EMI/RFI Shielding Formulations for Use in Advanced Electronic Systems

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Abstract

Higher data transmission speeds are requiring the use of cables and connectors which operate at higher frequencies. EMI emissions are more complex and crosstalk between data transmission lines is becoming more relevant in connector designs today and is expected to become prevalent in the future. Research and development by PolyOne has enabled the company to provide EMI/RFI polymer formulations which exceed the shielding requirements of today's demanding electrical and electronic systems.

Electromagnetic Interference

Electromagnetic interference (or "EMI"; also called radio frequency interference or "RFI") is a disturbance that affects an electrical circuit due to either electromagnetic induction or electromagnetic radiation emitted from an external source.[I] The disturbance may interrupt; obstruct; or otherwise degrade or limit the effective performance of the circuit. The source may be any object; artificial or natural; that carries rapidly changing electrical currents; such as an electrical circuit; the Sun or the Northern Lights. The electromagnetic spectrum covers the frequency ranges spanning AM radio; FM radio; broadcast television; microwave ovens; radar; visible light; infrared and ultraviolet light; x-rays; and gamma rays.

Figure 1 shows the electromagnetic spectrum in relation to common items. Most often; we are concerned about how electromagnetic radiation affects our radios; televisions; cell phones; computers; medical equipment and aircraft avionics systems. This covers the frequencies less than 60 Gigahertz (the frequency at which the latest 4G cell phones operate.) Increased use of plastics to replace metals to reduce weight is requiring that plastics take on the multifunctional role of providing both light weight structure and protection from EMI/RFI.

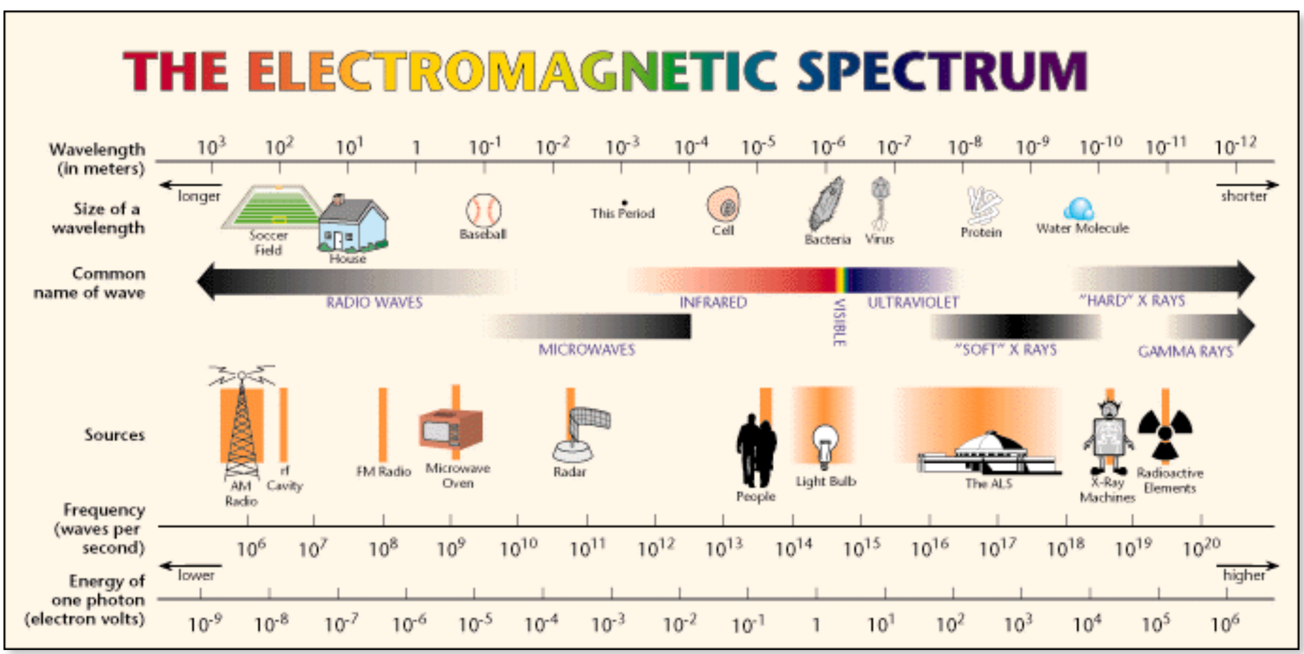

Figure 1. PolyOne Corporation Products Span The Entire Electromagnetic Spectrum[II]

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EMI can be intentionally used for radio jamming; as in some forms of electronic warfare. It can occur unintentionally; as a result of spurious emissions; such as through intermodulation products. It frequently affects the reception of AM radio in urban areas. It can also affect cell phones; medical devices; advanced electronic data systems; aircraft avionics; FM radio and television reception. Radiated EMI or RFI may be broadly categorized into two types: narrowband and broadband. Figure 2 shows that incident EMI/RFI can be transmitted though the material; reflected by the material or absorbed by the material.

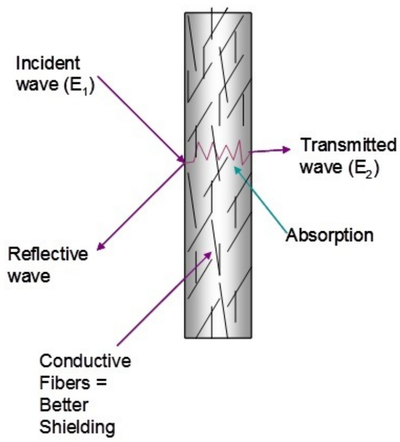

Figure 2. Electromagnetic Radiation Pathways

Narrowband interference usually arises from intentional transmissions such as radio and TV stations; pager transmitters; cell phones; etc. Broadband interference usually comes from incidental radio frequency emitters. These include electric power transmission lines; electric motors; thermostats; bug zappers; etc. Anywhere electrical power is being turned off and on rapidly is a potential source. Included in this category are computers and other digital equipment as well as televisions. The rich harmonic content of these devices means that they can interfere over a very broad spectrum. Characteristic of broadband RFI is an inability to filter it effectively once it has entered the receiver chain.[III;IV;V]

Conducted electromagnetic interference ("conducted EMI") is caused by the physical contact of the conductors while "radiated EMI" is caused by induction (without physical contact of the conductors). Electromagnetic disturbances in the EM field of a conductor will no longer be confined to the surface of the conductor and will radiate away from it. This persists in all conductors and mutual inductance between two radiated electromagnetic fields will result in EMI.

There are several general approaches to providing EMI/RFI shielding. These approaches include the use of all metal electronic enclosures; plastic enclosures using conductive metal paints; plastic enclosures using metal foils; and plastics filled with conductive fillers. The first EMI/RFI shielding devices consisted of all metal enclosures that used conductive gaskets to seal door and opening edges. These enclosures are heavy and require additional labor to fabricate and assemble. Plastic enclosures that are painted with conductive paints are lighter than all metal enclosures; still require the use of conductive gaskets for doors and openings; and are susceptible to scratches and metal flaking off of the enclosure walls. Plastic enclosures that use metal foils are labor intensive to produce and must use conductive gaskets to seal doors and openings. All plastic molded electronic enclosures that incorporate conductive fillers offer weight savings; reduced manufacturing cost; reduced scrap loss and are not susceptible to scratches.

Over the past several years; a number of companies have redesigned their electronic enclosures to be made from conductive polymer compounds. The polymer compounds have been made conductive by using conductive stainless steel fibers; carbon fibers; nickel-coated carbon fibers; metal flakes; and graphite flakes as the conductive/shielding filler. In recent years; carbon nanotubes; carbon nanofibers; metal-coated organic fibers; nickel nanofibers; graphite flakes; and graphene have all been tried as conductive fillers for static dissipative compounds; conductive compounds; and even EMI/RFI shielding compounds.

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These compounds have been very effective at protecting sensitive electronic equipment at relatively low radio frequencies (less than 500 megahertz and at relatively low levels of attenuation shielding effectiveness (less than 40 dB) with large/thick plastic walls. Two factors are increasing the need for low cost; light weight advanced EMI/RFI shielding compounds today: first; transmission frequencies of data transfer networks are increasing for ever smaller cell phones and data networks; secondly; the "penalty" for EMI/RFI on sensitive medical equipment in healthcare facilities and high speed data transfer networks is also rising. Current conductive compound products do not readily provide the levels of attenuation required by new standards and the broader electromagnetic frequencies being used.

Advancement of electronic systems has led to more and more stringent requirements for electromagnetic compatibility (EMC) and EMI shielding design. Mechanical and electrical design interfaces are challenging; especially for a new product development; in which a critical and early design decision has to be made either assuming EMC can be achieved with good electronic design to obviate the need for an EMI shield or anticipating the inclusion of an EMI shield. Moreover; the EMI shielding design should be optimized to meet the EMC requirements with the cost as low as possible. This also has increased the demand to select the correct EMI shielding materials and to develop new materials for EMI shielding applications. Many factors must be taken into account in order to arrive at the correct solution. The equation for emissions from a basic circuit is:

$$E = 1.316\,AIF^2/(dS) \qquad (1)$$

Where: E = field strength in μV/m; A = loop area in square centimeters; I = drive current in amps; F = frequency in megahertz; d = separation distance in meters; S = shielding ratio between source and point of measurement.

Equation 1 shows that frequency is the biggest contributor because the emissions increase as the square of the frequency (F) increases. For current (I); emissions increase linearly; which is also true for loop area (A). The distance (d) is set by the test specification; and 1.316 is a constant. The system designer has no control over these last two parameters; so they must not be considered. The equation for susceptibility (the tendency of an electrical circuit to absorb EMI/RFI); is:

$$V_i = 2\pi AEFB/(300S) \qquad (2)$$

Where Vi = volts induced into the loop; A = loop area in square meters; E = field strength in volts per meter; F = frequency in megahertz; B = bandwidth factor (in band: B = 1; out of band: B = circuit attenuation); and S = shielding (ratio) protecting circuit.

Equation 2 indicates that the susceptibility is directly proportional to loop area (A); frequency (F); and the bandwidth factor (B). Frequency (F) is dictated by the specification and the operating environment; as is the field strength (E). Of course; the engineer has no control over 2π; or 300; which is the speed of light divided by 1;000;000 for this equation.

Current conductive compounds products do not readily provide the levels of attenuation required by new standards...

From these two equations; it is possible to determine some key information. Emission levels are directly related to loop area; directly related to signal current; a function of frequency squared and inversely related to shielding effectiveness. Susceptibility levels are directly related to loop area; directly related to bandwidth; and directly related to the transmitted frequency and field strength.

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To reduce the effect of interference; product designers have a number of options:

- Use special shielding techniques; such as conductive compounds
- Move components
- Add/change ground planes
- Reduce the length of noisy printed circuit board traces and wires
- Match driver and return circuit traces or cables to cancel magnetic signals and reduce loop area
- Add special components; i.e.; inductors; capacitors; resistors; or combinations of these parts
- Change circuit components to less noisy components
- Add ferrite products (ferrites absorb EMI energy and dissipate as small amounts of heat.)

For conducted EMI, shielding techniques have little to no effect on performance. The noise (EMI) needs to be eliminated while not eliminating the desired signals. Using an electronic filter to selectively remove the offending noise and allow through the good signals generally solves this. Most filters are frequency specific. Ferrites can act as filters and absorbers.

For radiated EMI, shielding techniques can be quite successful in mitigating the interference. Technical requirements for EMI/RFI shielding depend on a wide variety of design considerations; including: wired systems; wireless systems; operating frequency; materials compatibility; corrosion considerations; EMC compliance specification (SAE; General Motors; etc.); operating environment; load and forces; cost; attenuation performance; storage environment; oil and fuel resistance; cycle life; shielding; grounding; electrical requirements; materials thickness; space and weight considerations; and product safety.

Table 1 shows the operating frequency ranges for both wired and wireless communication systems along with the projected EMI/RFI shielding effectiveness requirements at the operating frequencies. Figure 3 shows the Federal Communications Commission (FCC) licensed radio frequencies for selected applications.

Table 1. Operating Frequency Ranges and Shielding Effectiveness for Wire and Wireless Communication

Data and Voice Communication Systems	Approximate Operating Frequency (MHz)	Shielding Effectiveness Required (dB)
Cat 3 connectors	10	Unknown
Cat 4 connectors	20	Unknown
Cat 5e connectors	100	60
Cat 6 connectors	250	54
Cat 6a connectors	450	50
Cat 7 connectors	600	60
Cat 7a connectors	900	60

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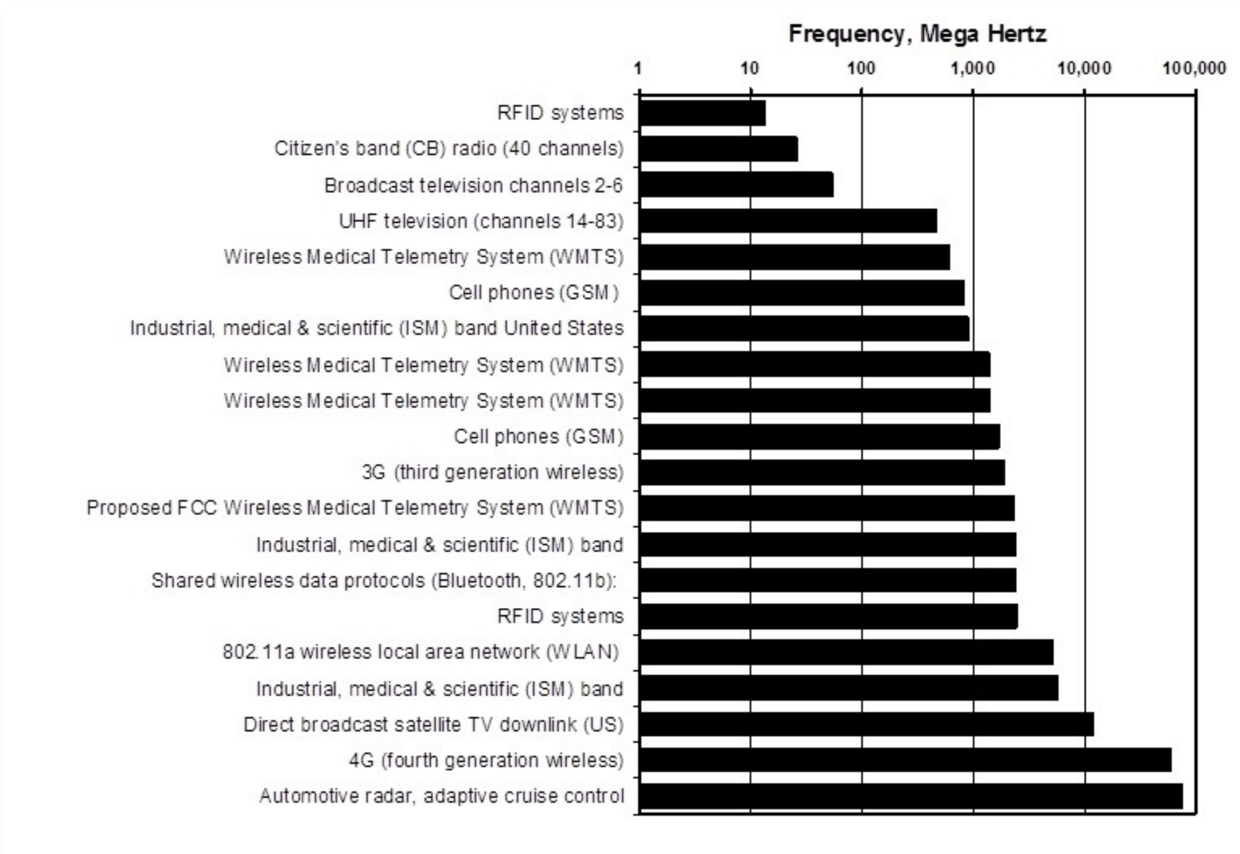

Figure 3. Selected Licensed Frequencies for Commonly Encountered Wireless Systems

Control of Alien Crosstalk in Communication Systems

Today's high speed data communication systems, while compact in design, enable alien crosstalk – interference due to electromagnetic emission from adjacent data transmission lines that affects data integrity. An example of affected data transfer devices is the Cat 6 cabling and connectors for internet connection for mass connection (offices; computer banks; etc); such as seen in Figure 4. Data digital pulses (binary 0's and 1's) generate electromagnetic emissions (EM interference). As data speeds get faster; the digital pulses generate a wider range of spectral emissions as compared to slow pulses.[VI] Speeds are getting faster and faster (up to 25 Gigabits per second). Therefore; EMI emissions are more complex and crosstalk between data transmission lines is becoming more relevant in connector designs today and is expected to become more prevalent in the future.

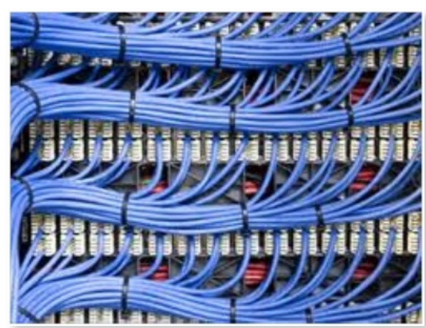

Figure 4. Densely Packed Cables

PolyOne Corporation has been providing nylon; liquid crystal; polycarbonate; and polyester polymer formulations for several years to provide EMI/RFI shielding for electronic connectors used in Category 5e connectors (the connectors used to attach desktop and laptop computers to local area networks.) Cat 5e systems operate at 100 Gigahertz and typically require 60 dB of attenuation.

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PSANEXT (Brown Pair)

Front Housing Material	Freq.	Value	Limit	Margin	Status
[illegible]506	481.0 MHz	48.09 dB	49.77 dB	-1.68 dB	Fail
[illegible]507	499.0 MHz	46.78 dB	49.53 dB	-2.75 dB	Fail
[illegible]508	494.0 MHz	48.91 dB	49.59 dB	-0.69 dB	Fail
[illegible]509	499.0 MHz	49.49 dB	49.53 dB	-0.34 dB	Fail

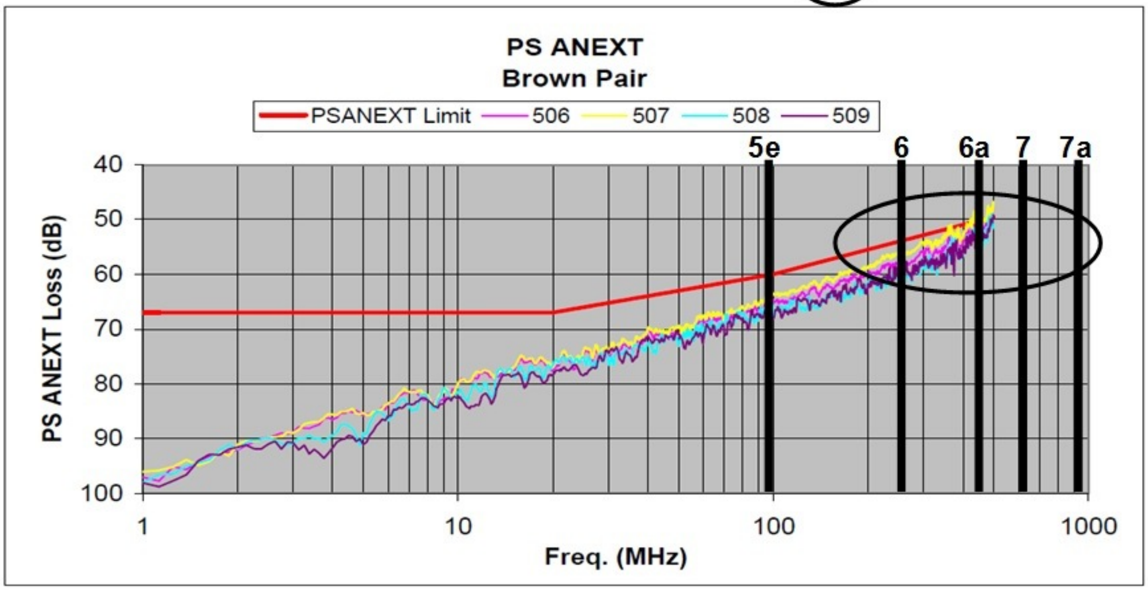

Figure 5. Older EMI/RFI Shielding Compounds Met Cat 5e and Cat 6 but Fail to Meet Cat 6a Shielding Needs

Higher data transmission speeds are requiring the use of Category 6; 6a; 7; 7a and 8 connectors and cables which operate at frequencies of 500 to 1;800 Gigahertz. Older EMI/RFI formulations are unable to provide compliant EMI/RFI shielding at the higher frequencies as shown above in Figure 5.

PolyOne undertook an extensive in-house effort to develop new polymer formulations to control alien crosstalk between cables and connectors. Candidate formulations were tested following the procedures prescribed in TIA 568-C.2 (Telecommunications Industry Association standard governing balanced twisted pair cabling systems in commercial buildings). The test method requires 7 cables. One victim cable is surrounded by 6 cables (bundle) as shown in Figure 6. 100 meters of the seven cable bundle were wrapped and draped in an enclosed adjacent room (suspended & hung). Connector jacks (7 input and 7 output) were set up for testing the shielded jacks ("victim" jack in the center).

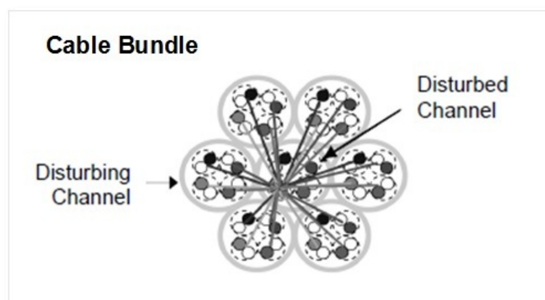

Figure 6. TIA 568-C.2 Alien Crosstalk Test Setup

Electrical test meters that generate and receive signals across the "disturber" and "victim" cables respectively were used in the testing. The data were sent to a computer and the dB of signal "shielding" or data integrity was measured.

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Permanent Link Average PSANEXT (Cat 6A U/UTP CMR)
Worst Margin (dB)

Pair	PC-1552510	PC-1552511	PC-1552512	
Average	7.2 dB @ 156.5 MHz	7.0 dB @ 156.5 MHz	6.9 dB @ 156.0 MHz	

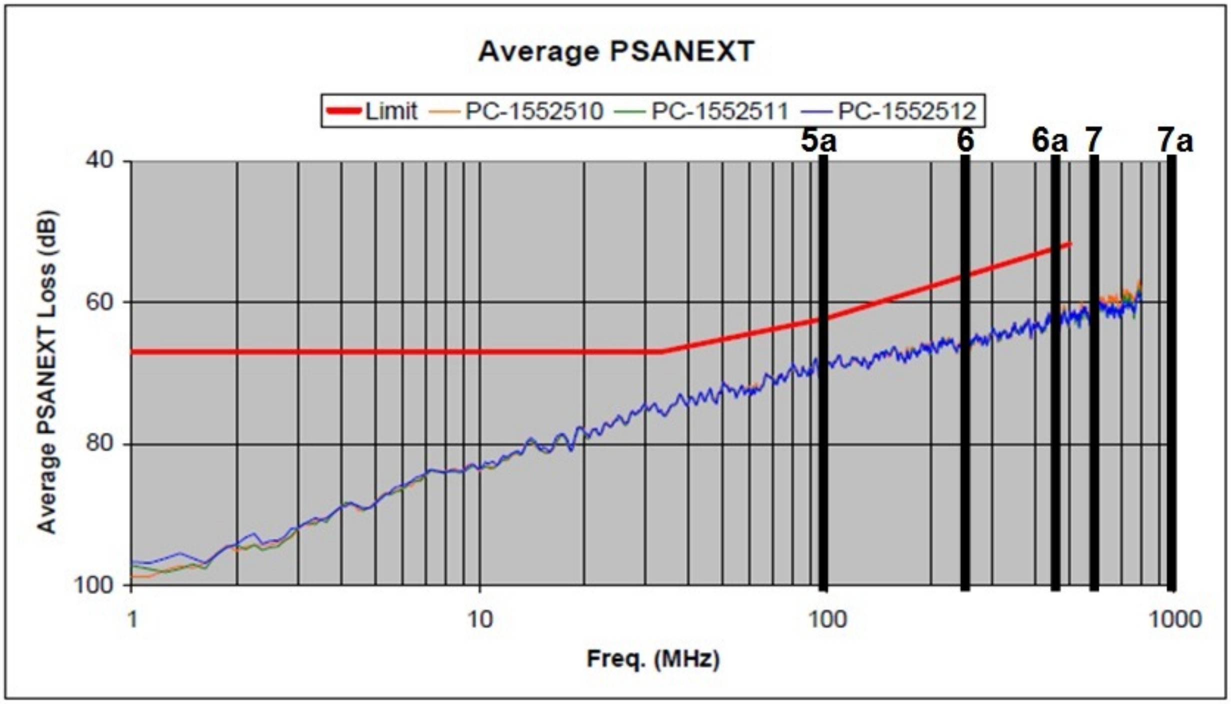

Figure 7. PolyOne Corp.'s New EMI/RFI Shielding Compounds Meet Shielding Requirements for Category 6; 6a; 7 and 7a Systems

Research and development recently conducted by PolyOne has enabled the company to provide EMI/RFI polymer formulations which exceed the shielding requirements for today's demanding wireless devices used in medical devices, data communication systems, industrial systems, and electrical and electronic systems as shown above in Figure 7.

Faster data communication speeds at higher frequencies are resulting in increasing levels of EMI, affecting data transmission and integrity. Conventional EMI/RFI shielding formulations have been unable to provide sufficient attenuation. Newly developed EMI/RFI shielding formulations have demonstrated the ability to exceed performance requirements for these demanding applications.

I. *Based on the "interference" entry of The Concise Oxford English Dictionary; 11th edition; online*
II. *US Department of Energy; http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html*
III. *http://www.radiosky.com/journal0901.html*
IV. *RadioSky Journal Radio frequency interference / editors;*
V. *Charles L. Hutchinson; Michael B. Kaczynski ; contributors; Doug DeMaw ... [et al.]. 4th ed. Newington; CT American Radio Relay League c1987.*
VI. *Radio frequency interference handbook. Compiled and edited by Ralph E. Taylor. Washington Scientific and Technical Information Office; National Aeronautics and Space Administration; [was for sale by the National Technical Information Service; Springfield; Va.] 1971. Introduction to EMC; Second Edition; Clayton R. Paul; 2006*

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