MAXMIN I+

EM SYSTEMS

OPERATIONS MANUAL

12 April 1998

Para. Page

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0. INTRODUCTORY NOTES

Year 1998 marks 25 years of service by Apex Parametrics Limited. The MaxMin EM Systems have seen many redesigns and improvements since the early MaxMin versions, first made in 1974. Only some of the improvements are noticeable from the outside of the equipment even though all of the circuitry and coils have changed during the intervening years. The MaxMin operating frequency range has been extended down to 110 Hz for highly conductive earth situations and up to 14080, 28160 and even to 56320 Hz, resulting in a significant increase in measurement sensitivity and interpretability for high resistivity situations or for shallow survey depts, even more so for the combination of both.

With the higher MaxMin operating frequencies the operators should be reminded that the transmitter and receiver coils should routinely be held symmetrically during the measurements, i.e. left hand holding the left side of the transmitter coil (or the leather strap, or at the receiver end the receiver leather case) and right hand holding the right side of the transmitter coil (or the leather strap, or at the receiver end the receiver leather case). This helps to minimize unwanted stray field effects by maintaining a balanced self-cancelling coupling between the system and the ground. Rubber footwear for the operators also helps to improve accuracy when using the higher frequencies, by maintaining higher resistance between the operators and the ground, and thereby a lower a leakage path, more important on wet ground.

For best accuracy, the use of the 56320 Hz frequency should generally be limited to coil separations of 50 metres or less, the 28160 Hz to 100 metres or less, and the 14080 Hz to 200 metres or less. Where a reduction in accuracy, particularly zero base level accuracy, is tolerated, e.g. in profiling for mineral exploration discrete bedrock targets, these recommended maximum separations may be increased somewhat. The greater requirement for the highest frequencies occurs in very resistive areas with thin overburden in conjunction with the use of the shortest coil separations, and therefore this instrumental coil separation limitation is mostly precautionary.

Improved MaxMin data acquisition computer, the MMC, was introduced a while back. The MMC has an operations manual of its own. Among the more noteworthy specifications of the MMC are: increased user frendliness with the liquid crystal display in full sight, the keyboard within fingertip reach, a high resolution display of the in-phase and out-of-phase readings and their relative noise levels and a display of apparent ground conductivity in milliSiemens/metre (millimhos/metre). Additionally, more accurate best fit apparent conductivity values and their standard deviations over the measured frequency range can be produced upon dumping the data to a PC. The use of the MMC greatly simplifies rough terrain survey procedures, computations, and corrections, and much more so when used in conjunction with the provided PC software application programs for DOS and for Windows*.

A new interpretation software program, the MaxMin Pro has also been introduced in 1997. The MaxMin Pro operates under Windows* environment and it facilitates computer aided interpretation for layered earth and for thin plate conductors. The MaxMin Utilities Windows*-based data transfer, editing, formatting, draft profile viewing and printing program is nowadays being distributed with every MMC. This MaxMin I+ manual documentation does not yet fully reflect the impact and benefits that the commonplace computerization of hardware with application software has created as a lot of the material in this manual predates the PC era, having been carried over from earlier manuals which were written predominantly for mineral exploration applications.

The latest developments have resulted in updated MaxMin I+ versions, being brought in production in the spring of 1998. These MaxMin I+ models have significant transmitter efficiency and dipole moment improvements in comparison with previous instruments. Please make the best use out of them!

Apex Parametrics Limited

* Windows is a registered trademark of Microsoft

1. THE RECEIVER

1.1 BASIC COMPONENTS

The MaxMin receiver is a one piece unit. There are two coils rather than one. They are solenoidal with ferrite cores and are mounted in the upper section of the fiberglass tubes on each side of the console. The electronic circuitry is located on printed circuit boards inside of the console. The readout meters, the commonly used control switches and the connectors are easily accessible on the console which is installed in a leather carrying case with two carrying straps.

1.2 INSTALLATION AND CARRYING INSTRUCTIONS

The description here is for the most commonly used mode, which is the MAX1 or Horizontal Loop mode. Descriptions for the other operating modes are in section 5.

The normal way to carry the receiver is with the two cross straps each passing under an armpit, across the back, and over the opposite shoulder. This permits day-long operation without strain on the neck.

1.3 CONTROL AND READOUT FEATURES

1.3.1 PTT (INTERCOM) and READ Switch: Dual function switch which operates the intercom microphone and speaker circuits and also reads the measured values into the MaxMin data acquisition computer. The switch is normally in the listening position and its lever is tilted left for talking to the transmitter operator or for giving an audible click to signal readiness for the next frequency. The transmitter operator can be accessed whether the receiver and transmitter units are switched on or off. The switch lever is tilted right to read the measured values into the data acquisition computer (e.g. MMC). The MaxMin Computer manual contains more details on this function.

1.3.2 ON/OFF Power Switch: Powers up the receiver for the taking of MaxMin readings. With the power on, the internal intercom speaker is off so as not to interfere with the measurements.

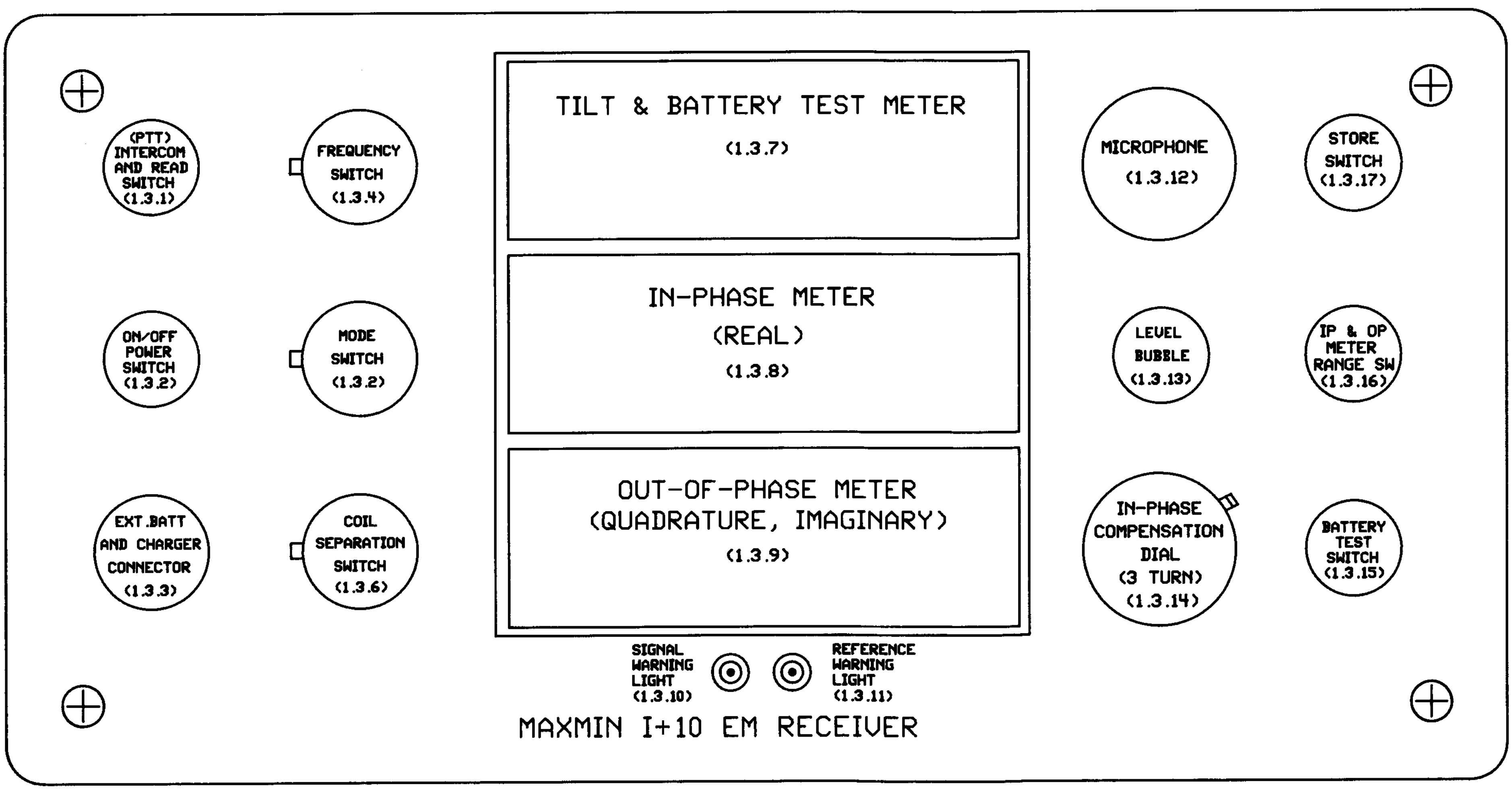
1.3.3 POWER CONNECTOR (OPTIONAL): receptacle for external batteries and/or for battery charging when using optional receiver rechargeable ni-cad batteries.

1.3.4 FREQUENCY Switch: Selects one of the octavely-spaced operating frequencies in the range from 110 to 56320 Hz, depending on the MaxMin model..

1.3.5 MODE Switch: Sets the mode of operation: MAX 1 = horizontal coplanar coils (Horizontal Loop, Slingram); MAX 2 = vertical coplanar coils; MIN 1 = perpendicular coils with transmitter coil turns horizontal and receiver turns vertical; MIN 2 = perpendicular coils with transmitter coil turns vertical and receiver turns horizontal. See manual section 5 for further information on the different operating modes.

1.3.6 COIL SEPARATION Switch: Used to choose one of the eleven available coil separations in the range of 12.5 to 400 metres by means of an internal grid switch. This range becomes 10 to 320 metres as an alternative second metric set, or 50 to 1600 feet as an imperial set, with the use of the internal grid switch. See note 2 in Appendix I for more details on the grid switch.

MAXMIN I+ EM RECEIVER FRONT PANEL LAYOUT:



1.3.7 TILT & BATTERY TEST Meter: Works in conjunction with the Mode switch to facilitate the tilting of the plane of the receiving coil turns to the desired tilt. In the MAX 1 and MIN 2 modes, the plane is referenced to the horizontal, in the MAX 2, and MIN 1 modes the plane is referenced to the vertical. The meter only responds to a forward and backward tilting of the receiver and not to sideways tilting. Information on the mechanical adjustment of the Tilt meter "0" is given in Appendix I note 4a. The meter also works in conjunction with the Battery Test switch to indicate the condition of the positive and negative battery banks. See section 3.1 and Appendix I note 6 for more information on the receiver batteries and the battery tests.

1.3.8 IN-PHASE meter: Gives a read-out of the in-phase component. Normal reading range is ±20% (per cent of the magnetic primary field at the receiving coils), which can be changed to ±4%,or to ±100% by the IP & OP Meter Range switch. The ±100% range can be further extended to ±115% if needed, by use of the In-Phase Comp potentiometer dial. See note 3 in Appendix I for more on this point. Mechanical adjustment of the In-Phase (or Out-of-Phase) meter "0" is described in note 4b in Appendix I.

1.3.9 OUT-OF-PHASE Meter: Reads out the Out-of-Phase component, the normal reading range being ±20%, which can be changed to ±4% or ±100% with the IP & OP Range switch.

1.3.10 SIGNAL Light: Flashes each time an excessive interfering noise pulse reaches the receiver. An occasional flicker only reduces the reading accuracy slightly, whereas a near steady or steady light indicates that prevailing interference levels are likely too high for accurate readings.

1.3.11 REFERENCE Light: Goes on solid if the reference signal is not supplied to the receiver. This would most likely be an indication of a disconnected or broken reference cable or an absence of transmitter output. There is more on this in section 6.5. The light flashes sporadically if the intercom is used while the receiver is "on", or if there are excessive noise levels in the reference line.

1.3.12 MICROPHONE: Component of intercom system, functions in conjunction with the PTT (Intercom) switch for speaking to the transmitter operator. Return communication is broadcast via speaker located inside the console.

1.3.13 BUBBLE LEVEL: Can be used as an alternative to the Tilt meter to keep the coil horizontal; can also be used as a check on the mechanical zero on the Tilt meter. See note 4a in Appendix I for more on this.

1.3.14 IN-PHASE COMP Dial: Permits the gain calibration and phase-mixing test, described in note 1 in Appendix I. The dial can also be used to change the zero base level of the Inphase meter readings. See note 5 in Appendix I for a description of this.

1.3.15 BATTERY TEST Switch: Functions in conjunction with the Tilt & Batt Test meter to test the batteries, as already mentioned in section 1.3.7.

1.3.16 IP & OP METER RANGE Switch: Changes the reading scales of both the Inphase and Out-of-Phase meters from the normal ±20% to ±4% or ±100% as described in 1.3.8 and 1.3.9. Both meters are affected simultaneously.

1.3.17. STORE Switch: This is used with the data acquisition computer (MMC) to store the readings. See the MaxMin Computer operations manual for more information.

1.3.18 CONNECTORS for Reference Cable and Data Acquisition Computer are located on the underside of the console.

2. THE TRANSMITTER

2.1 BASIC COMPONENTS

The functional transmitter consists of three components which are connected together with two retractile cords; these components are the console, the coil, and the 12 Volt battery pack. Two 14.5 to 14.8V transmitter battery chargers are also supplied. It should be noted that the retractile transmitter connecting cords for the MaxMin I+ models are shorter than those for some early MaxMin models.

The longer retractile cords from the early MaxMin models should not be used with the MaxMin I+ models as the highest frequencies would be detuned due to higher cord capacitance and especially the lowest frequencies would be handicapped because of the higher resistance of the early longer cords.

The transmitter coil is an oval-shaped loop with a small compartment at one end containing two bubble levels, a cable connector receptacle and an electro-mechanical tilt sensor. A leather carrying harness is installed on the coil.

The console contains the electronic circuitry. The read-out meter, control switches and connectors are mounted on the console, which in turn is carried in a leather case equipped with two carrying straps.

The standard battery pack consists of a set of 4 sealed 6Volt - 6.5Ah to 12Ah rechargeable lead-acid batteries, mounted in a nylon carrying belt, equipped with 20 ampere circuit breaker and a cable connector receptacle.

2.2 INSTALLATION & CARRYING INSTRUCTIONS

The description here is for the most commonly used mode; Horizontal Loop or MAX1 mode. Descriptions for the other modes are in section 5.

The battery belt is first installed around the waist, followed by the console (with cords connected) on the chest with the carrying straps passing over the shoulders and under the armpits, crossing on the back. The coil is then suspended from the shoulders by its carrying harness, so that it surrounds the hips in a horizontal position. The remaining connections between these three components are then completed with the retractile cords. The console should be carried far enough above the coil level with at least 15 cm (6 inches) between the console and the turns of the coil, in order to prevent detuning of the coil and undesirable anomalous effects (notable mostly on zero levels of the readings and on the transmitter battery test).

For short walks, such as between stations in easy terrain, the coil is best left in its normal position. It can be kept from swinging with one steadying hand. For longer walks, such as between lines, or for short walks under difficult conditions, the coil may best be cocked onto one shoulder.

2.3 CONTROL AND READOUT FEATURES

2.3.1 FREQUENCY Switch: Used to choose one of the eight to ten operating frequencies in the range of 110 to 56320 Hz, in one octave intervals.

2.3.2 TILT & BATTERY TEST Meter: Works in conjunction with the Batt Test switch; monitors the tilting of the turns/plane of the transmitting coil. The tilt of the turns is referenced to the horizontal plane (or vertical axis). The meter is driven by a tilt-sensor in the compartment on the coil, which responds to a forward and backward tilting of the coil, being unresponsive to sideways tilting of the coil or any tilting of the console. The meter functions as a tilt indicator only when the transmitter is connected to the coil and turned "on". In case of malfunctions, refer to note 7 in Appendix I. A zero offset, if any, in the meter needle can be verified by comparing it with the bubble level(s) on the coil and adjustments can be made if necessary; see note 4a in Appendix I. This meter also indicates the voltage level of the transmitter batteries as compared to the voltage required to drive the prescribed current through the transmitter coil. This battery test is only valid with the transmitter "on", with the <u>coil connected and kept away from conductive/metallic objects</u>. If the meter needle should settle below the left end of the Batt-OK line, it would mean either that the batteries are discharged or that there are other transmitter problems. There is more on this point in note 8 in Appendix I.

2.3.3 MICROPHONE: Is part of the intercom system and works in conjunction with the Intercom switch to communicate with the receiver operator. The return communication is aired through a separate speaker in the console.

2.3.4 INTERCOM (PTT) Switch: Works in conjunction with the microphone and the internal speaker; is normally in the "listen" mode; is depressed for the "talk" mode. The receiver operator cannot hear the transmitter operator when the receiver is "on" because the speaker would interfere with the field measurements, but the latter's voice would cause the receiver Reference warning light to flicker strongly and the Inphase and Out-of-Phase Meter needles to jump around, thus alerting the receiver operator to an attempt at voice communication.

2.3.5 ON-OFF Power Switch: Controls the power for the transmitter circuitry; has no bearing on the function of the intercom system which is always on. Sound of the transmitter coil current can be heard when the switch is on, it is weakest and ultrasonic at the highest frequencies. The sound becomes louder if the reference cable is disconnected or broken.

2.3.6 TILT & BATT TEST Switch: For the Tilt & Battery test meter, see 2.3.2.

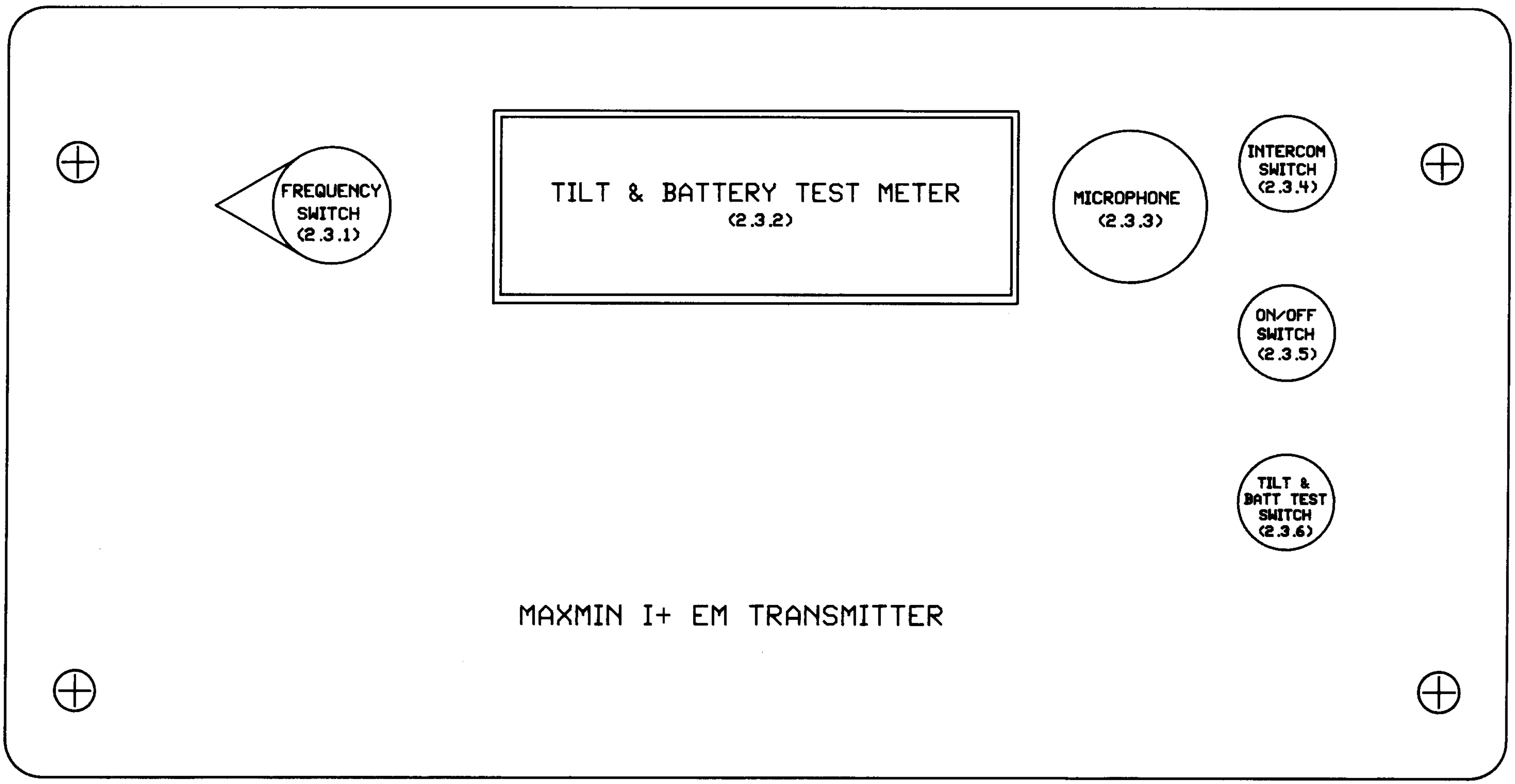
2.3.7 CONNECTORS (REFERENCE CABLE, BATTERY-CONSOLE, CONSOLE-COIL): Located on the underside of console.

<u>3. BATTERIES & CHARGERS</u>

3.1 RECEIVER BATTERIES

The receiver is normally powered by four 9 Volt-0.6Ah alkaline batteries (1604 type), split into positive and negative banks. A set of alkaline batteries should last a couple of weeks of surveying in warm weather and one to two days in very cold temperatures (like -40 deg C). Apex also stocks optional and superior 9V Lithium batteries, recommended for cold temperature operation. Fresh carbon-zinc batteries may last a few days in warm weather, but are inadequate in cold weather. The batteries are accessible after removal of the console case. They are installed on the underside of the inner case. It is a good practice to carry a spare set while surveying. Battery testing is described in note 6 in Appendix I.

MAXMIN I+ EM TRANSMITTER FRONT PANEL LAYOUT



3.2 TRANSMITTER BATTERIES

All current MaxMin I+ versions (presently the MaxMin I+8, I+9 and I+10) use 12 Volt transmitter battery packs and 14.5 to 14.8 Volt battery chargers. Care should be exercised so as not to try to use 12 Volt transmitter batteries and chargers with the 6 Volt transmitters of the earlier MaxMin I-10 and I-8S models, as this would result in equipment damage in time. As a general guideline, battery packs and chargers should be used and kept with the equipment for which they were supplied, unless it is known with certainty that the battery packs and chargers are compatible with other equipment.

The standard MaxMin I+ transmitter battery pack consists of four 6V-6.5Ah to 12Ah sealed rechargeable lead-acid batteries, installed in a nylon belt and connected to form a 12V-13Ah to 24Ah pack. The optional MaxMin I+ long-life ni-cad battery pack consists of four 6V-7.8Ah to 10Ah rechargeable nickel-cadmium batteries, configured for 12V-15Ah to 20Ah. A thermal circuit breaker, 20A nominal, is installed inside the belt connector housing for safety reasons. One battery pack has sufficient capacity to last for a day of surveying under most conditions. It is a good practice to recharge the pack daily after use, even when it is not heavily drained. If the transmitter is being kept on for long periods, especially on very cold days, it is a good practice to park the spare battery belt where the crew will be passing part way through the day.

3.3 TRANSMITTER BATTERY CHARGERS

All of the MaxMin I+ transmitter battery chargers supplied by Apex operate from 115 and 230 VAC, 50/60/400 Hz, mains supplies. The chargers have a mains voltage selector switch. The original equipment AC mains fuse is a slow-blow dual element fuse. The battery chargers also operate from 12 VDC sources, such as a 12V vehicle battery or electrical system (from 10 to 14 VDC). A binding post is mounted on the charger front panel for connecting wires to the 12 VDC supply.

The sealed lead-acid battery packs are recharged with the supplied chargers, having nominal regulated outputs from 14.5V-1.25A to 14.8V-3A, depending on the MaxMin I+ and the charger models. The chargers have three LED lamps: red, yellow and green in colour. When the red LED lamp turns off and switches the yellow LED on, the battery pack is approximately 80 per cent charged. When the yellow LED in turn switches to the green LED, the battery pack is fully charged and the charger automatically switches to 13.8V standby float mode, thereby keeping the battery fully charged and preventing the batteries indefinitely from being overcharged even if the charger will be left on. To fully recharge depleted lead-acid batteries requires 5 to 10 hours of charging time, depending upon the condition of the batteries and the combination of battery packs and chargers. Lead-acid batteries should always be stored in fully charged state, requiring recharging every 3 to 6 months to keep them fully charged.

Optional nickel-cadmium battery packs are charged at room temperature (0 to +40 degrees C) by connecting the provided current regulated output cord into the connector on the belt. Very cold battery packs should be allowed to warm up to above freezing point before charging them. There are LED lights on the charger front panel, numbered 1 and 2, one for each set of 12V battery pairs. These lamps normally remain lit during charging, indicating that the batteries are being charged at the standard (15 hour) rate. The lights do not indicate the level of charge of the ni-cad batteries. Instead, the charging is optimally terminated after 15 to 16 hours of charging for batteries that were initially empty or near empty. A timer switch may also be utilized for this purpose. The nickel-cadmium batteries should not be charged continuously for periods longer than 24 hours. The ni-cad batteries can be stored in fully or partially discharged state.

Please do not use a battery charger that is not intended for the battery pack to be charged, or damage or injury to the batteries, chargers, or even personnel could occur.

4. REFERENCE CABLES

4.1 DESCRIPTION & FUNCTION

A reference cable connects the transmitter and receiver. It is unshielded and contains four teflon-insulated conductors electrically connected as one twisted pair within a teflon jacket. It has two end connectors and stainless steel safety thimbles. A new reference cable is approximately 1% longer than its nominal length in order to allow for attrition through wear and tear. The cable supplies the transmitter primary field amplitude and phase reference for the receiver. It also serves as the intercom link between transmitter and receiver.

4.2 HANDLING INSTRUCTIONS

The reference cable is usually wound in a figure “8” for longevity. This can easily be done around the elbows with a little practice for cable lengths up to about 200 metres, and longer if wound in two sections. Alternative methods are to wind the cable in a figure “8” around two stakes in the ground, or directly into a winding reel.

The reference cable connects to (the bottom of) the transmitter and receiver consoles, with the safety thimble near each end of the cable clipped to the snap-hook on each carrying case. Although the latter step is intended to relieve the strain on the cable ends, it is recommended that each operator grip his end of the cable before starting in motion, to soften the effects of sharp jerks and high strain on the cable near the safety thimbles. Also, each operator can monitor the progress of the other and co-ordinate his moves accordingly, if he grips his end of the cable.

When going up steep slopes, or under any conditions with very large coil spacings, the reference cable pulls along most easily for the leading operator, if it is gripped by him and also passed over his shoulder. When going down steep slopes, the trailing operator should not outrace the leading operator; otherwise, the cable will run freely with loops developing along its length, which in turn may snag around any short growth on the line. The trailing operator should always keep a little tension on the cable to avoid this.

When crossing obstructions in the survey line, such as wide creeks, windfall and sharp precipices, it may be necessary for the leading operator to disconnect the cable, gather up a little slack, possibly tie a short stick to the end, and throw it across the obstruction. The operator will then be free to circumvent the obstruction safely. This technique is essential if the cable is being used to control the coil spacing. In any case, it is desirable to keep the cable straight for ease of pulling along the line. It may also be necessary for the trailing operator to disconnect the cable in order to safely circumvent the obstruction.

5. OPERATING MODES

5.1 GENERAL

The MaxMin I was designed for four self-contained operating modes: MAX1, MAX2, MIN1 and MIN2. All of these modes use a reference cable between the transmitter and receiver. This section of the manual deals primarily with the operating instructions for each mode, with a few words on their applications.

5.2 THE MAX1 (HORIZONTAL LOOP OR SLINGRAM) MODE

The MAX1 mode, commonly known as the Horizontal Loop or Slingram mode, is the standard mode in mining exploration. It is also an effective mode for the study of overburden properties, resistivity and thickness, important in many projects. The method of installing and carrying the equipment for this mode is described in sections 1.2 and 2.2.

There are two basic ways to hold the coils while taking readings: one is to keep the plane of the turns of the transmitting and receiving coils coplanar, the other is to keep them horizontal. The Tilt meters provide the means for setting the coils coplanar in sloping terrain. The bubble levels provide an alternative to the meters for keeping the coil planes horizontal at all times; their use is recommended for this purpose. There is more on this in Appendix II, for carrying out accurate surveys in rough terrain.

It is recommended that the coils be held steady during each set of readings. The transmitting coil should be gripped with one hand on each side for the steady control and for minimum stray coupling. Likewise, the receiver should be steadied holding the lowest part of each coil tube, above the metal case, preferably without touching the metal parts. With this, fingers are positioned for the receiver control switches, when required.

The MaxMin I system is designed for minimum stray coupling effects in and between transmitter and receiver, yet there is still a potential for these effects at the higher frequencies and larger coil spacings. These can be minimized if the transmitter and receiver operators habitually keep their bodies symmetrical with respect to each coil. The earlier instructions for the holding of the coils apply for this purpose as well as for keeping the coils steady.

5.3 THE MAX 2 (VERTICAL COPLANAR LOOP) MODE

This mode, commonly known as the vertical coplanar mode, usually has little application in mining exploration unless the grid lines are found to run parallel to the conductive targets. It is, however, a potent tool for overburden soundings. The method of installing and carrying the transmitter and receiver for this mode are as described in sections 1.2 and 2.2, with the exception that it may be preferable to hang the transmitting coil from one shoulder when moving from station to station.

While taking readings, both operators face perpendicular to the traverse line and tilt the turns of each coil to the vertical. This is readily done for the receiver by raising the console to eye level while sliding the antenna rods back over the shoulders. The front of the transmitting coil is placed on the ground with the bubble level facing the operator, the plane of the turns is held vertical and along the line. In order to keep the proper relationship between the primary field and the reference, each operator needs to face in opposite directions. So, if the receiver operator chooses to face east across a north-south survey line, then the transmitter operator and his coil should face west. A record should be kept of the directions faced because it will affect the sign of the anomaly from conductors parallel to the line. Alternatively, the transmitter operator can position his coil as described above, but continue to face along the line. This will permit a precise orientation of the coil.

The tiltmeter provides the means for keeping the turns of the receiving coils vertical. The appropriate bubble level on the coil compartment can be used to keep the turns of the transmitting coil vertical.

Steadying the receiver by holding the base of both coil tubes or both sides of the leather case is recommended. Steadying the transmitter coil by gripping it symmetrically about its highest point is also recommended.

5.5 THE MIN1 (PERPENDICULAR COIL) MODE

This mode is commonly referred to just as a perpendicular coil mode. It is equivalent to the MIN mode of the earlier MaxMin II systems, with the anomalies being measured as a percentage of the field strength along the plane of the transmitting coil. The min-coupled mode was originally conceived to help resolve the ambiguities of the Horizontal Loop mode as regards very wide or flat-lying, medium-depth conductors. However, the MIN1 mode can also be used for overburden property studies. The difficulty of keeping the coils accurately minimum coupled on other than flat ground and the high sensitivity of the system to small departures from perpendicular minimum coupling, made this mode difficult to use effectively in the past. In brief, small errors in the inclinometer-derived slopes cause large errors in minimum coupled readings. The addition of a second minimum-coupled mode has overcome some of the limitations of the first and has led to a new survey technique for rough terrain, as described in section 5.7. The method of installing and carrying the receiver and transmitter for this mode is as described in sections 1.2 ans 2.2.

While taking readings, both operators should continue to face in the direction of traverse along the line. The receiver operator raises his console to eye level, while letting the antenna rods slide back over his shoulders. The transmitter operator lets his coil hang around his waist as in the MAX1 mode. It is recommended to hold the turns of the transmitting coil horizontal and the turns of the receiving coil vertical, rather than to strive for exact minimum coupling between the coils. The reason for this is touched upon in section 5.7.

Because of the sensitivity of this mode to accurate coil tilts, it is recommended to use the appropriate bubble level to keep the turns of the transmitting coil horizontal. The Tilt meter is the only means of keeping the turns of the receiving coil vertical. And again, because of the sensitivity of this mode to coil tilts, the zero error of the Tilt meter should be checked every now and then. This is done by holding the receiver as in the MAX1 mode and proceeding as in note 4a in Appendix I.

Steadying the receiver system by holding the base of both coil tubes or both sides of the leather case is recommended. Steadying the transmitter coil by gripping it on both sides is also recommended.

5.6 THE MIN2 (PERPENDICULAR COIL) MODE

This mode also is usually referred to as a perpendicular coil mode. It is the reciprocal of the MIN1 mode. In other words, the plane of the turns of the transmitting coil are held vertical while that of the receiving coil is held horizontal. As with the MIN1 mode, anomaly amplitudes are measured as a percentage of the primary field along the plane of the transmitting coil. The method for installing and carrying the transmitter and receiver for this mode is as described in sections 1.2 and 2.2, except for the possibility of hanging the coil from a shoulder while walking.

As with the MIN1 mode, both operators should face in the direction of travel while taking readings. The receiver operator holds his coil as in the MAX1 mode, with the turns horizontal. The transmitter operator holds his coil with its bottom facing toward him and the plane of its turns both vertical and perpendicular to the line. As with the MIN1 mode, it is recommended that the operators do not strive for exact minimum coupling between the coils, but hold the turns of the transmitting coil vertical and those of the receiving coil horizontal. The reason for this will become obvious in section 5.7. In view of the sensitivity of this mode to coil tilts, it is recommended to use the bubble levels on both the transmitting and receiving coils for improved accuracy. Steadying the receiver system by holding the base of both coil tubes, and the transmitting coil by gripping it on both sides of its highest point, is recommended.

5.7 THE MIN1 + MIN2 (“SHOOTBACK”) MODE

Summing the MIN1 and MIN2 readings for a given station, with coil turns horizontal and vertical as described in sections 5.5 and 5.6, would result in a cancellation of anomalous inphase readings due to the effects of rough topography between two coils. Anomalous readings from conductive sources after summing would result in an anomalous profile very similar to that obtained by so-called shootback methods. The combination of the two minimum coupled modes gives in effect one more MaxMin survey mode for accurate rough terrain surveys without the necessity of monitoring topography.

As stated in sections 5.5 and 5.6, all MaxMin I-10 anomalous readings are measured as a percentage of the primary field strength along the plane of the transmitting coil for both the MIN1 and MIN2 modes. (In the MaxMin I-9 the min-coupled readings were measured with reference to the field strength along the axis of the transmitting coil, and hence their amplitudes were halved).

With the MaxMin I-10 the MIN1 + MIN2 anomaly amplitudes from conductive bodies are compatible with the MAX1 or Horizontal Loop anomaly amplitudes.

(For overburden property studies, the summed readings at each reading point are equal to the reading from the MIN1 or MIN2 mode as the primary field strength along the plane of the coil is used as the reference; so, interpretive diagrams based on the field strength along the plane can be used. However, in the case of small heterogeneities in the ground, it could be desirable to interpret the MIN1 and MIN2 readings separately for a clearer picture in places where one mode is less affected than the other by these heterogeneities. Separate MIN1 and MIN2 readings have to be doubled because plane of the transmitter coil is used as the reference).

<u>6 POTENTIAL PROBLEMS AND SOLUTIONS</u>

6.1 MOISTURE IN THE RECEIVER & TRANSMITTER CONSOLES

Persistently high moisture levels in the receiver or transmitter consoles may result in moisture condensation and inaccuracy in the readings. When working under prolonged moist or wet conditions, the outer cover of the receiver should be removed in the evening, and the unit left overnight in a dry warm place. If need be, the drying procedure can be accelerated by removing the larger inner panels and using a hair dryer or fan. Although the transmitter is generally less affected by moisture than the receiver, it is advisable at the same time to remove the outer case of the transmitter console and treat it in the same manner as the receiver.

6.2 MOISTURE IN THE METERS

Moisture condensation in the meters can be concurrent with moisture inside the consoles. This could cause the meter needles to stick and necessitate tapping the meters to free the needles. This problem would depart with the drying of the console, although more drying time would be required because the meters are more fully enclosed.

6.3 STATIC CHARGE ON A METER

Under exceedingly dry conditions, hot or cold, the plastic window of a meter could become statically charged, especially if brushed by a sleeve or glove, etc. This charge could become strong enough to cause the meter needle to move less freely, or even to stick. Such a charge could affect the readings, and it should be bled off by either breathing on the cover, or by running a damp finger across it, or by using an anti-static liquid. In more severe cases the treatment may have to be repeated several times.

6.4 SOLIDLY STUCK METER NEEDLE

A sharp knock, such as a mishap during transportation, could cause the tip of a meter needle lodge along the edege of the lower scale of a meter. The needle can usually be freed by persuasive tapping in different directions around the meter. On the other hand, if the internal taut band is broken, no effort would make the needle move freely and the meter would require replacement.

6.5 BROKEN CONDUCTOR IN REFERENCE CABLE

With extensive use, conductor breakage may eventually develop in the reference cable, usually near the connectors or the safety thimbles, where frequent flexing and stress take place. The location can often be found by flexing the cable near the connectors and safety thimbles at each end, while the cable is carrying the transmitted reference signal. An intermittent reference signal can often be heard in the receiver speaker or seen in the Reference warning light, when a defective spot is flexed and contact made or broken.

An operator with a pair of wire cutters or sharp knife, a roll of electrical tape, a spare connector with short presoldered leads (pigtail), and a few nylon ties can usually effect an on-the-spot repair and continue with the survey. Stripped wires can be twisted together (with due respect for the colour coding) and taped, without the benefit of solder. A knot beside the join will prevent it from pulling apart. When near the end of the cable, a knot will not snag as the cable moves along the survey line.

6.6 TRANSMITTER-RECEIVER PROXIMITY

Protection circuitry is installed in the receiver to prevent damage when the transmitter is turned on near the receiver coils. Nonetheless, <u>the transmitter should not be switched on if the receiver coils are within 2 metres of the transmitter coil and are switched to the same frequency.</u> It is a good practice to switch the receiver to a different frequency than the transmitter at the end of every survey session to minimize such a risk.

6.7 MOVING FROM 60 TO 50 HZ COUNTRIES OR VICE VERSA

Crossing power line frequency boundaries, as it were, would result in a degraded performance of the receiver, unless the two internal 50 and 60 Hz band reject filter switches are reset. Without this, the rejection of power line interference in the receiver would be reduced. This would increase the time it takes to obtain quality readings near power lines when using the four lowest operating frequencies. These 50/60 Hz receiver switches are originally set to attenuate the standard powerline frequency of the country of destination. The switches can be accessed by removing first the receiver can, then the inside panel closest to the chest of the operator when held as in MAX1 or horizontal loop mode. For 60 Hz countries the switch 2, in the extreme upper left corner of the exposed circuit board, should be “on” and switch 1 should be “off”, and vice versa for 50 Hz countries.

6.8 USING THE FULL LENGTH OF REFERENCE CABLE

A new reference cable is nowadays approximately 1% longer than its nominal length, as already stated in section 4.1. Using the full length of cable would result in a negative in-phase base or background level of approximately three per cent and the operators' standing "beyond" the station pickets for each set of readings. It is recommended that the cable length be measured and that a mark to be placed at the exact nominal length in a lasting manner. Using the nominal cable length to control the coil separation would keep the inphase base level essentially at 0% when surveying in gentle terrain. A technique based on the nominal cable length for accurate surveys in rough terrain is described in Appendix II.

6.9 CHOOSING THE OPTIMUM SEPARATION

It might be known or thought in advance of a MaxMin mineral survey that a property contains both shallow, closely-spaced conductors and deep conductors. A small coil separation would be more suitable for the former and a large coil separation more suitable for the latter. One solution would be to run the grid, or parts of the grid, twice using a different coil separation each time.

6.10 NEARBY THUNDERSTORMS

With lightning discharges in the immediate survey area, it is recommended to disconnect the reference cable at each end and to wait out the storm. Otherwise lightning induced damage to the equipment and/ or operators might result.

6.11 REFERENCE CABLE IN BUSH OVERNIGHT

Leaving the reference cable outstretched in the bush overnight could result in damage from the wildlife in the area. The most common damage is a chewing through the insulation and severing of one or more of the conductors in the cable.

It is recommended to wind up the cable at the end of each day of surveying. If carrying it out of the bush is a chore, then it could be hung in a tree, preferably in a plastic garbage bag, with minimal danger of damage. Should one or more of the cable conductors be severed overnight, the following day can be saved with repairs as described in section 6.4. There is a possibility of the subsequent knot snagging along the line; but, this has been found to be infrequent with the tight wrapping of plastic electrical tape around and beyond the knot, forming a tapered rather than a sharp bulge.

APPENDIX I: ELABORATING NOTES ON SECTIONS 1.3 & 2.3

NOTE 1. THE GAIN CALIBRATION AND PHASE MIXING TEST

This test is done individually for each frequency used, because separate circuits are involved. The tests can be performed anywhere along the survey line without being restricted to non-anomalous areas. Basically, the gain calibration test verifies the gain of the receiver for each frequency. The gains are preset and normally remain stable. The phase mixing test measures the amount of phase mixing or cross-talk between the in-phase and out-of-phase channels. Ideally, there should be zero cross-talk, but large temperature changes or mechanical abuse could result in some cross-talk in spite of temperature compensated circuitry.

Phase mixing or cross-talk means that a some of the in-phase component shows in the out-of-phase component and vice versa. Should there be excessive phase mixing, its removal is described after the next paragraph.

The gain calibration and phase mixing tests for the Max1 and Max2 modes can be carried out by turning the three turn In-phase Compensation dial (after unlocking the dial with the lock lever) from its normal position of 5.00 first to 3.50 and then to 6.50. Ideally, the In-phase meter reading should change by +30 per cent units (10 % per turn) when the dial is turned three turns from 3.50 to 6.50, with minimal resultant change in the Out-of-Phase reading (less than 1.5 units, or 1/20th of the In-phase change).

Should the phase-mixing become significant, e.g. greater than a 1.5 unit change in out-of-phase for a 30 unit (%P) change in in-phase, at any of the frequencies used, it can be removed. This is done by adjusting the appropriate phase-control potentiometer under the left antenna coil tube of the receiver, after removal of the outer case. A suitable small adjustment screwdriver is provided for this purpose with each MaxMin I unit. For these adjustements a short coil separation, such as 12.5 or 25 m should be used. As a point of procedure, it is recommended to tilt the receiver sideways, so that the proper marked trimmer potentiometer can be positively identified and engaged by the small screwdriver. With the receiver returned to its normal reading position, the potentiometer screw is then rotated in the direction which causes a decrease in the difference between the pre- and post-test Out-of-Phase meter readings. This rotation is continued until the pre- and post- readings are essentially identical. At this point, there is no phase mixing. A second test is usually worthwhile to confirm the result.

The gain calibration test could also indicate low transmitter batteries or other equipment problems. Should this test give smaller or larger than normal (9.5 to 10.5% per one dial turn) in-phase changes, then the next thing to check might be the transmitter batteries and regulation, more on this in section 2.3 and in note 8 of this appendix. The gain and phase mixing test is useful in determining whether the MaxMin is functioning properly but there normally should be no need to make any adjustements, except possibly when there are large seasonal temperature changes. It also should be noted that no amount of adjustement will correct malfunctions if such do exist. The proper remedy for those is repair.

NOTE 2. THE INTERNAL GRID SWITCH

This switch is accessible through the removal of the outer case of the receiver console. It is located on the underside of the inner case, near the batteries, and should be activated by a screwdriver only after loosening of the locknut which is provided to prevent inadvertent switching.

In effect, this switch permits the choice of three basic sets of coil separations, as multiples of 10 metres, 12.5 metres or 50 feet. The standard markings around the Coil Separation switch are for the set based on multiples of 12.5 metres, giving a set of eleven available coil separations from 12.5 to 400 metres. It is readily possible, however, to have the set of available coil separations range from 10 to 320 metres or from 50 to 1600 feet simply by changing the position of the Grid switch. Adhesive labels or other markings may be used for the Coil Separation switch of a receiver operating in either of the latter two sets of coil separations. Without other markings, the operator would need to multiply the engraved numbers by 0.8 and by 4 for the alternative metric and imperial sets, respectively.

NOTE 4A. CORRECTION OF A ZERO OFFSET ON THE TILT & BATTERY TEST METER

A zero offset, if any, on the Tilt meter would most likely be due to a severe mechanical shock. Small offsets can be removed by turning the small slotted recessed zeroing screw in the hole on the left side of the meter. A small screwdriver with a thin blade can be used for this. It would be necessary to press the screwdriver through the small silicone rubber plug to access the set screw.

The correct procedure is to turn the receiver "on" and to hold it with the level bubble on the top panel centered, and the Mode switch in either the MAX1 or MIN2 position. If the Tilt meter reading deviates from 0% grade, it should be brought to 0% by turning the zeroing screw.

NOTE 4B. CORRECTION OF A ZERO OFFSET ON THE INPHASE & OUT-OF-PHASE METERS

As with the Tilt meter, a zero offset in the Inphase & Out-of-Phase meters would most likely be due to mechanical shock. This offset, if any, would usually be small, e.g. one minor scale division; nonetheless, this is enough to cause a noticeable discrepancy between the reading taken on a given scale and its repeat value on another scale.

The recommended adjustement procedure starts with turning the receiver off. If the In-phase and Out-of-Phase meter readings are not 0%, they should be brought to 0% by turning the zeroing screw on the left side of the meter. As with the Tilt meter, the screw is accessed through a protective silicone rubber plug.

NOTE 5. ADJUSTING THE ZERO BASE LEVEL OF THE INPHASE READINGS

For a number of reasons, listed in the next paragraph, the base level of the non-anomalous inphase readings could be other than 0%. It is possible to bring this base level to 0% with the Inphase Comp dial, with an adjustement range of ±15%. The need to do this may be more real if the readings are to be hand plotted, because it can save considerable arithmetic.

An example of the non-anomalous base levels being other than 0% could be as follows: A constant chaining error which would result in an error in the coil spacing should the operators prefer the convenience of being at the station pickets for each set of readings.

If, for instance, the chain used to put in the pickets was 1% too long or too short and the operators prefer the convenience of stopping at or close to the pickets, then it would be necessary to pay out or take up an amount of cable equivalent to 1% of the nominal coil spacing. With this, the inphase base level would decrease or increase by about 3% of the primary field strength. This could be compensated for by changing the setting of the Inphase Comp dial from 5.00 to 5.44 for a decrease, or from 5.00 to 4.54 for an increase in the base level. The calculations are: A 1% increase in coil separation over the nominal value, e.g. 101m vs. 100m, would lead to a primary field strength at the receiver of $(100/101)^3$ = 0.9706 or 97.06% of the nominal value. This would show as a reading of -2.94% on the Inphase meter. Because the Inphase Comp dial is calibrated so that 3 full turns, from 3.5 to 6.5, give an Inphase meter reading change of +30%, it would be necessary to turn it from its normal setting of 5.00 to 5.3 (accurately 5.294) to bring the Inphase meter reading from -2.94% to 0%. The corresponding figures for a 1% decrease in coil separation are $(100/99)^3$ = 1.0306 or 103.06%; equalling +3.06% on the Inphase meter; therefore Inphase Comp dial turned from 5.00 to 4.7 (4.694) for 0% on the Inphase meter.

It is intended in the the preceding paragraph that the location of the pickets is to serve as a guide to making a fixed adjustment to the length of the reference cable to keep each coil operator generally close to a station picket for each set of readings. Total reliance on the picket locations would often result in inphase fluctuations during the survey. The reader is referred to Appendix II for details on methods of effective coil control to minimize this type of inphase noise.

NOTE 6. PRECAUTION WITH THE RECEIVER BATTERY TEST

The receiver batteries need to be tested periodically. If this is neglected, then the worn out batteries will eventually reach a state of depletion whereby the In-phase and Out-of-Phase meter needles will suddenly pin in opposite directions near the ends of their respective ±100% scales. At this point, the battery test may start to indicate a good battery condition, even though the batteries are finished. This is because the battery test actually measures the difference of voltage in the batteries and the voltage required to feed the receiver circuitry, similarly to the transmitter battery test. As a result, the battery test may also be used to indicate other potential problems apart from the battery condition. The operator should be aware that, in spite of the result of the battery test, if the In-phase and Out-of-Phase meter needles pin abruptly in opposite directions, even with the transmitter off or disconnected, the batteries should be replaced. Simultaneous replacement of all four batteries is generally recommended.

NOTE 7. IMPROPERLY FUNCTIONING TRANSMITTER TILT METER

A malfunctioning transmitter Tilt meter may also indicate problems in the retractile cord joining the coil to the console. There are two common symptoms: the meter needle staying at 0% grade or elsewhere along the meter scale in spite of tilting the coil, and the pinning of the needle either at the negative or the positive end of the meter scale. The first symptom is not serious if the operator is using the bubble level(s) for coil control. However, the second symptom (end pinning) can be serious, even if the operator is using the bubble level(s), because it may be an indication of a ground fault condition in the connecting cord which produces stray-coupling effects which in turn may lead to inaccuracy in the readings, more so with increasing frequency and coil separation. Because of this, the retractile cord joining the coil to the console should be replaced with one of the spare cords. If this remedies the problem then the faulty cord should be repaired. If a spare cord is not in the field, a temporary solution would be to interchange the coil cord and the battery cord. Generally, a cord which is defective for the coil connections works adequately for the battery connections.

NOTE 8. LOW READING ON THE TRANSMITTER BATTERY TEST METER

The battery test should be performed at <u>each one</u> of the frequencies being used. The usual cause of a low battery test reading is that the batteries are drained. Alternatively, transmitter cord or circuitry problems, or holding the coil too close to metallic objects can be the cause of a low Battery Test reading. Sometimes tuning problems may develop at one frequency only, resulting in a low Battery Test reading at that frequency, but not at the others. In such a case, an alternative frequency is recommended and the problem should be located and the transmitter should be repaired before using the malfunctioning frequency.

Although the transmitter could still be operational at a malfunctioning frequency, the gain calibration could be be affected. As a result, anomaly amplitudes could be changed, thus affecting the final interpretation if not taken into account. A calibration test at the receiver would indicate by how much the anomaly amplitudes are changed. For example, a gain calibration result of 20% change instead of the expected 30% (see note 1 in this appendix), would mean that anomalous readings are only 2/3 of their true value. This information could serve as a means of correcting inaccurate readings; but, the gain calibration for a malfunctioning frequency might or might not stay constant throughout the day, thus necessitating frequent checks.

APPENDIX II -ACCURATE SURVEYS IN ROUGH TERRAIN.

INTRODUCTION:

The MaxMin instrument calibration is based on a known and constant nominal straight line distance and on coplanarity between the receiver (Rx) and transmitter (Tx) coils, which requirements are readily achieved in flat terrain. However, inaccuracies in the separation and orientation of the Rx and Tx coils, due to rough terrain, can adversely affect the MaxMin in-phase readings to a significant degree, and the out-of-phase readings to a lesser degree. In such terrain, therefore, coil control methods can be used to minimize these inaccuracies; or alternatively, the topography is monitored in order to correct the MaxMin readings before interpretation and plotting.

Four methods of conducting MaxMin surveys in rough terrain are discussed in the following, but it should be noted that nowadays the MaxMin Computer simplifies matters greatly from the following write-up which preceeded the MMC and the availability of personal computer software application programs.

METHOD 1

This method presumes the use of a Data Acquisition Computer (DAC). The MaxMin Computers supplied by Apex Parametrics for the MaxMin are preprogrammed to make the necessary computations for this survey method. A hand-held inclinometer, such as the Suunto PM-5/SPC or the PM-5/360PC, is also an integral part of this method.

It is presumed in describing method 1 that the most common way of chaining a survey line has been used, i.e. that of putting in station pickets equidistant along the topography using a constant-length chain without any attempt to correct distances to the horizontal plane. This is the fastest method of chaining with the least chance of error, and therefore it is popular among line cutting contractors..

The leading operator of the MaxMin survey crew makes station-to-station inclinometer sightings during the course of the MaxMin survey. These sightings are entered into the DAC as per the instructions in the appropriate MaxMin Data Acquisition Manual. From these sightings, the DAC calculates and displays two parameters at each station:

a: the tilt at which the coils are to be held for coplanarity, and:
b: the amount of distance required to correct the coil separation to its nominal value.

The latter increment of distance is always positive to correct for the decrease in coil separation caused by the undulations in the topography. There are two ways to apply the increment of distance displayed on the DAC to reach the nominal coil separation:

1. If the quality of chaining is good and the station pickets are being used for the positioning of the Tx and Rx coils, then the leading operator can take steps of a known length forward from the initial stopping position, or use a set of graduation marks at his end of the cable (graduation done prior to the start of the survey). Every reference cable is typically (nowadays) 1% longer than its nominal length to allow for this. If the terrain is quite rugged, necessitating large separation corrections, these can be split between the two operators, with the trailing operator stopping a pace or two before a picket and the leading operator a pace or two past a picket. The trailing operator would also require a few graduation marks at his end of the cable to facilitate this procedure. It might be necessary to plug in a short extension cable to attain the nominal coil separation.

2. If the quality of chaining is variable across the grid, as may often be the case, it is preferable to use the reference cable as the distance guide. This is best done by first setting up the MaxMin where the nominal coil separation has been accurately measured on flat ground. Then with the trailing operator in position, the cable is marked at the exact nominal distance along its length, possibly with additional graduation marks between the nominal distance mark and the end. Plastic adhesive tape, applied to a clean cable, has been found to be an easy and effective way of marking the cable in a semi-permanent manner.

If there is a sharp change or discontinuity in the topography between successive station pickets, then the inclinometer sighting between the pickets is broken into two components about the discontinuity, and the entry of these two components into the data acquisition computer is done as described in the computer operations manual. In the field, the inclinometer operator does not need to guess about the discontinuity in the topography, but rather, he can advance to this point before making sightings and distance estimates. It is important to remember, however, that the sign of the inclinometer reading is always that for a sighting in the direction of survey travel. So, for an inclinometer reading made *backwards* toward the station just vacated, the sign of the reading must be *reversed* before entry into the computer. A backward sighting may also be necessitated by a fallen picket at the station about to be occupied.

The inclinometer readings stored in the MMC can be used later to compute a topographic profile and a horizontal projection of each line. The calculations for this are described in the next section of the appendix, because they are the same for methods 1 and 2.

METHOD 2

This method also requires the use of a hand-held inclinometer, such as the Suunto PM-5/SPC or PM-5/360PC, during the survey. It also presumes the most common way of chaining, as described for method 1. The inclinometer readings are entered into MMC or into a notebook. This method differs from the first inasmuch as no attempt is made to compensate for the decrease in coil separation due to terrain undulations. The coil operators stand beside the station pickets (if well chained), or alternatively, they base their positions on a constant length of reference cable, the nominal length, throughout the survey. There is a time saving of several seconds at each station by omitting the coil separation adjustment.

There are two possible scenarios as far as coil orientations are concerned: If a MMC is used, then the coil tilts for coplanarity can be derived as per the first method. If a note book is used, then the notekeeper needs to average the inclinometer readings in his notebook to achieve coplanarity. Alternatively, the coil planes can be held horizontal.

Method 2 requires the use of a personal computer following the MaxMin survey to correct for the changes in coil separation, and for the Tx-Rx non-coplanarity, if the coil planes were held horizontal. The computations utilize the station-to-station inclinometer readings, as with method 1. The correction programs are provided with each MaxMin Computer. The equations for the corrections are shown in the following for reference.

(1) True In-Phase = $[\{(\text{Observed In-Phase} + 100)\cdot K\} - 100 + 300\cdot \mathrm{Sin}^2 \varnothing m]$,
(2) True Out-of-Phase = $(\text{Observed Out-of-Phase})\cdot K$, where
(3) $K = (\text{Actual Coil Separation} / \text{Nominal Coil Separation})^3$,

and $\varnothing m$ is the mean slope of the terrain between the coils in degrees (not the %grade units of the inclinometer and Tilt meter scales) and it is derived from the equation:

(4) $$\varnothing m(deg) = \arctan \left[\sum_{i=j}^{j+n} \mathrm{Sin}\varnothing i(deg) \Big/ \sum_{i=j}^{j+n-1} \mathrm{Cos}\varnothing i(deg)\right],$$

for MaxMin plot point $j+(n/2)-1$ (Tx-Rx midpoint), where n is the number of STN (station) intervals between the Tx and Rx and j varies from 1 to t-n+1, with t being the total number of STN intervals along the line, and $\varnothing i$ is the slope of the terrain from STN_{i-1} and STN_i, measured in percent grade but converted to degrees by the following equation:

(5) $$\varnothing i(deg) = \arctan [\varnothing i(\%gr)/100]$$

Alternatively, $\varnothing i$ can be measured directly in degrees.
The value of K follows from the computation of the Actual Coil Separation as follows:

(6) $$\text{Act Coil Sep} = \text{Nom Stn Sep}\cdot\left[\left\{\sum_{i=j}^{j+n-1} \mathrm{Sin}\varnothing i(deg)\right\}^2 + \left\{\sum_{i=j}^{j+n-1} \mathrm{Cos}\varnothing i(deg)\right\}^2\right]^{1/2},$$

for MaxMin plot point $j+(n/2)-1$.
Combining equation (6) with equation (3) gives:

(7) $$K = \left[\left\{\sum_{i=j}^{j+n-1} \mathrm{Sin}\varnothing i(deg)\right\}2 + \left\{\sum_{i=j}^{j+n-1} \mathrm{Cos}\varnothing i(deg)\right\}2\right]3/2,$$

again, for MaxMin plot point $j+(n/2)-1$.
Where there is a topographic discontinuity between stations, e.g between STN_{i-1} and STN_i, requiring two inclinometer sightings, the terms $\mathrm{Sin}\varnothing i(deg)$ and $\mathrm{Cos}\varnothing i(deg)$ in the preceding equations become:

(8) $$\mathrm{Sin}\varnothing i(deg) = \mathrm{Sin}[(a/\text{Nom STN Sep})\cdot\varnothing ia(deg) + (b/\text{Nom STN Sep})\cdot\varnothing ib(deg)]$$
(9) $$\mathrm{Cos}\varnothing i(deg) = \mathrm{Cos}[(a/\text{Nom STN Sep})\cdot\varnothing ia(deg) + (b/\text{Nom STN Sep})\cdot\varnothing ib(deg)]$$

where a and b are the visually estimated distances between the station pickets and the discontinuity, in keeping with the condition (a+b) = Nom STN Sep, and $\varnothing ia(deg)$ and $\varnothing ib(deg)$ are the slopes of segments a and b, as derived by inserting the inclinometer-measured values $\varnothing ia(\%gr)$ and $\varnothing ib(\%gr)$ into equation (5). Alternatively, $\varnothing ia$ and $\varnothing ib$ can be measured directly in degrees. In the normal course of events, $\varnothing ia$ would be a backward sighting and its sign would be reversed before entry into the DAC or the note book. It is worthy of note at this point that the term 300*Sin2$\varnothing$m in equation (1) only applies if the coil planes are held horizontal. This term is deleted from equation (1) if the coils are held coplanar.

If the inclinometer data is available before the MaxMin survey is started, then the coil tilts for coplanarity can be had in advance by computing $\varnothing m$ in % grade (the Tilt meter units) rather than in degrees as per the following equation,

(10) $$\varnothing m(\%gr) = \left[\sum_{i=j}^{j+n-1} \mathrm{Sin}\varnothing i(deg) \Big/ \sum_{i=j}^{j+n-1} \mathrm{Cos}\varnothing i(deg)\right]\cdot 100,$$

for MaxMin plot point $j+(n/2)-1$.

Two by-products of the inclinometer data used in the computations for accurate MaxMin readings are a topographic profile and a horizontal-plane projection for each line. The equations for these are:

$$(11)\ \text{Elev STNq} = \text{Elev STN0} + (\text{Nom STN Sep}) \cdot \{\sum_{i=1}^{q} \text{Sin}\varnothing i(\text{deg})\},$$

where q varies from 1 to t, and both t and ∅i are as defined for equation (4) on the preceding page.

$$(12)\ \text{Horiz Proj STNq} = \text{Coord STN0} + \text{Nom STN Sep} \cdot \{\sum_{i=1}^{q} \text{Cos}\varnothing i(\text{deg})\}$$

Although the mathematics involved in method 2 are fairly simple the volume of calculations for each set of MaxMin readings is large and cannot be readily treated on a production-survey level without the aid of a personal computer.

Prior to the era of personal computers, other methods of coil control were used in rough terrain - methods with lesser computational demands. One effective method, still in use today, is the secant chaining method. It is described next as method 3.

METHOD 3

This, the secant chaining method, has been described at length in the MaxMin II operations manual and it is described briefly here for the benefit of those without a copy of the latter manual. In this method, the lines are chained or rechained before the MaxMin survey with the aid of an inclinometer, such as the Suunto PM-5/SPC. The secant scale of this inclinometer is used to determine the distance to be chained along the slope in order to have the nominal STN separation in the horizontal plane. At the same time, the corresponding reading for the slope, ∅i, is read from the adjacent scale on the inclinometer in % grade. This reading is recorded in either a MMC or a note book for future processing.

During the MaxMin survey which follows, each coil operator positions himself beside a station picket and tilts his coil for coplanarity with the other. The mean slope of the terrain between the coils, i.e. the tilt of the coils for coplanarity, is given by:

$$(13)\ \varnothing m(\%gr) = [\sum_{i=j}^{j+n-1} \varnothing i(\%gr)]/n \quad \text{for MaxMin reading plot point } j+(n/2)-1$$

(midway between the Tx and Rx), where n, j and ∅i are as defined for equation (4) on page AII-3; however, ∅i remains as measured in % grade and is not converted to degrees as it is for equation (4). In fact, it is because of the secant chaining method, and its place in the chronology of coil control methods in rough terrain, that the Tilt meters for the Tx and Rx coils are graduated in percent grade. As far as methods 1 and 2 are concerned, it is more direct to work in degrees than in percent grade. However, the extra calculations for methods 1 and 2, caused by working with inclinometers and Tilt meters graduated in percent grade, are not a significant problem, because computers or programmable calculators must be used in any event. This problem is minor compared to the alternative problem of having two types of Tilt meter graduation units in circulation.

In this method, the True In-Phase and True Out-of-Phase readings are again given by equation (1) on page AII-3, but in this case the term K is given by the equation:

$$(14)\ K = [1+\{\varnothing m(\%gr)/100\}^2]^{3/2} \text{ or } [1+\{\sum_{i=j}^{j+n-1} \varnothing i(\%gr)/100n\}^2]^{3/2},$$

where n, j and ∅i are as defined for equation (13).

Because the inclinometer readings are obtained prior to the MaxMin survey and the values of ∅m(%gr) are usually calculated in advance, the Tx and Rx coils are held coplanar during the MaxMin survey and the $300\cdot\text{Sin}^2\varnothing m$ term in equation (1) is deleted. The latter term stays in equation (1) for horizontal coil planes.

As with the other methods, a topographic profile can be computed from the inclinometer data as per the following equation:

$$(15)\ \text{Elev STNq} = \text{Elev STN0} + (\text{Nom horiz STN Sep})\cdot\{\sum_{i=1}^{q} \varnothing i\ (\%gr)\}/100,$$

where q is as defined for equation (11) and ∅i for equation (13). The horizontal projection of the line is predetermined in the secant chaining method. By definition, all of the stations are the nominal distance apart in the horizontal plane. Many people in exploration prefer this when plotting any kind of results in plan map.

This method is manageable with a simple scientific calculator to help in the ∅m(%gr) and topo computations and to apply corrections to the MaxMin readings. The need for more advanced computing facilities can be circumvented by the use of a permanent table relating ∅m(%gr) to Correction. This may not be a significant advantage today, but it was in the days before the personal computer. In fact, the use of a permanent table made this method viable. Such a table is Table 1 on pages AII-10 and -11, taken from the earlier MaxMin II manual. Methods 1 and 2 do not lend themselves to the use of a permanent table, so these methods did not come into being before the advent of personal computing equipment. With such equipment now available, however, secant chaining data can also be entirely computer processed, resulting in an appreciable saving in time.

One marked drawback of secant-chained grids occurs in terrain which varies widely from relatively flat to steeply sloping. In such terrain, the coil separation varies widely and consequently so does the required length of reference cable. For instance, the nominal length of reference cable is adequate in moderately flat terrain, but it must be increased in length by 22 percent along a sustained 70 percent grade slope. This means using a cable much longer than the nominal coil separation, in conjunction with a small winder for paying out and taking up cable as required. Although there are often places where several successive readings can be made from the same length of cable, it is not possible to cover an entire grid in rough terrain without considerable adjustment of the cable length. This in turn adds to the survey time. The amount of extra reference cable required for method 3 is considerably greater than for method 1.

METHOD 4

This method entails the use of two or more widespread operating frequencies, of which one is a quite low; it does not entail any rigorous means of coil control. The principle hinges around the fact that weakly-conductive bedrock zones and most overburdens have a noticeable anomalous in-phase response at the higher frequencies of the MaxMin I and I+ systems, but only a minimal in-phase response at the lower frequencies. It is simply assumed that any non-zero in-phase readings at the lowest survey frequency are due to changes in coil separation and/or orientation, or that they are due to the proximity of coil(s) to magnetically susceptible material. In other words, they are due to geometric or magnetic effects.

Because geometric and magnetic in-phase effects are identical at all frequencies, they are removed from each higher frequency in-phase reading by a simple subtraction of the lowest frequency in-phase reading. The next assumption then is that the remaining in-phase values at the higher frequencies are genuinely due to conductive phenomena. This assumption is correct. But, the quantitative interpretation, i.e. depth and conductance (conductivity times thickness), can be seriously affected for any moderately-to-highly conductive zone by using the subtraction technique, if and when the anomalous in-phase readings at the lowest survey frequency are well above the presumed zero amplitude level.

As a general practice with this technique, the lowest frequency in-phase profile should be closely scrutinized each time a conductive zone is recognized in the treated higher frequency profiles. If it is apparent that the in-phase readings are generally smooth on both sides of the conductive zone, then it can be assumed that the lowest frequency in-phase profile results from the conductive zone. With this the latter profile can be used in the quantitative interpretation for the conductive zone, both directly and in helping to reconstitute the higher frequency in-phase profiles. If on the other hand, it is apparent that the lowest frequency in-phase readings are “noisy” on both sides of the conductive zone, then it will not be readily feasible to extract the purely conductive contribution to the in-phase readings and the interpretation will be more qualitative than quantitative.

If there is interest in the absolute values of all of the MaxMin readings for the purpose of overburden or bedrock sounding calculations, then there is a way around the spurious in-phase effects. This way utilizes the fact that the anomalous in-phase amplitudes from a layer of overburden asymptotically approach zero as the frequency decreases to low values. So, a computer-assisted curve fit on each set of in-phase readings at the lower system frequencies can generate a curve which becomes asymptotic to zero or to the spurious in-phase value. The spurious in-phase value thus derived can then be subtracted from the measured in-phase readings at all of the survey frequencies before continuing with the interpretation. This method works for soundings because most or all of the existing MaxMin frequencies are used in overburden studies, and generally, of these, at least the three lowest frequencies are in the rapidly-decreasing part of the in-phase response curve, which allows for a reasonably accurate determination of the lower-limit asymptote.

In principle, the way of treating the in-phase data for overburden soundings is valid for bedrock conductors as well, but the lower MaxMin frequencies may not be low enough in the cases of moderate-to-good conductors to reach the rapidly-decreasing part of the in-phase response curve and a reasonable lower-limit asymptote cannot be determined in these cases. In the cases of poor bedrock conductors, however, the lower MaxMin frequencies are often low enough to approach the lower-limit asymptote, but it would generally require all of the lower frequencies to do this properly. Thus, the number of frequencies for a standard mineral-oriented survey would increase from 2 or 3 to 4 or 5 and the survey time would also increase. And still, the picture would be incomplete for good conductors.

Although there could be unresolvable spurious in-phase effects with this method, it is possible with a little effort on the part of the operators to keep these spurious effects somewhat under control and possibly improve the interpretation as a result: For example, the operators may rarely be in view of each other, but an inclinometer sighting along the terrain, adjusted according to pertinent comments over the intercom, will give an approximate value for ∅m(%gr) which in turn will lead to approximate coil coplanarity. An extra pace or two beyond the nominal length of cable will help offset the effects of a reduced Tx-Rx coil separation due to terrain undulations.

To this point in the description of this method, conductivities and frequencies have been indicated with qualitative terms such as, low, small, moderate, high, etc. In this paragraph, some values are assigned to these terms to help the reader decide if this method is suitable for a given area. Theoretical and scaled-modelling investigations have shown that the in-phase response is less than 1%P (primary field) for a moderately-shallow steeply-dipping conductive sheet if the induction number, i.e. [(coil sep in m) times (sheet thickness in m) times (sheet conductivity in Siemens/m) times (frequency in Hz)], is not greater than $5 \cdot 10^4$ units. The in-phase component is also less than 1%P for a horizontal conductive layer if the induction number, i.e. [(coil sep in m)^2·(layer conductivity in S/m)·(frequency in Hz)] is not greater than $3 \cdot 10^5$ units for a thin layer and not greater than $3 \cdot 10^4$ units for a thick layer. These induction numbers can be used to determine the maximum allowable steeply-dipping sheet conductance (conductivity·thickness) and the maximum allowable overburden conductivity, before the in-phase response becomes significant. For example, if the coil separation is 100 metres and the lowest operating frequency is 110 Hz, then the sheet conductance can be as large as 4.5 Siemens before the resulting in-phase response becomes significant. Likewise, the thin and thick-layer conductivities can be as large as 270 and 27 milliSiemens/m respectively, before the resulting in-phase response becomes significant. The latter statement can be translated to resistivities as small as 3.7 and 37 ohm·metres respectively, before the in-phase response becomes significant.

If experience in an area has shown the conductances and conductivities to be such that, with the chosen coil separation and the lowest survey frequency, they are likely to yield induction numbers below the above-stated upper-limit values, then method 4 can be used directly without the elaborate in-phase curve matching procedures referred to near the end of page AII-6. In its simplest form, this method could be carried out with the In-phase differences being calculated on a fairly basic calculator, although it would be somewhat time consuming.

SUMMARY

These four methods are now reviewed in terms of their comparative rates of ground coverage and quality of results.

Method 4 gives the fastest ground coverage and works well in areas of poorer conductors but does not allow for good interpretation of the better bedrock conductors. This method can be subdivided into two parts, 4a and 4b. Method 4a gives the fastest possible coverage for this type of equipment, because no effort is made to control the separation and orientation of the coils. The operators simply stop long enough to get the readings, then move on. With method 4b some effort is put into getting first-order accuracy in coil coplanarity and separation as described in the preceding section, but no station-to-station inclinometer data is recorded. This approach may increase the survey time by some 10% to 15%; but it also reduces spurious in-phase effects and at times permits better extraction of the conductor in the low-frequency in-phase readings from the spurious contributions. This is essential for a more complete interpretation for moderate-to-good bedrock conductors.

Method 3 gives a rate of coverage somewhere between methods 4a and 4b, assuming that the secant chaining has been done before the start of the MaxMin survey. The main slowdown then is caused by having to change the length of cable as the slope varies.

The inclinometer sightings and data entry involved in methods 1 and 2 are the main cause of the slower progress with these methods. Method 2 is about 5% to 10% faster than method 1, because with method 2 no coil separation adjustments are made, and sometimes no coil tilting is done. But, nonetheless, method 2 is from 25% to 30% slower than method 4a.

Methods 1,2 and 3 provide a means of removing, or greatly reducing, spurious in-phase effects, thus permitting a more comprehensive interpretation of the results than with method 4. Methods 1,2 and 3 also provide a topographic profile and a horizontal plane projection of each line, which can sometimes assist in the interpretation. Tests with methods 1 and 2 in rugged, resistive terrain (using a graduated cable as the main control for the coil separation and the station pickets as a general location guide) have indicated that the operating spurious in-phase envelope for a 100 metre coil separation is of the order of ±1% to ±1.5%. It appears to vary approximately inversely with the coil separation.

In principle, methods 1 and 2, when using the station pickets to control coil separation, and method 3, which always uses the station pickets, should have the same order of spurious noise envelope as the first two methods with the reference cable used as the coil-separation guide. This is the case when the quality of the chaining is consistently good. But experience has shown that, in spite of the best intentions of all concerned, the quality of chaining can be quite variable from grid to grid and even within the same grid. As a result, the spurious in-phase noise envelope is usually larger for the station-picket method than for the graduated-cable method of controlling the Tx-Rx coil separation.

For methods 2 and 3, horizontally levelled coils with subsequent corrections have been mentioned as an alternative to coplanar coils. On slopes which exceed 36 degrees or 72 per cent grade, however, horizontal coils lead to in-phase readings which fall below -100%P and are off the negative end of the In-Phase meter scale. Realistically, this situation would only be encountered with method 2 if a Data Acquisition Computer is not being used, and with method 3 if it has not been possible to reduce the inclinometer data before the start of the MaxMin survey. In both instances, it would be necessary to tilt the Tx and Rx coils toward coplanarity until the in-phase reading is well on scale, then to record the tilt at which the coils are held for this in-phase reading. A subsequent correction is necessary for this and it is achieved by replacing ∅m with (∅m-∅c) in equation (1) on page AII-3, where ∅c is the tilt of the coil planes in degrees. ∅c is first recorded in % grade, because it is read from the Tilt meter scale and it is converted to degrees as per equation (5).

Unlike methods 1, 2 and 3, method 4 does not provide the information necessary for generating topographic profiles or horizontal projections of lines. Method 4 does, however, automatically remove magnetic effects from the higher frequency in-phase readings. This can also be done with the other methods simply by subtracting the lowest frequency in-phase readings from the higher frequency in-phase readings, a simple matter if the data is computer processed.

All four methods are made practicable by the availability of computing facilities. For methods 3 and 4, these facilities can be as simple as a basic scientific calculator, although the data processing time would be somewhat long. With methods 1 and 2, on the other hand, a personal computer (or advanced programmable calculator) is necessary to keep the computation time at a reasonable percentage of the time spent collecting the data in the field.

TABLE 1

CORRECTION TABLE FOR METHOD 3 (SECANT CHAINED LINES)

Mean grade (+ or -), in % grade between Tx & Rx	In-phase correction for co-planar coils:	In-phase & quadrature correction: (multiply)	Mean grade (+ or -), in % grade between Tx & Rx	In-phase correction for co-planar coils:	In-phase quadrature correction: (multiply)
0	+0	x 1.000	38	+18.5	x 1.223
1	+0	x 1.000	39	+19	x 1.236
2	+0	x 1.000	40	+20	x 1.249
3	+0.1	x 1.001	41	+21	x 1.263
4	+0.2	x 1.002	42	+21.5	x 1.275
5	+0.4	x 1.004	43	+22.5	x 1.289
6	+0.5	x 1.005	44	+23.5	x 1.305
7	+0.7	x 1.007	45	+24	x 1.318
8	+1.1	x 1.010	46	+25	x 1.334
9	+1.2	x 1.012	47	+26	x 1.348
10	+1.5	x 1.015	48	+27	x 1.365
11	+1.8	x 1.018	49	+27.5	x 1.381
12	+2.2	x 1.022	50	+28.5	x 1.398
13	+2.5	x 1.025	51	+29.5	x 1.415
14	+2.9	x 1.029	52	+30	x 1.433
15	+3.3	x 1.034	53	+31	x 1.450
16	+3.7	x 1.038	54	+32	x 1.467
17	+4.2	x 1.043	55	+32.5	x 1.486
18	+4.7	x 1.048	56	+33.5	x 1.505
19	+5.2	x 1.054	57	+34.5	x 1.526
20	+5.7	x 1.061	58	+35.5	x 1.545
21	+6.3	x 1.066	59	+36	x 1.566
22	+6.8	x 1.073	60	+37	x 1.586
23	+7.5	x 1.080	61	+38	x 1.607
24	+8.0	x 1.087	62	+38.5	x 1.630
25	+8.7	x 1.096	63	+39.5	x 1.650
26	+9.3	x 1.102	64	+40	x 1.669
27	+10.0	x 1.111	65	+41	x 1.697
28	+10.5	x 1.120	66	+42	x 1.719
29	+11	x 1.128	67	+42.5	x 1.744
30	+12	x 1.139	68	+43.5	x 1.768
31	+13	x 1.147	69	+44.5	x 1.794
32	+13.5	x 1.158	70	+45	x 1.820
33	+14.5	x 1.168	71	+46	x 1.844
34	+15	x 1.178	72	+46.5	x 1.871
35	+16	x 1.189	73	+47.5	x 1.897
36	+16.5	x 1.200	74	+48	x 1.925
37	+17.5	x 1.213	75	+49	x 1.953

In-phase (additive) correction = $+[1-\{\text{Cos Tan}^{-1}(\%\text{Grade}/100)\}^3]\cdot 100$
(always positive, no matter the slope sign)

In-phase & Quadrature (multiplier) correction = $x\{1/\text{Cos }(\text{Tan}^{-1}\ \%\text{grade}/100)\}^3$

TABLE 1 CONTINUED:

CORRECTION TABLE FOR METHOD 3 (BACKCHAINING MISCLOSURES AT BASELINE)

(FORMERLY CALLED SHORT AND LONG COIL SPACING TABLE)

		In-phase correction:	In-phase & quadrature correction:
Nominal coil spacing:	600-400-300-200-100-50		
Actual coil spacing:	580 290	... -10.5	x 0.906
"	582-388-291-194 -97-48.5	... - 9.5	x 0.915
"	584 292	... - 8.5	x 0.924
"	586 293	... - 7.5	x 0.933
"	588-392-294-196 -98-49	... - 6	x 0.942
"	590 295	... - 5	x 0.952
"	592 296	... - 4	x 0.961
"	594-396-297-198 -99-49.5	... - 3	x 0.971
"	596 298	... - 2	x 0.980
"	598 299	... - 1	x 0.990
"	600-400-300-200-100-50	... 0	x 1.000
"	602 301	... + 1	x 1.010
"	604 302	... + 2	x 1.020
"	606-404-303-202-101-50.5	... + 3	x 1.030
"	608 304	... + 4	x 1.041
"	610 305	... + 5	x 1.051
"	612-408-306-204-102-51	... + 6	x 1.061
"	614 307	... + 6.5	x 1.072
"	616 308	... + 7.5	x 1.082
"	618-412-309-206-103-51.5	... + 8.5	x 1.093
"	620 310	... + 9.5	x 1.103

EQUATIONS:

In-phase (additive) correction = $+\{1-(\text{Nominal coil sep}/\text{Actual coil sep})^3\}\cdot 100$

In-phase & Quadrature (multiplier) correction = $\times(\text{Actual coil sep}/\text{Nominal coil sep})^3$