A OPERATING THEORY

The 350 System locates a target by:

1. Detecting the alternating magnetic fields associated with tone currents injected onto the cable.

2. Isolating the tone frequency from background noise.

3. Calculating the position of the target cable from the relative strengths of the signals on each channel.

This appendix describes these processes.

Magnetic fields surround any current-carrying conductor. These must be alternating fields produced by a tone current so that the 350 System can detect them.

The System uses an array of sensitive coils on the ROV to detect the alternating magnetic fields from the target cable.

The 350 System receives signals across a wide band of frequencies. These include noise together with the desired tone frequency. The System uses powerful signal processing techniques to reduce or eliminate background noise.

Combinations of signals on the six channels allow the 350 System to deliver measurements of target co-ordinates, forward search range, and the angle of skew.

A.1 Electromagnetic Fields

The 350 System uses an array of sensing coils to detect the presence of alternating magnetic fields and applies complex and powerful signal-processing techniques to locate the origin of these magnetic fields.

Alternating magnetic fields exist around any conductor that carries an alternating current and are of a strength that varies directly with the instantaneous magnitude of the current.

Figure A–1: Lines of magnetic flux

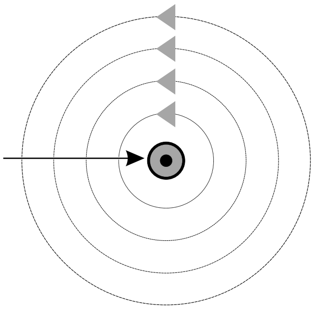


Figure A–1 shows the situation when a conductor carries a current. In this example, the conductor appears in cross-section with conventional current flow rising upwards out of the page. As the current begins to flow, lines of magnetic flux expand concentrically from the centre of the conductor with their polarity in an anti-clockwise direction as shown. The strength of the flux varies inversely with distance from the conductor.

When the amplitude of current varies, the flux lines will expand or collapse simultaneously. The flux lines will reverse polarity when the current changes direction.

A.2 Field Detection

Each sensing coil of the 350 System consists of a very large number of turns of fine copper wire wound around a ferrous metal core. The continuously changing magnetic fields that exist around a tone-carrying conductor act upon the sensing coils and induce in them an alternating voltage v. This voltage varies in magnitude according to the following relationships:

$$v \propto \frac{1}{d} \qquad v \propto f \qquad v \propto i$$

Where d = distance from the conductor to the sensing coil
f = frequency of current in the conductor
i = magnitude of current in the conductor

A.3 Signal Isolation

Marine survey environments suffer from significant levels of background noise produced by other electrical systems on board the ROV. The 350 System must remove this noise from the coil signals before it can perform meaningful calculations.

This noise reduction process involves many stages, including:

1. Band-pass filtering:

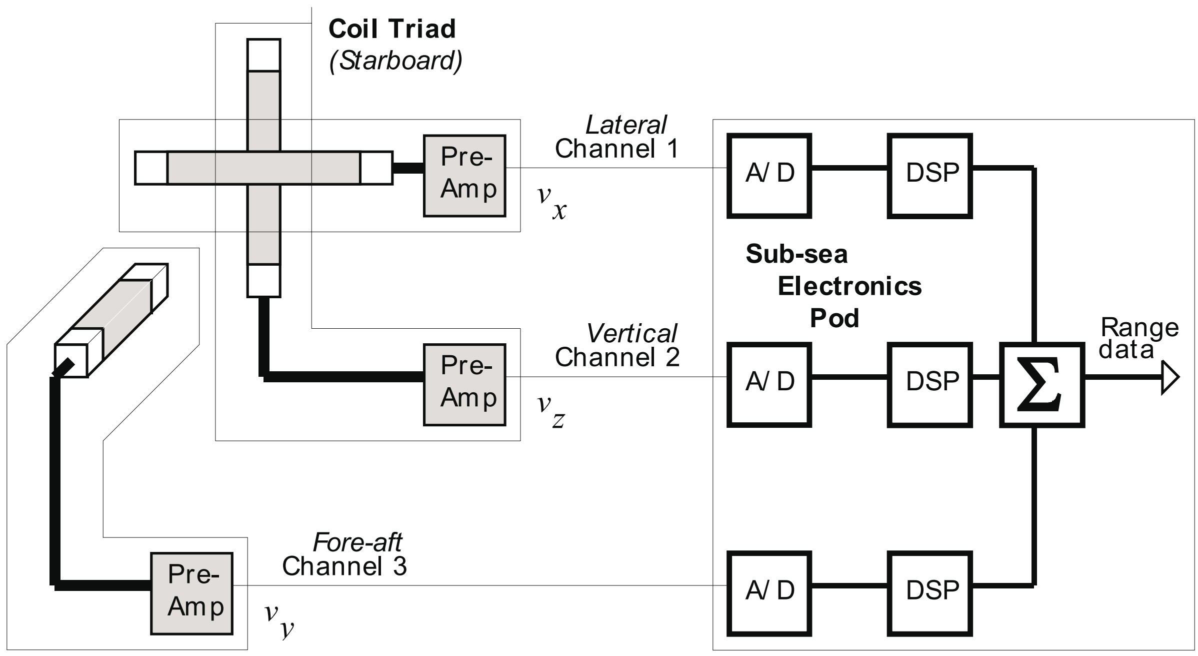
Signals received by the coils may be extremely weak – possibly less than 5µV in amplitude. Each of the six windings in the coil array therefore includes a precision pre-amplifier and filter board to apply amplification and signal conditioning before it transmits the signals to the relatively noisy environment on board the ROV. The pre-amplifier can vary its overall gain automatically according to circumstances.

An additional function of the pre-amplifier board is to apply high-pass and low-pass filtering. This function limits the pass-band of signals that arrive at the SEP to between 7.2Hz and 300Hz.

2. Frequency spectrum analysis

The SEP converts the analogue signals supplied by the coils to an 18-bit digital format for processing by the digital signal processor (DSP). Figure A–2 shows a simplified block diagram of the signal path for three of the six channels in the 350 System.

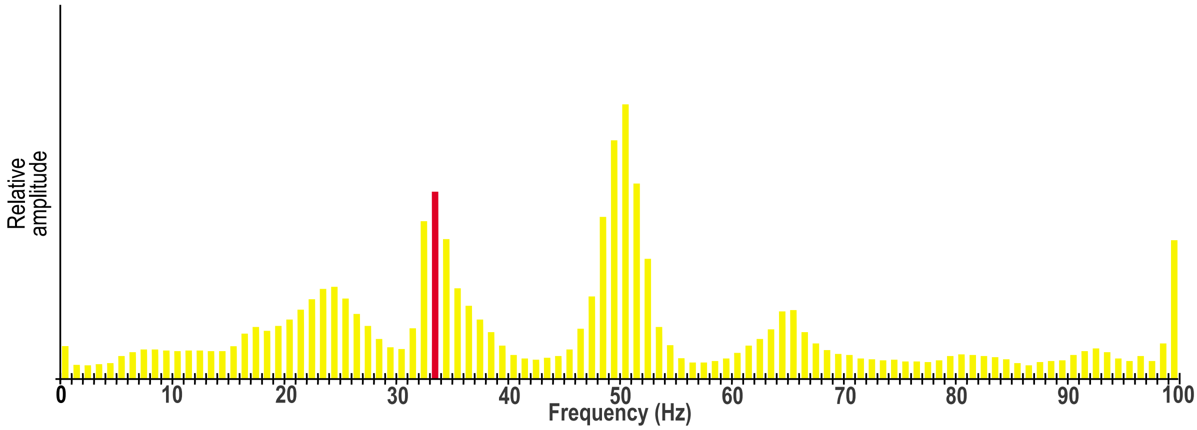
Figure A–2: Simplified signal path



The SEP samples the supplied signals approximately 1000 times per second and uses powerful signal processing techniques to determine the spectrum of received frequencies.

After processing the signals in this way, the SEP divides the entire received spectrum into narrow ‘windows’ as shown in Figure A–3. The System stores the instantaneous signal amplitude for each of these ‘windows’ in a series of memory locations.

Figure A–3: Frequency 'windows'



This process isolates the various frequency components in a signal very effectively so that the System can distinguish the tone frequency easily from among the background noise. The SDC display software provides a Frequency Spectrum feature similar to Figure A–3, with the tone frequency identified as a solid red bar. The example in Figure A–3 shows the tone frequency at 33Hz.

See sub-section 6.1.1.4 for a more detailed description of the complete Frequency Spectrum display.

A.4 Calculation

By using an array of two coil triads, the 350 System avoids potential sources of measurement error caused by changes in the amplitude of the tone signal. Calculations performed by the 350 System provide three modes of operation:

1. **Survey mode**:
   The SDC displays the vertical range to target and the lateral offset of the target relative to the centre of the coil array. If the System receives altitude information or you have specified a fixed coil height, this mode can also supply measurements of altitude and target depth of cover.

   See sub-section 6.1.1 for a full description of the Run Display screen.

2. **Forward Search mode**:
   The SDC can display an *estimate* of the range to a tone-carrying cable that lies along an intersecting course ahead of the ROV. This facility allows you to use the 350 System to conduct a search for a target in the survey area.

   See sub-section 6.1.2 for a full description of the Forward Search screen.

3. **Skew Measurement mode** *(operates with the Survey mode)*:
   The SDC displays and transmits the angle of skew measured between the track of the target and the ROV heading. Ideally, there should be no angle of skew present during a survey.

The SDC displays all measurements relative to the ROV. They might therefore contain errors if you operate the ROV with some angle of roll or pitch.

You may pass measurements made using any available mode to an external data logger for subsequent analysis.

See Sections 5 and 6 for a description of the SDC software. Refer to Section 7 for instructions to use the 350 System during a survey.

A.4.1 Survey Mode

To measure the target co-ordinates (vertical range and lateral offset), the 350 System uses signals from only the vertical and the lateral sensing coils in each coil triad.

Given a known frequency and magnitude of current in the conductor, the amplitude of signal voltage delivered by each coil winding will depend upon the relative angle between the coil and the conductor.

Figure A–4: The effect of incident angle on coil response

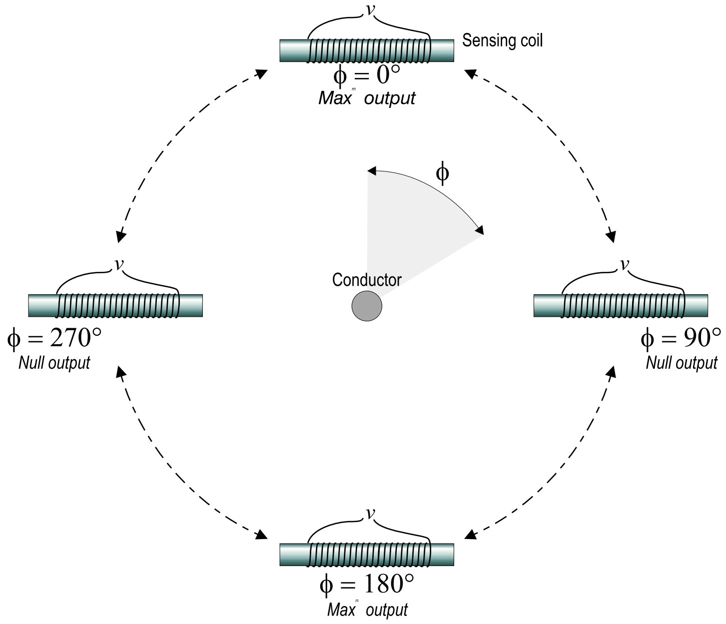


Figure A–4 shows the cross-section of a conductor carrying an alternating current that has a constant peak amplitude and frequency.

Figure A–5: Coil response as incident angle varies

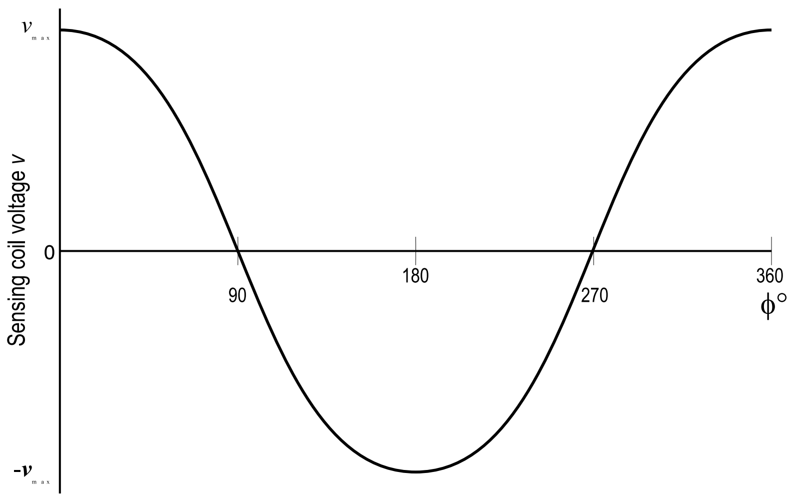


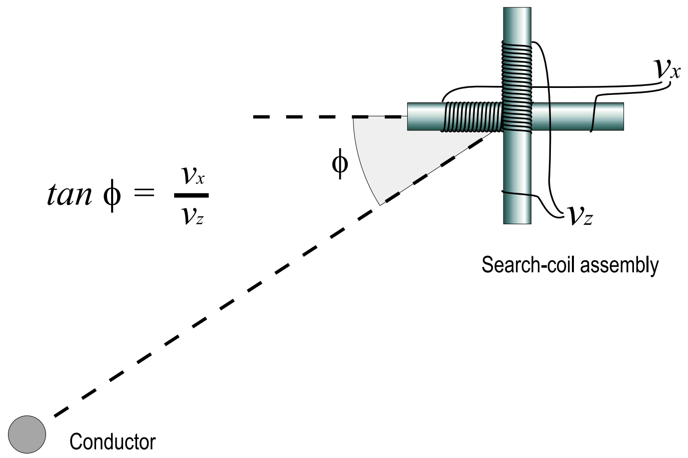
Figure A–5 shows the relationship that exists between the signal voltage v received by the coil in Figure A–4 and the angle ϕ between the coil and the conductor:

$$v \propto \cos\phi$$

- There will be no output (a null condition) when the conductor lies along the major axis of the sensing coil ($\phi = 90°$ or $\phi = 270°$).
- There will be maximum output when the conductor is on a line perpendicular to the major axis ($\phi = 0°$ or $\phi = 180°$).
- In all other conditions the coil output will be at some intermediate value between maximum and zero as defined in Figure A–5.

The 350 System uses two coils arranged at right angles to extend the coverage through a full 360°. By comparing the relative outputs from the two coils, the System can determine the angle between the centre of the coil pair and the target as shown in Figure A–6.

Figure A–6: Determination of relative angle using two coil voltages

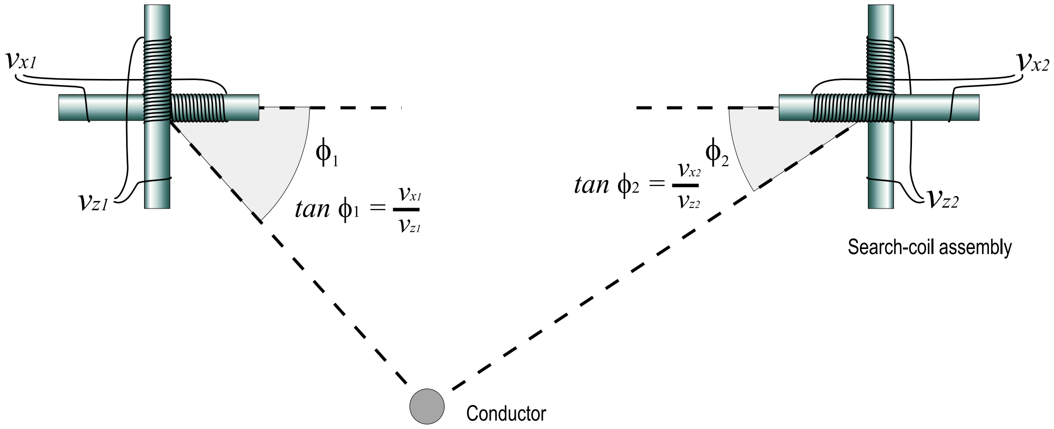


In Figure A–6 the two independent windings of the coil assembly supply signal voltages v_x (lateral coil) and v_z (vertical coil). The System uses these to derive the angle ϕ between the coil assembly and the conductor:

$$\tan\phi = \frac{v_x}{v_z}$$

Since TSS calibrates and matches the coil windings during manufacture, any changes to the tone frequency or current will have an equal effect on all coils. The ratio of their output voltages (and therefore the evaluation of ϕ) will therefore remain constant.

Figure A–7: Target location using two coil pairs



The 350 System uses an array of two coil pairs to determine the *position* of the target cable. Figure A–7 shows this situation.

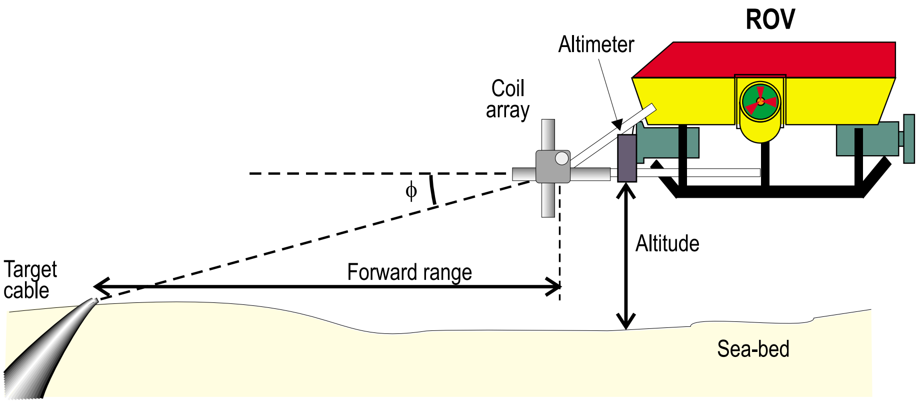
The SEP measures the strength of signals simultaneously on each of the four channels v_{x1}/v_{z1} and v_{x2}/v_{z2} and determines the target location by triangulation. The SEP extracts the co-ordinates for lateral offset and vertical range, and transmits these through the umbilical to the SDC.

A.4.2 Forward Search Mode

If the 350 System receives input from an altimeter, it can use this information to estimate the range to a tone-carrying cable that lies along an intersecting course ahead of the ROV.

You may find this facility useful if you are searching for a target in the survey area. You may use the display to steer the ROV towards the expected position of the target at a near-perpendicular angle and then switch to the run mode to steer a course along the target.

Figure A–8: Forward Range Calculation



When operating in the Forward Search mode, the 350 System uses signals from the vertical and the fore-aft coils.

Signals from the relevant coil pair allow the 350 System to determine the search angle ϕ to the target cable in the same way as described in sub-section A.4.1 above. The System then uses this information, together with the measured altitude of the ROV, to estimate the forward range:

$$\text{Forward range} \cong \frac{\text{Altitude}}{\tan\phi}$$

It is important to note that this range is an *estimate* only. Factors that affect the accuracy of this estimate are:

- The flatness of the seabed topography.
  The calculation assumes that the height of the coils relative to the target cable is the same as the altitude measured by the altimeter. Errors caused by uneven seabed topography are likely to be larger at greater forward ranges. The accuracy of the estimate will degrade further with a target buried beneath the seabed.

- Operating the ROV with pitch.
  Any angle of pitch will affect the forward search angle ϕ directly. The magnitude of errors caused by angles of pitch increases rapidly with forward range.

A.4.3 Skew Measurement

The Run Display screen includes a graphical element that shows the angle of skew between the ROV and the target cable (see sub-section 6.1.1 for further details of this display feature). The System uses the lateral and the fore-aft coils on one side of the array to measure skew.

Figure A–9 shows a survey ROV above the target cable. A small angle of skew exists between the target and the ROV.

The 350 System measures the target co-ordinates as explained in sub-section A.4.1 above. These measurements retain the specified accuracy for that part of the target directly between the two coil triads.

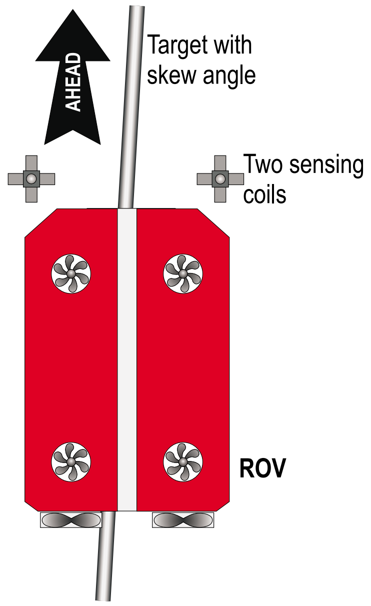


Figure A–9: Vehicle following target with skew angle

The example of Fig A–10 shows the target with a skew angle θ and the output voltages from the lateral coil (v_x) and the fore-aft coil (v_y) in the port coil triad.

Signal voltages supplied by the coil will be at a maximum with the major axis of the coil perpendicular to the target. A coil lying parallel to the course of the target will give a very weak output. The peak amplitude of output voltage will vary with the sine of the relative angle between the major axis of the coil and the target cable.

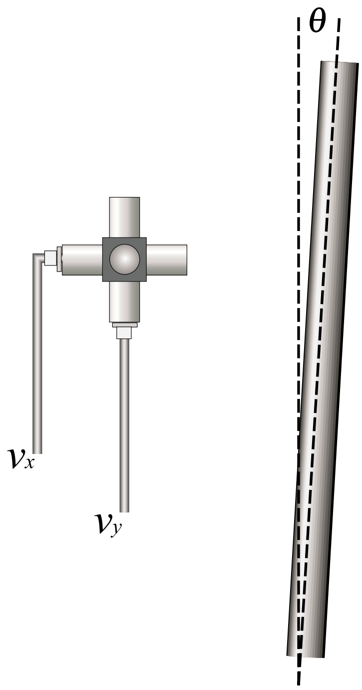


Figure A–10: Skew angle measurement

Because of this relationship, the System can determine the angle of skew θ:

$$\theta = \operatorname{atan}\frac{v_y}{v_x}$$

The skew measurement method described does not require you to locate the coil triad directly over the target cable. It can work to the specified accuracy over a considerable swath range.

The convention used by the 350 System is to define positive skew with the ROV rotated clockwise relative to the target.

The SDC displays measurements of skew only with the System operating in the Survey mode.

