NOVEL AM BAND GRADIOMETRIC GROUND PENETRATING RADAR CASE STUDY CONSTRUCTION RISK MITIGATION LOS ANGLES WORLD AIRPORT

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Abstract— **Subsurface utility engineering (SUE) concerns are risk mitigation problems requiring confirmation, denial and new evidence concerning long thin cylindrical conducting utilities illustrated on old; oftentimes, unreliable and out dated utility maps. This case study first presents a scientific, technology, engineering and mathematical (STEM) description about a revolutionary class of radio detection technology that applies regional AM band radio satiation ground wave electromagnetic (EM) energy to illuminated 100's of square miles of urban surface area. Buried conductor in the illumination region re-radiates AM radio signal becoming detectable only with proprietary gradiometric antenna-receiver (AMG) technology. The revolutionary technology is based on the long wavelength scattering limit theory of theoretical physics. We describe the nature of AM radio station ground wave EM energy illumination of subsurface utilities, principles of gradiometric detection of re-radiated phase-coherent AM signal energy and then compare images of long thin cylindrical conducting utilizes with in-place of maps of subsurface utilities. The utilities were buried near surface and down below 15 m (60 ft). Service area hydrocarbon plumes were mapped at the airport.**

Index Terms—**Utility Detection Buried Conductor, AM Gradiometric Detection. Hydrocarbon Plume Detection**

I. INTRODUCTION

How much does it cost to shut down and delay a large construction site for a day? A week? How about three months? What is the cost to stakeholders and employers when construction designs and drawing sets are changed, requiring re-mobilization, re-do and disruption of an organized plan. Worst, chaos related accident interfere with operations for days or even months. Always, a need to assign blame, speaking justice in the court systems by negations, mediation and trial. The nature of the project changes from being driven by STEM objectives to a project needlessly complicated by STEMless counter measures. The costs are staggering and reaching far below the bottom line. In this case sturdy, approaching $ 26 million dollars.

Locating underground utilities has been an industry nightmare for as long as machines have been digging in built-up areas. At any single construction site, nearly 40% of the utilities are not accurately located and marked (Turner

LAWA Construction, 2014). Further, almost 100% of all construction activity involving new construction or demo and remodel, will have one reported unintended utility strike at some point in the project (Clark Construction, 2015).

II. After the Fact Data Collection Instrumentation Applied at LAX Airport

AM radio station ground-wave electromagnetic (EM) energy illumination of 100's of square miles of the Earth' surface is one of two noteworthy features of this revolutionary subsurface utility detection technology. The second, re-radiated AM radio band EM energy from every buried utility becomes "brilliantly" detectable because it is phase-coherent with the illuminating AM radio band EM energy, becoming detectable with gradiometric antenna-receiver (AMG) technology [1].

Older STEM fellows will remember vertical receiving antennas installed on their automobiles. When the AM radio stations tower ground-wave vertically polarized electric field (EV) line of force component arrives at thin cylindrical conducting automobile receiving antenna, the lines of force accelerate mobile electrons inducing electric current flow in the antenna that enters the receiver. The automobile receiver detected the AM signal, recovering music and voice signals. The AMG utility detection concept is illustrated in Fig. 1.

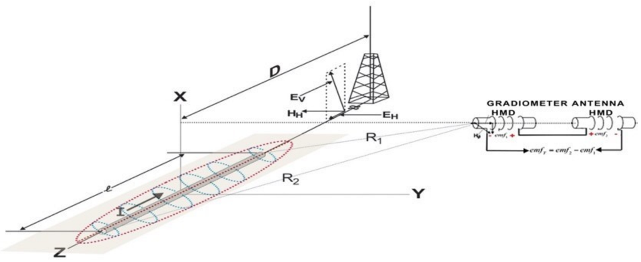

Fig. 1 AM Radio Station Ground-WaveTower and AMG RECEIVER: 1)AM Tower Ground Waves. 2) Utility Re-radiated AM magnetic (blue) and Electric (red) fields and 3) Detection with Differential Connection of Magnetic Dipole Antennas

AM radio station ground-wave feature two horizontally polarized electric (EH) and magnetic (HH) field line of force components that travel along radial surface paths from the AM tower, always "leaking" energy (heat loss) downward into the soil. For SUE problems, long thin cylindrical conductors are horizontal utilities buried in the soil. Horizontally polarized EH line of force accelerate mobile charge creating current (I) flow in underground utilities. Accelerating mobile charge always radiate an "expanding" cylindrically wave front of re-radiated electric (red) and magnetic (blue) fields as illustrated in the Fig.1. Expanding electromagnetic fields are observable all along the conductors [2]-[5]; surprisingly, on approach to each open end of the conductor, de-accelerating charge radiates a spherically expanding wave front as illustrated above [6]. Utility detection is carried out in the far-field of the AM radio station [7]. The AM band ground-wave wavelength (λ) depends on frequency and ground electrical conductivity (σ). In sandy-clay and damp-clay soils ranges between 80 m (262 ft) and 26m (85 ft); respectively.

The second noteworthy feature of this revolutionary utility detection technology related to the STEM fact that AM radio station" far field" radiated electromagnetic (EM) energy travels on a vertical plane wavefront. The ground-wave travel on a horizontal plane-wavefront. The horizontal and horizontal wavefronts travel together, each exhibiting an electric (EH) and magnetic (HH) field line of force. The EH and HH fields are polarized, orthogonal to each other, as required for transmission of energy. The ground-wave EH field is uniformly polarized along the utility, inducing uniform current (I) flows. The measured current flow is constant along the entire length of the utility, even when approaching the end of the utility. In practice, standing waves with periodic nulls in current are not observable when utilities are uniformly illuminated with AM radio station ground waves. The implication is that utility length of only a few meter can be detected.

The formidable but not intractable detection problem relates to the fact that the magnitude of the vertical wave front fields are more than 100 time (40 dB) greater than the "near-field" cylindrically expanding wave front re-radiated from the buried utilities. Only readily detectable with gradiometer differential connection of magnetic dipole antennas (i.e., gradiometer detection sensitivity increases with antenna separation distance). Synthetic gradiometer aperture measurements along survey lines crossing utilities are algorithmically processed to improve image quality, creating a "heat map" ensemble of buried utilities.

Gradiometric instrumentation and signal processing functionality takes the spatial derivative of the vertical and horizontal wave fronts. In the far-field of the AM radio station, plane wave front exhibits constant energy density. Mathematically, the derivative of a constant is zero. Gradiometric detection suppressed the magnitude of AM radio station broadcast energy at the gradiometer antenna-receiver location. The spatial derivative of the near-field cylindrically expanding wave front is not zero. For example, the differential connection of gradiometer antenna when located directly over the utility is a factor of two greater in magnitude than the re-radiated AM band utility signal (i.e., a passive gain of 6 dB).

Gradiometers have the remarkable capability of determining distance to the buried utility, a function independent of frequency and conductivity [8]. Mathematically, gradiometer response can be represented by Taylor's expansion of cylindrically spreading wave front to develop a formula for deterring distant from the receiver to the utility below a spatial cluttering geology interface.

Low false alarm rate (FAR) detection requires the ratio of the magnitude of the re-radiated to illuminating AM wave front fields must be greater than 5.5:1 (13 dB) for acceptable false alarm ratios (FARs). Commercial GPR ratios are typically less than 1/100. Re-radiated AM wave front fields from utility are not observable with a conventional radio or commercial GPR antenna/receiver. However, AM band (i.e., long wavelength) gradiometer antenna constructed with differential connections of magnetic dipoles will cancel the illuminating EM waves by a factor of up to 2000 (80 dB) [9]-[12]. The gradiometric antenna response detection signal **(S)** to noise **(N)** ratio is significantly increased up to 100 (40 dB). The increased **S/N** ratio factor reducing FAR with the additional gradiometer response benefit of exhibiting a sharp utility location peak (i.e. horizontal dipoles exhibit a shape null between twin peaks) directly over the utility.

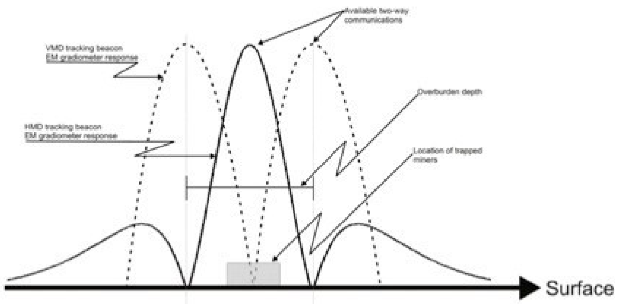

Fig. 2 Gradiometer Response Crossing Utility

Twin peaks in the gradiometer response are observed when crossing the buried conductor. The peak to peak separation relates to the burial depth.

The subsurface utility detection problem must consider surface vegetation, changes in soil moisture and irregular surface elevation change. The effect on the subsurface detection is called cluttering geology noise (CGN). For the long wavelength AMG detection problem, variation in CGN are insignificant. The short wavelength GPR detection problem is deferent. CGN variations are significant and deterministic, not random variables with zero average values. This fact along with the low S/CGN ratio are some of reasons for the high FAR and detection failure observed in commercial GPR failures

AMG receiver high S/CGN ratios enables horizontal thin cylindrical conducting non-metallic conductors to be detected. The reason for re-radiation from nonmetallic conductor is due to mobile charge created by anaerobic bacteria strain's methylation processes. Methylation processes strip electrons from the elements of The Periodic Table of Elements, Anaerobic bacteria stains rapidly acclimate In oxygen depleted environmental conditions where methylation processes create mobile and fixed charged ions in soils. Carbon methylation forms methane gas and hydrogen sulfide along with reduced ionic forms of trace heavy metals. For this reason, horizontal electric E_H field line of force accelerate the mobile ionic charge establishing random streaks of current flow in hydrocarbon plumes and underlying concrete pads and soil pipe. Crack and joint leakage of water and hydrocarbon support acclimation of anaerobic bacteria, detectable with AMG.leads to detection of moisture pooling and bedding failure.

Utility detection depth versus frequency is illustrated in Fig.3.

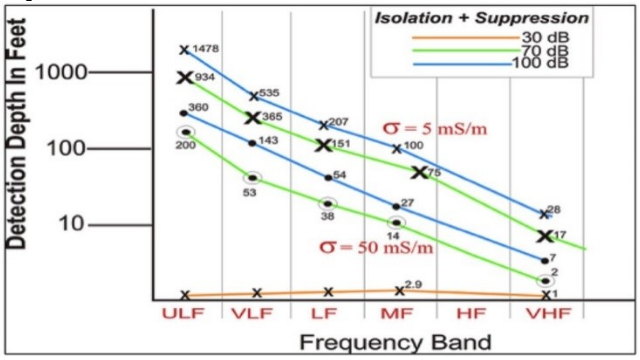

Fig. 3 Detection Depth versus Frequency for
Sandy-clay (σ= 5 mS/m) and Wet-clay (σ = 50 mS/m) soil

III. Gradiometer Tomography Images of Long Thin Cylindrical Conducting LAX Airport Utilities

Gradiometric data acquisition instrumentation are illustrated in Fig.4.

Fig. 4. Mounted Gradiometric Receiver Instrumentation.

The AMG instrumentation interrogation on cart acquired data inside of the buildings as show in the next picture.

Fig. 5 Cart Mounted Gradiometer Receive

This case study compares AM radio station wide area illumination and AMG tomography mapping with in-place maps. Deeply and shallow hurried utilities and hydrocarbon plumes were successfully at LAWA and Seattle Tacoma airport re-construction projects. A game changer in mitigating risk and constrain cost.

As a part of building foundation work at the LAWA Tom Bradley T4 passenger bridge project, more than two hundred twelve (212) 36" diameter 50-foot deep holes were auger-drilled into the earth for cast-in-drilled-hole concrete piers. The risk of hitting utilities was extremely high because there were so many utilities present, and no tool or technology was available to remove the risk. Every pier location was surveyed with AMG technology, and in more than 14 cases, utilities including electrical/communication duct banks, fire water pipes, sewer, storm & potable water piping were discovered, and damage to them avoided. Although foundation redesign was required several times to avoid AMG utility map discrepancies, all 212 piers were drilled in the earth without negatively impacting airport operations and avoiding long schedule delays, millions of dollars in cost and litigation, or worse.

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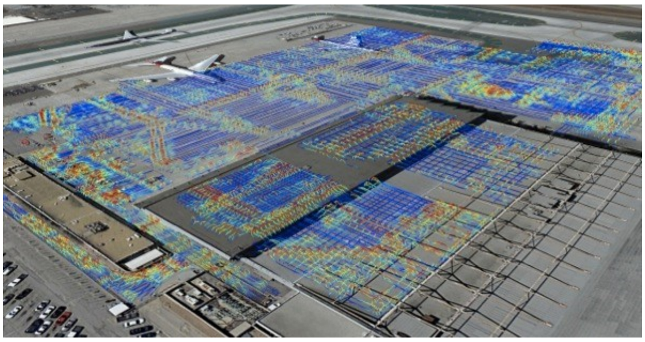

Fig. 6 Plane View Gradiometric Heat Map of LAX Airport Blue Ribbon illustrates Data Collection Paths 2) Red/Yellow Gradiometer Response

The image of Fig.6 is a HeatMap overlay onto Google imagery. The area depicted in the image is about 10 acres and includes areas that were interior to the hangers. The HeatMap image shows, clearly, the subterranean infrastructure of the area. It is important to note that the surface pads are 18-inch thick reinforced concrete. . The applied EMG system in this area also detected a significant contaminated soil zone. Dry coring of the plume revealed that the plume constituents where petrol and chemical in nature. Vacuum excavation was conducted in this area to identify the nature of the EMG detected subsurface infrastructure. In other areas of the airport where the EMG detected subsurface infrastructure, some proof positive validation exercises were carried out using vacuum excavation/day-lighting techniques. Enough positive validations were made, that current design plans were scrapped and entirely new designs arose to better manage the risk and to deal with the expansive underground infrastructure.Long wavelength gradiometer technology discovered 29 discrepancies from the "as-built" plans and competitor's initial survey. The estimated positive impact of this was over $24 million. Assuming $ 850K in losses from a single event, the benefit long wavelength gradiometer detection provides can be quantified as such: of all the work completed to date at LAX, 40% of that data has been used by the on-site construction teams (Turner). Of that 40%, 29 potential interference events were identified and avoided by changing the existing construction plans. These 29 avoided events represent a potential savings of $24M (assuming $850K per event). At the same rates, add the remaining 60% survey work (data taken), and this represents a total risk mitigation of as much as $60M as illustrated in the Fig.7.

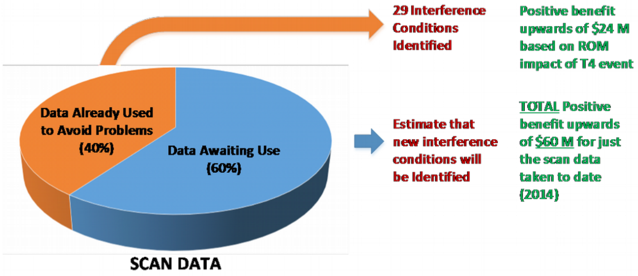

Fig. 7. Risk Mitigation Savings

Gradiometer detection can effectively be employed to map existing infrastructures. Because most of the record drawings or as-built are inaccurate, Gradiometer detection could be used to aid in mapping infrastructure to update the drawings of record and generate accurate distribution system maps. Utilities can easily trace and map are fuel lines, water lines, fire water lines, and any similar structures. It is not adequate for construction companies to rely upon drawings or as-built, nor upon standard utility detection technologies to safeguard against all the consequences associated with a utility strike (i.e., loss of life, property damage, down time for the project and businesses that rely on that existing infrastructure, etc.). An industry estimate shows current standard utility detection technologies fail to detect about 30% - 100% of all existing utilities (Turner, 2015, Smartgrid, 2014). Further, reliability of as-built are significantly less beneficial than standard utility detection technologies. For example, in an actual case, a senior member of the governing authority at LAWA stated that even today, when new utilities are placed at LAWA, only about 10% of the time do the contractors actually take the time to survey into plan the actual utility location (Hashemi, 2014).

Specifically, it is recommended that gradiometric detection be used the design phases being completed, most effectively applied after construction removes survey path obstacles such as planters Nd shrubbery. Having a precise and accurate as-built map of the underground saves time in the design phase, helps prevent utility breakage during the construction phase, and provides for accuracy for future development.

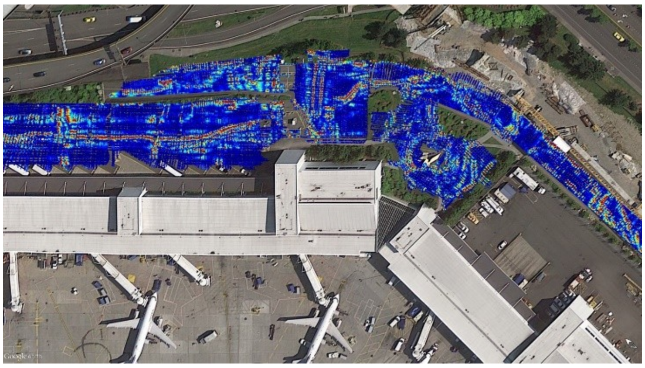

Fig. 8 AM Radio Gradiometer SEATAC Utility Detection Map

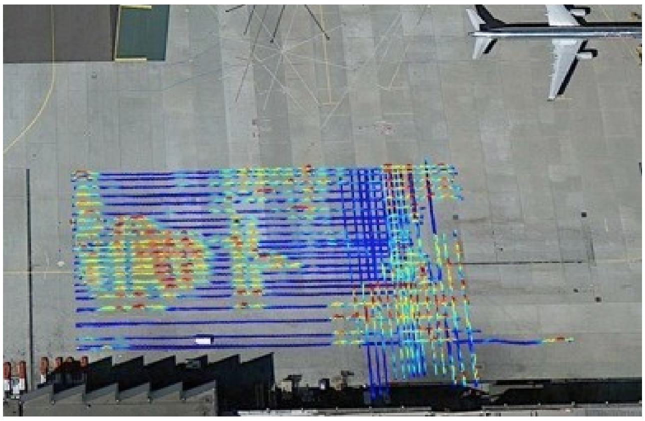

Fig.9. Red,Round Area Indicates Contaminated Soil and Core Sampled by the Construction Company and Confirmed to be Contaminated Soil

IV. Identifying Environmentally Hazardous Areas

LAWA is a long-lived, city within a city. The airport has been in operation in the same spot for nearly 86 years. Over this time, there has been a build up of environmental toxins as associated with plane refueling and maintenance fluids used in aircraft maintenance. Certain areas of the airport have had more exposure to these chemical than others. Further, the fuel distribution system at LAWA is aging and is known to leak significant amounts of jet fuel into the environment every year.

The LAWA the governing body has employed various techniques to identify areas of contamination around the airport. Most recently, they have engaged in core sampling activities at various locations around the airport. As of December, 2014, LAWA had 49 core sample holes drilled at various locations around the airport, and all samples returned "clean" or in acceptable ranges for environmental contamination.

A month-long utility detection project in a small area of LAWA in September 2014. The survey results showed an interesting and yet unidentifiable region in the data. Subsequent historical searches revealed that this area of the airport was used to wash aircraft and to do engine maintenance.

The results of the AMG survey and historical data were presented to LAWA. LAWA then ordered a core sample taken from this area. The personnel conducting the core sample said it was the most contaminated soil they had seen anywhere at LAWA so far. The core sample was sent to a lab for testing to determine the constituent make up of the contamination. Results were given to LAWA, but LAWA has elected to keep the chemical make up of the contamination a tightly held secret and will not release the information.

V. Summary

The AMG system has a capability pyramid with relative effectiveness as shown in the figure below. Preeminent among the capabilities of the AMG system is Detection, followed by X-Y Localization (location above the earth surface), then Z Localization (depth), and finally Classification (target identification).

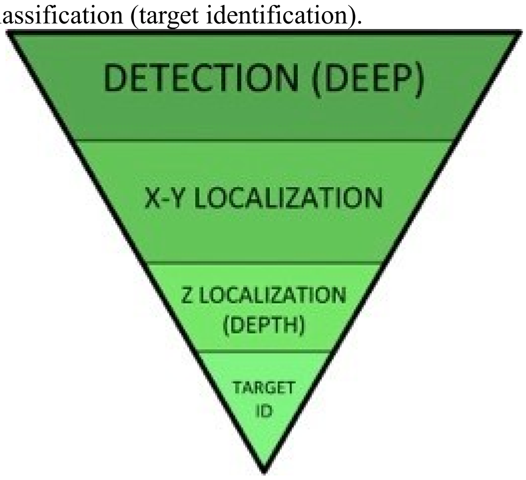

Fig.10. Capability pyramid for the AMG System

The physics associated with the surface scanning tool leads to the system being most effective at Detection, followed by X-Y Localization (location above the earth surface), then Z Localization(depth), and finally Classification (target identification physics that govern the data that the AMG scan tool generates in the presence of environmental clutter, noise, and valid targets of interest dictate what can and cannot be "seen" by the system, as well as what combination of targets or collections of targets may be more or less readily identified and located.

In summary, the AMG scan tool as deployed for commercial construction and environmental applications is:

a) Generally passive, electromagnetically; that is, it does not transmit any signals, only receives them.

b) Electromagnetically, very low frequency relative to other popular geophysical scan tools such as GPR; the

AMG is typically configured to operate over a frequency range of 200-1000 kHz.

c) Deployed in a length configuration best suited to shallow through very deep target detection.

d) Best suited to the detection and location of long, conductive targets such as cables, metal pipes, metal ductwork, and so on.

e) Moderately effective at detection of moderately-conductive targets such as water-filled plastic or concrete pipes.

f) Somewhat effective at detection of lower-contrast dielectric (i.e., non- or very low conductive) targets at reduced depths.

g) Able to "see-through" near-surface clutter such as rebar or built-up layered material.

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