Design Considerations for the Development of a High-Powered Geophysical Transmitter

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ABSTRACT

It is common belief that near-surface mineral resources have probably already been found due to their relative ease of detection. Future exploration will therefore need to focus on finding deposits that are deeper or more difficult to detect. The cost of deep drilling will undoubtedly increase the exploration industry's need for relatively inexpensive geophysical techniques capable of providing quality targets able to facilitate more focused and more cost-effective drilling programs.

Electrical techniques that use a controlled source such as induced polarization (IP), electromagnetics (EM) and sub-audio magnetics (SAM) use sensitive instruments to measure the earth's response to electrical or electromagnetic signals produced by a geophysical transmitter. The amplitude and quality of the measured response is in turn dependent on the strength and fidelity of the transmitted signal. As Explorers search for deeper targets, higher powered transmitters will be required to increase signal amplitudes in order to achieve greater depth penetration and acceptable signal/noise ratios.

Geophysical transmitters are characterized by inherent potential safety issues that include electrical, noise and manual-handling hazards. They are also required to function in hostile environments typified by extremes of temperature, remote locations and rough unsealed roads. This paper describes the many considerations involved in developing a new high powered geophysical transmitter capable of meeting these demands. In addition to having high performance, the transmitter needed to perform safely and reliably in harsh environmental conditions.

INTRODUCTION

Gap GeoPak Pty Ltd (GeoPak) was formed as a joint venture between Gap Geophysics Pty Ltd and electronic engineering company, Kayar Pty Ltd in 2007. The company's primary objective was to produce a new generation of geophysical transmitters to meet the increasing demand for higher performance, as well as to accommodate the more stringent safety standards required by the mining exploration industry today.

GeoPak's initial product, the HPTX-70 (see Figure 1), was first commissioned in 2009. The **HPTX-70** is a **H**igh-**P**owered transmitter (**Tx**) capable of output power of up to **70** kW. The system is designed for both electromagnetic and galvanic mode geophysical surveys. It produces precisely timed, high current waveforms in order to provide a better quality primary signal and consequently allow for high resolution, large scale or deep detection surveys.

The HPTX-70 project involved many design considerations relating to performance, safety and reliability that are described in this article. These may be of interest to the wider geophysical community, particularly at a time when international guidelines for the safe operation of electrical geophysics surveys are being developed.

Fig. 1. The HPTX-70 high-powered geophysical transmitter operating at Leinster, Western Australia in 2011.

DEVELOPMENT DRIVERS

There were two specific drivers for the development of the HPTX-70.

1. The requirement by Gap Geophysics for a high-powered general-purpose transmitter for use with large-scale Sub-Audio Magnetics (SAM), HeliSAM and SAMSON surveys. SAM may be configured as either Magnetometric resistivity (MMR) or Fixed Loop EM (FLEM) surveys. HeliSAM is a helicopter-acquired SAM survey.

   For SAM MMR surveys, grounded dipoles of up to 10 km separation are typical and may require up to 20 km of loop wire. SAM FLEM and SAMSON are deep penetrating EM techniques which use inductive loops. In FLEM mode, loops of 1000m × 1000m to 2500m x 2500m in size are common.

2. The requirement by Gap Geophysics and BHP Billiton – Nickel West for a high-performance EM transmitter to power their FLEM and Downhole EM (DHEM) and Downhole MMR (DHMMR) surveys. Nickel West's defined objective for the system was to achieve 200A into loops of up to 1000m × 500m.

FUNCTIONAL SPECIFICATION

At the outset of the project, a functional specification for the 'ideal' high powered transmitter was defined in collaboration with Gap Geophysics and Nickel West management, geophysicists, engineers and OH&S representatives. Commensurate with the required increases in electrical power and robust design were requirements for a very high level of safety.

In developing the HPTX-70, GeoPak endeavored to construct a functional transmitter with exceptional performance and reliability. Core to its design requirements were also unprecedented security and safety controls.

PERFORMANCE CONSIDERATIONS

Given the development drivers mentioned above, the HPTX-70 needed to be a general-purpose transmitter, capable of sufficiently high voltages for galvanic operations and of high currents for EM applications. However, in terms of defining the optimum output power, many factors needed to be considered, such as:

- the physical size and weight of the power supply (generator) and transmitter;
- transport logistics – would it need to be trailer or truck mounted?
- fuel consumption (which affects logistics and cost of fuel supply);
- cooling of both a stationary engine and transmitter in Australian temperatures of up to 50°C; as well as operating efficiencies and long-term reliability.

Other practical considerations included the output loop characteristics, such as:

- Practical loop sizes and configurations
- Loop resistances and inductances
- Electrode resistance for galvanic applications
- Wire sizes and current carrying capacity
- Wire insulation ratings for high voltages
- Wire weights and deployment techniques
- Wire joiners capable of high currents and
- Heat dissipation from the wire.

GapTxCalc

Key to understanding the constraints and implications of building a high-power transmitter was the development of a transmitter / loop performance calculator called "GapTxCalc". This software enabled modelling of the overall transmitter system. It was quickly determined that around 70-80 kW was the optimum size for a general purpose, high-powered transmitter.

In summary:

- Because of the heat generated, very high currents require high ampacity, low-resistance cable that can be very heavy due to the weight of copper. Heavy wire becomes impractical to deploy and transport without mechanical assistance. For this reason, the output current capability of the HPTX-70 was effectively limited by the practical constraints of wire handling.
- In Australia, because of safety concerns, there is a significant push by some Regulatory Authorities to limit output voltages of geophysical transmitters to the Low Voltage Range which is defined as 120V to 1500V (DC). In addition to this, High Voltages require high voltage insulation on the loop wire. This would be prohibitively expensive for the large dipoles being used for SAM and HeliSAM. For these reasons, the output voltage capability of the HPTX-70 was ultimately limited to 1200V.
- Power (P) is proportional to the square of the current (I). That is, $P = I^2R$ (where R is resistance). This relationship has significant implications for high power outputs. For example, for a given loop resistance, doubling the output power would only result in an increase in current by a factor of 1.4. Accordingly, doubling the current would require an increase in power by a factor of four. This would be achieved at significant cost in terms of weight, transport, cooling and fuel requirements.
- On a practical note, at the time of development, the transition from 70 kW to 85 kW for an industrial diesel engine usually coincided with an increase from four to six cylinders. This power upgrade increases the physical size and weight of the engine as well as fuel consumption and hence the required fuel capacity.
- The upper weight limit for safely towing a trailer behind a light vehicle on country roads was considered to be around 2.0 tonne. It was determined that the size and weight increase from a four cylinder to six cylinder diesel engine as

well the extra fuel capacity required to operate it, would increase the weight significantly beyond that limit. A larger system would therefore need to be mounted on a truck with a minimum load capacity of 5 tonne. The permanent assignment of a truck to the transmitter would therefore result in substantial additional cost.

- A significant increase in power also requires a significant increase in the ruggedness, availability and expense of electronic components in the transmitter. In addition, it results in a dramatic increase in heat generation, which would then require further cooling.
- Given the previously described wire constraints on current output, higher power could only be utilized if high voltages were also implemented.

The transmitter design used in the HPTX-70 is scalable and could accept input power well in excess of 300 kW. However, it was determined that a trailer-borne system would be the most versatile, most practical and most cost-effective platform for routine deployment.

THE HPTX-80

Three HPTX-70 prototypes were built and have now been in operation for eight years. However, they have been superseded. The most recent high-powered transmitter developed by Gap GeoPak is designated the "HPTX-80" (see Figure 2). Two HPTX-80 transmitters were commissioned in 2015.

Fig. 2. The Gap GeoPak HPTX-80 high powered transmitter.

The design of the HPTX-80 benefitted significantly from refinements made to the prototype HPTX-70's over six years of continuous operation. Major software, hardware and operational enhancements were added. Significant performance improvements were achieved with a more modern, lightweight turbo-diesel engine.

The layout and design of the HPTX transmitters is described in the following sections with specific reference to the HPTX-80.

Performance

The HPTX-80 has four selectable voltage ranges as shown in Table 1. The minimum and maximum current outputs for each range are also shown.

Table 1. Selectable voltage ranges for the HPTX-80.

Voltage Range	Minimum (V)	Maximum (V)	Maximum (A)
1	100	200	360
2	200	400	180
3	300	600	120
4	600	1200	60

- The high current capability means that the HPTX-80 is an ideal transmitter for electromagnetic surveys, particularly for FLEM or DHEM. *Note that high current output requires low resistance loops and appropriate wire capable of carrying the current.*
- The HPTX-80 is also routinely used for galvanic mode surveys such as SAM and IP. *The maximum output voltage of 1200V will, of course, limit the output power achievable in very resistive environments.*

Internal Layout

The internal layout of the trailer is shown diagrammatically in Figure 3. The trailer is partitioned into three main compartments. From front to rear of the trailer, these are referred to as:

A. Dummy load compartment,

B. Engine compartment, and

C. Electrical compartment.

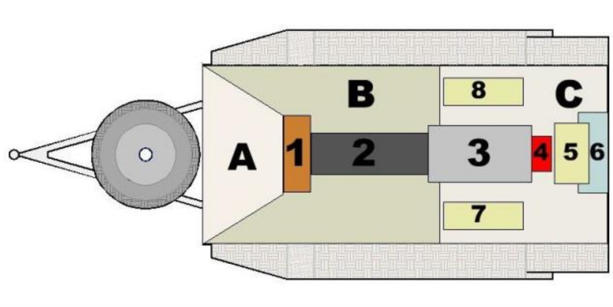

Fig. 3. Plan view of the HPTX-80 showing the dummy load compartment (A), the engine compartment (B), and the electrical compartment (C).

The other components of the system are:

1. Radiator
2. Diesel engine
3. Alternator
4. Circuit breakers
5. Control module
6. Capacitor box
7. Switch module and
8. Transmitter module.

Dummy Load

For time domain surveys, geophysical transmitters are required to produce current waveforms that consist of some **ON** time and some **OFF** time. That is, current may not be transmitted into the loop 100% of the time. Time domain waveforms are typically characterized by a 25 or 50% duty cycle, which means that current is only being transmitted (**ON** time) for 25 or 50% of the time. For the rest of the time there is no output from the transmitter. The variable load on the transmitter therefore results in surging of the engine during the **OFF** time. This may subsequently affect the integrity of the waveforms produced, as well as cause undue wear on the engine.

To alleviate this effect, the HPTX-80 has a built-in bank of resistors referred to as a “Dummy Load”. The dummy load compartment is located at the front of the trailer and can be seen in Figure 4. To balance the load on the engine, the transmitter switches the output current during the **OFF** time to the dummy load. The number of resistors required to balance the load is automatically determined by the transmitter.

Diesel engines also require a minimum load to operate efficiently. The HPTX-70 will also transmit some output current into a portion of the dummy load during the **ON** time if there is insufficient load on the engine.

Fig. 4. Front view of the HPTX-80 with the door open showing the dummy load protected by an aluminum mesh screen.

Engine Compartment

A photograph of the engine compartment is shown in Figure 5. The power supply used in the HPTX-80 is a four cylinder, 100 kW, Cummins turbo-diesel engine operating at 1800 rpm and driving a three-phase alternator.

Direct drive mitigates many of the mechanical drivetrain problems often encountered with gearboxes or drive belts, resulting in less maintenance and greater reliability.

Fig. 5. The HPTX-80 engine compartment showing the Cummins turbo-diesel engine and high capacity radiator. The fuel tank is located beneath the radiator.

Electrical Compartment

The electrical compartment can be accessed via the two rear side doors and the rear door. A rear view of the compartment is shown in Figure 6. With reference to the numbering in the schematic in Figure 2, the control module (5) is shown at the top and the capacitor box (6) at the bottom. Directly beneath the control module are the circuit breakers. The grey unit beneath the circuit breakers is the 3-Phase alternator (3).

To the left of the control module is the switch module (7). The transmitter module (8) is visible at the right of the control module. A close up photo of the Control Panel is shown in Figure 7.

Fig. 6. Rear view of the HPTX-80 with the rear door open showing the grey alternator, control module at top and capacitor box at the bottom. The switch module is located on the left side. The transmitter module is located on the right.

Fig. 7. The HPTX-80 LED Control Panel showing the digital engine display.

Cooling Systems

The HPTX-80 has been designed to operate in hot environments. It also generates a significant amount of heat internally from both the engine and transmitter compartments as well as from the dummy loads. Consequently, cooling was a major design consideration. By separating the engine and electrical compartments it was possible to design separate, and thereby more efficient, cooling systems for the different sections.

In normal operating mode, the HPTX-80 is operated with its side doors closed and its rear and front doors open. In addition, the two roof hatches must be kept fully open. A diagram showing the HPTX-80 in operating mode is shown in Figure 8. Also shown in this figure is the direction of airflow and the temperature gradient for each of the internal compartments.

Two high-speed fans are mounted beneath each of the roof hatches of both the engine compartment and the electrical compartment. The fans are responsible for volume and direction of airflow throughout the HPTX-70. In addition, there are seven fans mounted on the rear of the transmitter module and two fans mounted on the rear of the switch module.

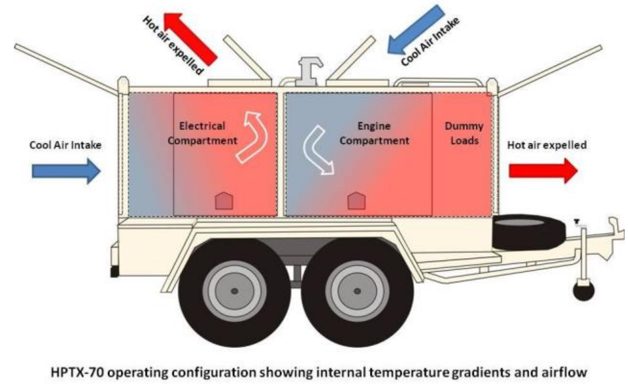

Fig. 8. The HPTX configured for normal operating mode. The side doors must all be in the closed position. The roof hatches and the front and rear doors must be kept open for optimal cooling.

Output Connectors

The output connectors are each comprised of a polycarbonate box containing an aluminum terminal block. The two transmitter cables are terminated with crimp-on copper lugs and attached to the terminals. A photo of an output connector with the lid open is shown in Figure 9.

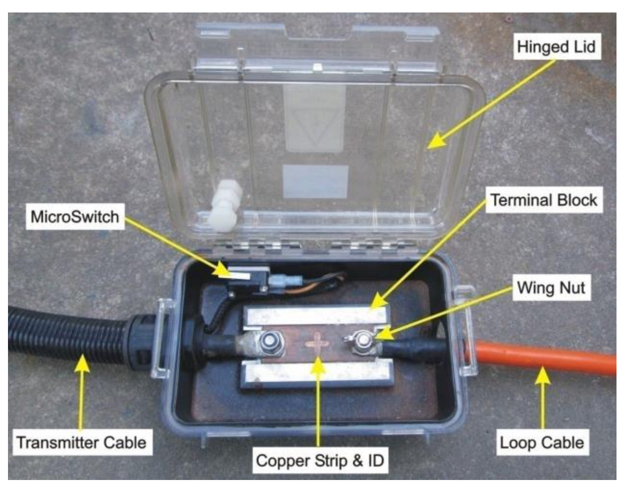

Fig. 9. Close up of a connector box with lid open showing internal components.

The loop cables are also terminated with crimp-on copper lugs. They are attached to the terminal block with wing nuts and spring washers for easy removal and attachment. The output connector boxes are also fitted with safety interlocks. The boxes must be closed for the HPTX-80 to operate. Opening the box while the HPTX-80 is operating will result in an emergency shutdown of the transmitter.

Software Control System

The HPTX-80 is controlled remotely by specialized software (HPTXUi) operating on a ruggedized handheld computer. The computer may be linked directly by cable to the control panel of the transmitter but is designed to operate via a radio link. The range of the radio link will depend on topography but is usually about 2 km. A photograph of the control system is shown in Figure 10.

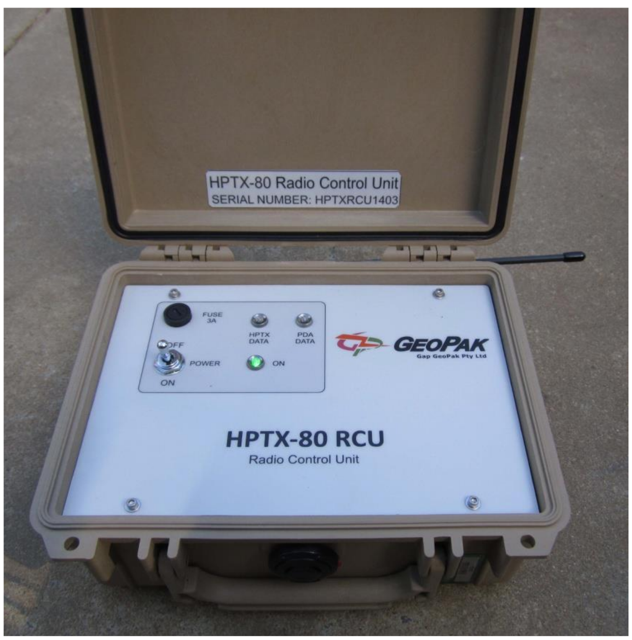

Fig. 10. The HPTX-80 Radio Control Unit.

HPTXUi

The HPTX user interface software requires the operator to log in to the transmitter via a security password. The operator is then required to review digital checklists prior to starting the transmitter. The alternator and hence the transmitter cannot be started without the use of this software. However, the engine alone can be started manually for maintenance purposes.

All transmitter functions including engine start/stop, transmitter start/stop, frequency, duty cycle and current are controlled on a setup panel (Figure 11). The output status panel provides real-time information on the various operating parameters including output voltage, output current and turn-off time. All internal temperatures, voltages and phases are monitored and broadcast by the transmitter.

Abnormal variations in critical parameters will initially result in warnings on the display. Critical errors will be trapped resulting in immediate shutdown of the system. All control and status information is logged to various files for later reference or for auditing purposes.

Computer control of the transmitter also provides the ability to run repetitive or routine procedures. HPTXUi has an inbuilt scripting language for that purpose.

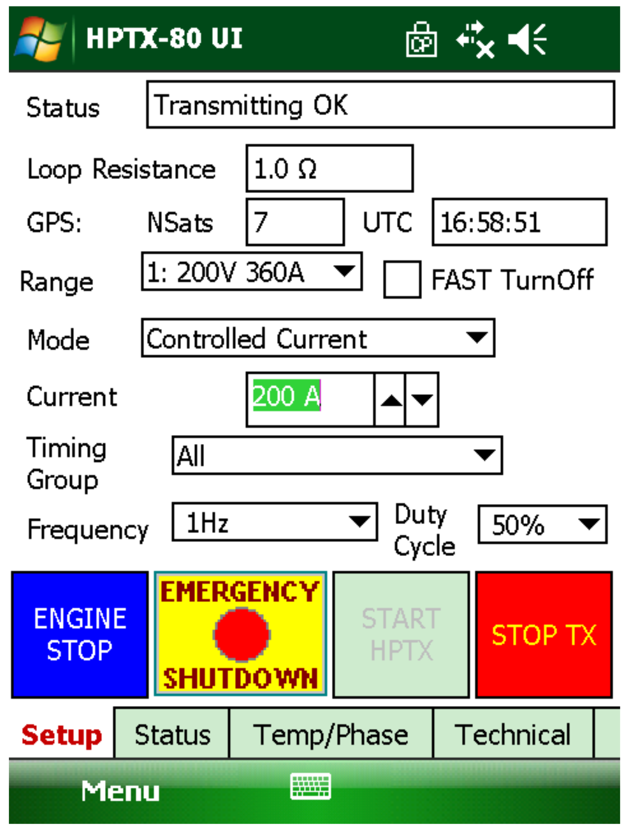

Fig. 11. HPTXUi – setup panel.

Fire Suppression System

As the HPTX-80 can be operated remotely, an automatic fire detection and suppression system is fitted inside the trailer. The control panel, located on the right side of the electrical compartment, is shown in Figure 12. Located beneath the control panel is a bottle of pressurized nitrogen, which acts as the propellant for the bottle of dry powder retardant located in the engine compartment.

Fig. 12. The fire suppression control system located in the right side of the electrical compartment.

Apart from their enhanced performance, the HPTX 70/80 design has been found to have significant implications for many aspects of their operation including safety, logistics, efficiency and reliability.

Safety

- Radio control – the operator does not need to be near the transmitter to operate it. This is a significant safety control as the operator is totally removed from electrical and noise hazards when the transmitter is operating.
- Electrical components are fully enclosed and protected from the environment.
- Electrical and mechanical components are enclosed and inaccessible when operating.
- Safety interlocks are installed on all doors and hatches and will initiate immediate shutdown of the system if they are opened (or closed) during operation.
- No manual lifting – the all-in-one design removes the requirement for manual lifting of heavy generators and transmitters during setup.
- Reduced trip hazards – all of the cabling is internal apart from the output loop and earth wires.
- Safety beacons – two high intensity safety beacons are activated when the HPTX-80 is operating and therefore provide a visual warning to anyone approaching.
- Safety guards are installed on all internal moving parts as well as the dummy loads.
- Steps and grab rails allow three points of contact when opening or closing roof hatches.
- Emergency shutdown – the HPTX-80 may be shut down by activating either of the emergency shutdown switches on the main control panel and near the dummy loads or by pressing the shutdown button on the handheld computer. In addition, shutdown will occur on opening of any of the side doors or by closing the rear or front doors.
- Automatic shutdown – the HPTX-80 also has 32 sensors throughout, which monitor internal temperatures, overcurrent and overvoltage. The transmitter will automatically shutdown if an error condition is detected.
- Open circuit protection – the HPTX-80 will shut down if a change in the loop resistance is detected (i.e. due to a break in the loop)
- Earth leakage protection – a current of 20 mA or more in the chassis to earth-stake cable will cause shutdown of the motor and transmitter system within 1 ms. A test button allows injection of 20 mA into the earth leakage detection circuitry to enable testing of this function.
- Bunding for the fuel tank – the fuel tank is built separate to the trailer. The trailer base itself is fully sealed so that if any puncture should occur in the fuel tank, the trailer provides internal bunding for the fuel leak. Drain plugs in the base of the trailer enable any spilled fuel to be easily removed.
- Aluminum construction – the HPTX-80 trailer has been built entirely from aluminum in order to minimize weight for towing and maneuverability purposes.
- Signage – HiVis reflective tape and appropriate signage is used as required.

Logistics, Efficiency and Reliability

- Wireless control means the transmitter may be operated and monitored remotely without the operator having to travel to it.
- Cooling system – the HPTX-80 has been designed to operate in hot conditions through implementation of a sophisticated cooling system.
- Reduced wear on connectors due to permanent attachment of all electrical connections apart from the output (constant connection and disconnection results in wear and tear of connectors and is generally one of the major causes of downtime in geophysical surveys).
- Very little setup required – when the HPTX-80 is moved to a new loop, the only setup required is installation of an earth stake and connection to the loop. This greatly reduces setup time and hence improves survey efficiency.
- Power source – the HPTX-80 uses an industrial quality diesel powered three-phase genset for fuel efficiency, reliability and long life. The engine runs at low speed, thereby extending engine life. Direct drive simplifies power

transmission to the alternator as no belts, gearing or hydraulic drives are required.

- Dummy loads – provide a balanced and adjustable load on the engine in order to reduce wear on the engine and help to maintain the integrity of the output waveforms.
- Fuel tank – the large fuel tank (~250 L) is installed for long duration.
- Rhino lining – the trailer base has been sprayed with a protective coating to prevent stone damage and thereby reduce maintenance. It also provides a non-slip surface on steps and guards.
- Rustproof – the HPTX-80 trailer will not rust due to the aluminum construction.

SUMMARY

The HPTX-70/80 transmitters have been in constant operation in Australia since 2009. The unprecedented performance of these transmitters has changed the face of EM exploration forever in Australia by significantly improving the depth penetration and quality of EM surveys.

However, the transmitters are only part of the transmitter "system" which also includes the transmit loop. The increased power of these transmitters has also required a significant increase in the size and weight of the loop. For EM surveys in Australia, Gap has standardized on 35 sq mm (cross-sectional area) loop cable. This is equivalent to #2 gauge AWG.

A standard 1km x 1km loop of this wire weighs over two tonne. A single reel with 200m of wire weighs about 100kg. Consequently, wire deployment needs to be largely mechanical.

Specialized trailers with on-board cranes have been built to transport the wire. Heavy duty reels and motorized winders have also been developed. UTV's have also been heavily modified to support these systems.

However, there is no one transmitter which will be optimal for all applications. It became apparent very early that the size and weight of the HPTX series transmitters is not conducive to use in areas where access is very difficult. In many places, due to topography, terrain, vegetation and access, it is also not practical to deploy heavy cable.

As was originally determined when developing the HPTX-70, the power achievable in these difficult areas is ultimately limited by the practical constraints of access and wire deployment. For this reason, Gap GeoPak has also designed a range of purpose-built modular transmitters.