Recent Innovations in 48 AWG Micro-Coaxial Design & Manufacturing

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Abstract

This paper discusses the challenges with manufacturing low capacitance micro-coaxial cable that uses cellular (foamed) insulation as a dielectric and improvements that can be made in order to achieve even finer gauges for diameters previously not achievable.

Hitachi has implemented a novel alternative approach to using cellular insulation. The new approach is in many ways comparable to a cellular construction however it yields a more consistent dielectric constant with improved electrical performance, improved product concentricity, and lower manufacturing cost.

From this approach we have proven that an alternative construction to foam is desirable to achieve smaller diameter low capacitance cable.

Keywords: Micro-coaxial; improved dielectric; foaming; fluoropolymer; high performance cable; 48 gauge; low capacitance

1. Introduction

There are primarily five styles of cable that can be considered when discussing micro-wire technologies. These are:

1) Single jumper wire/magnet wire cable
2) Micro-coaxial;
3) Twisted pairs (i.e. UTP unshielded twisted pairs and STP shielded twisted pairs);
4) Twin-axial cables; and
5) Quads

These cables will either employ single ended or differential signals when they are used. Single wire and micro-coaxial cables are single ended cables, whereas twisted pairs, twin-axial cable and quad cables can be used for differential signaling.

Cable Style	**Benefit/Application**
Singles / Magnet Wire	Lowest cost, commodity product, easy to implement, fine for non-critical or slowed down data rates.
Micro-coaxial	Isolated and clean signals, good for transferring digital or analog signals while limiting EMI interference. Micro-coaxial cable has better electrical and mechanical properties as compared to a STP or UTP, allowing it to be used for more harsh environments. Although higher cost than UTP and STP, it is more easily terminated, even at the smallest of sizes. This helps to control the cost of finished devices since it is less dependent on manual labor.
Twisted Pair	Flexibility with balanced signals. Twisted pairs are a good method for data transmission when using slower data rates. They are cost effective for single use medical devices but do have less consistent signal integrity and mechanical performance vs a micro-coaxial cable.
Twin-axial	Improved signal length, better balance with an overall shield for isolation. Used for critical impedance matching applications.
Quad	Can be used like two twisted pairs, making the overall bundle smaller but with reduced signal integrity compared to twisted pairs.

Good cable design is a balance of cost, size and performance. Sometimes the most desirable design doesn't make sense for the end application due to cost or complexity. Designers should keep in mind that it is important to work closely with their cable partners and disclose and discuss all of the various needs to avoid any unforeseen impacts on product manufacturing, performance, and cost.

Next generation devices such as surgical catheter components, advanced ultrasound equipment, medical robotic video / sensing devices, and endoscopy are pushing toward smaller constructions. Doctors need small cables for more accurate doctor-to-device controls delivering better medical outcomes for patients. This is one of the major drivers for smaller cables and partly why micro-coaxial cable is becoming increasingly prevalent in medical devices and other commercial applications requiring miniaturized footprints and high signal integrity.

Many of these applications use high definition video or have higher frequency transmission needs than previous generation devices. Micro-coaxials offer designers a good balance of the key performance factors (noise immunity, flexibility, transmission distance and size), which is why they are frequently used.

The construction of a micro-coaxial cable is quite simple. It is composed of four primary elements: the central conductor; the dielectric insulation; the shield; and the jacket (also called a sheath). The central conductor and the shield are the charged positive and negative plates that form the capacitor.

In recent years, the ultrasound industry has moved to two common micro-coaxial constructions. The first is a high capacitance (~50 ohms - low impedance) micro-coaxial cable. It is the workhorse of the industry and is used for many of the more common applications, providing an adequate cost versus performance versus size relationship. High capacitance micro-coaxial cable is good for general purpose applications that require low cost and small size.

The second construction is a low capacitance (~60 to 85 ohms - high impedance) micro-coaxial cable. Low capacitance micro-coaxial cable is ideal for improved signal quality over a greater transmission distance when compared to high capacitance cable with identical gauge wire.

It is important to note that impedance and capacitance are directly related. As the capacitance of a wire increases, the impedance decreases. This is why high capacitance cables are referred to as low impedance products and vice versa; low capacitance are high impedance products.

Low capacitance products are far more challenging to manufacture compared to the relative production simplicity of the high capacitance designs. If conventional dielectric thicknesses were employed then low capacitance products would simply be too large to be practical.

To reduce the overall micro-coaxial size and improve the dielectric constant, cable designers have employed a process called foaming, which applies a thin cellular dielectric of perfluoroalkoxy (PFA) as a replacement to the solid dielectric that is used for high capacitance products. The PFA material is applied by melted the mass and injecting air bubbles into the material in order to create foam that will harden over the central conductor once it cools.

The foam is then wrapped with a secondary layer of tape made from Polyethylene terephthalate (PET) to insure that there is no risk of shorting. Because air has the lowest dielectric constant, it is an ideal candidate to use as an insulator over the wire but consistency is critical.

Ultrasound cable products typically need to pass a 500 Volt AC test for 1 minute. This is called the *dielectric withstand* voltage, which is applied between the center conductor and the outer shield. There must not be electrical shorts in the micro-coaxial cable for it to function. This same test goes down to 300 Volt AC as the micro-coaxial cable size drops down to 46 AWG and smaller. This test is the reason why smaller diameter micro-coaxes have a layer of PET tape wrapped around the foam to provide for an extra layer of insulation and protection.

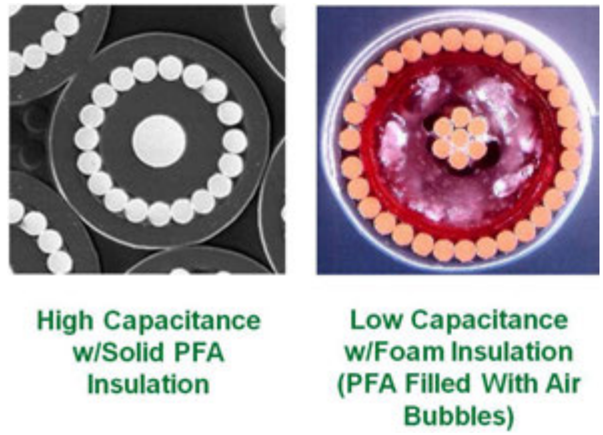

Figure 1 - High Capacitance and Low Capacitance Micro-coaxial Cables

Foamed insulation, for larger gauge products works well. However, it is not ideal for ultra-miniature products due to the manufacturing and performance limitations. Creating foam insulation with a uniform cross-section is very challenging to achieve. Unpredictable arrangements of the air bubbles within the PFA are common once the mass solidifies. When the structure becomes too thin, there is a potential for the dielectric insulation to contain voids. These openings are formed by air bubbles that may undesirably line up. This may result in electrical shorting between the conductor and the shield.

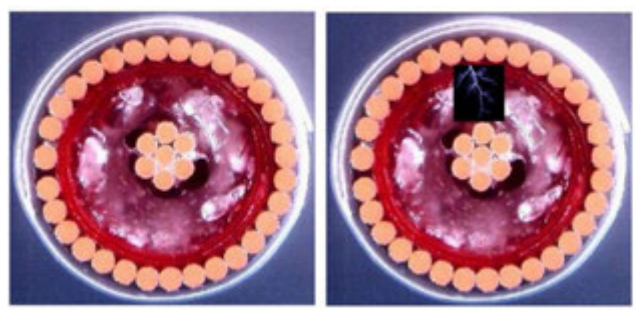

Figure 2 - Non-uniform cross-section, showing air bubble shorting potential (In black section)

Excessively thin cellular dielectric will also have impedance fluctuations due to the inconsistency of the solidified mass. This will invariably result in performance degradation over longer distances. All of these factors become significant obstacles in making even smaller micro-coaxial cable configurations.

Hitachi successfully uses foam for 46 AWG (7 strand of .0006 inches wire [7/0.016 mm]) products and larger gauge wires. But smaller than 46 AWG (such as 48 AWG (7/.0004 inches [7/0.012 mm]) and 50 AWG (7/.00039 inches [7/0.01

mm]), newer non-foamed technologies need to be employed to create high performance micro-coaxials with the desired mechanical and electrical characteristics.

As an alternative to the cellular insulation, Hitachi used solid fluoropolymer filaments and stranded them around the central metal conductor. Using these precision extruded filaments, eliminates the air bubble challenges and stabilizes the dielectric properties of the cable. With the new construction, sufficient air still remains around the conductor to achieve the performance needs while accomplishing the goal of making a smaller micro-coaxial low capacitance product.

For the construction to work reliably, an external tape is required to lock the filaments in place while providing a second layer of protection to achieve the requisite 300 VAC dielectric withstand voltage.

2. Experimental

2.1 Design Objectives

- *Achieve a 48 AWG low capacitance product with the smallest diameter possible*
- *Eliminate cellular insulation due to inconsistency*
- *Create more consistent air gaps for improved dielectric performance*
- *Provide more consistent diameter control with improved concentricity resulting in more stable impedance*
- *Reduce manufacturing failures*
- *Create more repeatable dielectric withstand voltage test results*
- *Achieve high impedances, 75 ohms or higher, comparable to the 46 AWG product*
- *Achieve a diameter comparable to the high capacitance 48 AWG product.*

2.2 Experimental Structure

To achieve the objectives, a design was proposed which used wound PFA monofilament and an outer PET tape vs. the conventional cellular PFA approach. The proposed structure is shown in the illustration below.

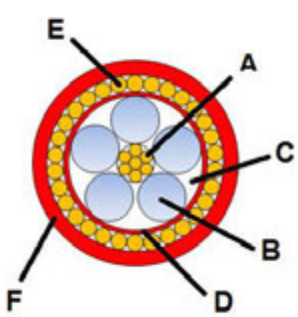

Figure 3 – Proposed new structure of low capacitance micro-coaxial cable

The inner 48 AWG conductor (A) would be formed by using seven strands of 56 AWG silver plated copper alloy wire. The insulation would consist of five .002 inch [50 micron] PFA monofilaments (B) wound around the central conductor. A skin layer of the PET tape (D), with a thickness of .00009 inches [2.5 microns], would then be wrapped over the insulation layer and this would enclose the air gaps (C). An outer conductor (E) consisting of thirty strands of 54 AWG silver plated copper alloy wire would form the spiral wrapped shield. The final outer jacket (F) would be formed using wrapped polyester tape.

2.3 Fabrication Method

The PFA monofilaments would be wound by a tubular style twisting machine on the central inner conductor, and the PET tape would then be wrapped over the PFA monofilaments using a taping machine. Because the proposed design uses conventional equipment and does not require an additional investment, the new micro-coaxial cable should result in a more reliable and less expensive product when compared to a conventional foamed approach.

3. Results and Discussion

3.1 Manufactured Sample

The proposed design proved to be highly effective. The cross section of the manufactured sample is shown and labeled in Figure. 4.

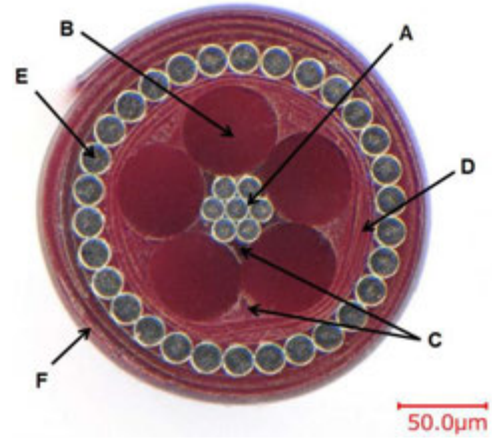

Figure 4 –The cross section of the sample

A. Inner conductor
B. PFA monofilament
C. Air gap
D. PET skin layer
E. Outer conductor
F. Jacket

An air gap was formed under skin layer and was controlled via the application of the wound PET tape as expected and desired. This was necessary in order to provide a more consistent dielectric constant throughout the length of the cable.

3.2 New Design Features

A. Inner conductor

- Seven strand alloy wire improves flex life
- Good for high frequency and sensitive signals
- Excellent solderability
- Good tensile strength and conductivity

B. PFA monofilament

- More cost efficient than foaming and eliminates unexpected air voids
- Available in 48 AWG and 50 AWG designs

C. Air gap

- Highly controlled and consistent pockets
- Predictable electrical characteristics

D. PET skin layer

- Used to tightly hold the PFA filaments together
- Required to pass the 300VAC dielectric withstand voltage test

E. Outer conductor

- Excellent solderability
- Good tensile strength and conductivity
- Good product flexibility

F. Jacket

- Used to lower the cost (one less manufacturing operation)
- Good chemical and thermal resistance

3.3 Sample Construction

Item		Estimation	Measured
Inner conductor	Strand	7/.00005 inch [7/0.013 mm]	7/.00005 inch [7/0.013 mm]
	Dia.	.0015 inch [0.039 mm]	.0015 inch [0.039 mm]
Insulation	# of Strands	5	5
	Dia. of strand	.002 inch [0.050 mm]	.0019 inch [0.049 mm]
Skin layer	Dia.	.0058 inch [0.149 mm]	.0061 inch [0.154 mm]
Outer conductor	Strand Dia.	.0006 inch [0.017 mm]	.0006 inch [0.017 mm]
	Dia.	.0072 inch [0.183 mm]	.0074 inch [0.189 mm]
Jacket	Dia.	.0084 inch [0.213 mm]	.0086 inch [0.220 mm]

3.4 Sample Capacitance

The measured capacitance with the LCR Tester is shown below in the comparison chart.

Item	Estimated Cap. (at 1 kHz)	Actual Cap. (at 1 kHz)	Outer Dia.
New Low Cap 48 AWG Design	216.86 pF/ft. [66.1 pF/m]	237.5 pF/ft. [72.4 pF/m]	.0087 inch [0.22 mm]
High Cap 48 AWG	N/A	110.8 pF/m	.0065 inch [0.164 mm]

Based on this data, we have validated that a low capacitance 48 AWG micro-coaxial cable is viable. The measured value is slightly higher when compared to the one estimated by the cross-sectional area of the air gap. We believe the reason for the higher capacitance is due to the fact that the air gap around the fluoropolymer filaments is reduced when the tape is applied, since the tape tends to fall into the voids between the filaments and does not create a fully circular shape over the central region.

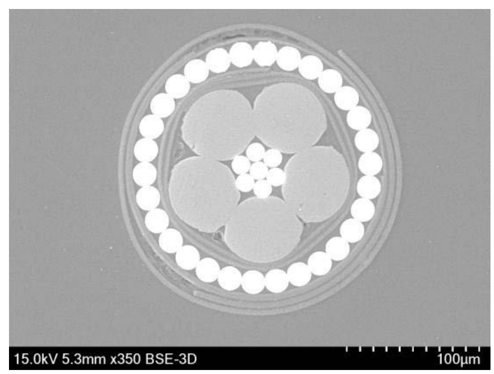

Figure 5 – Scanning electron microscope (SEM) photograph of actual 48 American Wire Gauge (AWG) Low Capacitance Product (Note the non-round, star shaped pattern formed by the inner taping operation, as explained above)

3.5 Other Sample Characteristics

Item	48AWG Low Cap	48AWG High Cap
Micro-coaxial diameter	.0086 inch [0.220 mm]	.0065 inch [0.164 mm]
Diameter of a 128 conductor micro-coaxial cable	.15 inch [3.8 mm]	.12 inch [3.1 mm]
Characteristic impedance (at 10MHz)	70 Ω	57.7 Ω
Capacitance (at 1kHz)	237.5 pF/ft. [72.4 pF/m]	363.5 pF/ft. {110.8 pF/m]
Inner conductor resistance	71.2 Ω/ft. [21.7 Ω/m]	71.2 Ω/ft. [21.7 Ω/m]
Attenuation (at 10MHz)	4.3 dB/ft. [1.3 dB/m]	6.2 dB/ft. [1.9 dB/m]
Attenuation (at 50MHz)	5.9 dB/ft. [1.8 dB/m]	8.85 dB/ft. [2.7 dB/m]
+/-90degrees bend test (R=2mm)	Over 500k cycles	Over 500k cycles

4. Conclusions

In this work we describe a new manufacturing method for applying a dielectric layer using fluoropolymer filaments instead of using direct extrusion. With a PET tape spiral wrap to achieve the direct electric withstand requirement, we delivered an overall cable diameter of .008 inches [0.21 mm], not much larger than a high capacitance 48 gauge product at .007 inches [0.17 mm].

The new approach provides superior product performance in many regards as compared to the cellular alternative. The new approach offers improvements in ease of manufacturing, a reduction in manufacturing failures and scrap, as well as improved tolerance control. These changes result in improved concentricity and diameter control with more stable impedance control because of fewer reflections. The final attenuation of the new 48 gauge approach provided 5.9 dB/ft. [1.8 dB/m] in the 1 to 100 MHz range.

The dielectric constant and resultant 70 Ohm impedance and 237.5 pF/ft. [72.4 pF/m] capacitance remained within an acceptable range for low capacitance applications. These improvements, unlike conventional foaming can be extended to smaller 50 AWG micro-coaxial cable with minimal difficulty. Plus variations to the design can be easily made by simply altering the fluoropolymer filament diameters. It is our belief that very high volume production with newly designed equipment can achieve desirable cost targets.

5. Acknowledgments

We would like to give a special thanks to all of the IWCS staff for the opportunity to present this material for this year’s publication.

6. References

[1] Takanobu, Watanabe, “Coaxial Cable and Medical Cable”. WO16/121000. (2016-08-04)

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