Albert Einstein:
Godfather of Modern Land Surveying Technology

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SUMMARY

The tools of Land Surveyors are some of the most advanced and exciting technologies in the architecture, engineering and construction (AEC) industry today. They have come a long way from the ropes used for ancient boundary resolutions and plumb bob's used for the earliest construction layout.
Even though the most basic tools, dating back at least 5,000 years, are still used with great success, the advent of the EDM, GPS and 3D Laser Scanners has taken our profession to unprecedented heights. We rely on these tools every day. Without lasers and Global Positioning Systems, our jobs would much tougher and much less efficient.

Throughout history, land surveying has championed the development and advancement of many different tools and technologies. Land surveying has served science and, in turn, science has served land surveying. Some of the greatest astronomers, mathematicians and physicists of all time have made great contributions to land surveying tool theory and technology advancements.

Edmund Gunter, Galileo Galilei, Sir Isaac Newton, Leonhard Euler, Pierre-Simon Laplace, Carl Friedrich Gauss, Sir George Airy, Simon Newcomb, Léon Foucault and Albert Michelson have all made significant contributions to the metrological technologies of the art of land surveying.

However, Albert Einstein might be considered to have made the greatest contributions to modern land surveying technologies.

Einstein's 1905 paper on quantization of the radiation field (photoelectric-effect), his famous 1915 presentation of the theory of general relativity and his 1917 theory of radiation have all had dramatic consequences on the development of modern land surveying tools and technologies, including Electronic Distance Meter, 3D Laser Scanning and Global Positioning Systems.

Einstein is synonymous with genius. Time magazine's 1999 "Person of the Century," demonstrated an early affection for the attributes that any land surveyor would appreciate. Einstein once stated that, when he was five, his father showed him a compass, and that the realization that something in 'empty' space was moving the needle had left "a deep and lasting impression."

From his earliest years, it seems that Albert was destined to become the godfather of modern land surveying technology. Indeed, land surveying would later realize many profits from his invaluable legacy of scientific discoveries.

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GENERAL RELATIVITY, GEODESY, GLOBAL POSITIONING SYSTEMS, VERY LONG BASELINE INTERFEROMETRY AND LUNAR LASER RANGING

The creation of a global geodetic reference frame would never have been possible, even with the most sophisticated observing methods and instruments, if Einstein had not first developed the theoretical framework of relativity.

General relativity (GR) is a theory of gravitation that Albert Einstein developed between 1907 and 1915. According to general relativity, the observed gravitational attraction between masses results from the warping of space and time by those masses.

For over two hundred years, Isaac Newton's law of universal gravitation was accepted as a compelling explanation of the gravitational force between masses. Using Newton's model, gravity is the product of an attractive force between the mass of objects. It was consistent and universal.

The mysterious nature of that gravitational force troubled even Newton himself, even while the basic framework of his law described motion exceptionally well. That was before Einstein's theory of general relativity.

Subsequent research and observations confirm that Einstein's description of general relativity accounts for several effects that Newton's law cannot. Newton's law does not explain infinitesimal irregularities in the orbits of planets, such as Mercury, for example.

General relativity also predicts novel effects of gravity, such as gravitational waves, gravitational lensing and an effect of gravity on time known as gravitational time dilation (expansion). General relativity has a number of physical consequences such as the gravitational frequency shift of light. Einstein predicted the gravitational deflection of light: in a gravitational field, light is deflected downward.

Using the analogy of an accelerating rocket with two observers on board, there is a natural notion of 'up' and 'down.' Unattached objects accelerate in the opposite direction of 'up' towards 'down.' If an observer is below the other and propels a light wave 'up' to an observer above, the acceleration, as may be calculated from special relativity, the light wave will be what is called ‘red-shifted.’ The lower observer will measure a higher frequency than the higher observer. This effect of frequency shift has been observed, experimentally, in a gravitational field.

This gravitational frequency shift corresponds to a gravitational time dilation: Since the observer from ‘above’ measures the same light wave to have a lower frequency than the observer from ‘below,’ time is passing faster for the observer ‘above’. Thus, time runs slower for observers who are lower in a gravitational field.

The effects of relativity, and understanding them, are essential for the operation of global positioning systems. GPS vectors for accurate Earth positioning, via Geometric trilateration, are only possible if extremely accurate time can be observed and recorded. Even though the atomic clocks located in satellites are slowed slightly because of the satellite’s orbital velocity, they nevertheless run faster than the identical clocks on the Earth’s surface because they orbit in a weaker gravitational field.
Within hours, the difference in time kept by Earth and satellite clocks would result in navigational errors of miles if these relativistic effects were not taken into account.
Correct and consistent relativistic formulations must also be used to translate the observations collected by very long baseline interferometry, lunar laser ranging and satellite to Earth coordinate values or inaccurate results would render the observations mostly useless. Common standards for properly applied relativistic corrections to observations took many years.

Thanks to Albert and his theory of relativity, vectors between points, measured by lunar laser ranging, very long baseline interferometry and GPS satellites, and separated by thousands of miles, can agree to the millimeter level.

THE QUANTIZATION OF THE RADIATION FIELD (PHOTOELECTRIC EFFECT), THEORY OF RADIATION, EDM’S AND LASER SCANNERS

Einstein also discovered the quantization of the radiation field, usually incorrectly called the photoelectric effect. This effect is a phenomenon in which electrons are emitted from matter after the absorption of energy from electromagnetic radiation.

When a metallic surface is exposed to electromagnetic radiation above a certain threshold frequency (typically visible light), the light is absorbed and electrons are emitted. In this context, the emitted electrons can be referred to as photoelectrons.

In 1905, Einstein first began describing light as composed of discrete quanta, now called photons, rather than continuous waves. Einstein theorized, based upon Max Planck's theory of black-body radiation, that the energy in each quantum of light was equal to the frequency multiplied by a (Planck's) constant. Above a threshold frequency, a photon has the required energy to eject a single electron, creating the observed effect. This discovery led to the quantum revolution in physics and earned Einstein the Nobel Prize in 1921.

The quantization of the radiation field is the discovery that enabled the development of the avalanche photodiodes and photomultiplier tubes that are used as sensors in laser-ranging instruments.

The concepts of spontaneous and stimulated emission, set forth in Einstein's paper *Zur Quantentheorie der Strahlung (On the Quantum Theory of Radiation)*, was a revolutionary re-derivation of Max Planck's law of radiation. Planck's law was based on the concepts of probability coefficients (later to be termed 'Einstein coefficients') for the absorption, spontaneous emission, and stimulated emission of electromagnetic radiation.

In optics, stimulated emission is the process by which an electron, stimulated by a photon having the correct energy, may drop to a lower energy level. Another photon is created. The stimulated photon is seemingly unchanged in the process, and the second photon is created with the same phase, frequency, polarization, and direction of travel as the original.

A cascade effect is produced if the resultant photons are reflected so that they traverse the same atoms or gain medium repeatedly. Stimulated emission is really a quantum mechanical phenomenon. It can be understood in terms of a "classical" field and a quantum mechanical atom. The process can be thought of as "optical amplification" and it forms the basis of both the laser and maser.
Lasers, (Light Amplification through Stimulated Emission of Radiation), are an important tool used for land surveyors around the world. With lasers surveyors are able to perform reflector-less measurements and 3D Laser Scanning.

Einstein's theory of radiation laid the foundation for the invention and creation of the laser some four decades later.

Very Long Baseline Interferometry, (VLBI), is a type of astronomical interferometry used in radio astronomy. It allows observations of an object that are made simultaneously by many telescopes to be combined, emulating a telescope with a size equal to the maximum separation between the telescopes. VLBI is most well-known for imaging distant cosmic radio sources, spacecraft tracking, and for applications in astrometry.

However, since the VLBI technique measures the time differences between the arrival of radio waves at separate antennas, it can also be used "in reverse" to perform earth rotation studies, map movements of tectonic plates very precisely (within millimeters), and perform other types of geodesy.

Using VLBI in this manner requires large numbers of time difference measurements from distant sources (such as quasars) observed with a global network of antennas over a period of time

VLBI - Scientific Results:
- Imaging high-energy particles being ejected from black holes at enormous velocities
- Definition of the celestial reference frame
- Motion of the Earth's tectonic plates
- Regional deformation and local uplift or subsidence
- Variations in the Earth's orientation and length of day
- Maintenance of the terrestrial reference frame
- Measurement of gravitational forces of the Sun and Moon the Earth and the deep structure of the Earth
- Measurement of the fundamental speed of gravity

Lunar Laser Ranging. The ongoing Lunar Laser Ranging Experiment measures the distance between the Earth and the Moon using laser ranging. Lasers on Earth are aimed at retro reflectors previously planted on the Moon and the time delay for the reflected light to return is determined.

Since the speed of light is known with very high accuracy, the distance to the moon can be calculated. This distance has been measured with increasing accuracy for more than 35 years. The distance continually changes for a number of reasons, but averages about 384,467 kilometers (238,897 miles).
This is considered one of the most precise distance measurements ever made - equivalent in accuracy to determining the distance between Los Angeles and New York to one hundredth of an inch. Work is progressing on increasing the accuracy of Earth-Moon measurements to near millimeter accuracy.
Additionally, the accuracy of these experiments has improved historic knowledge of the Moon's orbit enough to permit timing of solar eclipses up to 3,400 years ago

Lunar Laser Ranging-Findings:
- The moon is spiraling away from Earth at a rate of 38 mm per year
- The moon probably has a liquid core of about 20% of the Moon's radius
- The universal force of gravity is very stable
- Einstein's general theory of relativity predicts the moon's orbit to within the accuracy of the laser ranging measurements.

CONCLUSION

Land Surveyors today enjoy some of the most extraordinary technologies. Our tools of are some of the most advanced and exciting technologies in the world today. From the EDM, GPS and 3D Laser Scanners to the Very Long Baseline Interferometry and Lunar Laser Ranging, the world of land surveying and Geodesy can thank Albert Einstein and his genius. Although he didn't create the tools we use, his theories would prove essential for their development. He can truly be called "The Godfather of Modern Land Surveying Technology."