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Coax connectivi

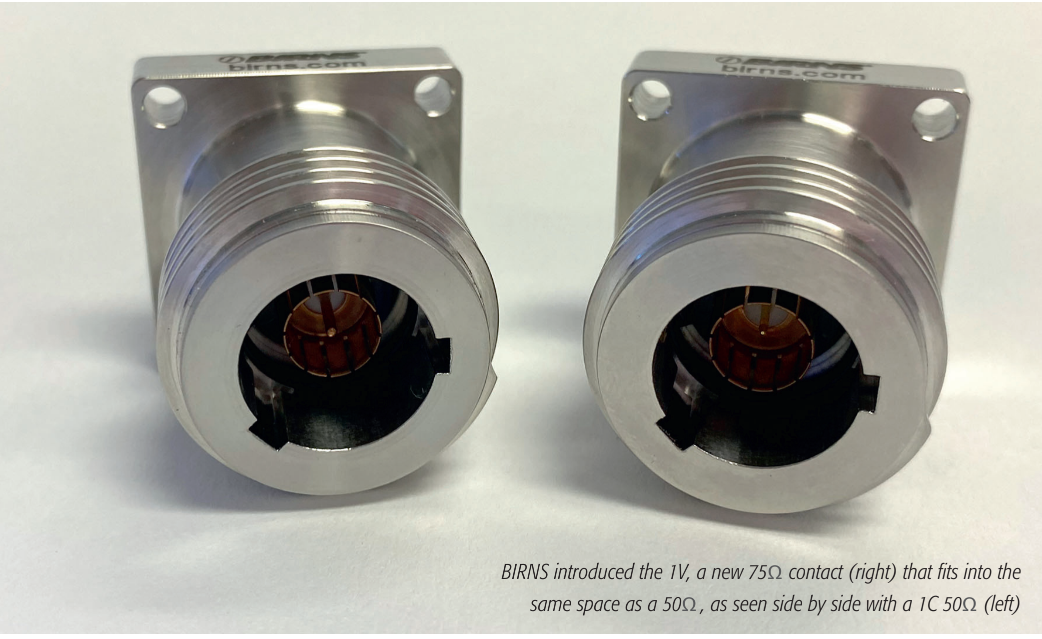
By Amy Brown, CMO, and Eric Birns, CEO, BIRNS, Inc., California, USA

New coax connectivity capabilities provide previously unheard of performance capabilities

Communication is mission critical, and today's subsea systems require real-time, reliable and field-proven solutions for communication and data transfer in both manned and unmanned submersibles. To meet these demands, BIRNS, Inc. is proud to have recently introduced a range of new coax connectivity capabilities that provide previously unheard of performance capabilities in subsea technology. The contributions include extremely low losses, high frequencies, open face pressure resistance, and new 50Ω and 75Ω configurations.

BIRNS started contributing to the advancement of custom RF (radio frequency) technology for the subsea market as early as 2001, with the development of 6km-rated

high performance 50Ω coaxial connectors with advanced polyethylene dielectrics for use with GPS-frequency military submarine antenna. Subsequent developments included M24231 connectors with unique NAVSEA PRO-020 overmoulding, also for defence applications. However, industry coax connector technology in the past had often included a series of tradeoffs, sacrificing the option of open face pressure ratings and in many cases, speed and throughput.



BIRNS introduced the 1V, a new 75Ω contact (right) that fits into the same space as a 50Ω, as seen side by side with a 1C 50Ω (left)

COAX DEVELOPMENT AND CHALLENGES

Coax can be an excellent way to conduct high frequency electrical signal as its construction offers fast signal transmission with low interference. Coax cabling features an inner conductor surrounded by layer of inert dielectric material, which is then shielded with metal jacketing or braiding. Signal is passed through both the central wire and the metal jacketing itself, which share a geometric axis. Because the electromagnetic field carrying the signal exists only in the space between the inner and outer conductors, the outer conductor acts as a shield which provides protection of the signal from external EMI (electromagnetic interference); thus,

ity breakthroughs

BIRNS Millennium 3P-2C6, with two 50Ω coax contacts, four 16AWG electrical contacts and two 22AWG electric contacts

coaxial cable assemblies are likely to be less susceptible to EMI or RFI (radio frequency interference) issues, and can offer higher transmission rates than twisted shielded electrical pairs in a cable. They tend to be more lightweight and more durable as well. Finally, as coaxial lines constrain nearly all of the electromagnetic wave to the interior of the cable, they can be bent and moderately twisted, and (with some preparation) can be strapped to conductive supports without inducing unwanted currents.

To derive the benefits of coax, however, certain challenging design requirements must be met. The most important is to maintain a uniform impedance throughout the system, which is critical to minimise loss in RF cable assemblies. Characteristic impedance is a function of the dielectric constant of the insulator and the ratio of the radii of the centre and outer conductors. The coaxial cable insulator is typically constructed of materials such as ETFE, PTFE, or HDPE (or any of these in a higher-dielectric "foamed" version such as FPE or FFEP). As each material has its own dielectric constant, each also has specific conductor diameters. The RF connector typically uses a different dielectric material than the coaxial cable so its conductors will be of different diameters than those in the cable; thus, when the connector is terminated to the cable, there is a connection zone in which the impedance does not match that of the cable or the connector itself. If the impedance change is "abrupt" (occurs over a very short length) it's called a discontinuity.

Attenuation, or loss of signal or power strength, is the loss or degeneration of RF signals within the assembly during transmission, measured in decibels (dB), i.e. 10 times the logarithm of the signal power at a specific input, divided by the signal power at a specified output. Several interrelated causes of attenuation exist which can be described by the example of a travelling wave in a rope – holding the rope with its far end attached to a distant wall. Snapping the rope like a whip sends a wave through the rope. As the wave travels, it gradually loses signal strength (attenuation).

While electrical signal is often considered to be a one-way path, signals can actually travel both ways, or reflect. Imagining the same scenario, but with two ropes of different diameters tied together in the middle – part of the wave will then reflect back from the knot, part of the wave continues past the knot, and some of the wave's energy is immediately dissipated. The knot represents a signal path discontinuity, causing both reflection and attenuation.

A third scenario could include two ropes of different diameters that are not tied but are woven together over some length. Although the signal is attenuated, far less of the wave reflects from the impedance change because the transition is not discontinuous. Electrical circuits can have discontinuities that affect the signal and can lead to an increase in standing waves, reflected waves passing each other in opposite directions. In analogue video, reflections can cause ghosting in the image.

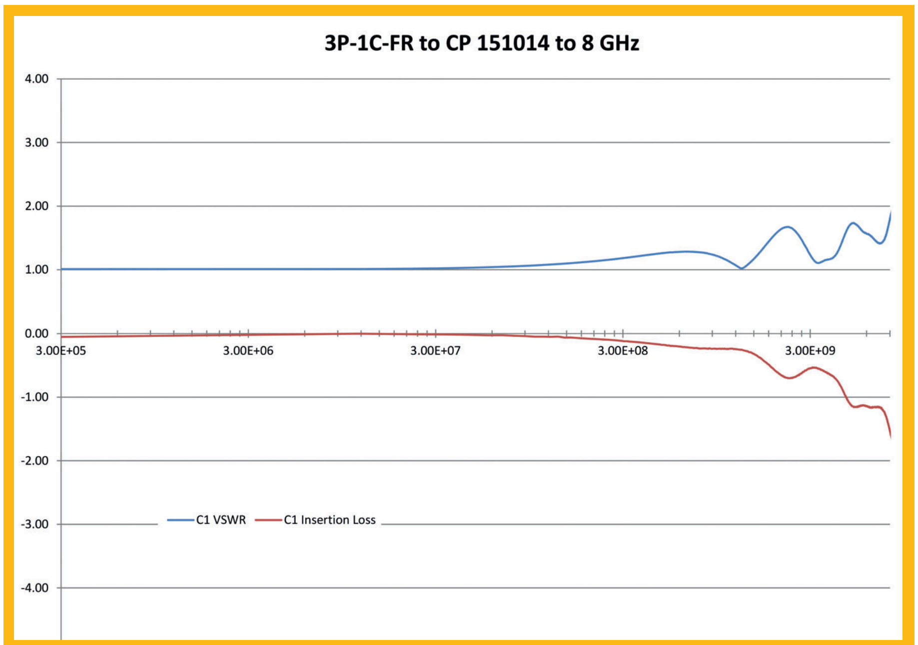
An impedance mismatch in the line causes standing waves. A wave is partly reflected when the signal hits any connection between components with different impedances, for example when a cable is terminated with a connector with an impedance different than the cable's characteristic impedance; this exacerbates transmission line losses which become increasingly significant at higher frequencies and for longer cables. The Standing Wave Ratio (SWR) is a measure of the standing waves depth, i.e. of the matching of the

The company recently introduced new 1B ultra-low-loss RF pressure-rated connectors for use to SHF band Ku (18GHz) for the US military load to the transmission line. It's often thought of in terms of the highest and lowest AC voltages along the line, and is thus called the Voltage SWR or VSWR. A completely matched load, with zero reflected wave, would result in a VSWR of 1:1, while a completely mismatched system (100% reflected wave) would result in infinite SWR. A VSWR value of 1.5:1 means that an AC voltage, due to standing waves in the transmission line, has a peak value 1.5 times that of the minimum AC voltage along that same line (assuming the line length is at least half a wavelength).

The subsea world brings an additional layer of challenges and subsea coax cable assembly development has historically faced limitations not found in electrical or optical assemblies. In particular, most engineering materials offer tradeoffs in their mechanical and signal qualities. For example, GRE (glass-reinforced epoxy) offers excellent mechanical and electrical properties but is extremely "lossy" and unsuitable as an RF dielectric. Conversely, FPE (foamed polyethylene) is an excellent RF dielectric but provides minimal pressure resistance.

The common wisdom is that the pathway discontinuities (abrupt impedance changes) are acceptable provided that they are short relative to the wavelength. Thus, in the early days some connector manufacturers would even 'break' the coax, by terminating the inner and outer conductors to two individual pins in the connector. But ever-increasing data requirements have pushed demand for more data transmission, higher performance, lower losses and higher signal frequencies. However, as signal frequency increases, wavelength decreases, so at higher signal frequencies it becomes increasingly challenging to make good low-loss connectors. This is particularly so because when the RF frequency is above a few GHz (a frequency determined by the cable construction), multiple electromagnetic transmission modes can appear in the line; these have different phase velocities which can interfere with each other. Below that cut-off frequency, the signal propagates mostly in the transverse electromagnetic mode in which neither the electric (E) nor magnetic (H) field is in the direction of propagation but are perpendicular to the center conductor.

Subsea connector manufacturers have long struggled with preventing the dielectric and or centre conductor from being extruded from the outer conductor or creating a leak path under pressure. This is exacerbated by the fact that most good dielectric materials happen to be low surface energy plastics (≤36 dynes/cm), making them very difficult to bond. For years, subsea RF connectors were unable to withstand any open face pressure whatsoever (or would offer poor signal performance), due to the design demands of controlling electrical impedance and the challenges found affecting characteristic performance of dielectric materials.



Graph of a BIRNS 3P-1C mating pair tested for insertion loss and VSWR to 8GHz (in standard logarithmic format)

> The overmoulding for connectors and custom cable assemblies is a critical component of the viability of any such assembly, to successfully withstand harsh marine environments, mechanical abuse, and repeatability

BIRNS' NEW RF TECHNOLOGY AND SOLUTIONS

Recently, however, the BIRNS team developed completely new proprietary RF technology that has provided elegant solutions to many of these issues. It started with exclusive BIRNS 50Ω coax contacts that provided open face hydrostatic pressure to depths of 1433 metres. To achieve this, BIRNS engineers optimised transitions to prevent extrusion and minimise impedance discontinuities, and also incorporated seals made of low dielectric constant materials to prevent leakage under pressure. But open-faced pressure resistance is only part of the advantage of these new coax contacts and pin configurations in the 6km-rated BIRNS Millennium series. These connectors and cable assemblies offer low loss data transmission even up to GPS frequencies, which is critical for real time data provision. For instance, BIRNS Millennium 1C cable assemblies provide UHF insertion loss ≤0.7dB at signal frequencies to 3GHz and maximum UHF voltage standing wave ratio (VSWR) of 1.7:1.

RF transmission technology in the subsea market had been hampered by the limitations available in previous commercially available coax connectors. But compared to others' performance of approximately -3.5dB and -2.5dB, respectively, at 1.5GHz BIRNS RF designs are better by a full order of magnitude, and exhibit only -0.32dB loss and 1.17 VSWR. It's challenging to design subsea coax connectors due to the engineering tradeoffs between mechanical (pressure-resistant) and signal performance. However, BIRNS has taken a novel approach to achieve a blend of both, and has integrated aspects of leading "dry" RF technology to virtually eliminate impedance mismatches within the system.

BIRNS has just launched the new BIRNS 1V series, featuring a compact coax contact that offers 75Ω impedance in the same footprint of a 50Ω contact. The new 1V is ideal for HD/SD video with signal frequencies to 3GHz, for shortwave antennas, or for low-power RF needing minimal signal attenuation. And, due to its extraordinarily compact size, it will fit into any of the many BIRNS coax pin configurations, offering a range of flexible, powerful new options in a small space.

BIRNS offers a number of shell sizes which are available with impedance of 50Ω and/or 75Ω and most can be hybridised with electrical contacts and/or optical ferrules. A popular hybrid coax pin configuration is the BIRNS Millennium 3P-2C6, with two 50Ω coax contacts, four 16AWG electrical contacts and two 22AWG electric contacts. Now, with the advent of the 75Ω 1V, this same configuration is also available as a 3P-2V6 or a 3P-1C1V6 (one 50Ω and one 75Ω) – all in one compact connector with a diameter of just Ø1.94 inches (Ø4.92cm). All of the company's new coax connector designs include open face pressure-resistance capability.

Plus, BIRNS offers new ultra-low-loss RF pressure-rated connectors for use to SHF band Ku (18GHz). The company recently developed these 1B pressure-rated low-loss RF connectors, exclusively for the US military, for use to SHF band Ku. The 1B connectors have previously been qualified for US Navy applications and are presently undergoing additional US Navy qualification including transmission and open-face in saltwater under conditions of cold (27°F/-3°C) and hot (100°F/38°C) hydrostatic pressure. These new solutions provide both strategic and tactical advantages, in delivering synchronous, continuous key positioning data, communication and location coordinates, from the submarine to the ship or tactical air cover, without the need to resurface. It will greatly advance both internal and external submarine communications and data sharing, providing a more significant opportunity to make mission-critical decisions.

SPECIALISED DEVELOPMENT AND TESTING

The overmoulding for connectors and custom cable assemblies is a critical component of the viability of any such assembly, to successfully withstand harsh marine environments, mechanical abuse, and repeatability – thus, the utmost care must be taken in the process. Materials used for overmoulding can include epoxy, polyurethane, polychloroprene and a wide range of other substances, and custom moulding facilities are now capable of producing tailored solutions for a diverse suite of highly specific environments and applications. BIRNS has a NAVSEA PRO-020 certified overmoulding facility – one of the few approved by the US Navy for the manufacturing of outboard cables for naval submarines. The stringent protocols require highly specific methodology and testing, as well as the use of specific compounds used for NAVSEA overmoulding work, including a clear/amber military grade polyurethane. This military grade material has higher tear strength, and is highly resistant to oils, gasoline, seawater, while providing outstanding protection against corrosion.

Testing these high performance coax assemblies includes measuring the amount of input signal that is reflected back toward the source. For high-frequency VSWR testing, BIRNS uses an ENA series network analyser with E5063A-2H5 two-port test set (100kHz to 18GHz) and N4691B 3.5mm two-port ECal module (36.5GHz), in addition to requisite high pressure testing.

LOOKING AHEAD

The team at BIRNS is proud to have had such a long legacy of contributions that have helped improve communication and exploration at depth. It looks to the future and welcomes the opportunity to continue offering RF solutions that create safer, more powerfully efficient subsea system operation and data transfer at rates that had never before been possible. ■