, a Registered Land Surveyor operating from Hamlet, North Carolina. Rice provided a first person account of his firm's experience with the Wild DI-10 Distomat. According to Rice, the instrument began production delivery in October of 1969 and the firm accepted their delivery in November 1969. The first major project for their new instrument was a

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[101] Kenneth E. Reynolds, "DI-10 Distomat System," *Journal of the Surveying and Mapping Division – Proceedings of the American Society of Civil Engineers* 96, no SU2 (September 1970): 137.
[102] Raymond W. Tomlinson, "New Distance Measuring Instruments," *Journal of the Surveying and Mapping Division – Proceedings of the American Society of Civil Engineers* 96, no. SU2 (September 1970): 150.
[103] Tomlinson, "New Instruments,"152.
[104] Reynolds, "Distomat", 140.

boundary survey of a 1,600 acre pulp timber farm. The second project was the surveying layout for a $76 million steam electric plant in Charleston, South Carolina and the third task was measurement of control lines for fifty five miles of overhead transmission lines.[105] The magnitude of these efforts shows that Rice's company was no small player in the surveying world. In fact, Rice and Associates worked throughout the United States, achieving notoriety in the field of Uranium mine surveying. Rice employed one of the very first civilian applications of a sophisticated north-seeking gyroscope, and pioneered the concept of mounting his DI-10 vertically to precisely determine the depth of mine shafts. The article praised the efficacy of the instrument, with Rice reporting that the new equipment allowed a four man crew to perform the work of a five man crew in less than half the time. The operational ease of the Wild DI-10, according to Rice, was "…near foolproof."[106]

The author did not disclose the price paid, but records in the Smithsonian Institution disclosed the suggested retail price to be $6,850.00.[107] For comparison, a 1969 Pontiac GTO convertible retailed for $ 3,382.00. According to the U. S. Census, the median 1969 family income for craftsmen and operatives was $8,025.00, an increase from $6,408 in 1959.[108] In comparison with the cost of Tellurometer equipment in 1959, the cost of electronic distance measuring equipment was decreasing while wages were increasing.

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[105] David Rice, "Land Surveying Applications of the Wild DI-10," *Surveying and Mapping* 31, no. 1 (1971): 281-282.
[106] Rice, "Applications," 284.
[107] http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=748493, accessed 28 September 2004.
[108] U. S. Bureau of the Census, *Current Population Reports*, Series P-60, Number 73, "Occupations and Earnings of Family Heads in 1969, 1965 and 1959," U. S. Government Printing Office, 1970.

A very large private engineering and surveying company in Canada purchased their Wild DI-10 sight unseen. The decision was made entirely on the specifications and pricing structure. Marshall Macklin Monaghan Limited (MMM), of Ontario, Canada, was quite a large firm in 1969, employing approximately two hundred fifty workers. Half were assigned to the survey department, which fielded thirty to thirty five field parties daily. In 2004, the largest surveying companies in North Carolina field no more than twelve to fifteen parties, and the number of companies this size can be counted on one hand.

J. W. L. Monaghan of MMM presented a report at an annual meeting of the American Congress on Surveying and Mapping in 1972. Monaghan's presentation included an economic analysis of the impact of the Wild DI-10 on a 2,150 acre tract on the north shore of Lake Erie. MMM Limited ran fifteen miles of control with thirty nine stations in the traverse using a two man party in four days. The estimated effort using conventional equipment would have required forty days and covered thirty three miles.[109]

The careful reader will note that not only would conventional techniques have increased the time needed by a factor of ten, the distance required was doubled. Undoubtedly, this is a result of the ability of the EDM to measure over water, a feat encountering significant difficulty using traditional steel tapes. Recall that the development was on the north shore of Lake Erie. Monaghan kept detailed records of the time required not only on this project, but all project employing the DI-10. In his words,

[109] J. W. L. Monaghan, "The DI-10 Distomat in a Canadian Land Surveying Practise," *Papers from the 32nd Annual Meeting American Congress on Surveying and Mapping*(1972): 398-405.

"generally speaking, the traversing time portion of the work is reduced by 50% to 60%."[110]

Traverse, in the jargon of the professional surveyor, is to measure angles and distances between seemingly random points interspersed between points of known interest. For example, to survey a two thousand foot farm boundary, it is neither necessary nor prudent to attempt to measure the line directly. A series of intervisible points are placed between the two boundary markers (note that intervisible may, and usually does, require substantial clearing of vegetation). At each point, the angle formed by the point immediately behind and immediately ahead is measured. For higher precision work, multiple angles are measured and the results meaned. The distance between each point is measured with a measuring device of some variety. By simple principles of trigonometry, the distance and relative direction between endpoints is computed. Conditions in the Piedmont of North Carolina tend to yield traverse points at intervals ranging between one hundred and three hundred feet. Obviously, the ability to measure the distances with an electronic device while the tripod is set over the point greatly increases the productivity. For the private practice surveyor, the increase in precision was not a consideration, but a welcome collateral benefit. The traverse method was used to determine the boundary of a parcel having established corners. To create new lots, or subdivide, a different technique was required: layout.

Layout was previously explained as the act of setting a marker at a previously determined position. For the practicing land surveyor, the residential subdivision required massive layout: the streets, sewer and water lines, storm drainage and lot lines all had to be marked on the ground based on a plan. Using traditional equipment (transit and tape),

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[110] Monaghan, "Canadian Practise", 405

an instrument man occupies a known position with his transit, obtains a directional reference, turns a pre-determined angle and sends out the front chainman. When the transit is sighted along the proper direction, and the tape is held at the correct length, the unknown point has been located and may be witnessed on the ground.

MMM Limited experimented with using their DI-10 to layout control stakes for a roadway network on an eight hundred lot development in Mississauga City in March of 1971. Employing an IBM 1130 computer, the office staff computed and printed out "…angle and distance to each point specified within a radius of 1,200 feet." Armed with this information, the field parties occupied known stations. The instrument man turned the angle and the forward rodman paced the distance. When the rodman reached his terminus based on his step count, the instrument man used the EDM to "shoot" the rodman, determining the distance between the instrument and the rod. The difference between the desired distance and the measured distance was then measured on the ground to set a mark at the desired location. One problem noted with this technique was that the DI-10 was mounted over the standards of the Wild T-2 theodolite used to measure the angles. To fine tune the electronic alignment (i.e., maximize returned signal strength), it was necessary to employ the tangent screws on the T-2, which caused the theodolite to improperly point. After ranging the distance, it was necessary to re-set the T-2.[111] For the surveyors in North Carolina reading this, amazement must have set in at terrain and ground cover that would allow points to be staked up to a quarter mile away. To attempt this technique in this Pine Tree State would have been roundly ridiculed and labeled as pie in the Canadian sky.

[111] Monaghan, "Canadian Practise," 407-410.

This layout method presented a problem that Monaghan did not discuss, specifically, the problem of slope distance versus horizontal distance. When using a steel tape, the instrument may be set to a level line which serves as a reference for the measurement. Since all surveying measurements must be horizontal, the slope distance returned by the distance meter must be reduced to horizontal. The horizontal distance is obtained by multiplying the cosine of the zenith angle (the angle of elevation or depression where 0° is straight up) by the slope distance. Since a handheld calculator capable of computing trigonometric values had yet to be developed, the instrument operator would have had to resort to a table of trigonometric values (see page 74) and then perform a rather extensive multiplication operation (perhaps 0.999231 multiplied by 1103.15) by pencil and paper.

Early in 1972 Monaghan took it upon himself to send a questionnaire to forty users of the DI-10 in Canada, and obtained fourteen replies. The instrument received an "…overwhelmingly enthusiastic response from the users," with an estimate of time savings ranging from 25% to 50%.[112]

Other manufacturers began to offer equipment based on the nascent semiconductor technology. In 1971, Donald Farkas of Raritan Valley Engineering in New Jersey boasted that his company "…considers itself fortunate in being the first consulting firm in the United States to acquire a Tellurometer MA-100."[113] Farkas described the MA-100 as a short range, infrared DME which was well made, reliable and highly accurate.

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[112] Monaghan, "Canadian Practise," 416.
[113] Donald R. Farkas, "Electromagnetic Distance Measurement And Computers In Private Practice," *Papers from the 31st Annual Meeting American Congress on Surveying and Mapping* (March 1971): 313.

Figure 12. Tellurometer MA-100 (1971)
Source:http://www.sli.unimelb.edu.au/collection/item_details_6.html

That glowing evaluation was not shared by Francis L. Ingram of the Land County, Oregon survey department. He chose to test the MRA-101 against known baselines before using it to extend control throughout his county. Following procedures promulgated by the National Geodetic Survey, Ingram determined that the manufacturer supplied refractive correction index was incorrect, and that field determination of the correct indices was mandatory before using the instrument.[114]

Dr. Joseph Dracup of the National Geodetic Survey encountered a similar problem while supervising control surveys for a high speed test tract in Colorado. Dracup determined, and the manufacturer concurred, that the Tellurometer MRA-101

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[114] Francis L. Ingram, "An Evaluation of the Model MRA-101 Tellurometer," *Papers from the 1971 ASP-ACSM Fall Convention* (September 1971): 234. The refractive correction index adjusts the distance measurement to reflect changes in the speed of light based on atmospheric conditions, specifically, temperature and barometric pressure.

suffered from an internal frequency deviation. This resulted in shortages of eight parts per million in measured distances.[115] While this error can become significant when accumulated over long distances, the effect of the shortage on a measurement of one hundred feet on a city lot amounts to one hundredth of an inch.

Farkas evaluated another infrared Tellurometer in July of 1974, reporting to his fellow surveyors in 1977. This model was the Tellurometer CD-6, a "…compact, extremely light, 5.5 pounds, easily operated instrument."[116] By this time, Farkas was a Professor at the New Jersey Institute of Technology. He described the simple operation: peep sight the target, set switch to external, tweak meter to maximum signal strength by use of horizontal and vertical tangent screws, null needle to center of green range by using red gain control, set switch to internal, null needle to center of green range by using yellow gain control, and finally, switch to external to read distance. Repeat several times and average readings. This doesn't sound like simple operation, but things got worse. "If the needle cannot be nulled when the CD-6 is in internal mode, the strength of the signal must be modified by switching to external, and utilizing a detachable attenuator which is placed in either the transmitting or receiving port."[117] In his concluding remarks, Farkas praised the CD-6 as a "well-engineered, simple to operate instrument."[118] One might speculate that Professor Farkas suffered from brand loyalty at the expense of pragmatic evaluation.

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[115] Joseph F. Dracup, "The Pueblo Test Track Project—A High Precision Alignment Survey," *Papers from the 1971 ASP-ACSM Fall Convention* (September 1971): 265.
[116] Donald R. Farkas, "The Tellurometer Cd-6 A Field Evaluation," *Papers from the 37th Annual Meeting American Congress on Surveying and Mapping* (March 1977): 202.
[117] Farkas, "Tellurometer CD-6," 203.
[118] Farkas, "Tellurometer CD-6," 205.

Harry R. Feldman purchased and lauded the Laser Ranger which was introduced in 1970 by Laser Systems and Electronics of Tullahoma, Tennessee. Utilizing a three milliwatt helium-neon laser, the instrument had a range of 1 meter to 6 kilometers. Feldman said that "[b]eing one of the first users of the Geodimeter, the visible light beam had much more appeal to me than the infra-red system."[119] He was also impressed with its American heritage. Just to make sure the equipment worked as advertised, Feldman tested its readings against his old Geodimeter Model 4-D and found agreement within an inch or so over nineteen thousand feet. While it took this experienced surveyor ten minutes to obtain a reading with his comfortable Model 4-D, the Laser Ranger only took twenty to thirty seconds to make the measurement. The Laser Ranger sold for $8000 and contained computer chips designed in collaboration with Texas Instruments.[120]

By the early 1970s, most surveyors were becoming convinced of the need to acquire EDM. Raymond Tomlinson, a Geodetic Technician with the National Geodetic Survey, suggested "[i]f you are still relying on a transit and tape to perform your surveying projects, I hope you are about ready to retire before being forced out of business."[121] Tomlinson wrote that the majority of surveyors measure lengths shorter than 2,000 meters, a view shared by Gilbert V. Noice, an Assistant Professor of Surveying at Metropolitan State College in Denver, Colorado. Noice stated that short to medium

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[119] Harry R. Feldman, "Laser Ranger – The New Distance Measuring Instrument For Surveyors," *Papers from the 31st Annual Meeting American Congress on Surveying and Mapping* (March 1971): 517.
[120] http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=748794 accessed 5 October 2004.
[121] Raymond Tomlinson, "Short Range Electronic Distance Measuring Instruments," *Papers from the 1971 ASP-ACSM Fall Convention* (September 1971): 236.

range measurements represent ninety five percent of all surveying measurements.[122] By 1973, due to the enhanced capability and aggressive pricing structure of infrared EDM devices, they were "…being purchased almost as rapidly as they can be manufactured."[123] By 1978, Noice noted that "[t]here is practically no surveying organization in this country that doesn't have some type of EDM."[124] In 1979, Mackenzie Laurence Kelly opined, "The development of Electronic Distance Measuring devices at a cost most surveyors can afford is the most important advance in the practice of Land Surveying in this decade."[125]

Harry Feldman spoke at the ACSM annual meeting in 1980. "Perhaps the most significant advancement of all is in the area of linear measurements."[126]

Papers published during the mid 1970s tended to be thinly veiled manufacturers' advertisements, extolling the strengths of their offerings. B. Q. Cutshaw, a Product Manager for Keuffel & Esser found his way to St. Louis in March of 1974 to present a paper to the attendees of the Annual Convention of ACSM. K&E's entry into the field was the Microranger, a compact seven pound fully automatic unit capable of coaxial mounting over a standard optical transit or theodolite. Cutshaw reported that by this time there were over thirty models available with pricing ranging from $4,000 to $40,000. His

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122 Gilbert V. Noice, "Electronic Distance Measurement An Overview Of Procedure," *Papers from the 1978 ACSM Fall Convention* (September 1978): 234.
123 Paul R. Wolf and Steven D. Johnson, "Trilateration With Short Range EDM Equipment And Comparison With Triangulation," *Papers from the 1973 ACSM Fall Convention* (September 1973): 63.
124 Noice, "Overview," 234.
125 Mackenzie Laurence Kelly, "Field Calibration Of Electronic Distance Measuring Devices: A Method of Determining and Computing Corrections to Measurements Taken with EDM Equipment," *Papers from the 39th Annual Meeting American Congress on Surveying and Mapping* (March 1979): 425.
126 Harry Feldman, "Modern Surveying Trends And Their Application To Consulting Engineering," *Papers from the 40th Annual Meeting American Congress on Surveying and Mapping* (March 1980): 405.

paper contained a chart of short range EDM systems that had been "delivered in significant quantities for consumer use and evaluation."[127] Five instruments were listed: the AGA 76 (a Geodimeter), the Cubic DM60, the HP3800, the K&E Microranger and the Wild DI-10. Cutshaw re-plowed the same ground many before him had tilled, suggesting that every surveyor could benefit from increased accuracy and higher levels of productions. By 1974, this sermon was directed squarely towards the choir loft. Concluding his remarks, Cutshaw opined, not surprisingly, that the K&E Microranger was the only short range EDM that exactly fit the bill for every survey task.

Paul D. Donnelly was a Wild representative who presented at the 1975 Annual Convention of ACSM. By this time, the Swiss company had introduced the DI-3 which incorporated on-board reduction of the slope distance to horizontal. Donnelly indicated that Midwestern Consultants of Ann Arbor, Michigan did two days worth of work in one half day using their DI-3. Land Systems of Indianapolis claimed a one thousand percent increase in their productivity, and citing personal observations, Donnelly claimed that using the DI-3 to determine trigonometric levels required between one fourth and one half the time of traditional spirit leveling methods.[128]

In the face of new technology there is always the contrarian. A prescient Dexter M. Brinker observed, "Judging from the recent proliferation of electronic distance measuring devices appearing on the market, it might seem that the surveyor's tape will soon be

[127] B. Q. Cutshaw, "The New Panorama Of Electronic Distance Measuring Equipment," *Proceedings of the American Congress on Surveying and Mapping 34th Annual Meeting* (March 1974): 572.

[128] Paul D. Donnelly, "The Wild Di-3: Practical Methods And Experience In Usage," *Papers from the 35th Annual Meeting American Congress on Surveying and Mapping* (March 1975): 148-150.

found only in museums."[129] Perhaps he did not know that the United States Geological Survey had placed a K&E No. 12, a one hundred foot steel tape, in the Smithsonian in 1907.[130] Brinker offered three reasons for his position: not all surveyors will be able to afford EDM for many years to come, some types of measurement do not "lend themselves" to EDM, and many situations will show that EDM has no advantage over good taping practice. In a less than persuasive offering, Brinker concluded with the bold assertion that it is "…reasonable to conclude that for many jobs the steel tape can easily compare with the more sophisticated electronic machines."[131] Why this contrary view? Brinker had been selected by the Lufkin division of Cooper Tools, the primary supplier of survey quality steel tapes, to prepare a booklet explaining the proper methods for correcting a tape for tension and temperature. Everyone has an agenda, it seems.

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[129] Dexter M. Brinker, "Modern Taping Practice Versus Electronic Distance Measurement," *Papers from the 1971 ASP-ACSM Fall Convention* (September 1971): 355.

[130] http://americanhistory2.si.edu/surveying/object.cfm?recordnumber=762993 accessed 19 October 2004.

[131] Brinker, "Taping Practice," 355.

CHAPTER SEVEN

THE FUTURE ARRIVES

Figure 13 Carl Zeiss RegElta 14 (1970) Source: http://www.e-messmer.de/technik5.htm

One year before Wild delivered their first DI-10 to the United States, the European surveyors who attended the 1968 Meeting of German Surveyors in Stuttgart were introduced to the Zeiss RegElta14 electronic tacheometer, the first recording total station.[132] In addition to the RegElta14, Zeiss offered the SM-11 as a complete total station but with optical angle measurement and no recording capability.[133]

A total station is surveying nomenclature for a unified instrument capable of measuring both angular and linear units. All other electronic distance measuring instruments of the time, whether in production or on the testing lines, were autonomous

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[132] Helmut Leitz, "Ten Years Of Electronic Tacheometry – Zeiss: 1968, RegElta-14-1978, Elta-2 and Elta 4,", *Papers from the 33rd Annual Meeting American Congress on Surveying and Mapping* (March 1973): 527.
[133] "What's New at Zeiss" *Zeiss Information* 74 (March 15, 1970): 141.

stand-alone units. The smaller ones, like the Wild DI-10, Tellurometer MA-100, Laser Ranger, Akkuranger and other prototype units were capable of being mounted on the standards of a traditional optical reading theodolite. The RegElta14 was a fully electronic theodolite: that is, electromagnetic sensors on the horizontal and vertical angle circles were capable of reading and reporting the circle readings electronically. Although this was a major technological breakthrough, Zeiss went one step further and offered an optional paper tape output that would permit the recorded data, via a paper tape reader, to be input directly into a computer system to compute the closure, adjust the observations and compute the final coordinates.

The RegElta-14 made its world debut during the 1972 Summer Olympics in Munich. It was used to measure the distances achieved by the athletes competing in the javelin, discus and hammer throw events. The impact point was marked by an Olympic judge who placed a reflector prism at the exact position. The RegElta-14 operator sighted the prism, and the output of the instrument was fed into a computer interface that, by a trigonometric calculation, determined the distance of the throw. If approved by an Olympic judge, the official distance was displayed on a large electronic leader board wired to the computer interface.

Gunther Greulich of Boston Survey Consultants provided his report to American surveyors on the efficacy of the instrument for a more practical use. Greulich teamed with Dieter F. Schellens of Keuffel & Esser Company to take the RegElta14 on a trial run. They re-surveyed a portion of downtown Boston that had previously been mapped by a combination of aerial photography and field survey for an urban renewal project. Details to be located included differing pavements, utility covers, light posts, traffic signals, parking meters, traffic islands and other assorted urban elements. The RegElta with its battery system weighed in at eighty pounds. Greulich and Schellens reported that they could accommodate the instrument, battery pack and required tripods in the trunk of an automobile. Upon completion of the field work, the punched paper tape was fed into a tape reader attached to a Digital Equipment PDP 11/45 minicomputer. Four hours were expended reviewing the veracity of the input data, twenty seconds of CPU time was required to perform the computations and the located points were plotted on a Contraves computer plotter. The field time required with the RegElta14 was fifty nine man hours, while the previous survey was estimated to have required one hundred thirty six hours. Greulich estimated that the fieldwork was completed with a time savings of fifty six percent and office computations reduced by fifty nine percent.[134]

Somewhat different results were obtained by Klaus Hendrix of the United States Bureau of Land Management. Operating in the significantly rougher terrain of the lower Rockies in Colorado, Hendrix noted several problems using the RegElta14 during a section breakdown survey. One traverse leg failed to close, and a re-run was required. It was found that the RegElta14 had mis-measured the distance by one meter. Several positions could not be measured with the Zeiss instrument because the distances exceeded the two kilometer range limitation. Redundancy checks on several three point resection computations failed by over a meter due to the insufficient angular accuracy of the total station. The work was in the wilds of Colorado, and the instrument was transported by vehicle over rugged terrain. Even though it was always transported in its protective case, the alignment of the axis of the electronic theodolite and the distance

[134] Gunther Gruelich and Dieter F. Schellens, "Surveying With The Zeiss Reg Elta 14 In Densley Populated Areas," *Papers from the 33rd Annual Meeting American Congress on Surveying and Mapping* (March 1973): 452-464.

meter continually diverged, requiring realignment as often as twice daily. The large facial profile prohibited use during winds in the twenty five to thirty five mile per hour range, buffeting the instrument so severely that it could not maintain a return signal from distant reflectors. Prior testing in Arizona in the fall of 1976 resulted in overheating of the internal circuitry. In spite of these problems, Hendrix estimated the cost savings from the use of the instrument to be $8300 on the section breakdown, using $1800 per man/month. The primary savings came from the use of a five man party compared to a nine man party for traditional equipment.[135]

Geodimeter recognized the benefit of combining the angular measurements with the distance and produced, in 1971, the Model 700. This incarnation required the operator to observe and record the angles; that is, the Model 700 did not have electronic angle sensors. By 1978 they had produced the Model 120 with an internal tilt sensor to reduce slope distances to horizontal, and it was not until 1981 that a fully electronic total station, the Model 140, was brought to the market.[136]

Nearly ten years after Carl Zeiss produced the RegElta14, Keuffel & Esser produced a total station. K&E, now defunct in 2004, was a venerable American company producing and marketing almost any item required by design professionals. Kent Erickson presented a paper in the spring of 1977 to introduce their new instrument, the Electronic Surveying System. Other than substantial weight and size reductions, the only difference from the original RegElta14 was an onboard microprocessor that could convert the native polar reading to rectangular values and a magnetic memory system that could

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[135] Klaus P. Hendrix, "Surveying With The RegElta 14 Surveying System," *Papers from the 38th Annual Meeting American Congress on Surveying and Mapping* (March 1978): 307-310.
[136] Marc Cheves, "Geodimeter".

store the observations and then "dump" them onto magnetic tape.[137] If this seems progressive, remember that by 1976 Jobs and Wozniak were marketing the Apple I computer to the home market.

[137] Kent E. Erickson, "Electronic Surveying System," *Papers from the 37th Annual Meeting American Congress on Surveying and Mapping* (March 1977): 209,217.

CHAPTER EIGHT

THE HEWLETT PACKARD STORY

Figure 14. Hewlett Packard HP 3800. (1971) Source: http://www.gmat.unsw.edu.au/currentstudents/ug/projects/f_pall/html/e5.html

Hewlett-Packard deserves a special place in a historical examination of electronic distance meters. Unlike European companies like Wild Heerbrugg and Carl Zeiss, or American companies like Keuffel & Esser, HP had not produced anything of value for the surveying community. Best known for test instruments used in a laboratory, they came to the market afresh. They had no established network of experienced dealers who spoke the arcane language of the land surveyor. There were no HP company stores selling oscilloscopes and radio frequency tone generators to the public. Nonetheless, Hewlett Packard had established a reputation for building reliable, quality products.

People who were familiar with Hewlett Packard and the distance meter recount the story of Bill Hewlett and his trip to Afghanistan in 1965. Hewlett, one of the two founders, observed a surveyor measuring a distance with an electro-optical device. According to the Smithsonian, he was “struck by how long it took to set up the device,” and thought that HP technology may have some contributions to make. Paul Stoft designed the block diagram for the instrument and, although eighty two years old as this is written, still agreed to answer a few questions about the development.

The HP3800 pictured above was the first in a series of HP distance meters. Its range, 10,000 feet, represented "…the limitation of the light source" as well as a thinking that it "… would be adequate for most work."[138] Stoft was adamant that had Bill Hewlett not taken a personal interest in the development of a distance meter the company would have never considered making surveying instruments.

Dr. Francis H. Moffitt, a professor of Civil Engineering at the University of California offered his thoughts on the HP3800 at the Annual Meeting of the Canadian Institute of Surveying in April 1970. The new instrument was compared and tested with a precise baseline established along the Colorado and Southern Railway at Berthoud, Colorado. The operation was described by Professor Moffitt as very simple: orient the instrument over the point, aim at distant reflector prism. This prism was a round glass assembly about the size of a baseball in diameter, ground such that the angle of reflection was the same as the angle of entry. Contrast this with a standard flat mirror, where the exit angle is dependent on the entry angle. The returned infrared signal was optimized by adjusting the aim until the return signal was maximized. Prior to measurement, the five mechanical rotary switches on the face of the instrument are set to 0. Starting from the leftmost switch, it is cycled through the ten switch positions until an analog meter is nulled. Coaxially mounted on the switch stem are the numbers 0 through 9. Depending on the switch position, only one number is visible in a window above the switch. As each switch is moved to the position that nulls the meter, the distance is refined. After the first adjustment, the distance to the nearest thousand feet is shown. The next switch

[138] Email from Paul Stoft, received 18 October 2004.

determines the hundreds unit, the next the tens, and so on until all switches have been nulled. The distance is then read directly from the windows above the switches. Professor Moffitt and his team averaged less than two minutes to measure each of sixty eight distances. With respect to precision, they found a relative precision of one hundredth of a foot or less for distances between one hundred feet and seven thousand feet. To test the range, they successfully measured two miles to a triple prism assembly. Moffitt concluded that the HP3800 was "…just about as accurate as the manufacturer claims, even under very difficult daylight conditions of air turbulence."[139]

Professor Moffitt's evaluation was given in April of 1970. The official press release authored by David B. Kirby of Hewlett Packard that announced the new instrument was dated October 7th, 1970, six months later than the Moffitt paper. The test site was at Berthoud, Colorado. The press release disclosed that the instrument was developed and would be produced at HP's Loveland, Colorado Division. Berthoud is approximately five miles south of Loveland. Obviously, HP invited Dr. Moffitt to Colorado for a sneak preview of the new instrument. In return, the distance meter received a glowing review.

The first advertisement for the Hewlett Packard HP3800 distance meter appeared on page 21 of the March 1971 issue of the ACSM publication *Surveying and Mapping.* HP claimed first order accuracy, fifteen minutes of training time and two minutes of measurement time in an American made instrument costing $4110.[140] Remember that the Wild DI-10 sold for $6850 and the Laser Ranger was $8000.

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[139] Francis H. Moffitt, "Field Evaluation of the Hewlett Packard 3800A Electronic Distance Meter," *Surveying and Mapping* 31, no.1 (March 1971): 79-86.

[140] Geodetic surveys are classified by order and class. The actual definition of the order is a specification of the type of instruments permitted and number of redundant

Hewlett Packard would become a major player in the EDM market during the 1970s. All HP distance meters carried a four digit model number starting with 38. As the technology increased, the final two digits increased. The final product aimed at the land surveying market was the 3820. It would be difficult to find a field surveyor working with EDM in the 1970s who did not at some point interface with the HP line of instruments. The current websites for HP and Agilent (the spin-off of HP's test and measurement division) provide pages documenting the history and timeline of the companies. Curiously, neither makes any mention of what became an extensive line of Civil Engineering products.[141] The HP virtual museum contains two photographs of HP cameras made during the 1960s, a product not typically associated with the early years of HP. There are no images of any of the distance meters.

In an admittedly non-scientific effort to determine the popularity of HP products, I posted a request for information on a popular website frequented by surveyors around the country (www.rpls.com). I asked the older guys for their recollection of EDM instruments during the 1970s. There were five questions:

1. What instrument did you or your firm acquire that was infrared?
2. Do you recall about when you purchased?
3. What was considered? cost? ease? precision?

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observations required. The specifications are written to obtain a given level of acceptable misclosure. By referring to first order accuracy, HP is implying that the distance measurements obtained with this instrument are sufficiently precise for use in first order work. To the surveyor, accurate and precise are entirely different concepts. Accurate means exact, and surveyors often say the only accurate measurement is a count. There are exactly five fingers on the normal human hand. Precise is proximity to an absolutely known value, generally understood to be the ability to take repeated measurements with a very small relative standard deviation from the mean.

[141] http://www.hp.com/hpinfo/abouthp/histnfacts/museum/chronological/index2.html see also http://www.agilent.com/about/newsroom/facts/history.html both accessed 6 October 2004.

4. What did your competitors use?

5. Do you feel that one company dominated the EDM market in the 1970s? If so, who? Why?

Very few answered each question, most responders answered questions 1 and 5. Here are the salient responses. Note that some of the posters use nicknames or "screen names" rather than their real names:

E. Andy Bruner of Marietta, Georgia used an HP 3800. It was "large and HEAVY" and had to be dialed in, was a "pain in the butt" but was very accurate. Richard Erskine used a Wild DI-10 in California. Judson Coppock in Oregon used a 3800 and several other instruments. Dan Beardslee used the HP3800 and HP3805. Luke from Colorado used a 3800 and a 3805. Loyal Olsen said, "Around these parts [Utah] the HP-3800 (and later the 3805) pretty much ruled the roost." Michael Binge thought "The 3800 seemed to dominate the EDM market from 1971 to 1975 or 76… I think many would agree, it was the machine that put EDM's "on the map" (so to speak)." Rich PLS used a 3810 while working in Mississippi, and thought that HP should have stayed in the market. "A lot of loyal supporters would have kept them strong." Marc Witalec first used the 3805A in Lansing, Michigan. Phillip Reed of Scarborough, Maine used a Wild Distomat (the DI-10). True Corner (a screen name) mentioned HP and thought that "EDMs changed the face of surveying much more so than GPS or total stations." Forrest Shoemaker worked for the US Forest Service in the Olympic National Forest. He started with a CubiTape, used it for a season and then began using the HP3805. Mr. Shoemaker thought "HP definitely had the USFS sewn up as a major buyer. We bought dozens of 3805s, 3808s, 3810s, and their total station 3820s. We tried out a lot of brands and settled with HP as toughest and most accurate". Jerry Wahl worked for two private firms that acquired the HP 3800 and then joined the Bureau of Land Management (BLM) where he used a 3805. Wahl related that BLM had acquired a Wild DI-10 before his employment, but “It was awkward and unwieldy to set up and operate, but it was still worth it in rough country if you could drive near to the setup point. You wouldn't want to have packed it.” Jim Drumm used a Wild Distomat in New York. Greg Shouts remembered dialing in the 3800 in Midland, Texas while it was hooked up to the truck [battery]. Angelo Fiorenza of New York used a Kern Accu-Ranger. The posting received seventeen replies in one day. Twelve mentioned Hewlett Packard. There must have been a reason, and there was.

It is readily apparent that the field aspects of surveying can be arduous. Extremes in temperature and terrain combine with the sheer physical labor required to tire even the best after a long day in the field. For land surveyors operating in the private sector, the mental efforts required to transform the field data into boundary map details could be overwhelming.

Traditional angular units employed by surveyors in the United States are based on the sexagesimal notation, a system also associated with time. The addition and subtractions of values in the sexagesimal system could not be easily performed with standard computing machinery available in the 1960s. Adding 4 degrees and 50 minutes to 8 degrees and 15 minutes would produce an answer of 12 degrees and 65 minutes on an adding machine. That is easily converted to 13° 05’, but when subtracting, the mental arithmetic is not as straightforward. For example, if one used an adding machine to subtract 4° 15’ from 13° 05’, the answer would be 8° 90’. When adding, it was easy to see that 65 minutes is greater than a degree, so with little effort the degrees unit is increased by one and the minutes unit decreased by sixty. However, if we apply the same conversion principle to the subtraction example, we might think the proper result to be 9° 30’, nowhere near the actual answer of 8° 15. This example only involves degrees and minutes. When the minutes are divided into seconds, an adding machine is more hindrance than help, and paper and pencil the only solution.

Once the tired and weary surveyor, working late at night to get the map ready for the client tomorrow, had used paper and pencil to convert his raw field angles into directions, or bearings based on the standard compass rose, latitudes and departures had to be computed in order to calculate the area of the parcel. This calculation, known as polar to rectangular, requires that the cosine of the direction be multiplied by the distance to derive the latitude, and the sine value multiplied by the same distance to yield the departure. Sines and cosines were not available except by reference to previously computed values published in tabular form. In the North Carolina State University D. H. Hill library there remain three copies of Jean Peters *Eight-place tables of trigonometric functions for every second of arc, with an appendix on the computation to twenty places*. The call number is QA55.P443, publication date is 1968, and there are 954 pages in the book. This is just one of many volumes of tabular trigonometric data in the library.

In 1972, Hewlett Packard introduced the world’s first handheld scientific calculator.[142] Using algorithms developed by David S. Cochran of HP, the HP-35 provided (among other transcendental functions) the sine, cosine and tangent functions.[143]

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[142] http://www.hp.com/hpinfo/abouthp/histnfacts/museum/personalsystems/0023/, accessed 13 October 2004.

[143] David S. Cochran, “Algorithms and Accuracy in the HP-35 Scientific Calculator,” *Hewlett Packard Journal* (June 1972). Available in PDF from http://www.hp.com/hpinfo/abouthp/histnfacts/museum/personalsystems/0023/, accessed 13 October 2004.

The calculator was priced at $395. HP hoped to sell 10,000 units, a break even point. The first year, over 100,000 were sold.[144]

Lawson Deaton was a Hewlett Packard salesman in 1972. His territory included Virginia and the Carolinas, and HP described his job as salesman of surveying instruments. Deaton recalled demonstrating the new HP-35 at a Randolph County, North Carolina Society of Surveyors meeting. One old timer was, in Deaton's words, "so incredulous and disbelieving that he actually took out his trig tables to make sure that that *[sic]* the handheld unit was providing accurate data."[145] In addition to the handheld unit, HP was heavily promoting their 9810 desktop computer, sold with pre-programmed surveying solutions. Sales of the desktop computing machine constituted Deaton's bread and butter, a testament to the mental efforts and strain involved in reducing field survey data by hand. In Deaton's view, it was the HP-35 that provided HP with credibility across the spectrum: "From soup to nuts" was how Deaton put it. One might argue that the affordable desktop computer revolutionized the practice of Land Surveying, but then, there aren't many tasks that the 1983 Man of the Year did not impact in some manner.

In a sound marketing move, HP began to bundle the 9810 computer and 3800 distance meter as companion instruments, and offered the practicing Land Surveyor a complete survey solution. The computer and distance meter could be leased through HP for a term of three years with a $1 buyout at the end of the lease term.

HP's press release about the 3800 indicated that delivery would commence in January 1971. An advertisement on page 1 of the July 1972 issues of the ACSM journal *Surveying and Mapping* boasted of over fifteen hundred surveyors in the United States

[144] http://www.hp.com/hpinfo/abouthp/histnfacts/museum/personalsystems/0023/, accessed 13 October 2004.
[145] Email from Lawson A. Deaton dated October 10, 2004.

who were using the instrument. The advertisement contained a quotation, ostensibly from a user that it was "great to have an American product in the field of surveying that beats all foreign competition—for less money." The September issue of that journal carried an advertisement by HP boasting of 2000 units sold. By September of 1973 Hewlett Packard advertising claimed 2500 users. Lawson Deaton remembered selling five to eight units per month over an eighteen month period. There were twenty five HP sales associates covering the United States, and according to Deaton, that was about normal for the other salesmen. Assuming seven units per month, twenty five salesmen, and eighteen months of sales, the HP claim seems quite reasonable.

Surveying and Mapping for March 1974 was the first advertisement offering the HP3805, an instrument that Deaton recalled as the largest selling of the HP line. The combination of weight and price qualified it for Deaton's assessment as the "sweet spot" in the HP lineup. When the introductory price of $3395 was combined with the absolute simplicity of operation, the 3805 represented an instrument that could not be ignored. Advances in the internal circuitry, particularly with large scale integration, had brought about an instrument that was, simply, point and shoot. There were no switches to turn and no meters to null (except for a signal strength meter to permit exact pointing). The operator simply sighted the prism target through the internal telescope, tweaked the return signal by horizontal and vertical tangent screws, and pressed the yellow button. Within seconds, the distance was displayed on a LED screen. A single slide switch on the panel converted between feet and meters, and surveyors quickly adopted the practice of recording the distance in their field book in feet as well as meters. Transposition of numbers has always been a problem whenever people, pencils and numbers assemble. If a survey mathematically failed to close, the surveyor could check his notes looking for a difference between the converted metric units and the value recorded in feet. If the converted metric value resolved the closure problem, a return trip to the field was avoided.

James W. White, the Product Manager for the HP Civil Engineering Division presented the HP3805 to members of the ACSM attending the March 1974 Annual Conference. HP, drawing on the technology in their handheld calculators, had developed integrated circuits to perform specialized tasks automatically for the second generation of instruments. White's presentation centered on three aspects of the 3805's internal circuitry: automatic electronic self test, statistical evaluation of the measurements and utilization of the LED display to communicate with the operator.

"The benefit of a self-check is obvious, since it allows the operator to ascertain that his distance meter is operating correctly before traveling to a remote job site."[146] The battery is checked under a full load condition, all segments of the LED display are lighted, and an actual distance measurement is performed. If any of the internal checks fail, the display flashes a zero. The operator must ensure that all LED segments are operating properly.

Competing automatic distance meters derived multiple values for the distance and then displayed the averaged results. Obviously, the inclusion of an incorrect value could adversely affect the validity of the averaged measurements. If there were 999 instances of a distance of 100 feet, and one instance of 8000 feet, the average might be skewed just enough to escape notice, but enough to affect the closure. HP engineers designed a

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[146] James W. White, "The Changing Scene In Electronic Distance Meters." *Proceedings of the American Congress on Surveying and Mapping 34th Annual Meeting,* March 1974, 620.

microprocessor capable of calculating not only the average, but the standard deviation of over 3,000 independently determined values. The deviation was then compared to an internally defined acceptable value. In the case of unacceptable residuals, the instrument would reject the first set of data and re-cycle the measurement phase. The 3805 used two varying frequencies, one to determine the high order value and the other to determine the low order value. Each was independently verified by the on-board chip. If the first 2,000 low frequency measurement failed, the instrument would take additional readings in multiples of two hundred fifty and reprocess the data. If an acceptable variation could not be determined after 16,000 iterations, the instrument display would flash a zero. When the low frequency value was determined to an acceptable tolerance, the high frequency portion of the cycle would begin, following the same flow chart logic. The meter required only 21 seconds for initial measurement, verification, and progressive increment to maximum cycles for both frequencies. HP claimed that the 3805 was the only instrument capable of immediate internal verification of the measurement. If, four years later, the Carl Zeiss company had employed the appropriate internal circuitry in their RegElta equipment, Klaus Hendrix would not have had to re-run a traverse loop (see page 65).

Dr. A. J. Robinson, a Professor at the University of New South Wales, made the long flight from down under to present his analysis of the HP3805 to the 1974 Fall Convention of ACSM. Professor Robinson proclaimed that the new instrument had "found wide acceptance by the civil engineering and surveying professionals around the world," and concurred with Mr. White of HP that the electronic self-check and microprocessor evaluation of measured data represented very important contributions to the development of EDM equipment.[147]

In comparison to other EDM units available, the HP series was bulky. Although HP suggested that it could be mounted on instrument standards, the fear that the heavy instrument would damage the internal components of a delicate optical instrument precluded such operation by careful surveyors. Precise instruments of the era were manufactured with various alloys, none of which had any ferrous content which could interfere with magnetic compass observations. In operation, the surveyor fitted his theodolite to a tribrach (see Figure 16) mounted on a tripod, observed the horizontal and zenith angles, and then replaced the theodolite with the distance meter. The distance meter was supplied with a T-handle to facilitate handling of the bulky unit as Figure 15 shows.

Figure 15. HP 3805. (1974) Source: Ebay listing, available 14 October 2004, item # 3845998299.

[147] A. J. Robinson, "Field Investigation Into The Hewlett-Packard Distance Meter," *Papers from the 1974 ACSM Fall Convention* (September 1974): 376.

Figure 16. Tribrach. (2004) Source: Topcon Positioning Systems.

By September of 1975 HP had introduced the HP3810, advertised as a "New—Total Station."[148] In outward appearance, the units resembled the previous models and remained bulky and heavy. Lawson Deaton reported that this model did not sell as well as others, suggesting its weight and bulk were the primary concerns. Although Zeiss had produced an electronic digital theodolite in 1968, the HP3810 unit of 1975 simply incorporated an optical system for reading horizontal angles with an electronic unit to determine zenith angles. Using circuitry and algorithms developed for the HP-35 handheld calculator that had proved their worth in the 3805 series, the 3810 extended the capability by providing direct horizontal distance readouts as well as the vertical deflection component (elevation difference).

Michael Bullock of Hewlett Packard spoke to the 1975 Fall Convention of the American Congress on Surveying and Mapping to highlight a particular benefit of the 3810. He informed the membership that during the previous five years, HP had received many requests to manufacture an instrument that incorporated the ability to measure horizontal and vertical angles as well as electronic distances into a single unit. This was no surprise, since Zeiss had developed and marketed an operating, although unwieldy,

[148] Advertisement in ACSM *Surveying and Mapping* September 1975.

item seven years earlier. With an appearance and weight quite similar to its predecessors, the 3810 was touted as the "layout machine."[149] Recalling the difficulties experienced by Monaghan using his Wild DI-10 and T-2 to layout locations (see page 55), the coaxially mounted optics were combined with automatic on-board reduction of slope distance to horizontal. The 3810 represented a substantial forward step towards a total station. However, as Bullock fairly disclosed, the shortcomings were an inability to plunge the instrument and an optical alignment vertically offset from the measurement axis. This offset required the use of tilting prisms and targets to achieve precise results over short distances.

Hewlett Packard's Civil Engineering division would continue development of surveying instruments, finally introducing the HP3820, a true total station with fully digital electronics and interfaces to permit storage, loading and retrieval of survey data. Gordon Moore's is known for his axiom regarding computer chips: they double in capacity every year.[150] This was certainly applicable to the EDM field in the late 1970s. The HP3820 was reviewed by Alfred F. Gort in 1977. His paper recounted the objectives the design team had developed based on market investigation as well as customer and consultant input. The objectives were:

- Angle and distance in a single instrument.
- Angle accuracy of one second or greater.
- Compensation of horizontal and vertical axes for mislevel.

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[149] Michael L. Bullock, "HP3810A—The Layout Machine," *Papers from the 1975 ACSM Fall Convention* (September 1975): 14.
[150] Ross Knox Bassett, *To the Digital Age: Research Labs, Start-up Companies, and the Rise of MOS Technology* (Baltimore: The Johns Hopkins University Press, 2002), 168-170.

- Data processing on-board and electronic data output.
- Comparable in size to a second order theodolite.

Not only did the instrument meet these objectives, it provided four hours of continuous battery operation and was offered with an optional portable data collector that stored 1023 lines of data.[151]

The 3820 was the end of the line for HP in the surveying instrument field. The last hurrah for HP's distance measuring equipment was the HP 3850A, an industrial distance meter intended to "…eliminate or reduce mechanical downtime that often plagues industrial measurement applications."[152] HP suggested that this instrument could combine with an external controller to determine position, velocity and acceleration. The 3850A did not sell well. According to Deaton, it was a solution in search of a problem.

When asked for his opinion on why HP finally closed its doors to the Civil Engineering division, Lawson Deaton explained, "In short, the competitive landscape evolved, pushing the solution towards a commodity—with commodity margins—that is, HP no longer had the niche plus the attempt to expand the EDM market with new industry-driven enhancements failed, which I think was THE major reason." By 1983, authors of surveying textbooks concurred with Deaton's assessment of EDM as a commodity, writing, "Less than a decade ago, electronic distance measurement, EDM, was considered a novelty among practicing surveyors. Today's practicing surveyor

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[151] Alfred F. Gort, "The Hewlett-Packard 3820A Electronic Total Station," *Papers from the 1977 ACSM Fall Convention* (September 1977): 322-326.
[152] Hewlett Packard Products Catalog, 1981: 677.

cannot meet competition in the contract market if furnished only with conventional [instruments]."[153]

The 1980s brought the Asian invasion to the surveying world, with Japanese competitors like Topcon and Nikon overtaking the European and American manufacturers with smaller, lighter, faster and cheaper equipment. By then, this had become a familiar tune as xenophobic Americans, while complaining that Japan would soon own most of New York City and all of Detroit, continued to line up to buy their products.

The Civil Engineering Division of Hewlett Packard had become one more entity whose improvements and enhancements overestimated the market. "When the performance of two or more competing products has improved beyond what the market demands, customers can no longer base their choice on which is the higher performing product. The basis of product choice often involves from functionality to reliability, then to convenience, and, ultimately, to price."[154] At first, Geodimeter and Tellurometer were not only functional, there was no other choice. HP equipment was reliable and convenient during the 1970s, but by 1980 Topcon and Nikon had become not only efficient, they were cheap (relatively speaking).

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153 Simo H. Lauria, *Electronic Surveying in Practice* (New York: John Wiley & Sons, 1983), vii.

154 Clayton M. Christensen, *The Innovator's Dilemma When New Technologies Cause Great Firms to Fail* (Boston: Harvard Business School Press, 1997), xxiii.

CONCLUSION

Advances in civilization owe an inestimable debt to the yearning of man to improve, adapt and refine. With these advances came an exponential increase in productivity that acted as an accelerant to the dissemination of knowledge. The combined efforts of many people melded to produce a complex tool required by a very small group of people. Albert A. Michelson dedicated his career to the search for an accurate value of the speed of light using a rotating mirror. Erik Bergstrand substituted the shutter developed by Reverend John Kerr to refine Michelson's efforts, producing an instrument capable of relatively accurate measurement of long distances. Laboratories working under government contracts developed the maser, allowing Wadley to use microwave signals instead of visible light to measure distances. Those laboratories went on to develop the laser. Laser research led to the discovery the lasing property of a Gallium Arsenide diode. Bill Hewlett realized that his company's research into light emitting diode technology might fill the need for short-range distance measurement. Earlier along the way, Bell Laboratories development of the transistor and their government imposed policy of maintaining a free flow of research information had allowed smaller, lighter and more durable instruments to be available. Integrated circuits allowed the meter to make rapid calculations internally, allowing the instruments to gauge the veracity of the measurements and assure confidence in the results. In twenty five years, accurate non-contact distance measurement had been transformed from a chimera to a commodity.

The private practice surveyor of the Twenty-First century no longer maintains an electronic distance meter as a stand-alone instrument. The distance meter has become an integral part of the total station, the workhorse of production surveying. Most progressive firms today find that in addition to the total station, GPS technology is fast approaching commodity status even though current state of the art equipment carries a price tag over $40,000.00. Some modern total stations have incorporated accurate servo motors and automatic prism tracking technology, allowing them to operate without an operator's attention. These instruments are dubbed 'robotic' and have introduced the reality of solo surveying. Other total stations employ 'prism-less' measurement technology, allowing them to precisely measure distances to non-reflective surfaces.

The argument was made in this thesis that the development of electronic distance measurement instruments was the most profound advance in surveying since World War II. In this conclusion, perhaps it should be argued that this breakthrough was the most significant in the history of surveying. For a surveyor of today to sit before her computer with all of the sophisticated CAD software available, and contemplate her field survey crews continuing to measure distances with a steel tape is unimaginable. Before the computer became a commodity item, it had become a must-have item for production surveying, not only because of the relief from oppressive calculations it afforded, but in order to keep up with the productivity increases brought about by measuring distances in seconds. Even GPS owes a debt of gratitude to Dr. Bergstrand and Dr. Wadley— the positions determined by GPS receivers depend on calculating the distance from each orbiting satellite to the receiver by the phase shift of radio signals transmitted at microwave frequencies. For all of its benefits, GPS will never measure the depth or length of a mine shaft, nor would it have allowed the Chunnel to have been constructed simultaneously from Folkestone, UK and Sangatte in France and meet each other within two centimeters.

Researchers, scientists, academics and dreamers over the past half century have sought solutions to grand problems, and along the way, provided the raw materials that allowed niche markets to adopt and then adapt to their own particular purposes. Although much gratitude is owed to Bergstrand and Wadley as pioneers, the contributions of unknown thousands changed the practice of land surveying forever.

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