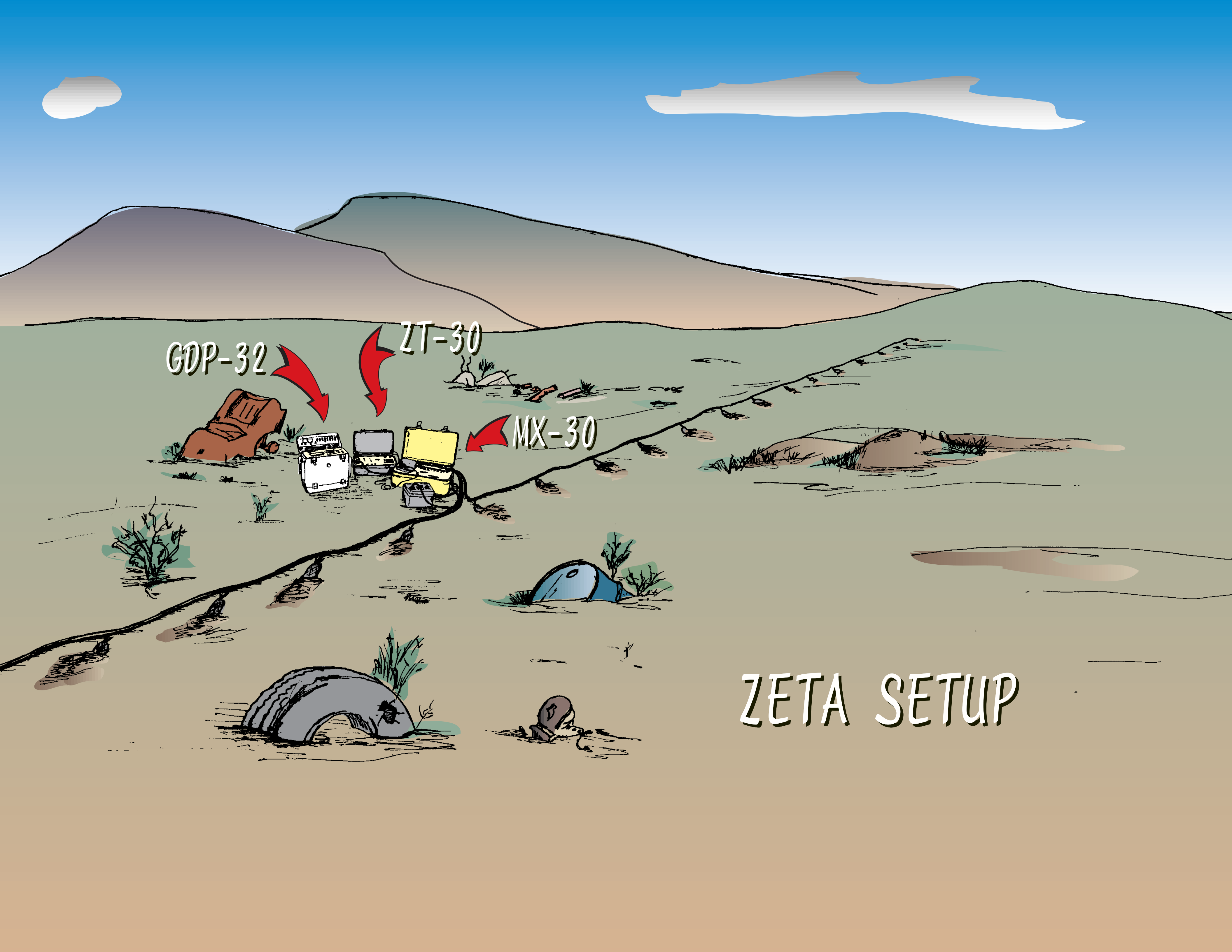
Equipment


GDP-32
ZT-30
MX-30
ZETA SETUP

Zonge Electrical Tomography Acquisition System

For a number of years, Zonge Engineering has been involved in the development of instruments for electrical resistance tomography (ERT) in connection with ongoing research and development at the Lawrence Livermore National Laboratory, a facility funded by the U.S. Department of Energy. ERT is being used to generate resistivity images of the "plane" defined by the space between two boreholes or other electrode strings. ERT is presently being applied to monitor leakage at hazardous waste sites, to monitor dynamic fluid injection processes that are often involved in waste site remediation. Other applications for ERT technology exist and are simply waiting for the availability of equipment and software that can economically acquire the necessary resistivity data required and the software required for its interpretation.

ERT involves the acquisition of hundreds, even thousands of 4-electrode resistivity measurements that are possible between multiple strings of electrodes. For example, given two strings of 15 equally-spaced electrodes (30 electrodes total), there are 632 different dipole-dipole measurements that can be made (including all reciprocal measurements) involving transmitter and receiver dipoles with a fixed length of 2 electrode spacings. The dense data provide the basis for solving sophisticated inverse computer models of the conductivity distribution in the ground. When both resistivity and IP are measured, the resulting data set relates to the complex ***impedance*** of the earth and the term EIT (Electrical Impedance Tomography) is sometimes used to describe the technique.

Obviously, there are too many measurements to be acquired manually. To efficiently measure all the desired transmitter-receiver electrode combinations requires a computerized acquisition system that automatically switches both transmitter and receiver electrodes and has multi-channel measurement capabilities. The Zonge ERT/EIT acquisition system has unique capabilities for the efficient acquisition of ERT or EIT data sets. With the Zonge ERT/EIT system, acquisition of the dense data sets is now economically feasible. Such data sets are required to generate conductivity images using sophisticated inversion software. These capabilities greatly improve the usefulness of the venerable resistivity measurement for problems wherein the resistivity method is traditionally applied. Moreover, the capability of ERT/EIT to generate "images" of conductivity distribution greatly expands the applicability of the electrical resistivity method to many problems in engineering and hazardous waste site characterization and monitoring, and in geophysical and groundwater exploration as well.

ERT Acquisition System

The system developed by Zonge (see Figure 1) includes the following equipment:

1. GDP-32 Multi-Function Receiver
2. MX-30 Electrode Multiplexor
3. ZT-30 12-120Vdc Transmitter
4. ISO/1 Isolation Amplifier
5. Laptop PC with ZETA Acquisition Control

GDP-32 Multi-Function Receiver – The GDP-32 is a general-purpose multi-function instrument capable of making both frequency-domain and time-domain resistivity/IP and EM measurements. For ERT data acquisition, the firmware in the GDP-32 has been modified so that resistivity measurements can be performed under the control of an external controller by means of commands sent to it through the serial data port. The GDP-32 can be configured so that as many as 16 independent analog channels can be measured simultaneously.

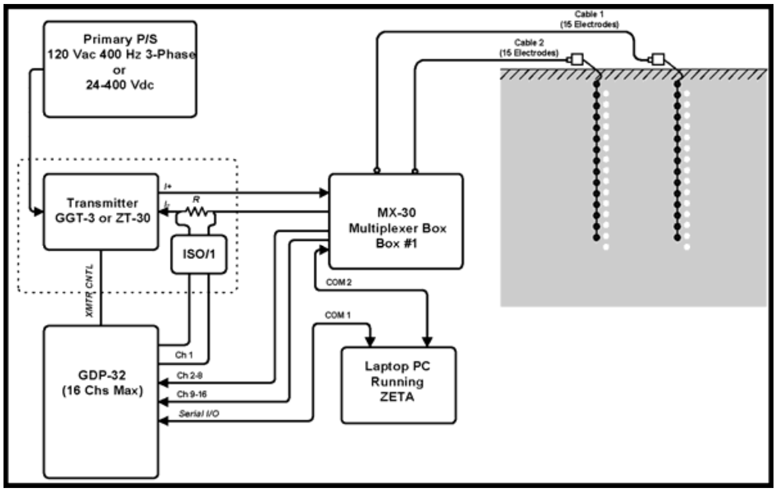


Figure 1: Function block diagram of a Zonge ERT system.

MX-30 Electrode Multiplexer – The MX-30 performs two multiplexing functions under external control. First, it is able to switch each of the two transmitter lines to one of 30 possible electrodes. Secondly, it is able to select any pair of electrodes not connected to a current electrode and route the differential signal to one of 16 possible differential output channels. The MX-30 is configured with commands received through a serial RS-232C data port.

ZT-30 Transmitter – The ZT-30 is the smallest Zonge transmitter available. It is suitable for small-scale ERT surveys (electrode dipole sizes of 2-3 m). The power supply may be as simple as one or more 12 Vdc storage batteries in series. Any DC power supply with a voltage of 400 Vdc or less and an output current of less than 5 Amps can be used. The GDP-32 is able to switch the transmitter current ON and OFF as well as to commutate its polarity at the chosen frequency.

ISO/1[1] **–** A current-regulated transmitter is not appropriate for ERT because the resistive load produced by the grounding resistance of the transmitter electrode-pair can vary widely. The **ISO/1** isolation amplifier is used to sense the voltage drop across a current-sensing resistor. This signal is routed to one of the GDP-32 receiver channels where it is scaled by the value of the sensing resistor so that the measured receiver dipole voltages can be normalized by current.

Laptop PC – The system is controlled by a computer running Windows 95 or NT with two serial ports. The proprietary Zonge ERT control and acquisition software (ZETA) configures the MX-30, connecting the transmitter to the appropriate electrode pair and routing the receiver dipoles to the GDP-32. ZETA uses a predefined "schedule" consisting of a list of MX-30 configurations. A schedule is a text file that can be generated using user-developed software. ZETA can generate simple dipole-dipole schedule files. Measurements from one MX-30 configuration are transferred to the computer for formatting and storage, and the next configuration is automatically setup and measured.

An 8-ch GDP-32 can acquire approximately 500-1000 dipole-dipole measurements per hour.[2]

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[1] Early systems used a separate isolation amplifier to provide an electrically isolated voltage proportional to the current waveform for the receiver to measure. The latest version of the ZT-30 includes an appropriate sense resistor and isolation amplifier so that a separate amplifier, the ISO/1, is not required.

[2] Acquisition productivity depends on a number of parameters including frequency measured, number of data stacks, and whether or not the MX-30 configuration schedule has been "optimized". Naturally, the time may be reduced considerably by adding receiver channels (16 channels maximum).

Roll-Along Dipole-Dipole Resistivity/IP

Dipole-dipole resistivity and IP surveys are routinely acquired in mining exploration. In many mining applications dipole lengths can be as large as long as 300 m and in rare cases even 600 m. The advantage of the dipole-dipole method is that it provides both profiling and depth-sounding information in a systematic way. The dipole-dipole survey technique can also applied in engineering, groundwater, and hazardous waste site applications, usually on a much smaller scale (5-10m dipole lengths). But even at scales of a few meters, the logistics of collecting dipole-dipole data out to n = 6 are considerable and, consequently, the cost of a dipole-dipole profile may be prohibitive. However, using the Zonge ERT system, the economics of high-density dipole-dipole resistivity and IP profiling for small-scale engineering and waste site characterization become more reasonable. Figure 2 is a block diagram of a system used for acquisition of high-density dipole-dipole resistivity and IP. With this system, Zonge has demonstrated that it can acquire dipole-dipole data with 15-ft dipoles at 7.5-ft move-out intervals out to a maximum spacing of 90 ft. (dipole n-spacings from 0.5 to 6) at a rate of 2000 line-ft per day.

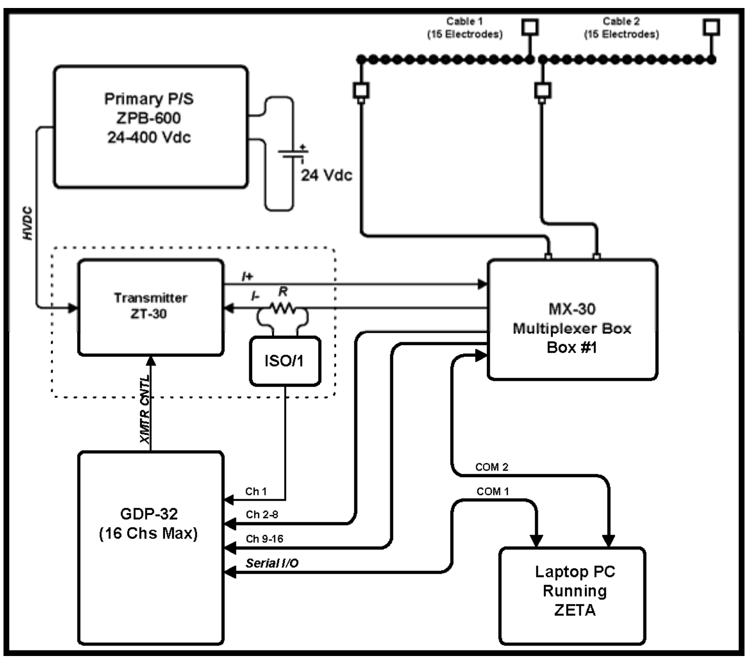

Figure 2: Function block diagram for a Zonge system for roll-along dipole-dipole resistivity and IP.

Data Interpretation

Data Quality Control: There is no way of viewing the resulting data graphically in order to evaluate data quality. The only measure of data quality is the degree to which reciprocal measurements agree.[3] The data files are sorted and filtered according to a user-specified reciprocity error threshold. The remaining measurements are then used as the observed data for inversion and display.

[3] Reciprocal measurements are measurements in which the transmitter electrodes and the receiver electrodes have been interchanged. Thus the electrode geometry remains the same. Ideally, reciprocal measurements should be identical.

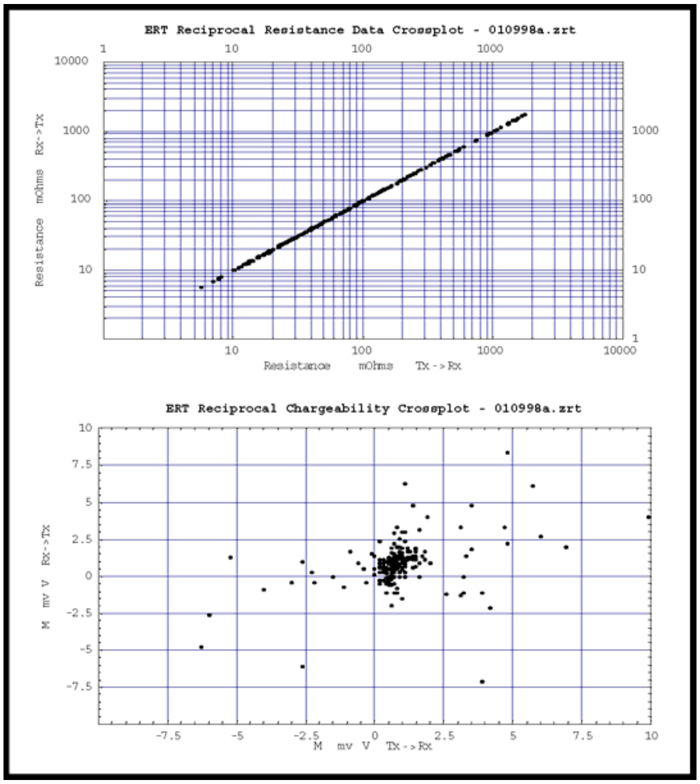

Figure 3: Crossplots that summarize the quality of an ERT data set based on reciprocity.

2-Dimensional Inversion: Two-dimensional ERT inversion provides estimates of the resistivity distribution in the “plane” defined by the cross-sectional area between two drill holes. A 2-D inversion algorithm is based on the assumption that there is no variation in resistivity in the direction normal to the image plane. Zonge has developed a proprietary 2-D inversion program (TS2DIP) that can invert a typical “plane” of ERT data (i.e., 2 boreholes, each with 15 electrodes) in less than an hour on a 166MHz Pentium PC. Lawrence Livermore National Laboratory has developed a similar algorithm for 2-D inversion. The LLNL program can be licensed for use by outside parties by contacting Lawrence Livermore Laboratories directly.[4] This program can also invert extended surface profiles involving hundreds of electrodes.

3-Dimensional Inversion: In many cases, the 2-D assumption is not valid. But experience has shown that the resulting resistivity image nonetheless provides useful qualitative and semi-quantitative information about the subsurface distribution of resistivity. A fully 3-D imaging technique based on data obtained from 4 or 5 drill holes located on a grid (4-spot; 5-spot) magnifies the problem of inversion to the point where it is presently impractical on a PC. Lawrence Livermore has developed a program that runs on a workstation that can invert a 5-spot data set overnight. Other groups are working to develop similar 3-D inversion codes that run on high-performance workstations. To our knowledge, none of these inversion codes are commercially available.

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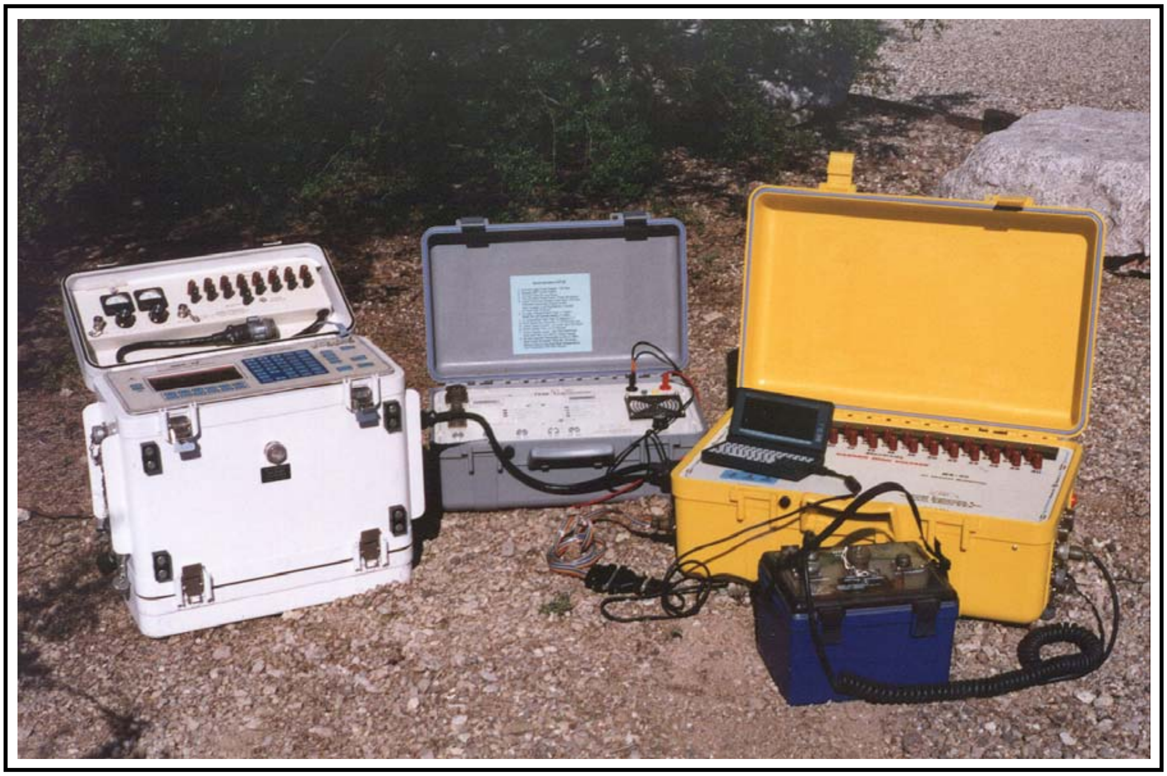
[4] Contact William Daily or Abelardo L. Ramirez:
Lawrence Livermore National Laboratory — 510 422-6909 (tel.)
P.O. Box 808, L-206 — 510-422-3118 (FAX)
Livermore, CA 94550 — email: ramirez3@llnl.gov

THE MX-30

Multiplex Switch



DESCRIPTION

The MX-30 was developed to provide a computer-controlled switching interface between a transmitter, a multi-channel receiver such as the GDP-32^{II}, and an array of electrodes. The MX-30 features a transmitter input multiplexer which can connect the transmitter leads to any pair of electrodes. A receiver multiplexer permits the operator to select any number of electrode pairs (up to half the number of electrodes) for input to the receiver. Multiplexer configuration is controlled by commands transmitted over an RS-232C serial communications channel. A control program is available for a laptop computer. The MX-30 is an essential component of any system designed to rapidly acquire resistivity data using cabled electrode arrays. Customers are currently using the MX-30 together with a GDP-32^{II} receiver and a ZT-30 transmitter to gather data for **Electrical Resistivity Tomography**. The MX-30 can be configured to provide fewer channels at a reduced cost. The unit can be upgraded in the field at a later date to give it increased output channel capacity.

FEATURES

- Selectable Electrode String – 30 electrodes Max
- External Control – RS-232C Serial (4800,N,8,1)
- Signal Output Channels (differential) – 16 Max
- Transmitter Output Relay Specs - ±500 Vdc 5 A
- Transmitter/Receiver Channel Isolation – 1000V
- High Speed Optical Relays on Receiver MUX
- Fully compatible with GDP-32^{II} Receiver
- MX-30's may be cascaded together to address several electrode arrays

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SPECIFICATIONS FOR THE MX-30 MULTIPLEXOR

Mechanical Characteristics
Enclosure: Heavy-Duty Environmentally Sealed
ABS Plastic Case
Size: 55 x 23 x 37 cm (22 x 9 x 15 in)
Weight: 16 kg (35 lb)

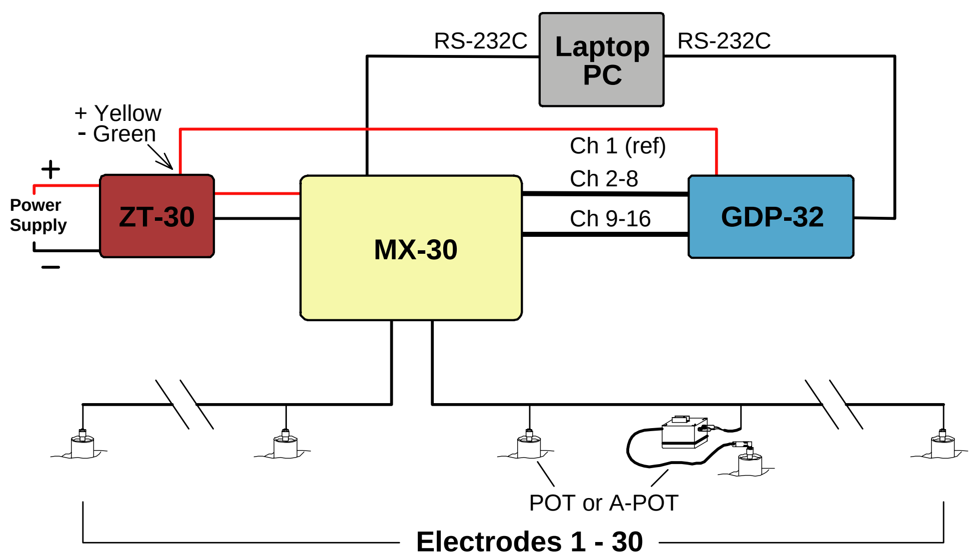
Electrical Characteristics
Transmitter Multiplexer: 500 Vdc (max); 5 A (max)
Signal Multiplexer: ±18 Vdc

Controls & Displays
Power ON / OFF switch
LED indicators for:
POWER ON, SERIAL DATA, and CPU

Power
External battery: 10-14 Vdc
(6 Amp-hr recommended)

I/O Connectors
External Battery
RS-232C IN
RS-232C OUT
RS-485 IN
RS-485 OUT
Signal Channels 1-8
Signal Channels 9-16
TX Current IN
Electrodes IN (1-30)

Applications
Electrical Resistance Tomography
Automated Resistivity Soundings
Automated Dipole-Dipole Resistivity/IP Profiling



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20080303

ZT-30 TRANSMITTER

Battery-Powered EM / Resistivity Transmitter

DESCRIPTION

The ZT-30 is a battery-powered transmitter capable of producing time-domain or frequency-domain waveforms into either resistive or inductive loads. As a TEM transmitter, the ZT-30 can deliver up to 30A into a 100m loop with a turnoff time of less than 200 μs. Because the ZT-30 also performs well while transmitting into resistive loads, some customers are using it as a low-power resistivity transmitter. When used for resistivity, it is necessary to monitor the current since the transmitter does not have current regulation circuitry.

FEATURES

- Bipolar current output up to 30 A
- 50 or 100% duty cycle
- 1 microsecond turnoff into resistive load
- Less than 150 microseconds turnoff into a 100 meter loop at 20 amperes
- Lightweight, battery powered

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SPECIFICATIONS FOR THE ZT-30 TEM TRANSMITTER

Mechanical
Case size: 45 x 18 x 28 cm
(17.7 x 7.1 x 11.0 in)
Weight: 8 kg (17.6 lb) *(without batteries)*

Electrical
Input voltage: 14 to 136 Vdc (400 Vdc selectable)
Peak output current: 30 A unregulated
Transmit control by GDP receiver or XMT-series
Transmitter controller
(DC $\leq$ f $\leq$ 32 Hz TD, DC $\leq$ f $\leq$ 512 Hz FD)
Isolated current monitor output
Automatic overcurrent shutdown (set for 33 A)
IGBT power output current switch
Power contactor to remove voltage from
transmitter during fault conditions
Lamps to indicate state of transmitter:
power on, transmitting, fault, polarity
Fan-cooled heatsink

Controls & Displays
Power on / off
Transmit / Reset
Damping Select
Meter Select
LCD Displays:
Input voltage
Internal battery voltage
Output current
Turnoff time
Heat sink temperature

Fault Indicators
Over / Under Voltage
Over Current
Over Temperature

Output Jacks
Current monitor terminals, isolated output
100 mV/A or 1 V/A ranges
Output current terminals

Power
Internal battery: 10.9 to 14V, Logic Power
Main Power connector: four-pin military twist-lock,
14 – 400 Vdc

Applications
TEM transmitter, 136 Vdc max @ 30 amps
Low current transmitter for TD & FD Resistivity/IP,
400 Vdc max @ 7 amps

Options
ZPB-600 400 Vdc Power Booster

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GDP-32^{II} Geophysical Receiver

Multi-Function Receiver

The GDP-32^{II} is Zonge Engineering's fourth generation multi-channel receiver for acquisition of controlled- and natural-source geoelectric and EM data.

ENHANCEMENTS

- **133 MHz 586 processor**
- **Expanded keyboard**
- **½-VGA graphics display**
- **Ethernet port**

UNIQUE CAPABILITIES

- **Remote control operation**
- **Broadband time-series recording**
- **High-speed data transfer**

FEATURES

- 1 to 16 channels, user expandable
- Alphanumeric keypad
- 133 MHz 586 CPU
- Easy to use menu-driven software
- Resistivity, Time/Frequency Domain IP, CR, CSAMT, Harmonic analysis CSAMT (HACSAMT), AMT, MT, TEM & NanoTEM®
- Screen graphics: plots of time-domain decay, resistivity and phase, complex plane plots, etc., on a 480x320 ½-VGA, sunlight readable LCD
- Internal humidity and temperature sensors
- Time schedule program for remote operation with the XMT-32S transmitter controller
- Use as a data logger for analog data, borehole data, etc.
- Full compatibility with GDP-16 and GDP-32 series receivers.
- 0.015625 Hz to 8 KHz frequency range standard, 0.0007 Hz minimum for MT
- One 16-bit A/D per channel for maximum speed and phase accuracy.
- 512 Mb flash RAM (up to 4 Gb) for program and data storage, sufficient to hold many days worth of data.
- 128 Mb dRAM (up to 256 Mb) for program execution.
- Optional 40 Gb hard disk for time series data storage.
- Real-time data and statistics display
- Anti-alias, powerline notch, and telluric filtering
- Automatic SP buckout, gain setting, and calibration
- Rugged, portable, and environmentally sealed
- Modular design for upgrades and board replacement
- Complete support: field peripherals, service network, software, and training

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SPECIFICATIONS FOR THE GDP-32^{II} MULTI-FUNCTION RECEIVER

General

Broadband, multichannel, multifunction digital receiver.
Frequency range: 1/64Hz - 8KHz (0.0007Hz - 8KHz for MT)
Number of channels: Large case, 1 to 16 (user expandable)
Small case, 1 to 6 (user expandable).
Standard Survey capabilities: Resistivity, Frequency- and Time-Domain IP, Complex Resistivity, CSAMT (scalar, vector, tensor), Harmonic Analysis (CSAMT, Frequency-Domain EM, Transient Electromagnetics, NanoTEM®, MMR, Magnetic IP, Magnetotellurics, Downhole Logging.
Software language: C++ and assembly.

Size:	Large case	43x41x23cm (17x16x9”)
	Small case	43x31x23cm (17x12x9”)

Weight: (including batteries and meter/connection panel):
Small case 13.7 kg (29 lb)
Large case:
8 channel, 10 amp-hr batteries, 16.6 kg (36.5 lb)
8 channel, 20 amp-hr batteries, 20.5 kg (45 lb)
16 channel, disk, 10 amp-hr batteries, 19.1 kg (42 lb)
Enclosure: Heavy-duty, environmentally sealed aluminum
Power: 12V rechargeable batteries (removable pack)
Over 10 hours nominal operation at 20^{o}C (8 channels and 20 amp-hr batteries). External battery input for extended operation in cold climates, or for more than 8 channels.
Temperature range: -40^{o} to +45^{o}C (-40^{o} to +115^{o}F)
Humidity range: 5% to 100%
Internal temperature and humidity sensors
Time base: Oven-controlled crystal oscillator; aging rate <5x10^{-10} per 24 hours (GPS disciplining optional)

Displays & Controls

High-contrast sunlight readable ½-VGA (480x320) DFT-technology LCD graphics display, with continuous view-angle adjustment (optional heater for use down to –40^{o}C).
Sealed 80-key keyboard
Analog signal meters and analog outputs
Power On-Off

Standard Analog

Input impedance: 10 MΩ at DC
Dynamic range: 190 db
Minimum detectable signal: 0.03 μV
Maximum input voltage: ±32V
SP offset adjustment: ±2.25V in 69μV steps (automatic)
Automatic gain ranging in binary steps from 1/8 to 65,536
Common-mode rejection at 1000 Hz: >80 db
Phase accuracy: ±0.1 milliradians (0.006 degree)
Adjacent channel isolation at 100 Hz: >90 db
Filter Section: Four-pole Bessel anti-alias filter (software-controlled) Quadruple-notch digital telluric filter (50/150/250/450 Hz, 50/150/60/180 Hz, 60/180/300/540 Hz, specified by user)
Analog to Digital Converter (Standard Channel)
Resolution: 16 bits ± ½ LSB
Conversion time: 17 μsec
Continuous self calibration
One A/D per channel for maximum speed and phase accuracy

NanoTEM® Analog

Input impedance: 20 KΩ at DC
Dynamic range: 120 db
Minimum detectable signal: 4 μV
Automatic gain ranging in binary steps from 10 to 160
Analog to Digital Converter: 14 bits ± ½ LSB, 16 bits optional
Conversion time: 1.2 μsec
One A/D per channel for maximum data acquisition speed

Digital Section

Microprocessor: 133 MHz 586
Memory: 128 Mb dRAM (up to 256 Mb)
Mass Storage (program & data storage):
512 Mb flash RAM (up to 4 Gb).
Hard disk drives with capacities to 40 Gb optional
Serial ports: 2 RS-232C ports (16650) standard
Network Adapter: Ethernet adapter standard (100 Base-T)
Mouse, CRT (VGA), and standard keyboard ports
Optimized operating system

Additional Options

Number of channels: (maximum of 3 NanoTEM® channels)
Large case: 1-16, Small case: 1-6
External battery and LCD heater for –40^{o}C operation

Other Acquisition Software

External RPIP/TDIP/CR Control*:* Remote control through serial port on GDP-32^{II} for electrical resistance tomography (ERT).
Streaming RPIP/TDIP*:* Continuous acquisition of TDIP or RPIP data (time domain or resistivity/phase IP) using a towed electrode array.
Borehole TEM*:* Remote control through GDP-32^{II} serial port for efficient logging of borehole TEM and MMR data. Compatible with Crone and Geonics 3-component probes.
Extended Broadband Time Series Data Recording*:* Continuous recording of up to 5 standard analog channels sampling at 32 K samples/sec (bandwidth 8 KHz with 2x oversampling) with no loss of data. The recording time is limited only by the size of the hard disk drive. Developed for recording broadband magnetotelluric measurements.
Equal-Interval Mode TEM (TEME)*:* Uniform sampling and storage of TEM transients as time series. Used for LOTEM data acquisition and any application that requires uniformly sampled TEM transients.

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