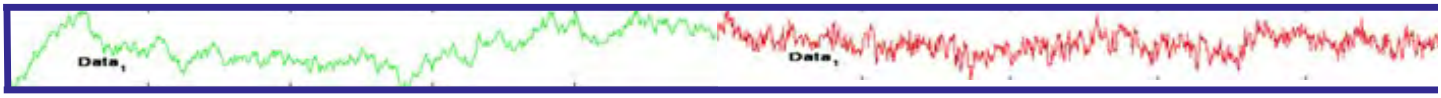
KMS Technologies
Innovating Solutions

Microseismic & Electromagnetic Array data acquisition system



Main components

Land

KMS-820 data acquisition unit
KMS-831 32-bit interface module
LEMI-701 non-polarizable, lead-free electrodes
LEMI-120 induction coil sensor (0.0001 – 1,000 Hz)
LEMI-118 induction coil sensor (1 – 70,000 Hz)
LEMI-152 Super- broadband induction coil sensor (0.00025 – 10,000 Hz)
KMS-029 fluxgate magnetic sensor 32-bit, (DC – 180 Hz)
Multicomponent geophones

Borehole

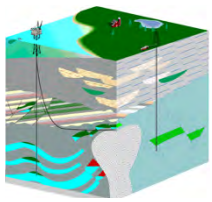
KMS-888 Shallow borehole data acquisition unit & sensors

Marine

KMS-870 broad-band seismic/EM marine deep-water node

Optional

KMS-5100 land transmitter (100/150 KVA)
KMS-500 transition zone transmitter



KMS Technologies

KJT Enterprises Inc.
11999 Katy Freeway, Suite 200
Houston, TX 77079
USA

Tel: +1.713.532.8144

Email: info@KMSTechnologies.com
www.KMSTechnologies.com

Product overview

The KMS Array data acquisition system is developed for EM (ElectroMagnetic) and micro-seismic applications to obtain subsurface resistivity and velocity structure for oil and gas and geothermal exploration. It also can be used in general purpose acquisition and long term monitoring services.

The system comes with various options to facilitate microseismic and electromagnetic reservoir monitoring. It also synchronizes and integrates with our borehole acquisition system and our marine MT acquisition node (KMS-870).

The core of the system is the KMS-820 Data Acquisition Unit which has six 24-bit low noise, low drift analoge channels and, through the digital port, and the KMS-831, unlimited channel expansion. Typically, the digital port is used to record 32- bit fluxgate magnetic fields, at the same time as acquiring coils. The 24-bit architecture goes to 100 KHz sampling, and the 32-bit architecture to 4 000 Hz. All channels are sampled simultaneously and synchronized with GPS.

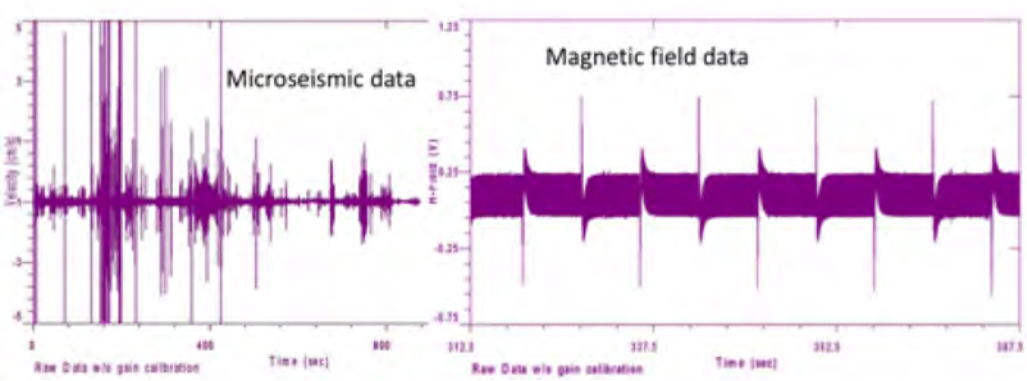
In addition, the KMS-820 can be used to control the KMS-500 marine or the KMS-5100 land transmitter. Multiple communication and data harvesting options exist: USB cable, SD card exchange, long range wireless WI-FI via router (when available), and WIFI point-to-point direct connections. LAN is optional.

All EM methods can also be run on a seismic crew.

A variety of survey configurations, from single recording station to 3D acquisition arrays are possible.

System highlights:

- Acquire microseismic data independently or simultaneously with EM
- Combined CSEM & natural source EM (magnetotellurics – MT) acquisition in one receiver deployment
- Same layout can acquire different methods by adding optional transmitters or geophones
- Combined MT/AMT measurements to give high resolution mapping and great depth
- MT: Fully synchronized SIMULTANEOUS acquisition for ultra-low frequencies (KMS-029: DC-180 Hz), standard MT band (LEMI-120: 0.0001 – 1000 Hz), AMT band (LEMI-118>: 1 – 50,000 Hz)
- Lightweight, portable, rugged, low power consumption
- Wireless network (long range), GPS synchronized, wide bandwidth & dynamic range
- 24-bit or 32-bit digital resolution, DC to 50 kHz signal bandwidth
- Low cost with large channel count (unlimited)
- Efficient field operations with or without cables
- Each KMS-820 can be expanded to unlimited channels with multiple KMS-831 (32-bit)



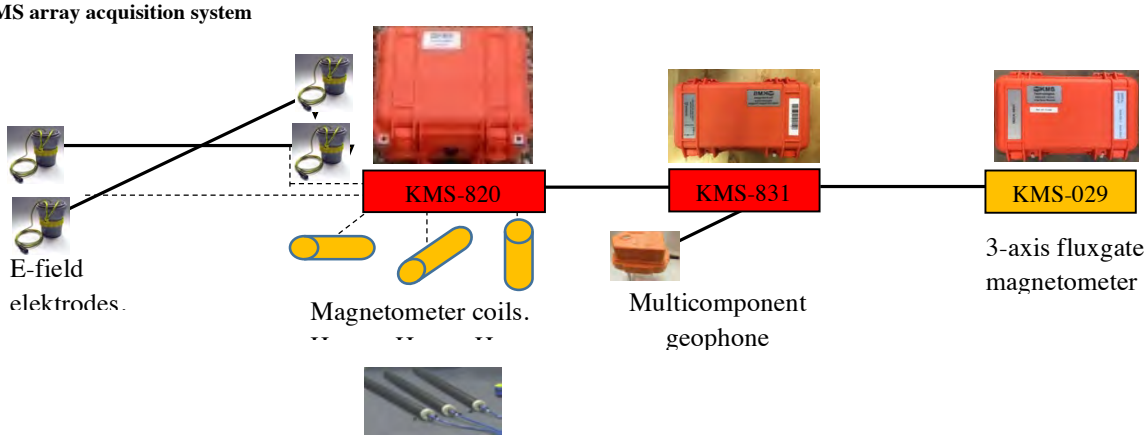
Main components

1. KMS-820 digital acquisition system	2. KMS-831 sub-acquisition controller
3. KMS-029 (fluxgate magnetometer)	4. LEMI-120 (low frequency magnetometer)
5. LEMI-118 (low frequency magnetometer)	6. LEMI-701 electrode
7. S-20 (air coil magnetic sensor)	8. Multicomponent geophone
9. Misc. interconnect cables	10. Accessories (KMS-300, USB cable)
11. Laptop computer 11A KMS-410 Lithium Ion batteries	12. KMS-5100 transmitter (not to scale)

Single receiver station layout (example only)

The KMS array data acquisition system allows great flexibility in acquisition design adjusting with survey requirements, including that all receiver stations may not be identical. The acquisition scheduler allows the system to be used for different acquisitions and even method sin one drop. The figure below shows a sample layout only, purely to illustrate how a receiver station might be configured.

KMS array acquisition system

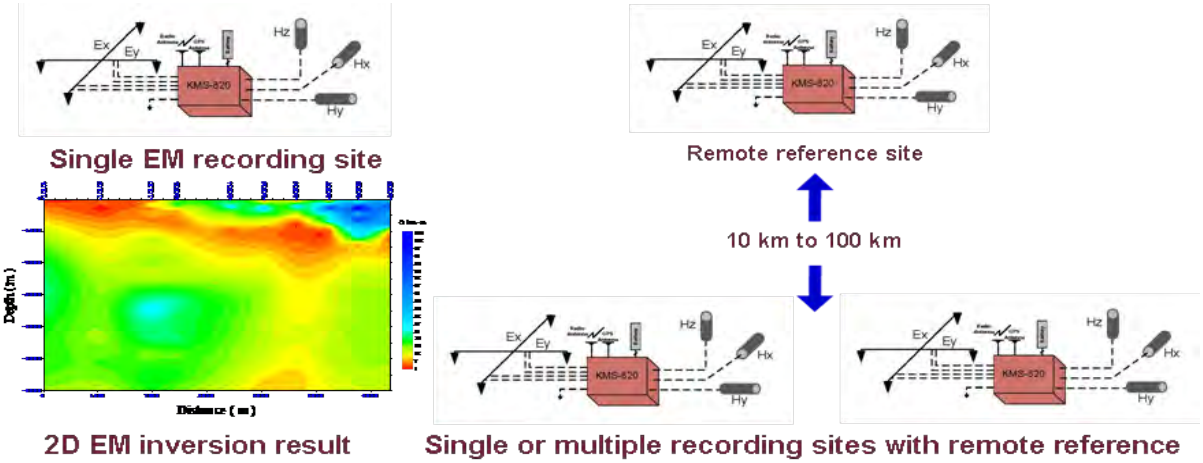


Applications

- Reservoir monitoring
- Oil and gas exploration (land & marine)
- Hydrocarbon reservoir dynamics & CO2 storage monitoring
- Porosity mapping within carbonate reservoirs
- Geothermal exploration & induced seismicity monitoring
- Engineering & environmental studies
- Earthquake prediction research
- Deep crustal research
- Metals and mineral exploration
- Integration to reservoir via borehole (KMS-borehole system)

EM methods & microseismics

For magnetotellurics (MT) one often uses single site or remote reference recording as shown below.



- MT, AMT: Magnetotellurics and Audio MT are used for basin reconnaissance and structure studies including near surface applications, mostly oil &gas and geothermal applications.
- CSAMT: Controlled Source Audio MT uses a transmitter to get better Signal-to-Noise (S/N) ratios for detailed structure investigations of the upper 2 km.
- TFEM, IP: Time-Frequency Domain ElectroMagnetics and Induced Polarization combine time and frequency domain electromagnetics for hydrocarbon and mineral exploration. (he eta al., 2015)
- LOTEM: Long Offset Transient ElectroMagnetics is applied to detailed structural investigations of the upper 5 km for hydrocarbon and geothermal Exploration & Production. Focused TEM is also possible. (Strack and Pandey, 2007)
- All EM methods can be combined with simultaneous microseismic acquisition, The KMS-870 includes broadband microseismic and marine MT acquisition in one unit.

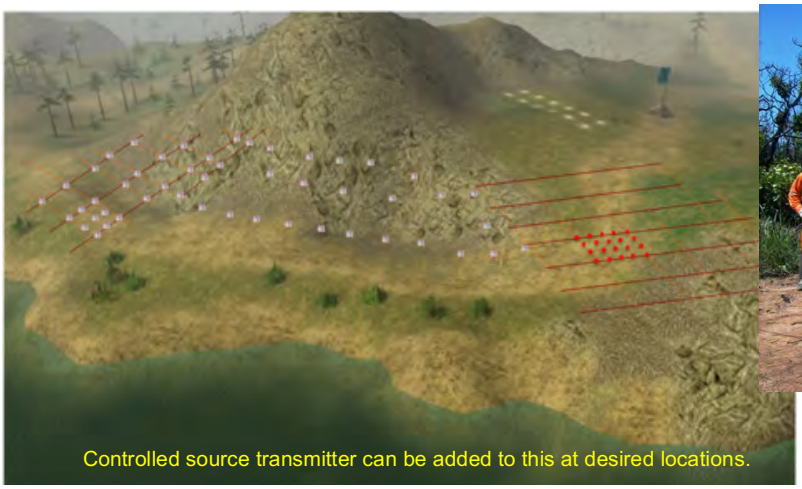
3D EM/seismic array layouts

KMS acquisition systems can be used for large scope 3D EM survey with densely spaced electric sensors and sparsely installed magnetometers. The system's wireless network feature makes field operations very efficient when conducting massive 3D EM survey. Depending upon distance between sites, KMS-820 or KMS-831 with digital interconnect (≈100 m) can be used. KMS-831 is about 5 times less expensive than the KMS-820 and connects to a KMS-820.

The figure below shows a layout where on the right you have 3D acquisition using bins where only one site in the bin has all the magnetic sensors. The rest has only electric fields. The center shows mountainous operation for complex terrain which has portable site and can even be helicopter assisted. On the left are 2D lines where each site has the full sensor component set.

When running MT on as seismic crew, you usually run the MT site ahead or after the seismic line to avoid operations related noise on the MT data.

With CSEM you have multiple option between moving receiver and/or transmitter. Since the CSEM operations are busy you might want to run it after the seismic line.



KMS team as part of a seismic crew in Brazil acquiring MT data.

System configuration table

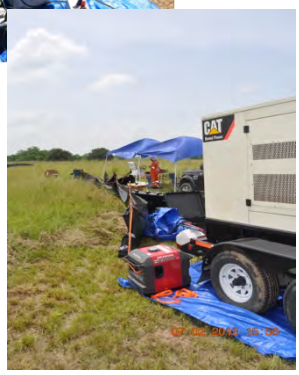
Following table shows the various system configuration options for different surveys and applications. System components can be mixed and matched in a modular fashion. Seismic sensors can be added to each configuration. Each configuration is expandable by adding more KMS-831 sub-acquisition controller. **NEW 2016**: shallow borehole seismic/EM receiver KMS-888 and LEMI-152 Super-Broadband induction coil.

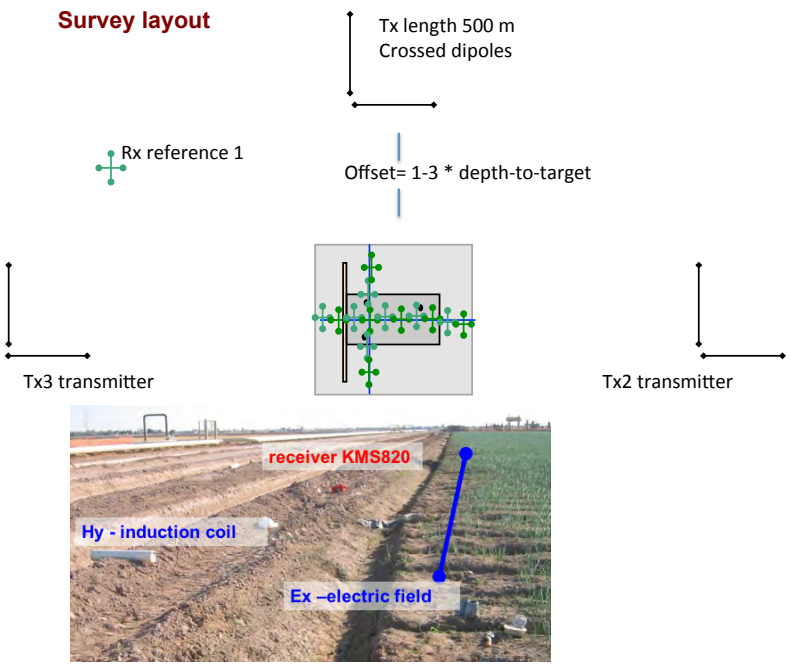
Survey	Receiver	Transmitter	Sensors	Applications / Depth
MT	KMS-820 & KMS-831	N/A	Electrode: LEMI-701 Magnetometer: LEMI-120 LEMI-118 LEMI-152 KMS-029	Onshore / Deep targets & basin study
CSAMT	KMS-820	KMS-500	Electrode: LEMI-701 Magnetometer: LEMI-118 LEMI-152	Onshore, transition zone / Shallow targets
TFEM	KMS-820 & KMS-831	KMS-500 KMS-5100	Electrode: LEMI-701 Magnetometer: LEMI-140 LEMI-120 LEMI-118 LEMI-152 KMS-029	Onshore, transition zone /Shallow to mid-depth targets
LOTEM	KMS-820 & KMS-831	KMS-500 KMS-5100	Electrode: LEMI-701 Magnetometer: LEMI-140 S20-air coil	Onshore, transition zone / Shallow to mid-depth targets Sub-basalt, sub-salt
TFEM, IP	KMS-820 & KMS-831	KMS-500 KMS-5100	Electrode: LEMI-701 Magnetometer: LEMI-140 LEMI-120 LEMI-118 LEMI-152	Onshore, transition zone / Shallow to mid-depth targets
CSEM	KMS-820 & KMS-831	KMS-500 KMS-5100	Electrode: LEMI-701 Magnetometer: LEMI-120 LEMI-118 LEMI-152	Onshore, transition zone / Shallow to mid-depth targets
MMT & CSEM	KMS-870	on request	Seismic & EM included	Deep water ocean bottom imaging
Reservoir monitoring	KMS-820 & KMS-831	KMS-5100 100 or 150 KVA	Seismic: 3C or borehole 3C Electrode: LEMI-701 Magnetometer: LEMI-120 LEMI-118 LEMI-152 KMS-029 S20-air coil Shallow Borehole Tool KMS-888	Water-flood monitoring Porosity mapping in carbonates Monitor induced seismicity CO_2 monitoring Depletion monitoring

Reservoir monitoring layout

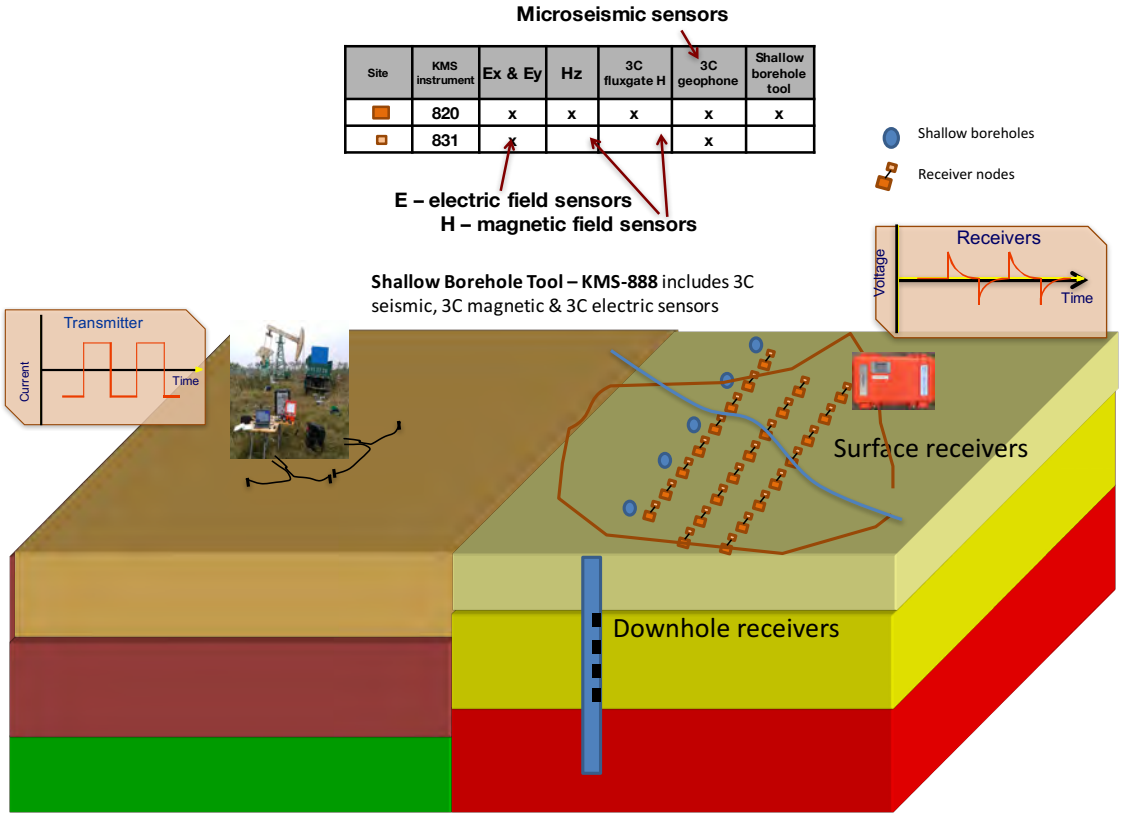
Reservoir monitoring has many different options. Since the reservoir changes are always 3D, careful design is required and multiple transmitter must be used to understand the 3D effects. We use at least two transmitters. Below are examples of the CSEM transmitters, receivers and a sample layout. (Colombo et al., 2010; Hu et al., 2008; Strack, 2010).

KMS recommends to carry out a 3D modeling Feasibility including and on-site noise test as FIRST STEP. Below on the right is a typical noise test sensors layout in the field.





Survey layouts are usually design as per specific objectives. The example figure shows a layout for **water-flood monitoring**. The transmitters in this case are not shown. You may add the Shallow Borehole Tool to the receiver sites.



MT applications

Magnetotellurics (MT) and Audio MT (AMT) target different depth of investigation in hydrocarbon and geothermal exploration. For hydrocarbon exploration, high resistivity lithology such as salt, basalt, and over thrusting often mask underlying sediments. They are difficult to image with seismic data due to high velocities and diffuse scattering. But they can be easily imaged by MT or Lotem method because of their associated large resistivity contrasts.

MT utilizes natural variations in the Earth's magnetic field as a source. Natural MT signals come from a variety of induced currents caused by thunderstorms and the ionosphere. The frequency ranges of MT data spans from 0.0001 Hz to 1000 Hz and for AMT from 10 Hz to 20 kHz.

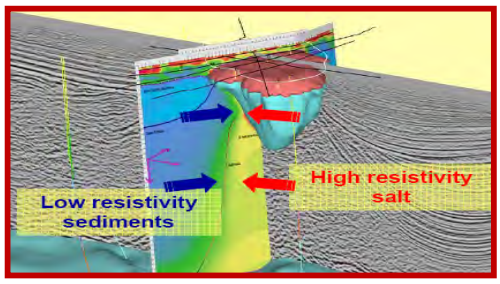
MT is usually used to map conductive zones like geothermal zones or sediment packages. To map resistors like hydrocarbon reservoir you must use a grounded dipole transmitter (Passalacqua, 1983; Strack et al., 1889), which means you use Controlled Source ElectroMagnetics.

2D or 3D MT survey configurations

For large site count 2D and 3D MT or AMT surveys, the array configuration is more cost effective. The central control unit of the array can control several thousand recording units wirelessly. Standard distances are 5 miles without and- principally- unlimited with wireless relays.

Commercial benefits:

- Low cost for 2D or 3D MT and AMT surveys
- High speed sampling rate allow acquiring MT & AMT data with the same unit
- Fast and easy operation and deployment of multiple recording units
- Customized wireless system for remote system monitoring
- Designed for dense acquisition spacing for data redundancy & high resolution data recording



After Buehnemann et. al., 2002

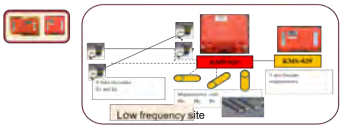
Low cost geothermal array application (AMT – MT)

For geothermal application, one often requires the high frequencies and only limited low frequencies. For this we developed a combination of array with sub-acquisition nodes and combined it with a low frequency fluxgate receiver (KMS-820 MT-Mini package). We are adopting here the concept of 3D bin based MT acquisition which uses limited magnetic field but dense electric fields. With the new broadband sensor LEMi-152, we have sufficient overlap with the fluxgate based site,

The AMT system include an AMT or broadband coil. It records only for a few hours. The MT-Mini record for at least 6 hours or a full day. Magnetic field from the fluxgate sensor and coil are matched (left figure below). In this case coil and fluxgate have been matched and shown the difference between the perpendicular components.

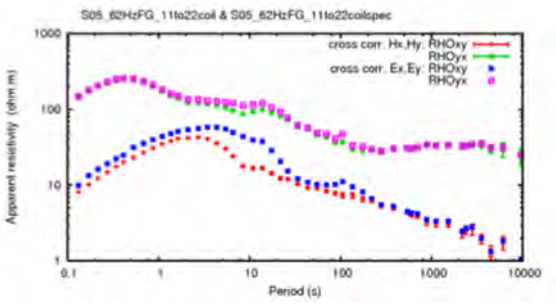
Advantage:

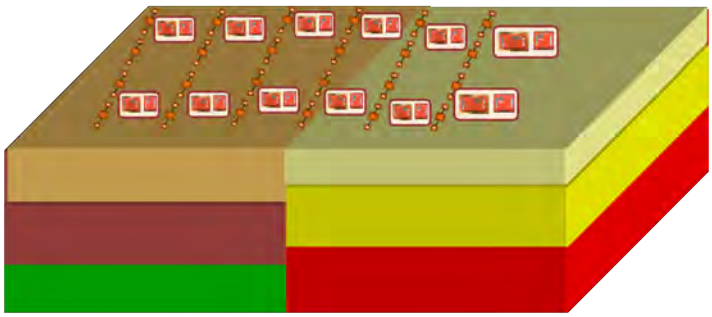
- Lower equipment cost
- Faster acquisition
- Consistent high quality data



AMT roving sites
LF MT – reference for basin depth

Receiver nodes: KMS-820 & 2 KMS-831





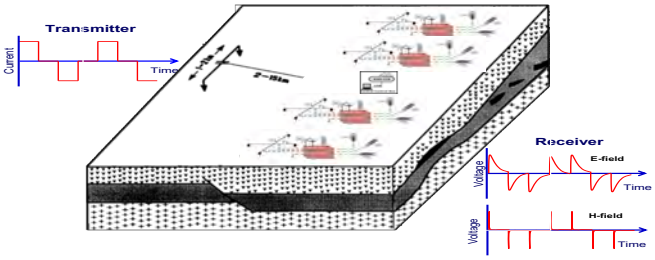
TFEM method

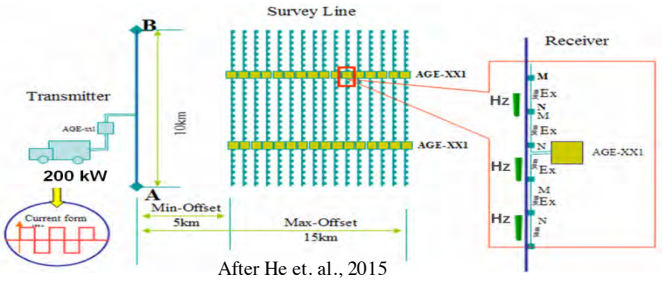
Time-Frequency ElectroMagnetics (TFEM) applies the Transient ElectroMagnetic (TEM) and Spectral Induced Polarization (SIP) techniques. It records broad-band frequency and time domain following a scheduled process.

An anomaly with the combination of high resistivity and high Induced Polarization (IP) can indicate an oil or gas reservoir. The high-power transmitter signal can penetrate the overlying formations to detect this oil and gas anomaly directly.

The layout comprises of a transmitter synchronized with the receivers. A frequency optimized high power square-wave current is injected into the ground by an electric dipole, allowing Ex (horizontal electric field) and Hz (vertical magnetic field) to be recorded.

The KMS array system includes scheduler and synchronization with transmitter to be able to follow any pre-defined transmission and acquisition sequence.





After He et. al., 2015

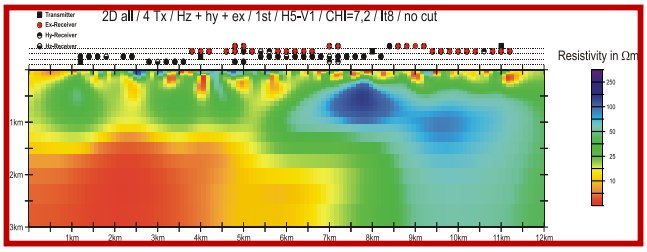
LOTEM method

The Long Offset Transient ElectroMagnetics (LOTEM) method is a Transient ElectroMagnetic (TEM) method in which a primary field is generated by a grounded current dipole. The signal transmitted by the dipole consists of a series of alternating step functions that create a collapsing field that in turn induces electric and magnetic fields in the conducting subsurface. Subsurface properties and features at great depth can be deduced by recording these fields at greater and greater distances from the transmitter during the off times. (Strack, 1992 & 1999)

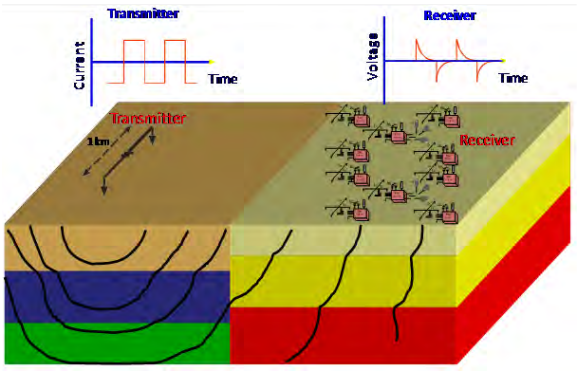
Using the KMS array system scheduling function and synchronization with multiple transmitters, the system can realize focused TEM applications, which give better volume focusing.

The LOTEM method can be applied to any of the following targets:

- Sub-basalt and sub-salt mapping (Strack and Pandey, 2007).
- Mapping of thin resistive layers, like hydrocarbons (electric fields).
- Determining conductive structures, like geothermal anomalies (magnetic fields, MT combined).
- Focused source EM (Davydycheva and Rykhlinski, 2009).



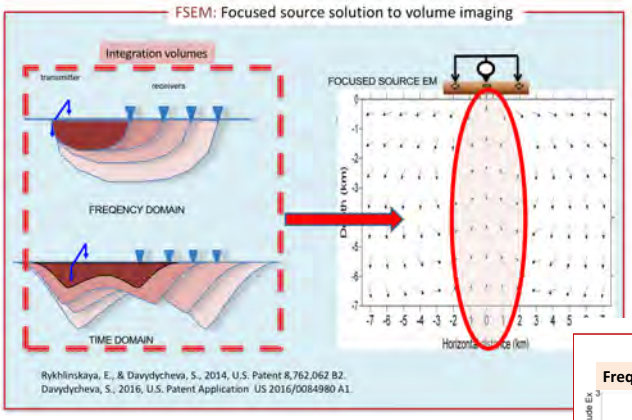
after Martin, 2009



FSEM method

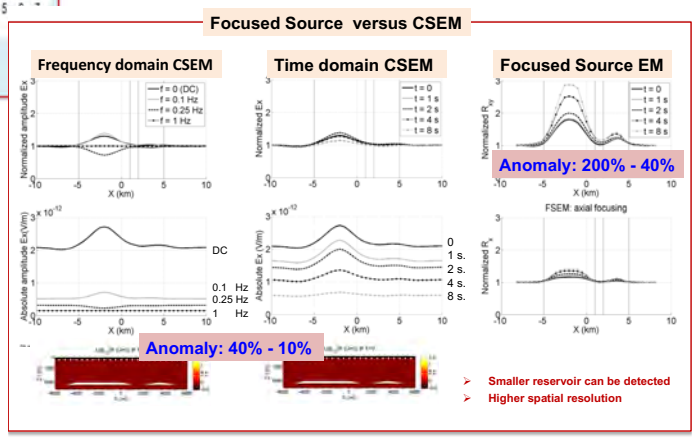
The differential Focused Source EM method FSEM (Rykhlinskaya and Davydycheva, 2014; Davydycheva 2016) obtains an equivalent vertical electric field measure. The vertical electric field Ez more sensitive to deep and shallow resistors, than the horizontal electric field, since such structures significantly affect the vertical current flow. It is also possible to measure Ez in shallow vertical boreholes on the Earth surface with the KMS-888 Shallow Borehole Tools. If borehole Ez measurements are unavailable, the FSEM method helps. It allows accurate determination of small vertical leakage of the electric current.

KMS array acquisition system



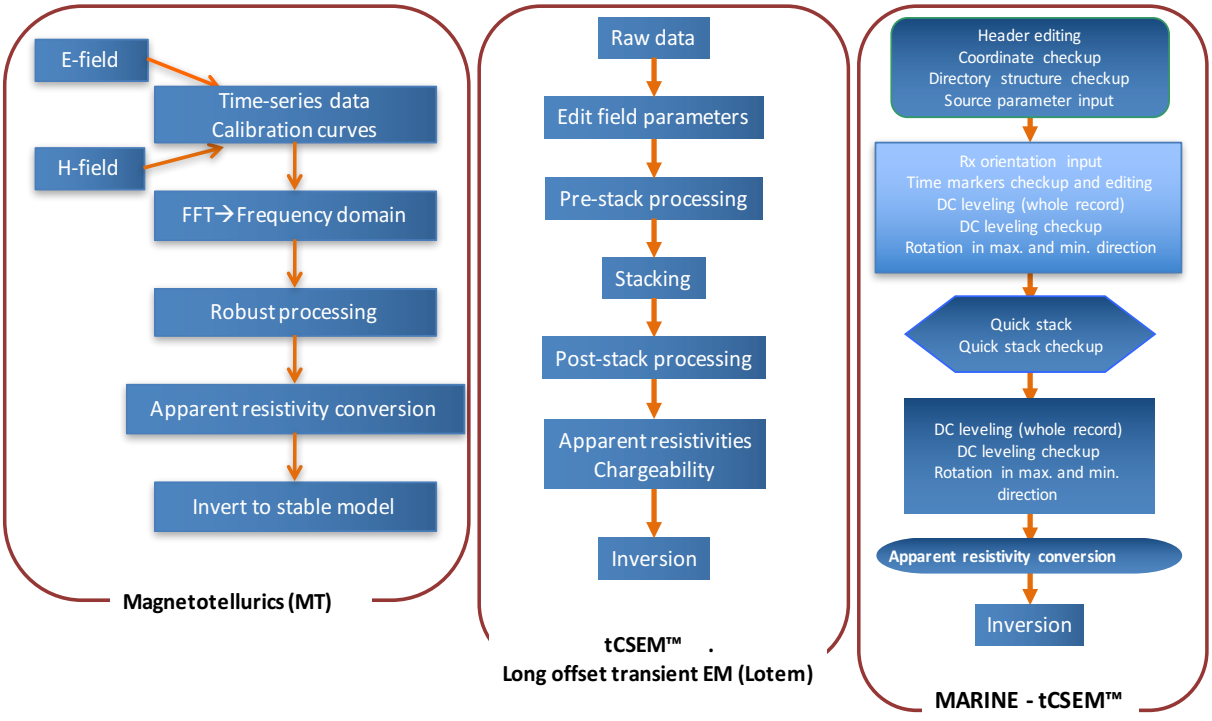
On the left the 2D sensitivity volumes for frequency and time domain are shown as a function of receiver-to-transmitter distance. On the right is the focused source EM current flow depicting that the information comes from below the receiver.

On the right, we have 3D modeling results simulating the response of an oil reservoir at 2 km depth. Frequency and time domain show anomalies between 10-40% while the FSEM anomaly is 40 – 200 %.



Software

The KMS-820 array system come with basic acquisition and monitoring software. Different products have different software policies. For magnetotellurics we work with the world's most experienced consultants and provide multiple software version for affixed price with the purchase. For Lotem and EM reservoir monitoring we only lease the software due to the proprietary nature of the algorithms. All software is available in commercial versions and leads to 3D models of the data. Below is a flow chart of the software for magnetotellurics, Lotem and marine time domain CSEM. (tCSEM™)



Software deliverables:

- Magnetotellurics: Robust processing – EDI files, 1-D inversion – sections; Options: 2-D & 3-D inversion software and custom modeling services.
- Lotem: Robust CSEM processing (time or frequency); Microseismic & EM data separation – SEGY files; Apparent resistivities – ASCII files, time lapse section; 3-D modelling software and custom modeling services. LEASE only
- TFEM: Robust CSEM processing (time or frequency); Apparent resistivities – ASCII files, time lapse section; 3-D modelling software and custom modeling services. BETA RELEASE only

3D modeling & inversion

For magnetotellurics we offer the full suite of 3D software and inversion in alliance with Modem Geophysics Inc and Oregon State University (Egbert).

For CSEM and borehole applications we offer 3D forward modeling license and services using full 3D anisotropic models (MAXANIS).

See KMS Technologies website for the latest at http://kmstechnologies.com/3D_modeling_services.html

Networking

In addition to SD card swapping and wired connection, the KMS-820 has multiple wireless options.

1. The KMS-820 system comes a default wire 900 MHz long range wireless. The laptop transceiver is quote separately
2. In addition, a Wi-Fi chip is available. It allows the unit to be controlled from any Wife enabled laptop or router with Wi-Fi.
3. I additional full **network kit** can be added that includes: LAN and WAN, Bluetooth, HDMI and keyboard and monitor channels.

Since we always recommend large oversampling, we suggest to acquire larger data volumes. Networking makes sense with small number of units only because copying the data in the field takes too long. If you sample many channels at 1 kHz or larger, field operations are best using SD card swapping. KMS SD card can be hot swapped at 40 KHz sampling rate.

Application history - references

Since 2010, the system has been used in: Argentina, Azerbaijan, China, Germany, Kenya, India, Indonesia, Israel, Italy, Saudi Arabia, Slovakia, Thailand, and Ukraine, USA (CA, CO, HI, NV, and TX).

Applications include magnetotellurics, Audio-magnetotellurics, Lotem, microseismics (intrusion monitoring), bottom hole-to-surface communication, marine CSEM.

Please check our website for an update list of publications using our system: http://www.kmstechnologies.com/KMS_flyer_archive.html

Patents: the system and methods are covered by various patents – see our website for the latest list. KMS provides their clients a license to the respective patents.

- Strack, K. -M., 2003, Integrated borehole system for reservoir detection and monitoring, **US 06541975 & US 06670813.**
- Strack, K. -M., 2004, Surface and borehole integrated electromagnetic apparatus to determine reservoir fluid properties, **US 06739165.**
- Strack, K.M., Thomsen, L. A., and Rueter, H., 2007, Method for acquiring transient electromagnetic survey data, **US 07203599.**
- Strack, K. M., Rueter, H., and Thomsen, L., 2008, Integrated earth formation evaluation method using controlled source electromagnetic survey data and seismic data, **US 07328107.**
- Strack, K.M., 2009, Method for combined transient and frequency domain electromagnetic measurements, **US 7474101.**
- Rykhlinskaya, E., and Davydycheva, S., 2014**,** Method for marine geoelectrical exploration with electrical current focusing**, U.S. Patent 8,762,062 B2**.
- Davydycheva, S., 2016, Method and apparatus for detecting and mapping subsurface anomalies**, U.S. Patent Application US2016/0084980 A1.**
- Jiang, J., Aziz, A.A., Liu, Y., and Strack. K.M., 2015, Geophysical acquisition system, **US 9,057,801**.

References:

Buehnemann, J., Henke, C.H., Mueller, C., Krieger, M.H., Zerilli, A., and Strack, K.M., 2002, Bringing complex salt structures into focus - a novel integrated approach: 72nd Annual Meeting, Society Exploration Geophys. Expanded abstracts.

Colombo, D., Dasgupta, S., Strack, K.M., and Yu, G. , 2010, Feasibility study of surface-to-borehole CSEM for oil-water fluid substitution in Ghawar field, Saudi Arabia: Geo 2010, poster.

Davydycheva, S., and Rykhlinski, N., 2009, Focused-source EM survey versus time-domain and frequency-domain CSEM: The Leading Edge, 28, 944-949.

Davydycheva, S., and Rykhlinski, N.I., 2011, Focused–source electromagnetic survey versus standard CSEM: 3D modeling in complex geometries, Geophysics, 76, no.1, F27-F41.

Davydycheva, S., Kaminsky, A., Rykhlinski, N., and Yakovlev, A., 2015, A large-scale field study in Eastern Siberia using novel time-domain electromagnetic technology, Interpretation, Interpretation, 3, No.2, T109-T120

He, Z., Yu, G., Cheng, H., Wang, Z. Quin, J., and Meng, Y. 2015, Drilling risk assessment through joint EM and seismic data integrated interpretation, Society Expl. Geophys., GEM Chengdu 2015: International Workshop on Gravity, Electrical & Magnetic Methods and Their Applications Chengdu, China.

Hu, W., Yan, L., Su, Z., Zheng, R., and Strack, K.M.,2008, Array TEM Sounding and Application for reservoir monitoring: SEG Las Vegas Annual Meeting, 634-638.

Martin, R., 2009, Development and application of 2D and 3D transient electromagnetic inverse solutions based on adjoint Green functions: A feasibility study for spatial reconstruction of conductivity distributions by means of sensitivites, Dissertation, Inst. f. Geophysics & Meteorology, University of Cologne, 213 pp.

Passalacqua, H., 1983, Electromagnetic fields due to a thin resistive layer: Geophysical Prospecting, 31, 945-976.

Strack, K.-M., Hanstein, T., Lebrocq, K., Moss, D.C., Petry, H.G., Vozoff, K., and Wolfgram, P.A., 1989, Case histories of LOTEM surveys in hydrocarbon prospective areas: First Break, 7, 467-477.

Strack, K.-M., 1992, *Exploration with deep transient electromagnetics,* Elsevier, 373 pp. *(reprinted 1999)*

Strack, K.M., and Vozoff, K., 1996, Integrating long-offset transient electromagnetics (LOTEM) with seismics in an exploration environment: Geophysical Prospecting, 44, 99-101.

Strack, K.-M., and Pandey, P.B., 2007, Exploration with controlled-source electromagnetics under basalt covers in India: The Leading Edge, 26, 360-363.

Strack, K.M., 2010, Advances in electromagnetics for reservoir monitoring: Geohorizons, June 2010, 15-18.

Strack, K.-M., 2014, Future directions of Electromagnetic Methods for Hydrocarbon Applications, Surveys in Geophysics, 35, 157-177.