Subsea electrics – design for diagnosis and reparability

P MANE
Mobil North Sea Limited, Aberdeen, UK (a subsidiary of ExxonMobil Corp.)

ABSTRACT

At the end of the twentieth century, 200 years after the discovery of electricity, 50 years after the first subsea well, subsea electrical systems are one of the major causes of modern subsea control system failures, costing operators significant operational downtime and operating expenses (opex).

This paper reviews the electrical insulation resistance problems that the ExxonMobil group in the North Sea has had to deal with in recent years with regards to their subsea tie-backs. It explains the tools and methods used to identify the location and causes of the faults, and also shows how the currently available techniques are still inefficient and time-consuming. In addition it includes suggestion for industry consideration.

In most cases, a design that enables fault diagnosis and simple repair methods, mixed with meticulous quality control in manufacturing, is the key to minimising expensive future subsea controls interventions and ensuring greater reliability of the systems. This paper will highlight the following, often under valued, lesson learned: that minimal upfront expenditure for engineering and quality control at the project phase could save hundreds of thousands of dollars of opex in the future.

With the industry driving subsea technology into deeper water, there is an urgent need to design subsea architecture that facilitates diagnosis and future interventions, as well as the need to develop subsea intelligent diagnosis instrumentation in order to locate faults in complex subsea architecture and monitor the performance of subsea electrics remotely.

INTRODUCTION

Mobil North Sea Limited (MNSL), a subsidiary of ExxonMobil Corp, operates over 40 subsea wells in the southern and northern North Sea of the UK sector. The first subsea wells, installed around 1976, were single tie-backs to existing platforms. With the improvement of technology, and an increased demand to develop fields adjacent to platforms that could not justify the high costs of a new fixed installation, more complex subsea field architectures were developed. The MNSL portfolio of subsea wells includes all generations of wells ranging from the first subsea electrical systems, which were backed-up by sequential hydraulic systems, through to today's modern electro-hydraulic control systems, which have some redundancy but do not have a fully independent backup.

It would be expected that over 30 plus years of subsea technology improvements, subsea electrics would no longer be a concern for operators but, for MNSL, electrical problems have been one of the major subsea operational challenges faced during recent years.

MNSL have experienced electrical problems in the Nevis, Ness, Buckland and Gawain fields. The wells affected by these problems account for 88% of all the MNSL subsea wells and constitute a significant proportion of MNSL's current production. These wells are located between depths of 30 and 120m. None of these developments are considered to be in deep water and they were installed by divers, although they contain some ROV compatible features. Most of the electrical problems experienced are due to a loss of Insulation Resistance (IR), which impedes communication and power to the subsea control modules.

This paper will describe in detail the experience gained in subsea control electrical system operations by MNSL during the last few years, highlighting how the faults were first diagnosed and rectified in three different fields. Additionally, a presentation of the lessons learned from the investigations of the recovered components aims to raise operators' awareness of potential failure modes of electrical connectors presently installed. The paper will continue to explain the history of design weaknesses, underlining the need to consider the failure of each component. In conclusion, a list of issues and guidelines, which designers should consider taking into account when designing new subsea fields will be discussed.

The paper is divided into the following four sections:

Section 1 – The Electrical Problems: This section describes the electrical problems experienced in the Buckland, Nevis and Gawain fields, exploring the methods used to find and rectify the faults.

Section 2 – Lessons Learned: This section outlines the lessons learned from the faulty components retrieved from subsea and subsequently inspected.

Section 3 – A Close Look at the Design: This section analyses the problems with the design of field architecture in the Nevis and Gawain fields, which has complicated the diagnosis and rectification process.

Section 4 – Design for Diagnosis and Reparability: This section outlines high-level concepts that should be considered when designing complex subsea field architectures, especially for deep-water developments where diagnosis work is also hindered by the need to use remotely-operated tools.

This paper does not aim to identify problems with the design of any particular manufacturer's product, design or solution, or advertise any particular service provider. Both service providers and electrical components manufacturers have been involved in the investigation process and collaborated in the development of this paper. The aims are to stimulate thought around issues to be considered when designing new fields and preparing intervention campaigns for existing fields.

SECTION 1 – THE ELECTRICAL PROBLEMS

Nevis

The Nevis field was a phased development starting in 1996 with initially two subsea wells connected to a single Subsea Distribution Unit (SDU). There are currently 11 wells connected to this SDU. The depth of the well-heads varies between 110 and 115m (refer to Figure 1.1.1). The control system is served by two power and two signal lines, Line A and Line B, via a 7.5km umbilical connected to two separate electrical distribution units. Figure 1.1.4 represents a simplified version of the electrical field architecture (based on the original design of 10 wells).

Originally in 1996 the single Electrical Distribution Unit (EDU) was installed inside the SDU to support 10 wells. This unit failed in 1998. Unfortunately it could not be retrieved for investigation since this unit also included the hydraulic system supply for the field. Two new EDUs, splitting Line A from Line B were retrofitted by a diver, resolving the IR problem. Each of these units supplies one power and one signal to each well.

In 2000 the platform reported that the Line Insulation Monitoring (LIM) system was indicating low IR values oscillating between 100 kΩ and 200 kΩ on both Power A and Power B, compared with design values greater than 1 GΩ. Taking readings every day to monitor the situation was inconclusive and no trends were found in the data to predict when failure would occur. Although the system had not failed, it was decided to investigate the root cause of the problem and how to rectify it in order to prevent a future, potentially significant, impact on production.

Time Domain Refractometry (TDR) and IR megger were used from the platform, aiming to localise the fault within the system. The results of this first investigation are shown in Figures 1.1.2 and 1.1.3.

Both signal and power cores indicated leakage at the end of the main umbilicals. Due to the distance, it was not possible to identify the precise point of the defect, so the fault could have been in the umbilical end terminations; Electrical Distribution Units (EDUs); individual well jumpers; the tree cables or the Subsea Control Modules (SCMs). Additionally, Power B indicated an area of water leakage, which seemed to be isolated to the first 500m of the umbilical, and was therefore affecting the insulation of the umbilical.

NOTE 1: Figure 1.1.2 shows a leakage in the A signal line at 2.6km, which could be a manufacturing splice or early signs of a defect.
NOTE 2: Figures 1.1.2 and 1.1.3 illustrate poor performance at the interface to the EDU with earth leakage being indicated.

The results excluded the umbilical as the major contributor to the problem, however they could not identify the exact location of the fault or whether multiple faults were present in the system. This was due to the fact that both channels were experiencing what seemed to be identical problems. It therefore seemed logical that the fault could have been located in any components hosting both lines. With failures of this type having been observed previously with this design of SCM, it was determined that multiple faults were likely to be present within the system.

Knowing that the fault was beyond the subsea umbilical termination and having exhausted topside diagnosis methods, a subsea investigation was required to test individual components. The subsea diagnosis were designed to minimise the number of tests required by first testing the segment of the system where it was thought (from previous experience) the faults were most likely to be. In the field, six different types of connectors were present, including 3-pins/4-pins, male and females, diver-matable and bulk-type (refer to Figure 3.1.4). Therefore a testing downline, complete with six connectors to interface with the combination of subsea connectors, was designed and manufactured (refer to Figure 1.1.6).

The diagnosis process was based on testing the longest possible branches of the system first in order to identify where specific components needed to be tested individually, thereby reducing intervention times. An additional advantage of testing a "well branch" was that only electrical isolations were required, which could be accomplished as per original design without the loss of production. A risk assessment verified that it was acceptable to run the field without electric power whilst maintaining ESD capability through the hydraulic system.

The normal IR specification for subsea electrical systems is in the region of 100 MΩ. However, based on the age of the system facilities and knowing that the system would have worked efficiently at lower values, a 10MΩ acceptance criteria was used to identify failed components.

Upon completion of the preparation of the diagnosis program it was estimated that in the worst-case scenario, it would take 8 days of diving intervention time to locate all possible faults. This estimate was based on 15 minutes per test. For safety reasons, the diver had to walk in and out of the SDU for each individual test (refer to Figure 3.1.1). This aspect will be further discussed in Section 3, underlining how to design for diagnosis to improve diver and intervention costs.

In order to minimise the campaigns required and the high mobilisation costs of using a DSV to rectify the faults, a spare strategy was put in place based on the requirement to rectify at least one full channel (power and signal A or B) in the system during the same diagnosis campaign. A "like-for-like" replacement for each of the components was the base case spares procurement strategy, with the exception of the tree jumpers (Components "C" and "D" (refer to Figure 1.1.5)) as these components were considered to be too difficult to rectify due to the lack of access. Should these parts require remedial action, it was accepted that a new engineering solution would have to be developed with the repair being carried out under a separate mobilisation.

The completion of a 5-day campaign identified multiple faults. The following components were identified as faulty by not meeting the set 10 MΩ criteria:

- Well #1 Power A, Signal A, Power B, Signal B, Component "C" (2x) and "D" (2x) tree jumpers
- Well #2 Power A, Signal A, Power B, Signal B, Component "C" (2x) and "D" (2x) tree jumpers
- Well #9 Power A and Signal A line of Component "F" jumper bundle assembly (1x) between the SDU and the tree
- Well #10 Signal A and Signal B lines, Component "C" tree jumpers

An electro-hydraulic jumper bundle (Component "F") was rectified using a purchased spare, but most of the faults were located in the tree jumpers (Components "C" and "D"), for which replacements were not available for the reasons stated above.

Detailed video surveys using divers and ROVs were taken to enable the feasibility of "like-for-like" replacement of the tree jumpers (Components "C" and "D"). With the previous data collected, the risk of performing this operation during a campaign without any contingency was considered too high, therefore a contingency based on the bypass of the SCMMB (Subsea Control Module Mounting Base (Component "B")) was designed (refer to Figure. 1.1.7). Figure 1.1.7 below summarises the options available for the second campaign: (NOTE: The diagram shows only one line for two wires and only one Power and Signal Line are shown for simplicity.)

a) In **Green**: "Like-for-like replacement of tree jumpers". The successful solution.
b) In **Blue**: Contingency designed in case "like-for-like replacement" did not succeed. This was based on the modification of the SCM using sideways top-entry connectors (refer to Figure 1.1.8).
c) In **Red**: A further contingency was designed in case the connectors at the tree stabplate "E" could not be disconnected and replaced. This solution involved bypassing the tree stabplate, therefore losing the ROV operability.

This latter contingency was not the preferred solution since it was going to remove the ROV change out capability of the current design of SCM (Component "A") and tree stabplates. In addition, the field would have two different designs of SCM, complicating future spares management.

A second campaign took place and, with meticulous planning, the substitution of the faulty jumpers proved possible, therefore the bypass contingency was never utilised. Two signal lines and one power line were rectified, using a total of two power jumpers "C" for Well #1 and Well #2, and six signal jumpers "D" for Wells #1, #2 and #10. The second power line could not be rectified due to the lack of spare components available at the time of the second campaign. The objective of the campaign was to rectify one power and one signal line IR but all of the signals had to be replaced in order to meet the objective because it became apparent that the signal lines were connected in the SCM, therefore if "A" was faulty, it would "affect B" as well. This issue will be further discussed in Section 3 when discussing weakness in design. The faulty components were recovered and investigated. The results are detailed in Section 2 of this paper.

After the second campaign, Power A IR was improved from 0.07 MΩ to 16 MΩ, Signal A IR was improved from 0.07 MΩ to 12 MΩ and Signal B IR was improved from 0.1 MΩ to 14 MΩ. These values are acceptable, although they are not in the GΩ range as per design specification. This is acceptable because with aging, virtually all materials absorb water, and this is true for the conductor insulation material and explains why in-service IR readings will be lower than post-manufacture readings taken before deployment.

Buckland

Installed in 1998, 12.5km from the host platform, this five well development is in 110m water depth. The control system is based on a short 300m electro-hydraulic umbilical that takes the controls from the platform to the bottom of the riser to interface with a pipeline bundle. As in the case of the Nevis field, two power and two signals lines are present. In this case Power B had completely failed in 2002, with the system continuing to operate on Power A alone (refer to Figure 1.2.2).

TDR and IR testing from the platform indicated that the fault was at the connection between the bundle and the tie-in short umbilical. Closer interpretation of the traces suggested it was probable that the fault would be in the umbilical side of the connector. If this was the case, a bypass jumper could be connected from the bottom of the platform J-tube spare connection to the bundle towhead, thus bypassing the faulty umbilical connector. However if the fault were located in the bundle side of the connector, a simple rectification would not be available since the bundle connector could not be replaced.

A bypass jumper was manufactured and using the same downline used for the Nevis IR (refer to Figure 1.1.6) the connection between the umbilical and the bundle was tested. The fault was confirmed to be in the umbilical connector as predicted, and the bypass jumper was installed thus rectifying the fault.

Unfortunately the faulty connector on this occasion was not retrieved because the operation of clearing the faulty flying leads from the other leads was too complicated and time-consuming. In addition, it was judged unsafe for the diver to perform a cutting operation with other live cables in close proximity. Therefore no investigation on the causes of failure could be performed.

This is a good example of where TDR traces used to determine the location of in-line connections are a successful method of locating faults when combined with expert interpretation. Figures 1.2.3, 1.2.4 and 1.2.5 summarise the results obtained during the TDR investigation.

Figure 1.2.3, representing the full signal line trace (0km to 12.5km), is fairly uneventful. This is typically due to the high impedance of the system. The trace shows that the signal systems are healthy and no faults are present.

Figure 1.2.4 represents the full power line trace. The bundle towhead midline (4) (Figure 1.2.1) at 10km and the towhead (5) (Figure 1.2.2) at 12km can all be clearly seen (indicated by vertical lines). The interface at the end of Bundle 2 (~10km) is downward because the loads of the individual SCMs are parallel connected at this point.

Figure 1.2.5 represents the initial TDR trace section of the power lines (up to 2km). **Note:** In this trace the two waveforms are separated and moved from the centre line for clarity. Due to high capacitance, a fairly large pulse width was used for this short-range test; this resulted in a large initial pulse with a secondary reflection at around 160m. The point of interest is the interface between the riser short umbilical and the bundle.

Note 1 shows that the general transition between the umbilical and the bundle appears to be good although it seems that the cable Power B is slightly flooded. However, providing that the integrity of the conductor insulation remains good, this normally would not cause a problem and the connector seems to be healthy.

On the other hand, **Note 2** shows a classic wet joint trace and indicates complete breakdown to water within the riser umbilical interface with Bundle 1 (refer to Figure 1.2.2).

Note 3 (Figure 1.2.6) shows an expanded comparison between the good trace (Power B – Green) and the bad trace (Power A – Red). The point where the trace falls is an indication of a transition. The fact that the trace falls, indicates leakage at the transition point; a transition with no leakage would be reversed. The small flat just before the trace dropped is irregular, normally the transition from the line or slight curve is instantaneous (ie no flat). This line was in fact caused by a leakage fault before the main transition; this would normally be shown as another dip, but because of the close proximity to the main transition dip, it has been cancelled out by a reflection (the reflection being inverse to the original). Hence a flat trace is displayed.

Gawain

Located in the southern North Sea, the Gawain field installed in 1996 is a three well template in 30m of water, 15.5km away from the host platform (refer to Figure 1.3.1). The umbilical serves an oil-filled Electrical Distribution Unit (EDU) located inside the umbilical termination unit via two power/signal lines with the signal superimposed on the power (refer to Figure 1.3.2). The umbilical is connected to the EDU by a single quad connector. In 1998 the Platform Line Insulation Monitoring (LIM) system started to show low IR in the 50 kΩ range. This value should be in the GΩ range, but after only 4 years it dropped dramatically. In 2001 the values dropped further to below 30 kΩ, tripping the system. The Line Insulation Monitoring system had to be taken off-line in order to allow uninterrupted production to continue.

As for the previous cases TDR and IR tests were performed from the platform indicating that the umbilical was healthy and that the fault lay at, or beyond the umbilical end (Figure 1.3.2). Figures 1.3.3 to 1.3.7 summarise the TDR results. The circle with the arrow represents the location of the fault, which was then confirmed by adjusting the range of the instrument (Figures 1.3.4 and 1.3.6).

In 2001 during subsea inspection, the individual jumpers and SCMs were megger tested using a downline from the intervention vessel and they showed no sign of fault. It was decided not to disconnect the quad connector from the EDU due to lack of access since no contingency was available in case the diver damaged the connector during disconnection. This could have caused the field to be shut-in for an undetermined period of time.

A contingency was developed to replace the EDU, and retrieve the umbilical and re-terminate it, if required. This operation would have been very expensive and time-consuming, due to the excavation of the trenched umbilical. In addition, the procedures and tooling were prepared to perform a full umbilical splice should water be found to have entered the umbilical cores.

If subjected to water ingress it was impossible to determine how far the water could have passed along the umbilical. Therefore it was decided that the umbilical should be re-terminated 15m from the Umbilical Termination Distribution Assembly (UTDA) using a double barrier connector that would return contain the water within the umbilical, but reduce the risk of contact with the termination inside the connector that would be pre-terminated to a new UTDA.

Due to the declining production from this field and the cost of the rectification, the repair would only be undertaken in the event of full failure. To date the system has not failed, therefore the electrical fault has not been rectified.

SECTION 2 – LESSONS LEARNED FROM NEVIS

This section outlines the results of the investigation performed on the components, which were retrieved from subsea. The following components were retrieved:

- The electro-hydraulic jumper bundle (Component "F" in Figure 1.1.5) illustrated in Figures 2.1.1 and 2.1.2
- Two tree power jumpers from Wells #1 and #2 (Component "D" in Figure 1.1.5) illustrated in Figures 2.1.3 and 2.1.4
- Six signal jumpers, two from each Well #1 and #2 (Component "C" in Figure 1.1.5) illustrated in Figures 2.1.3 and 2.1.4

These components were first tested at the subsea control system supplier, where IR testing and assembly checks for obvious signs of a misfit were performed on the electrical cable and the connectors. The results obtained were as follows:

Investigation after the First Nevis Diagnosis Campaign

The jumper bundle assembly had two faulty connectors, Power 1 and Signal 1. The electrical cable was healthy.

All of the results obtained by the manufacturer showed that the problem was inside the connectors. The electrical power connectors were "controlled environment connectors" so no further testing could be done. Since the signal electrical connector was not a controlled environment connector, it could be further taken apart. It was found on removing the insert from the housing that the IR fault disappeared and when refitting the insert in the housing, the IR fault re-appeared.

Because the insert and the power connector were sealed and purchased directly from the manufacturer, the connectors were returned to the manufacturer for further testing.

At the manufacturer, the initial investigation found that the power connector of the jumper bundle was extremely contaminated at the solder connections, whereas the signal connector was clean. Initial megger testing on the signal and the power connectors proved that there was tracking between the solder connection and the body of the housing (refer to Figure 2.15). When both connectors were removed from their housing and re-tested with the megger, tracking was still present, more so on the contaminated power insert. Only a small amount of contamination was retrieved during the investigation, which unfortunately was not sufficient to perform gas testing to determine its composition. Thereafter a solvent was used to remove the contamination from the power and signal connectors. Although this improved the condition of the IR fault, it was still evident. A solvent flux remover was then applied to the two connectors, which were then re-tested. The results showed that the two inserts had fully recovered and showed no breakdown of the insulation resistance.

Investigation after the Nevis Rectification Campaign

Divers removed six signal, and two power tree, jumpers (Components "C" and "D" (refer to Figure 1.1.5)). Of the eight cables, all had faulty connectors. These were identified by performing IR testing on the back harness; they all gave readings lower than acceptable. Due to the findings from the first investigation, the jumpers were sent directly to the electrical connector manufacturer.

After testing all the retrieved connectors, the worst power and worst signal cable were selected to be stripped down for further investigation. The investigation started with testing of the individual connectors at either end of the cable. From this testing all four connectors displayed low IR values.

Once the connector was stripped down, the cable was cut rather than de-soldered from the connector, to identify if the fault lay with the soldering. All solder joints were acceptable and both electrical cables were healthy, therefore the fault was elsewhere.

The dielectric oil was removed from the connector and collected in beakers for further investigation. The connector was then stripped down and tested, and the IR fault was still evident. However, when the connector was cleaned using a degreasing agent and reassembled the fault was no longer evident.

It was therefore concluded that the fault was due to incorrect assembly. It was possible that during assembly the connector was placed in a vice with the solder buckets vertical (Figure 2.16 shows the correct orientation). Prior to soldering a cleaning agent would be applied and the joints would then have been soldered. The connector would then be fully assembled and oil-filled. Should there have been too much flux cleaning agent used, this would have found its way into the body of the connector, and not been allowed to evaporate prior to oil-filling. This trapped solvent would have no immediate affect on the electrical integrity of the connector. However, over time the solvent could use the dielectric oil as a carrier and creep along the surface of the insulating components until it reached the point of soldered termination (refer to Figure 2.1.5). At this stage degradation of the electrical integrity would become evident. When the connector was initially tested it would have passed the initial testing, but once in operational mode there would have been a breakdown of the IR of the connector. This is because this mode of failure is time-dependent, ie it requires some time before the contaminant can reach the solder cup from the interface of the insert back plate with the insert main body.

Figure 2.1.5 shows the leak path of the solvent contaminant, which with time, break the oil molecules and migrate through the interfaces of the insert following the contours and reaching the solder cup.

The subsea connector manufacturer recommendation was that the connector be placed horizontally in a vice for soldering and a special type of degreaser and solder be used for the soldering of the joints. Moreover, since the initial connectors were made the subsea control system manufacturer no longer uses dielectric oil to fill the enclosure, and it is now recommended (by the connector manufacturer) to use silicon to fill the back of the connector.

All four connectors investigated showed the same results when cleaned and re-assembled. They recovered to more than acceptable results.

The flux residue, as shown in Figures 2.1.8 and 2.1.10, needs to be completely removed when performing a termination. In this case the traces shown could have been a mode of failure, however in fact the temperature induced by the current through the wire can activate a reaction between the flux and the gold plating which reduces the amount of gold plating. This alone doesn't necessarily cause IR degradation however flux residue on the insulated upstand below the solder cup could lead to IR degradation over time.

Conclusion

In conclusion, it was found that the cause of failure was a conductive deposit (refer to Figure 2.1.5, interface between main insert plate and back insert plate 'red line' and on top plate 'blue line') on the connectors assembled by the supplier (potentially from the dielectric fluid used to protect the cables or an extensive amount of flux or degreaser used during assembly). The cause of failure was most likely the way the connector was terminated to the cable, as it is unlikely that the dielectric fluid itself is the cause of the fault.

The assembly of the cables was started in 1996 by the subsea control supplier, who used dielectric fluid to protect the solder joints. At some point shortly after this, the supplier changed and adopted the recommended practice of the electrical connector manufacturer; using silicon to fill the solder joint cavities and gel filling instead of the dielectric fluid, which is now becoming standard practice. Protection to the solder cup-conductor assembly is provided by individual termination sleeves. The dielectric gel which is hydrophobic, prevents water ingress to the connector cavities and affords pressure compensation in the same way as a fluid; this would not protect against any contaminants introduced during the termination process by incorrect termination methods. The use of gel should minimise the risk of contamination of the solder cup arrangement. Due to its high viscosity, the gel tends to stay in place and not migrate through the void interface spaces.

With the benefit of hindsight it is evident that there were quality issues in the manufacture of jumpers, in particular involving personnel training and competence, and adherence to standards and qualifications.

Due to the fact that electrical termination procedures are to be performed with a high level of accuracy and precision, without omitting important procedural steps, it is important for all subsea control suppliers to enforce strict quality control and quality assurance practices. To support the above, the leading manufacturers of electrical connectors provide high quality training courses for termination of connectors and familiarisation courses for project managers and engineers.

An inspector experience in the termination of electrical connectors can play a vital role in saving large opex costs at a very low up-front investment.

Another lesson was related to the doubt that the tree jumpers on the tree could be replaced. This led to tree jumpers not being purchased as part of the spares strategy at the beginning of the project. Following consultation with the system designers, the engineers involved with the diagnostic process thought that these components were unlikely to have failed and assessed that they were not replaceable subsea. Although the jumpers were not purchased, the rectification due to multiple faults in the system could not have been performed in only one campaign. Although, being prepared to repair multiple faults is unlikely to be cost effective, consideration of repairing all modes of failure should be given at the planning stage.

SECTION 3 – A CLOSE LOOK AT THE DESIGN

Section 1 discussed the complex diagnostic process required to find an IR fault in an electrical system. This section of the paper will look in detail at some aspects of the design of these fields that complicated the diagnostic process.

Nevis

The design of the electrical system at Nevis is typical and widely used in the subsea industry. Although diagnosis and repairs were performed on the electrics, the system could have been designed better had it been designed considering that electrical faults could develop during the life of the field.

Diver Access to the EDU inside the SDU
The SDU distributes electrics, hydraulics and chemicals to 11 wells; although it was originally designed to serve 10 wells. The divers were located at this location for the majority of the campaign time, performing electrical tests on the umbilical, the EDUs and each branch of the system to the wells. The IR testing was performed using a test downline from the DSV (refer to Figure 1.1.6). For safety reasons, during IR testing, the diver would have to locate himself 5m away from the connections tested, this meant that for every connection the diver had to climb into the structure, locate the connector to be tested, connect it to the test downline from the diving support vessel, clear the structure and wait for the test to be completed prior to re-entering the structure. This operation took between 10 and 15 minutes for each connection. Inside the SDU the diver was required to perform over 60 connections/disconnections.

Figure 3.1.1 is a photograph of the SDU before deployment. The two retrofitted EDUs are installed in the middle of it, as shown in the plan view Figure 3.1.2. The diver has to climb into the protective structure to access the units for each test.

Bulk Head Connector versus Diver Locking Mechanism
At the EDUs, the diver had to use an Allan Key to unscrew all the connectors. Figure 3.1.3 shows the EDU assembly. Marine growth and lack of space between each of the connectors lengthened the time required to disconnect and reconnect.

To connect a right-angle connector to the downline connector, a bolt and a nut were also required. This process can be simplified either by using pressure-balanced connectors such that the diver need only to stab the two connectors together (held by a set of latching keys), or using a diver-matable connector, which only required the diver to turn the manual hand-tight nut. In this case the designer was limited since the EDUs were retrofits and they had to be compatible with the current jumpers connectors.

Figures 3.1.4, 3.1.5 and 3.1.6 above illustrate the difference between the bulk head connectors which require screws to hold them engaged and a standard diver-matable connector which is kept engaged by the locking thread.

Combined Electric Jumpers with Hydraulic or Chemical Jumpers
Components "F" and "G" shown in Figure 1.1.5 are jumpers serving both electrics and hydraulics to the wells and terminated with single stabplates. Due to this arrangement, the electric-hydraulic jumper bundle needed to be disconnected to allow testing during the diagnosis work. To complete this operation, the hydraulics had to be isolated and the wells shut-in, resulting in production losses. Most of the diagnostic work performed on only electrical lines did not require isolation of hydraulics so the field could be fully tested whilst still producing.

The SCMMB to Tree Stabplate Jumpers (Components "C" and "D")
The design of the electrical jumpers that serve the SCM, ie connecting the receiver tree stabplate to the SCM via the SCMMB (Components "B"), assumed full reliability of the components. These have proved to be the most problematic, however it was believed that replacement was not going to be required during the life of the field, whereas, in fact these jumpers are difficult to install onshore. The design of this section of the system had several negative points:

- Very little access underneath the SCMMB inside the tree for a diver to position himself
- Underneath the SCMMB, the connectors were all packed closely together not allowing sufficient space between the cables joining the connectors (refer to Figures 3.1.6 to 3.1.9). Figures 3.1.14 to 3.1.16 show the diver struggling to pass the connector within the pipework. In certain instances he had to spread apart the pipework with his hands being careful not to permanently damage the hydraulic system
- The welded hydraulic pipework had to be routed on top of the connector from the centre of the SCMMB (refer to Figure 3.1.18)
- The size of the screws used was not ideal for any normal diving intervention. Figure 3.1.9 displays the screws packed together. Figure 3.1.12 shows the tool the diver used to unscrew the connectors
- The earthing strap required by each of the connectors was very small and hard to access for installation and removal. Figure 3.1.19 shows the diver struggling to connect the earthing strap
- Insufficient space was allowed behind the stabplate to connect and disconnect the connectors (refer to Figure 3.1.18)
- The stabplate needed to be rigged to the tree to ensure it would not fall when disconnected. In this case, longer centre bolts would have allowed the diver to either disengage the stabplate without having to rig it, or completely remove it, when performing electrical testing

The above sequence illustrates the disconnection of a connector from the SCMMB. The diver struggles to undo the small screws and manoeuvre the connector out between the pipework.

The above sequence illustrates the disconnection of the connectors at the tree stabplate. It is important to underline that in order for the diver to be able to disconnect the right bottom corner connector, the diver had to remove the left and right top connectors first to allow him access to the screw (refer to Figure 3.1.26). This configuration, having two connectors on top of another two connectors, with limited space to access the screws between the two rows, is not ideal. In fact, in cases where only the bottom line connectors need to be replaced, the top row of connectors will have to be removed to create space for the bottom row, incurring lost time.

The Combined Signal at the SCM

During the initial 5-day diagnostic campaign it was found that each time a signal line was reporting a low IR, the redundant line was also showing a low IR. This generated suspicion since the values read for Line A were almost identical to Line B. This situation resulted in an unnecessary SCM change-out at Well #10. In fact, when testing subsea through the signal tree jumpers (Component "C") with the SCM connected, both lines were showing low IR. It therefore seemed logical that the fault would be located in the SCM. When the SCM was tested on the vessel by inserting a blanking cap on one of the two signal lines, it was found that the SCM was healthy and therefore it was concluded that the signal lines had to be connected in the SCM. Thereafter the manufacturer explained that the electrical wiring in the SCM connected Signal A to Signal B but that the system would function if one line failed completely. This was due to a series of resistors in the internal wiring, which guaranteed protection in case of a short circuit. This problem underlines the importance of verifying the design details of the equipment and using detailed documentation when preparing a diagnosis program.

The Original Electro-hydraulic Distribution Unit

The first electric distribution unit, installed at Nevis in 1996, was a single, oil-filled chamber, combining the two powers and two signal lines. This design reduced the redundancy of the system. Also, this unit distributed the hydraulics to the field; in the unlikely scenario of catastrophic failure the field could have lost both electrics and hydraulics. The unit was not retrieved to minimise intervention costs. At the present time the original electro-hydraulic distribution unit is still operational and serving the hydraulics to the entire field.

Gawain

The Gawain example is different from Nevis because in this field, not only was the Umbilical Termination Distribution Assembly (UTDA) not designed for diagnosis and reparability, but the design of redundancy was minimal (refer to Figure 1.3.2 and 3.2.3).

Redundancy Design Problems

1. The use of a quad connector for the termination of the umbilical gave rise to the possibility of a single point of failure, therefore removing redundancy. The two service Lines A and B were terminated in one connector only. Failure of this connector would have brought down both lines at the same time (refer to Figure 3.2.4).
2. Only one EDU was used to distribute both Line A and Line B. The redundancy in the system is again taken away. Figures 3.2.1 and 3.2.2 show the electrical schematic and the physical shape of the EDU.
3. Superimposing power and signal not only reduces the amount of subsea facilities in terms of jumpers and EDUs but also decreases the redundancy of the system. Loss of Power A automatically means loss of Signal A. In many cases the Master Control Station (MCS) can communicate with the SCMs through poorly insulated signal lines.

Design Problems for Diagnosis and Repairs

1. The umbilical was terminated into a quad connector without accommodating for any slack in the cable inside the UTDA (refer to Figures 3.2.1 and 3.2.8). By turning the locking nut, the diver could have potentially damaged the connector during removal because the repelling force between the two mating parts of the connector would have acted on the connector gland. This could have potentially damaged the termination in the connection body (refer to Figure 3.2.4).
2. Another fundamental problem raised by the lack of slack in the cable concerned the re-termination of the umbilical in case the connector required replacement. In order to re-terminate the connector, at least 150cm of cable was required. In this instance, once the umbilical had been recovered to the vessel and the faulty connector removed (most likely at the connection), there would not have been enough cable to perform a re-termination with a new connector, and it would therefore have required a full umbilical splice further up from the UTDA.
3. Access to disconnect the connector from the EDU, as shown in Figures 3.2.7, 3.2.8 and 3.2.9, is extremely limited.

The UTDA housed the EDU. Although the manufacturer designed the EDU to be removable for replacement, the diver access was very limited and the actual removal of the EDU would have been a complex and time-consuming operation.

Figure 3.2.7 shows the quad connector that needs to be disconnected to identify the location of the fault. This quad connects the EDU to the umbilical. Access to the connector is obstructed by the chemical and hydraulic piping inside the UTDA.

To understand the feasibility of disconnecting the connector and what problems may arise, a mock-up wooden Umbilical Termination Distribution Assembly was manufactured. The test results showed that sufficient bend could be forced on the cable to make the disconnection. A clamping mechanism, to be mounted by the diver, was designed in order to minimise cable movement inside the connector. This would protect the cable seals and the clamping mechanism within the plug connector gland (refer to Figure 3.2.11).

SECTION 4 – DESIGN FOR DIAGNOSIS AND REPARABILITY

The following section aims to stimulate thinking on possible ways to improve the current design of subsea electrical architectures, based on the lessons learned within 2 years of troubleshooting on the small number of subsea systems described within this paper. The guidelines and suggestions made in this section need to be considered on a case-by-case basis when designing new fields and they are not intended to be mandatory for future subsea electrics designs.

When designing new electrical field architecture, regardless of water depth, several issues should be given consideration to ensure that the field will operate reliably and will be intervention-friendly in case of failure:

1. Reliability of the electrical components. Strict Quality Assurance (QA) and Quality Control (QC) system must be ensured.
2. A "True" redundant system should be designed and implemented.

3. The field should be designed with intervention-friendly features, although this needs to be balanced with additional failure points and increased complexity.
4. Design for diagnosis. Operators should promote innovation in the design of electrical field architecture if they want to find a better balance between designing to minimise the intervention time, to optimise capital investment and to minimise the number of failure points.
5. Research efforts should be made to design intelligent diagnosis systems, which are able to identify the location of the faulty components without extensive and costly subsea intervention, or any reduction in the overall reliability of the system.

Reliability of Electrical Components

The reliability of the electrical components is paramount in subsea applications. The more reliable the field, the less diagnosis and intervention will be required. When selecting manufacturers and their electrical components for assembling systems, it is important that all possible efforts are made to guarantee the reliability of the system chosen. This paper has discussed the consequences of the particular instance a few years ago where QC and QA were not given what is now considered to be the correct level of attention. This resulted in component failures and high costs rectifying these problems. Control system suppliers and operators should not only fully adopt the recommendations of the electrical components' manufacturers, but also challenge their standards and practices. From the information gathered for this paper, it seems that today it is not common practice to have experienced, qualified Quality Inspectors witnessing the termination of electrical connectors because operators tend to assume that this is a well-known process which has been done many times over the years. The criticality of terminating a connector should be regarded as very high and the cost of well-trained inspectors to ensure that the proper process, and a proper level of testing, is performed is very low when compared to the cost of failure.

Ensuring "True" System Redundancy

Generally the beginning of the project, when the conceptual design is laid down, is the best time to analyse redundancy requirements and understand how the electrical architecture should take shape in the detailed engineering phase. Gathering information from leading subsea control system suppliers, it would seem that the industry tends to design good electrical systems with the right level and type of redundancy. However, as the project moves into implementation and capital cost reduction starts, the industry should try to avoid any temptation to cut redundancy and minimise the number of components in order to reduce costs. Potentially, this practice could cost significant intervention time in the future.

A "True" redundant system should be a system that carries at least two signal lines and two power lines from topside source to each of the wells. It is not sufficient to install two lines in the umbilical if these lines are then unified, either in the electrical distribution unit, connectors or inside the wiring of the control modules. An example of this is the Gawain system, which is not a truly redundant system because the failure of the umbilical connector (quad) or the EDU would cause both redundant lines to fail at once. Therefore it is critical that redundant lines are maintained separate throughout the whole field design. As part of the rectification strategy for Gawain, a new EDU was purchased. This new EDU was based on individual, oil-filled jumpers. This design was specified mainly to reduce manufacturing lead-time and potentially lower the probability of losing the whole system at once in case of a component failure. The new EDU was initially designed as illustrated in Figure 4.2.2, where a 1 atm splitter box served the first three wells and the second box served the remaining. The design was then changed to have each of the 1 atm splitter boxes serving Line A or Line B; this kept the lines separate ensuring that if a failure occurred in one of the 1 atm splitter boxes, the other would continue to serve the system. The final design is illustrated in Figure 4.2.3. However, this design could not remove the problem of lack of redundancy with the quad connector. Note the extension jumper on the left inside of the drawing - - this was purchased to make up for the lack of slack in the umbilical termination.

Designing for Intervention

Although operators should always try to ensure the highest standards of quality assurance and quality control in order to assure the highest reliability, and they also should consider ensuring that a proper level of redundancy is included in the design; they should not overlook the detailed engineering for post-commissioning intervention. Although it should not happen, it is possible that intervention within the electrical system will be required during the life of the field.

The following paragraphs suggest some high-level concepts which promote ease of intervention.

Power and Signal Interchangeability

Analysing the design of the fields in this paper, it seems that when separate lines are used to supply power and signal, the screening of the power conductor is left un-terminated, since it is only required on the signal lines. This is done to reduce induced electrical noise from the power conductors to the signal conductors. Power and signal conductor sizes are chosen to accommodate the offset distance, the worst-case, subsea power loading and the acceptable signal attenuation for any given project. However in some cases, the signal conductors have a different cross-sectional area than the power conductors. This is often specified in order to reduce costs but also to avoid confusion between the two lines at the first installation phase, since at commissioning time misplacing the power with the signal can have catastrophic consequences. For the above reasons, the power and the signal are not interchangeable. If the two are made the same, and subsea failure occurs, in certain cases the time to repair can be shortened by swapping connections subsea without requiring lengthy fault-finding. Interchangeability needs to be carefully managed at first hook-up but this feature could deliver good results for minimal effort and costs.

Note: Communication on the Power System may or may not have screens. In this instance the issue is cross-talk between channels. In all cases if screens are used in the main umbilical they will be earthed at the surface and only electrically-isolated subsea. It is now usual to screen infield umbilical power and signal cables, but if deemed necessary this can be achieved via additional connector pins.

Diver Access and Position of the Components

An adequate level of access to each of the components should be considered. The designer should go through a rigorous process of visualising each of the components and thinking that the diver or ROV has to be able to access them for intervention or diagnosis. Operators and designers should consider avoiding the assumption that the electrical components will be reliable for the life of field; in Nevis and Gawain erroneous assumptions of reliability prompted the design of a separate SCM and SCMMB which congested pipework and made electrical cable non-diver friendly. The position of the SCM and SCMMB should also have been planned for intervention. Today the industry has made great advances in SIT practices to ensure that ROVs are able to access all the areas required for the installation and operation of the tree or manifold; has the industry thought about SIT for repairs?

Type of Connector, Sizes of Screw and Interface with Hydraulics
For diving applications, diver-matable connectors should be used as much as possible, limiting the number of screws which complicate an intervention process. In cases where bulkhead connectors cannot be avoided, as in the example of stabplates, diver-friendly sized screws and the relative position of the connectors on a plate should be accurately specified. Electrics should be kept as far apart from hydraulics as possible to ensure that no unnecessary hydraulic isolation or pipe removal is required when intervening on electrical components. To implement the above, designers should consider balancing the size of the SCM in order to accommodate more generous spacing.

Design for Diagnosis and the Balance between Initial Capital Investment, Reliability and Intervention
Taking a close look at the design of current typical EDUs , it can be found that most designs are based on connecting the "well branches" (refer to Figure 1.1.5) of the system in parallel. As in the example of the Nevis EDU, which is a common design for many subsea fields in the industry, it was required to test all of the branches one-by-one, going in a circle around the EDU, in order to find which branches were faulty. It is possible to minimise the number of tests by designing the EDU based on a cascade arrangement (refer to Figure 4.4.1). With a cascade arrangement, it is possible to localise the fault a lot faster, in fact it is possible to exclude half of the field components with a first test, with a second test, another quarter of components are excluded. The downside of this approach is that the number of connectors required to serve 12 wells significantly increases. Increasing the number of connectors, increases the number of failure points, the initial capital investment and the complexity of the electrical architecture. Although, this design is a valuable theoretical solution to decrease the time required to diagnose a complex field, it may not be practical for the reasons above therefore the importance of ensuring reliability through QA/QC should not be undermined. The use of this approach should be considered on a case-by-case basis, after a detailed costs benefit analysis has been conducted. Considering that the probability of an IR fault occurring should be minimal if quality control procedures and rigorous testing are strictly adhered to, it is suggested that the right reliability balance is found. Adding only one extra connector reduces the time for diagnosis by half; after this the law of diminishing returns applies. Depending on the field size, it should be possible to define an optimum cascade level. Regardless of the EDU design chosen for the field, the designer should consider allowing for possible future interventions.

Figure 4.2.4 and 4.2.5 represents a comparison between a cascade electrical architecture arrangement and the common parallel electrical distribution arrangement.

Research for the Future
Today a lot of money is invested in improving the reliability of subsea connectors and the development of fibre optics and high power connectors. Although the current subsea connectors are a lot more reliable than some years ago, they still fail. The industry should consider investing resources and applying innovation in developing a system for intelligent diagnosis, which would allow remote identification of the components that have failed or are about to fail in a complex electrical architecture. The costs of troubleshooting a complex architecture using the conventional method of testing individual components can be prohibitive, even without considering the impact of production downtime. In deep-water development, conventional methods may not be possible.

There are several areas to be considered in which more efforts and resources would be of benefit. This paper lists three:

1. The use of a subsea robotic "electrician".
2. The use of subsea intelligent diagnosis tools to locate faults. Diagnosis equipment located subsea.
3. The use of subsea electrical switches in order to isolate a segment of the system to allow fault-finding by exclusion.

1. *Using a Subsea Robotic Electrician*

   For deep-water, IR investigation, the industry has used a subsea robotic "electrician". This is a stand-alone unit, which contains an IR testing capability attached to an ROV. The ROV disconnects each of the components to be tested, and tests them individually using an ROV-mounted, subsea megger. This approach is the same one used during the Nevis investigation described earlier, the difference is the use of an ROV versus a diver. It is easy to imagine that this process can be very time-consuming, given that ROV flexibility is much lower than that of a diver.

Figures 4.5.1 shows the subsea robotic electrician used for rectification of deep-water electrical problems.

2. *Using a Subsea Intelligent System*

   The following are concepts that require further study and their feasibility should be assessed in order to provide remote diagnosis capabilities:
   - Install a diagnosis unit on each tree. This unit should be stand-alone and separate from the SCM, to avoid loss of functionality in case of SCM failure. In case of failure of the unit itself this can then be substituted without changing the SCM which would also require field shutdown
   - The diagnosis unit should be designed to take power from not only the system (ie power lines that supply the SCM) but also from a hot stab source (ie ROV) allowing diagnosis to continue
   - With more research, it could potentially be possible to determine which component has failed in the system if SCM and IR tests can be performed from every tree location. Looking at the polarisation of the conductor versus time, which could be used as a distance indicator, the location of the fault in a component could be identified
   - It should also be possible to determine the location of the faults in the system by running multiple TDR traces from different locations within the system. This principle is based on having a TDR instrument at each tree with an appropriate scanning range. The TDR traces will indicate IR faults if the electrical wire that is tested is not split (as in an EDU). The data will be sent back through the main signal system, if this is operational, otherwise through the ROV hot stab

As an alternative to the suggestions above, which would allow for continuous "intelligent" monitoring of subsea electrical facilities, a simpler solution of installing only a wired hot stab on each tree, where a downline can be connected, should be considered for passive monitoring.

3. Using Subsea Switches

According to a leading subsea control system supplier "on long offset development, where step-down transformers are used, it is possible to use an "intelligent" distribution system where each output leg features remote on/off control from the surface, output current monitoring with automatic shutdown and an LIM, again with automatic shutdown, monitoring the leg as far as the isolation transformers in each SEM". The use of this technology is currently under review. Adding subsea switches to the system would allow the platform operator to fully diagnose the system from the platform, however the number of components installed subsea increases the complexity and the cost of the system, while also increasing the number of potential system failure modes.

CONCLUSION

Today's field electrical architecture designers should consider the probability of component failure in their design. They should consider designing fields without assuming full reliability of subsea electrical components, even though these components are now standard technology and are the result of years of research and development. From the learning acquired during the recent years of operation in the North Sea, it is evident that for future subsea developments, some attention should be put into the following areas:

The importance of strict QA and QC is paramount when dealing with subsea electrical components. The initial low-cost expenditure of ensuring that termination and components used are of the highest integrity and specification is the key to success in the reliability of subsea electrical architecture throughout the life of the field. It is suggested that highly-trained quality inspectors are used to witness all of the termination and testing of new electrical cable in order to guarantee that components are assembled to manufacturers' guidelines and recommendations.

Redundancy should not only be specified at the beginning of the project, but also maintained if cost/benefit analysis justifies it during the entire life of the project phases. The right level of redundancy and redundancy-flexibility can prevent complex and costly interventions. In particular, deep-water developments cannot afford significantly high opex exposure and significant loss in revenue because they are not repairable. These costs can be offset by relatively minimum capex investment at the design phase of the projects, with expert engineering resources. Increasing redundancy in the system might not seem such a small investment at first, when in complex field architectures the number of components can grow tremendously, but if the consequences of electrical failures are analysed on a total system costs basis, the later intervention cost and loss of revenues should justify it for green field developments. However, this philosophy can be difficult to implement on marginal fields development, where initial capex expenditure is extremely sensitive. For both examples, case-by-case basis studies should be undertaken.

Designing the detail of the architecture to allow for diagnosis and reparability should be considered. This includes choosing the right type of "intervention-friendly" components and positioning the elements for ease of access. However, it is not recommended that the complexity of the system is increased too much in order to cut the intervention time because increasing the number of components will increase the likelihood of electrical failure and the degradation of IR. It is suggested that the system engineer aims for a system where each of the electrical components is repairable without having to pull the entire subsea assembly (ie x-mas tree or manifold) out of the water.

With today's deep-water developments and extended-reach fields producing directly to onshore facilities, commitment, focus and resources are required in order to develop new concepts for diagnosing and identifying the faulty components remotely without the need for any subsea campaign.

AKNOWLEDGEMENTS

The following people helped and collaborated in the development of this paper, supplying great expertise and mentorship. The suppliers mentioned contributed sharing experience and design expertise.

Alan Meara, Kvaerner Oil Field Products, Aberdeen UK, Subsea Engineer
Andy Byne, Imes Group, Aberdeen UK
Andy Thompson, ExxonMobil, Aberdeen UK, Subsea Xmas Tree Engineer
Gordon Moir, Pegasus International Ltd, Aberdeen UK, Senior Subsea Controls Engineer
James Lund, ExxonMobil, Aberdeen UK, Subsea Engineer
Jim Dunnett, ExxonMobil, Aberdeen UK, Instrument Technical Authority
John Bairstow, J & S Marine, Aberdeen UK
Lorraine Keep, Kvaerner, Oil Field Products Aberdeen UK, ExxonMobil Contract Liaison
Lou Powell, Tronic Ltd UK, Service Manager
Roger Walls, ExxonMobil Aberdeen UK, Subsea Pipelines Engineer
Steve Williams, ExxonMobil, Houston USA, Central Technology Subsea Engineerr
Vernon Hutchings, ABB Offshore System, UK Subsea Control Engineer

REFERENCES

Doc No 6521-200-001, ExxonMobil Buckland Summary Report, John Bairstow, J & S Marine Ltd, Issue 1 July 2002
Doc No 6521-200-002, ExxonMobil Nevis Summary Report, John Bairstow, J & S Marine Ltd, Issue 1 July 2002
Doc No PRE009/001, ExxonMobil Gawain Umbilical Study, ABB Offshore System, Issue 22 August 2002
Doc No CC 03-0803, ExxonMobil Electrical Connector Failure Report, Tronic Ltd, Issue 10 December 2003

INDEX OF PHOTOGRAPHS

Figure 1.1.1	Nevis Field Schematic	Courtesy of MNSL
Figure 1.1.2	TDR Trace for Signal A & B Lines	Courtesy of MNSL, extract from J&S Marine Report
Figure 1.1.3	TDR Trace for Power A & B Lines	Courtesy of MNSL, extract from J&S Marine Report
Figure 1.1.4	Nevis Field Simplified Electrical Sch.	Courtesy of MNSL
Figure 1.1.5	"Well Branch" Electrical Sch. Nev.	Courtesy of MNSL

Figure 1.1.6	Nevis Testing Downline	Courtesy of Kvaerner Oilfield Products
Figure 1.1.7	Rectification of the Tree Jumpers	Courtesy of MNSL
Figure 1.1.8	Modified SCM	Courtesy of Kvaerner Oilfield Products
Figure 1.2.1	The Buckland Field	Courtesy of MNSL
Figure 1.2.2	Electrical Schematics Buckland Field	Courtesy of MNSL, extract from J&S Marine Report
Figure 1.2.3	Full TDR trace section of Sig Lines	Courtesy of MNSL, extract from J&S Marine Report
Figure 1.2.4	Full TDR Traces for Power Lines	Courtesy of MNSL, extract from J&S Marine Report
Figure 1.2.5	Initial TDR trace section of Power A & B	Courtesy of MNSL, extract from J&S Marine Report
Figure 1.2.6	TDR Trace Detail Power A	Courtesy of MNSL, extract from J&S Marine Report
Figure 1.3.1	Gawain Template	Courtesy of MNSL
Figure 1.3.2	Gawain Electrical Schematic	Courtesy of MNSL
Figure 1.3.3	Dual Barrier Connector Schematic	Courtesy of Tronic Ltd
Figure 1.3.4	Gawain TDR Trace Line A	Courtesy of MNSL, extract from ABB OS Report
Figure 1.3.5	Gawain TDR Trace Line A – Detail	Courtesy of MNSL, extract from ABB OS Report
Figure 1.3.6	Gawain TDR Trace Line B	Courtesy of MNSL, extract from ABB OS Report
Figure 1.3.7	Gawain TDR Trace Line B – Detail	Courtesy of MNSL, extract from ABB OS Report
Figure 2.1.1	Electro-hydraulic Jumper Bundle	Courtesy of MNSL
Figure 2.1.2	Electro-hydraulic Jumper Bundle Dwg	Courtesy of Kvaerner Oilfield Products
Figure 2.1.3	Tree Signal Jumpers	Courtesy of Kvaerner Oilfield Products
Figure 2.1.4	Tree Signal Jumpers Dwg	Courtesy of Kvaerner Oilfield Products
Figure 2.1.5	Insert Assembly Section Dwg	Courtesy of Tronic Ltd
Figure 2.1.6-10	Tronic Connectors Details	Courtesy of MNSL, extract from Tronic Ltd Report
Figure 3.1.1	The Subsea Distribution Unit	Courtesy of MNSL
Figure 3.1.2	The SDU GA Plan View	Courtesy of Kvaerner Oilfield Products
Figure 3.1.3	Electrical Distribution Unit	Courtesy of Kvaerner Oilfield Products
Figure 3.1.4	Typical Bulk Head In-line Connector	Courtesy of Tronic Ltd
Figure 3.1.5	Typical Bulk Head Right Angle Con.	Courtesy of Tronic Ltd
Figure 3.1.6	Typical Diver-matable Connector	Courtesy of Tronic Ltd
Figure 3.1.7-11	Diver Photos of SCMMB & Stabplate	Courtesy of MNSL, extract from Subsea 7 Videos.
Figure 3.1.12-19	Diver Photos of SCMMB Con. Removal	Courtesy of MNSL, extract from Subsea 7 Videos

Figure 3.1.20-27	Diver Photos of Stabplate Con. Removal	Courtesy of MNSL, extract from Subsea 7 Videos
Figure 3.2.1	UTDA Topside View	Courtesy of FMC Konsberg
Figure 3.2.2	UTDA Sideview Inside	Courtesy of FMC Konsberg
Figure 3.2.3	UTDA Isometric	Courtesy of FMC Konsberg
Figure 3.2.4	Risk of Damage Termination Dwg	Courtesy of MNSL
Figure 3.2.7	Diver photos of umbilical connectors	Courtesy of MNSL, extract from Subsea 7 Videos
Figure 3.2.10	UTDA Wooden Mock Up Trial	Courtesy of MNSL
Figure 3.2.11	Diving Cable Clamp	Courtesy of Tronic Ltd
Figure 4.2.1	The New Replacement Gawain EDU	Courtesy of MNSL
Figure 4.2.2	First Draft of the Gawain EDU Design	Courtesy of FMC Konsberg
Figure 4.2.3	Gawain EDU Final Design	Courtesy of FMC Konsberg
Figure 4.2.4	EDU Cascade Arrangement	Courtesy of MNSL
Figure 4.2.5	EDU Common Electrical Arrangement	Courtesy of MNSL
Figure 4.5.1	Subsea Robotic Electrician	Courtesy of Imes Group

Nothing in this paper shall be construed as any form of admission of liability of any kind by MNSL or any ExxonMobil affiliate. The information provided herein may not be reproduced in any form or relied on in any manner without the permission of MNSL.

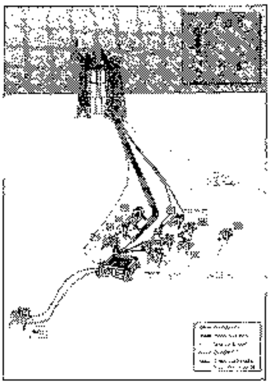
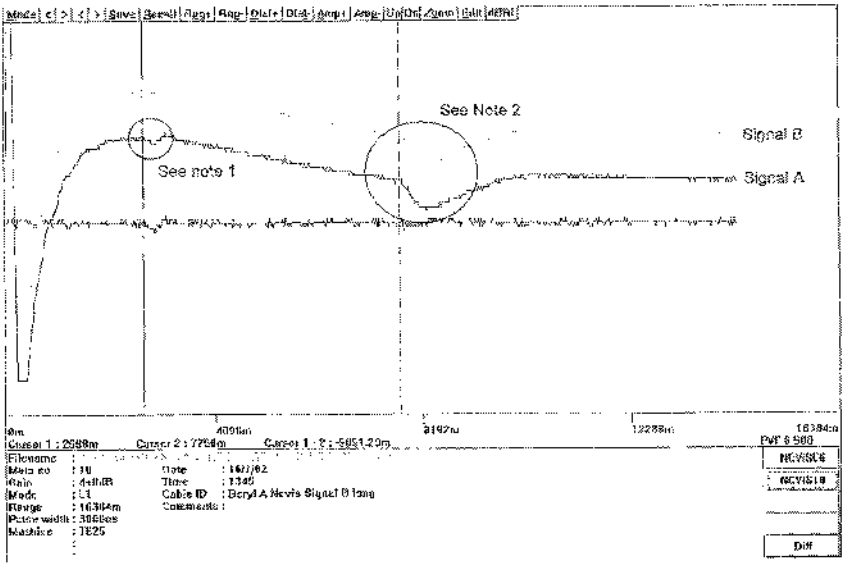
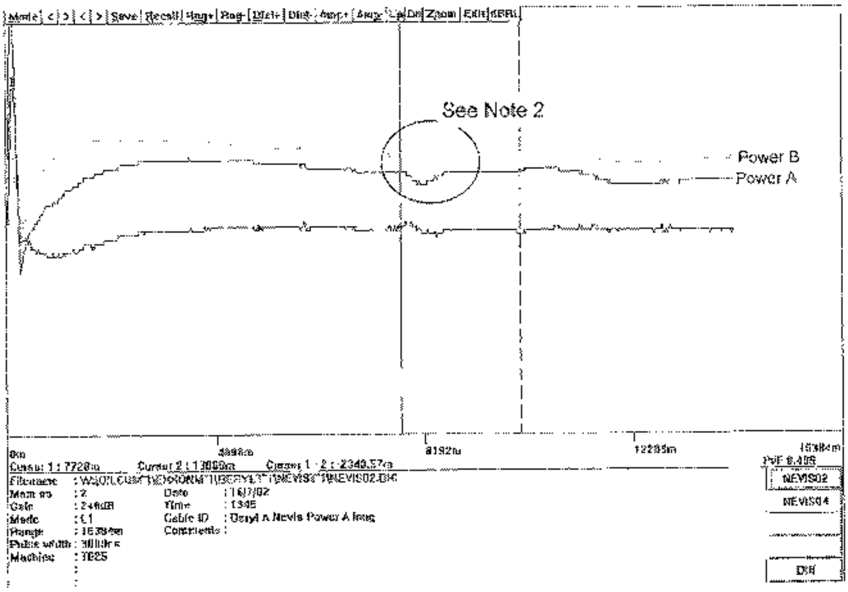


Figure 1.1.1 - Nevis Field Schematic TDR Trace for Signal A & B Lines



Cursor 1 : 2588m Cursor 2 : 7784m Cursor 1 - 2 : -5051.20m
Filename :
Mem no : 10 Date : 16/7/02
Gain : 44dB Time : 1345
Mode : L1 Cable ID : Beryl A Nevis Signal B long
Range : 16384m Comments :
Pulse width : 3068ns
Machine : TE25

Figure 1.1.2 - TDR Trace for Signal A and B Lines



Cursor 1 : 7728m Cursor 2 : 10068m Cursor 1 - 2 : -2340.57m
Filename : W:\07\LOUS\TNEXSON\M1\BERYL3\NEVIS\NEVIS02.DHC
Mem no : 2 Date : 16/7/02
Gain : 24dB Time : 1345
Mode : L1 Cable ID : Beryl A Nevis Power A long
Range : 16384m Comments :
Pulse width : 3010ns
Machine : T025

Figure 1.1.3 - TDR Trace for Power A & B Lines

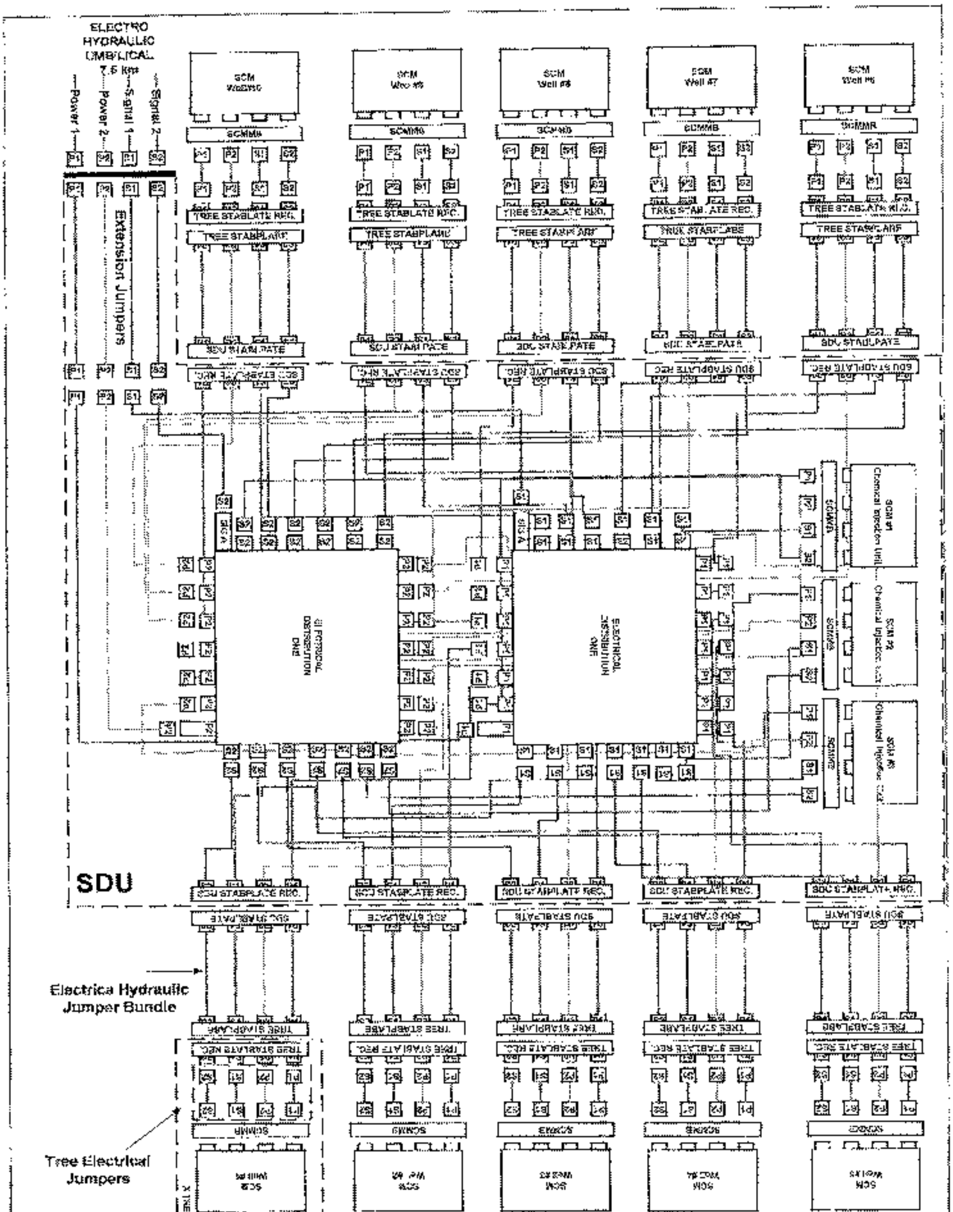
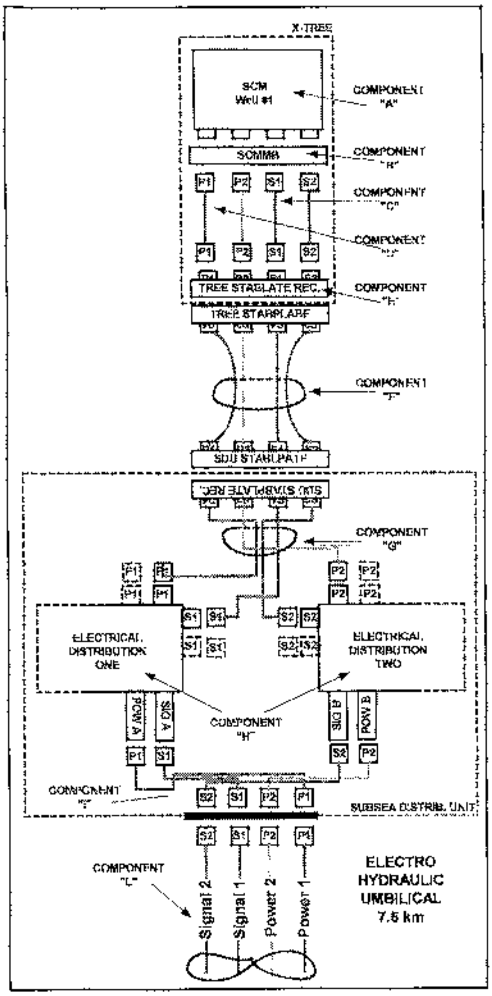


Figure 1.1.4 - Nevis Field Simplified Electrical Schematics TDR Trace for Signal A & B Lines



COMP	DESIGNATION
A	SUBSEA CONTROL MODULE (SCM)
B	SUBSEA CONTROL MODULE MOUNTING BASE (SCMMB)
C	SIGNAL TREE JUMPER (2x) ELECTRIC ONLY
D	POWER TREE JUMPER (2x) ELECTRIC ONLY
E	TREE ELECTRO HYDRAULIC STABPLATE
F	ELECTRIC HYDRAULIC JUMPER BUNDLE - SDU TO TREE 2x Signal Lines, 2x Power Lines, 2 x HP and 2 x LP Lines
G	ELECTRO HYDRAULIC JUMPER BUNDLE - EDU TO SDU
H	ELECTRIC DISTRIBUTION UNIT (EDU) (2x)
I	EXTENSION INDIVIDUAL JUMPERS 2 x POW, 2 x SIG (These were installed to bypass the Electro Hydraulic Distribution unit that failed in 1998)
L	ELECTRO-HYDRAULIC-CHEMICAL UMBILICAL

Figure 1.1.5 A "Well Branch" Electrical Schematic of Nevis

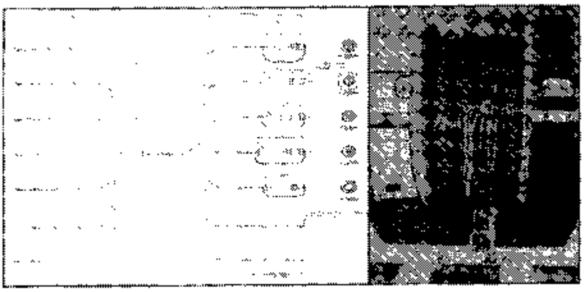


Figure 1.1.6 - Nevis Testing Downline

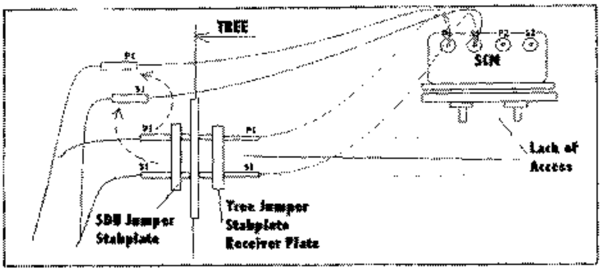


Figure 1.1.7 - Rectification of the Tree jumpers.

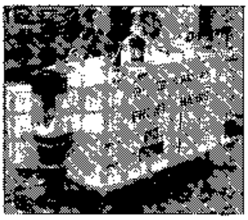


Figure 1.1.8 - Modified SCM

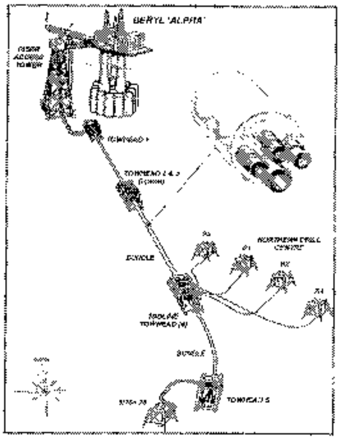


Figure 1.2.1 - The Buckland Field

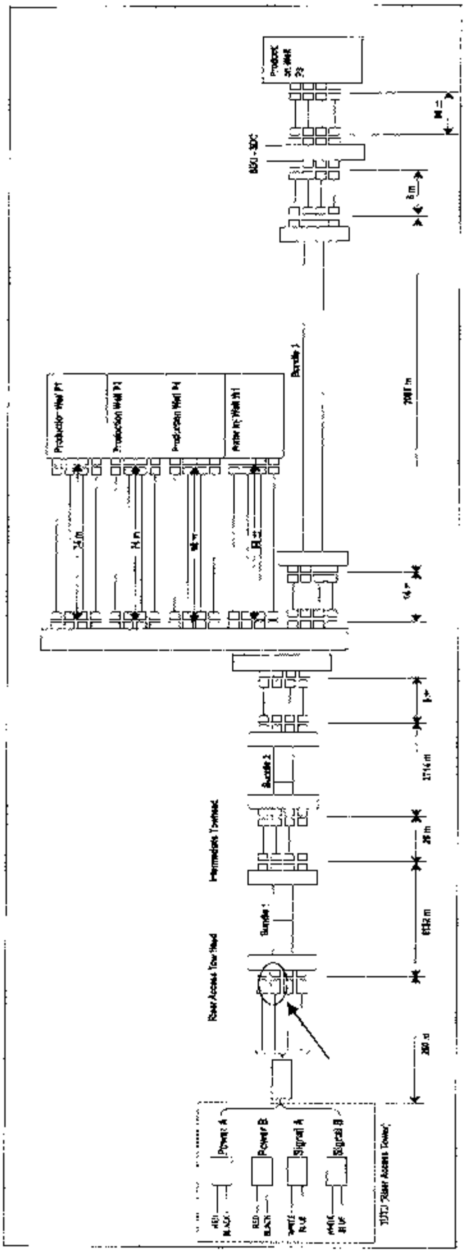


Figure 1.2.2 - Electrical Schematics Buckland Field

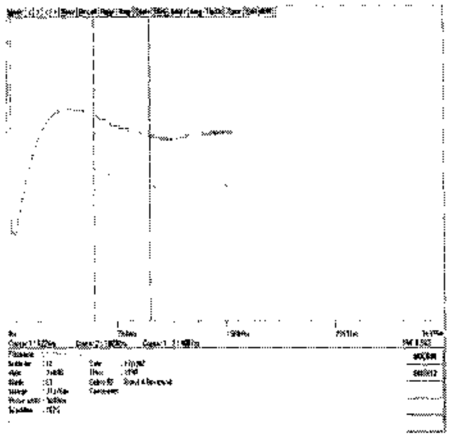


Figure 1.2.3 - Full TDR trace section of Signal lines

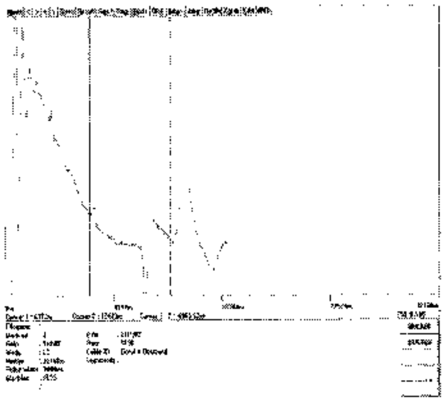


Figure 1.2.4 - Full TDR Traces for Power Lines

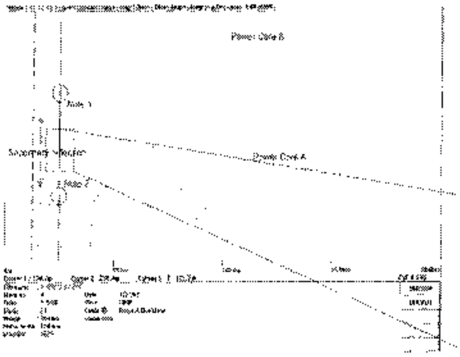


Figure 1.2.5 - Initial TDR traces of Pw A, B lines (up to 2km).

Figure 1.2,6 - TDR Trace Detail Pow A

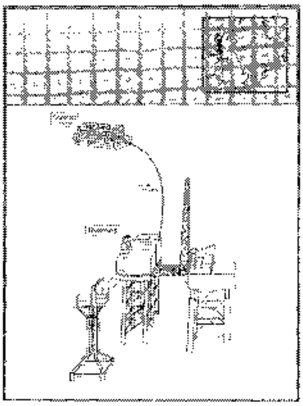


Figure 1.3.1 - Gawain Template

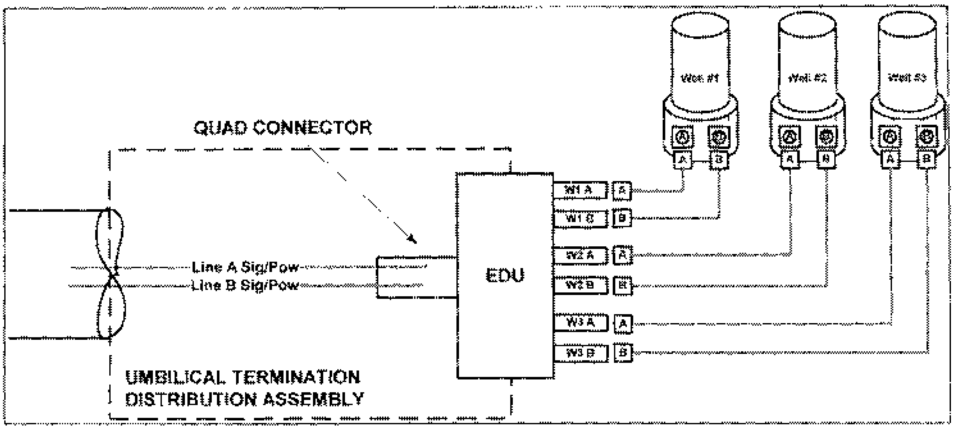


Figure 1.3.2 - Gawain Electrical Schematic

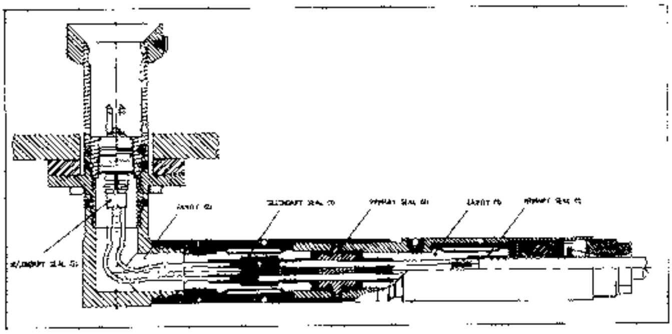


Figure 1.3.3 Dual Barrier Connector Schematic

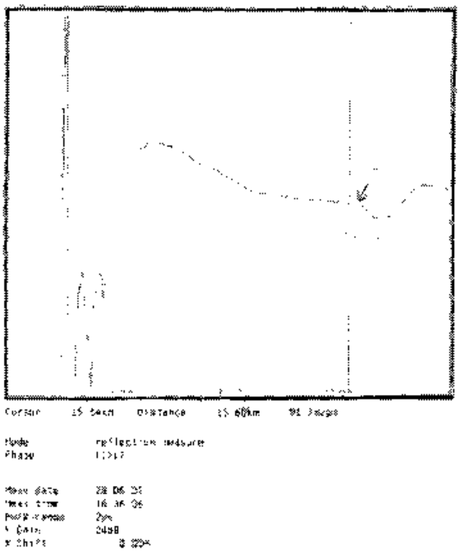


Figure 1.3.4- Gawain TDR Trace Line A - Full length

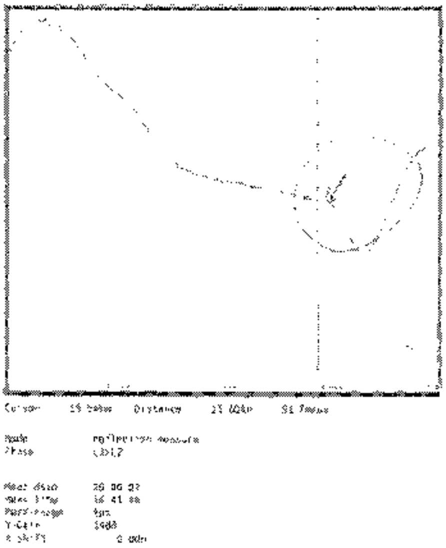


Figure 1.3.5 - Gawain TDR Trace Line A - Detail of fault at15.5km.

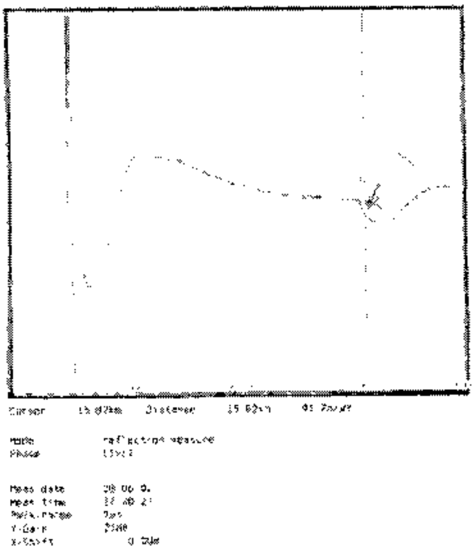


Figure 1.3.6 - Gawain TDR Trace Line B - Full length

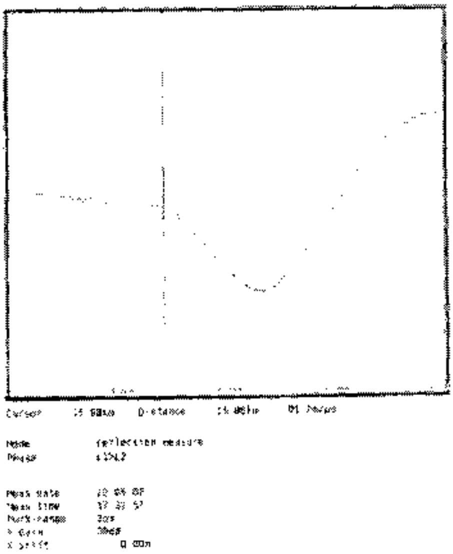


Figure 1.3.7 - Gawain TDR Trace Line B - Detail of Fault

Figure 2.1.1 Electro-hydraulic Jumper Bundle Component "F"

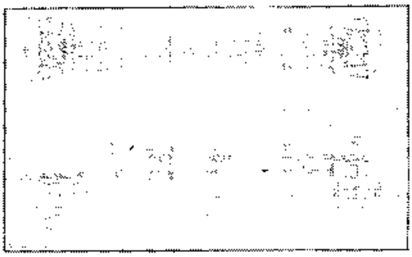


Figure 2.1.2 Electro-hydraulic Jumper Bundle Component "F"

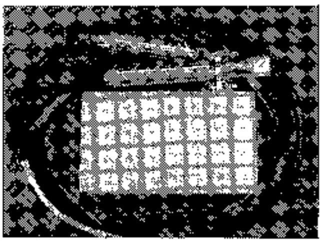


Figure 2.1.3 Tree Signal Jumpers Component "C"

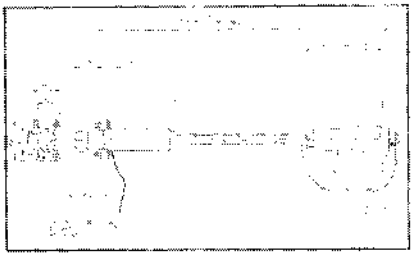


Figure 2.1.4 Tree Signal Jumpers Component "C"

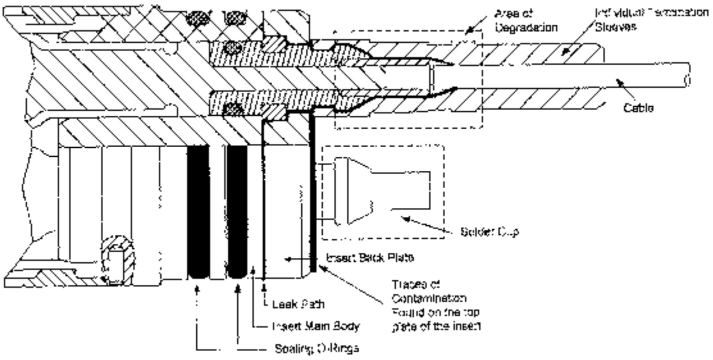


Figure 2.1.5 Insert Assembly Section Drawing - No housing shown

Fig 2.1.6 Connector orientated at 90 Deg. on the vice.

Fig 2.1.7 Traces of solvent on insert top plate

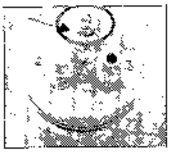


Fig 2.1.8 Not removed Flux in termination 1

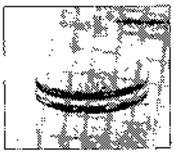


Fig 2.1.9 Not removed Flux. Black Line

Fig 2.1.10 Flux Contamination

Figure 3.1.1 The Subsea Distribution Unit

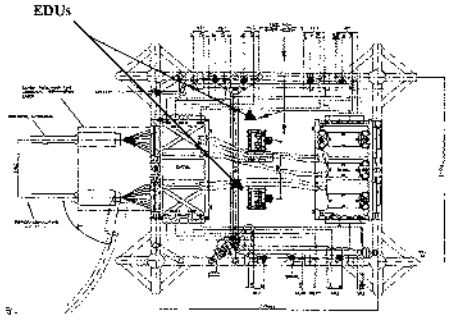


Figure 3.1.2 The Subsea Distribution Unit GA - Plan view

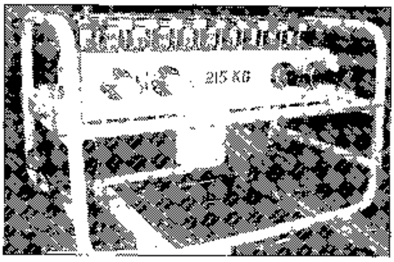


Figure 3.1.3. Electrical Distribution Unit

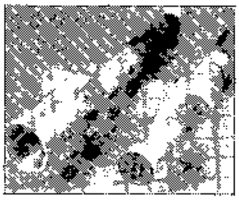


Figure 3.1.4 Typical Bulk Head In Line Connector

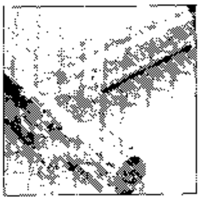


Figure 3.1.5 Typical Bulk Head Right Angle Connector

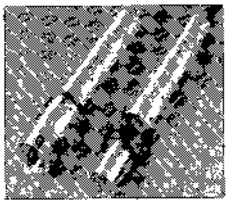


Figure 3.1.6 Typical Diver-matable Connector

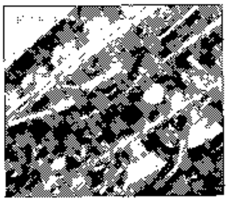


Figure 3.1.7 Restricted Access underneath the SCMMB

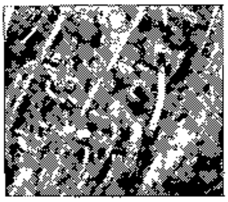


Figure 3.1.8 Obstructive Pipework

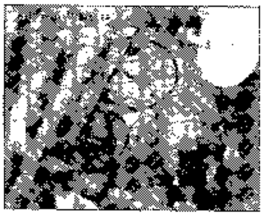


Figure 3.1.9 Connector detail. Limited space and small screw

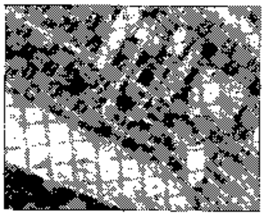


Figure 3.1.10 Restricted Access at the Tree Stabplate

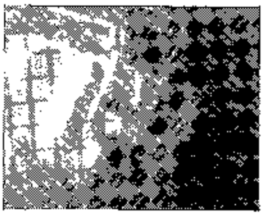


Figure 3.1.11 Tree Stabplate Close-out

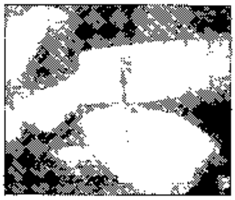


Figure 3.1.12 - Diver Tool for Connector screws

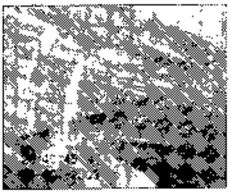


Figure 3.1.13 - Diver unscrewing connector

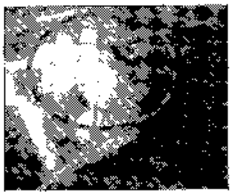


Figure 3.1.14 -Diver Removing Connector

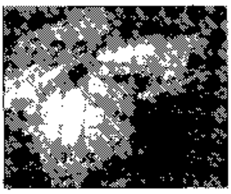


Figure 3.1.15 - Diver bending pipework

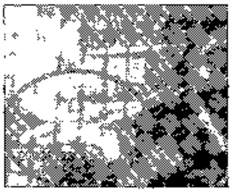


Figure 3.1.16 - Diver maneuvering connector through pipework

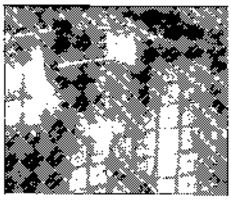


Figure 3.1.17 - Diver Inserting new connector

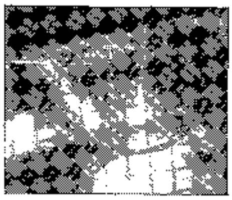


Figure 3.1.18 - Diver pushing new connector into position

Figure 3.1.19 -Diver connection earth strap

Figure 3.1.20 - Diver locating connector to remove at Stabplate

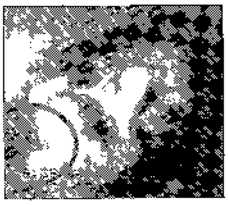


Figure 3.1.21 - Diver using bend tool to unscrew the connectors

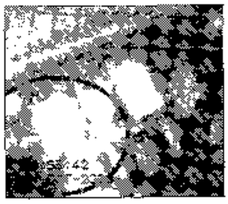


Figure 3.1.22 - Diver removing Left Corner Connector

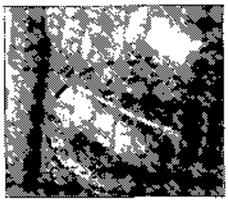


Figure 3.1.23- Diver unscrewing right Corner Connector

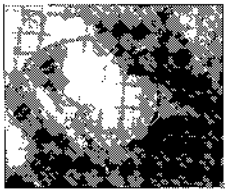


Figure 3.1.24 - Diver Removing right corner connector

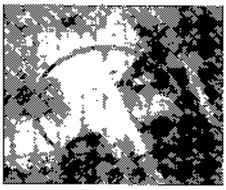


Figure 3.1.25 - Diver unscrewing bottom right connector

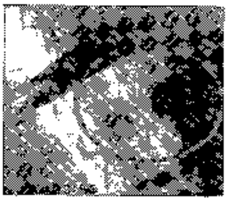


Figure 3.1.26 - Diver removing bottom right connector

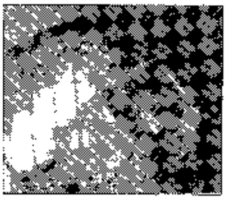


Figure 3.1.27 - Preparing new connector

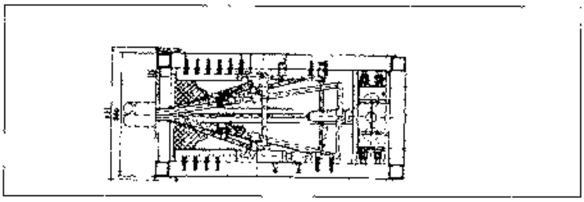


Figure 3.2.1 UTDA Top view

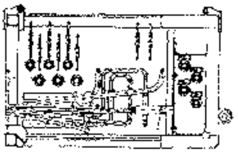


Figure 3.2.2 UTDA Side view

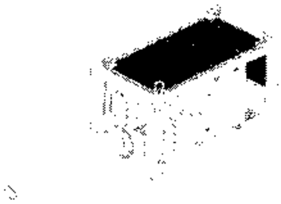


Figure 3.2.3 Isometric UTDA

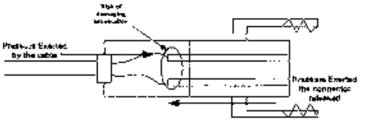


Figure 3.2.4 Risk of Damage Termination

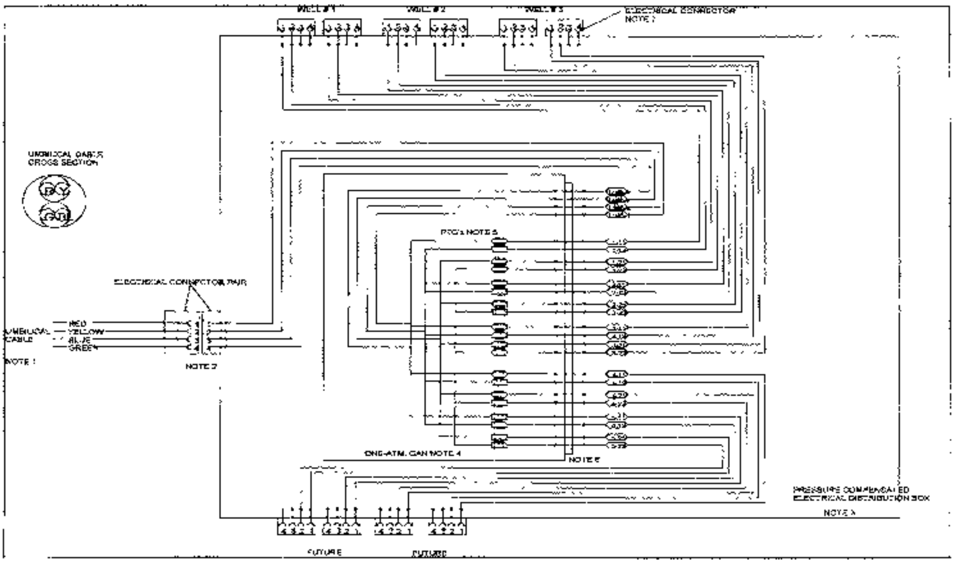


Figure 3.2.5 Electrical Schematics Electrical Distribution Unit

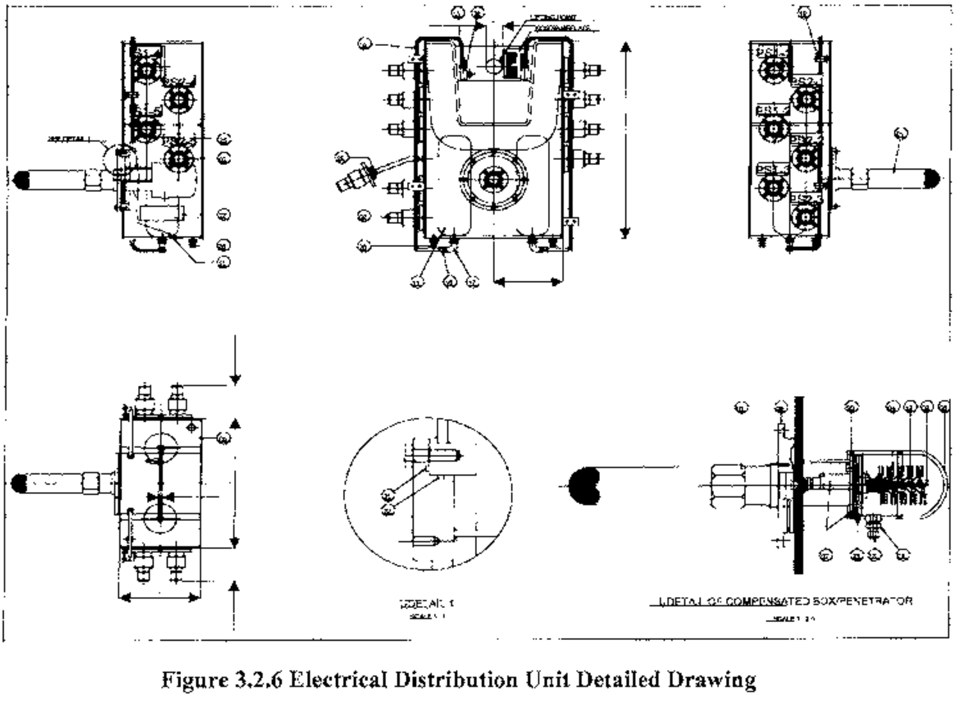


Figure 3.2.6 Electrical Distribution Unit Detailed Drawing

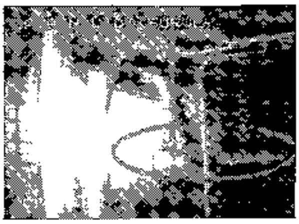


Figure 3.2.7 Umbilical Connector inside the UTDA. Close Up

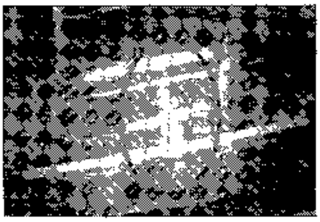


Figure 3.2.8 Umbilical Connector. Pipe work obstruction

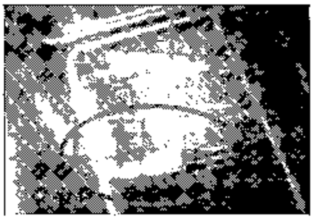


Figure 3.2.9 - Connector and Cable

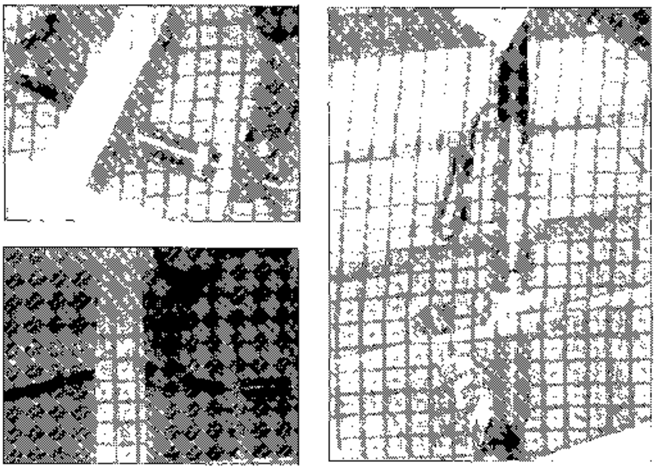


Figure 3.2.10 UTDA Wooden Mock Up Trial

Figure 3.2.11 Diving Cable Clamp

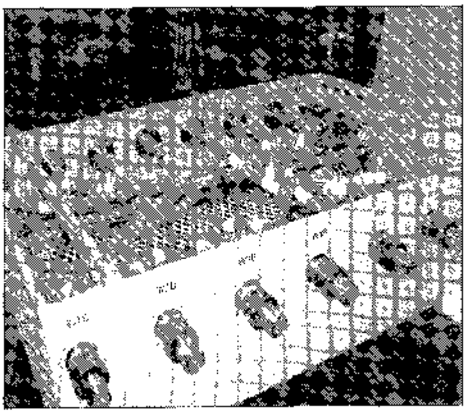
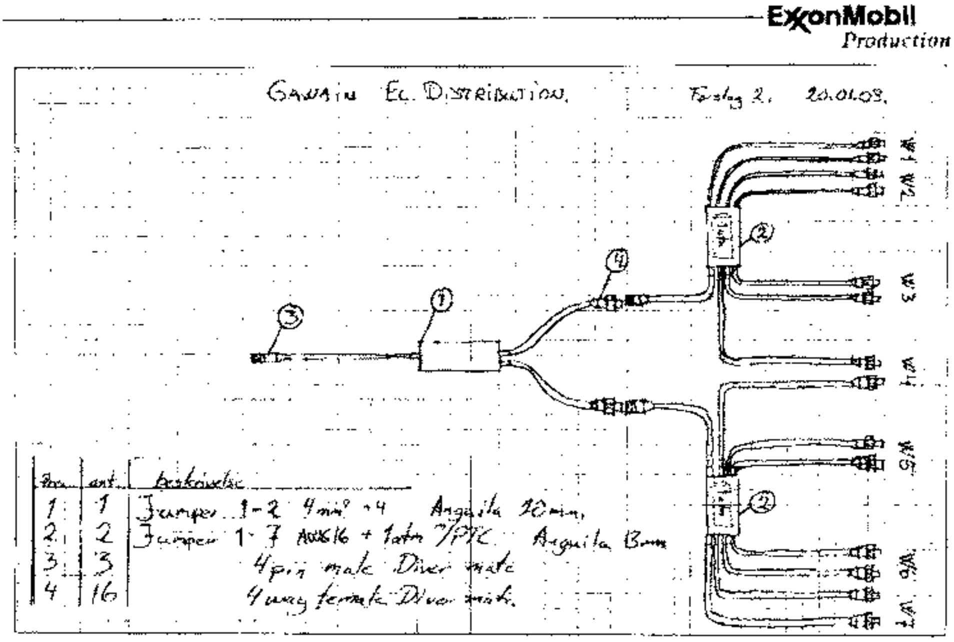


Figure 4.2.1 - The New Replacement Gawain EDU



Pos.	ant.	beskrivelse
1	1	Jumper 1-2 4mm² +4 Anguila 10m,
2	2	Jumper 1-7 AWG16 + 1stk T/PTC Anguila 8m
3	3	4pin male Diver mate
4	16	4way female Diver mate.

Figure 4.2.2 - First Draft of the Gawain EDU Design

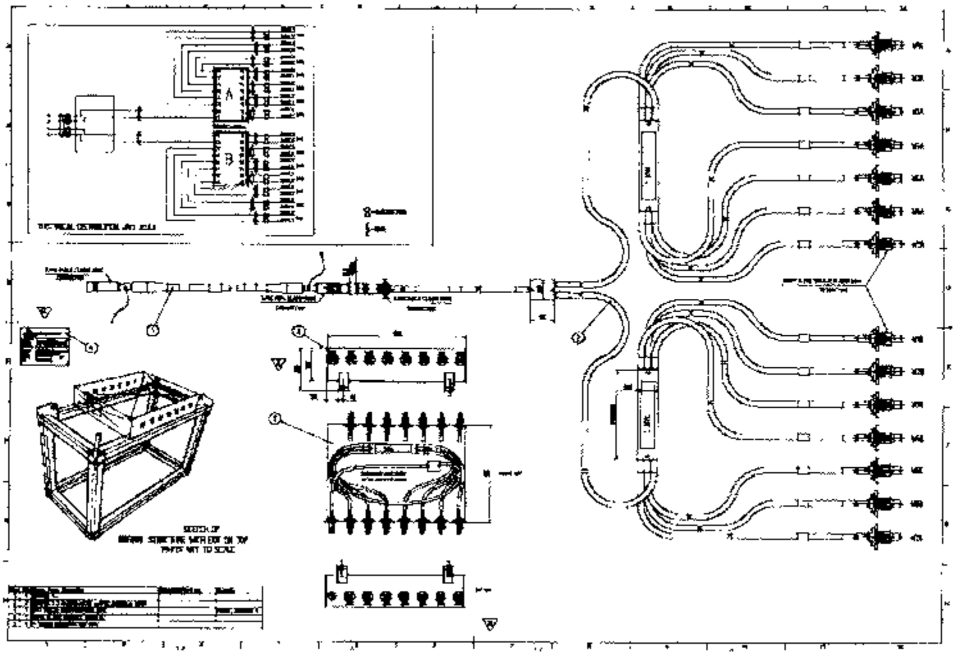


Figure 4.2.3 - Gawain EDU Final design

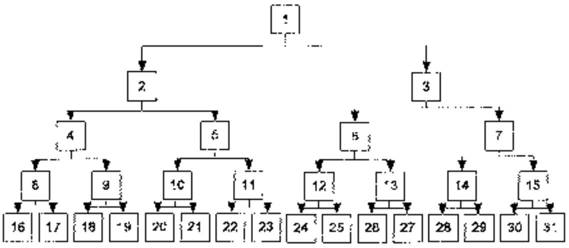


Figure 4.2.4 Theoretical Representation of Cascade Well Arrangement

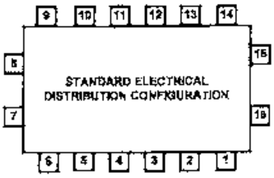


Figure 4.2.5 Standard Electrical Distribution Configuration

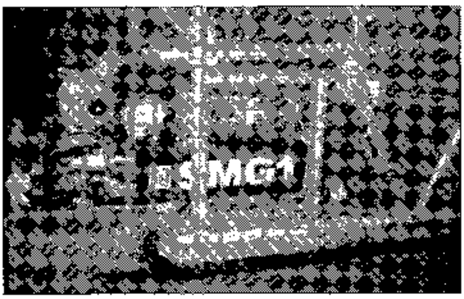


Figure 4.5.1 - Subsea robotic electrician mounted on the ROV