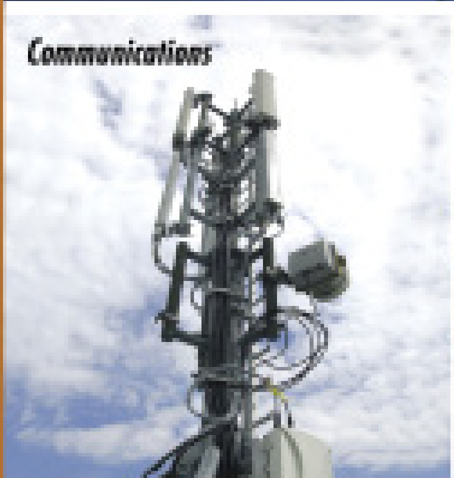
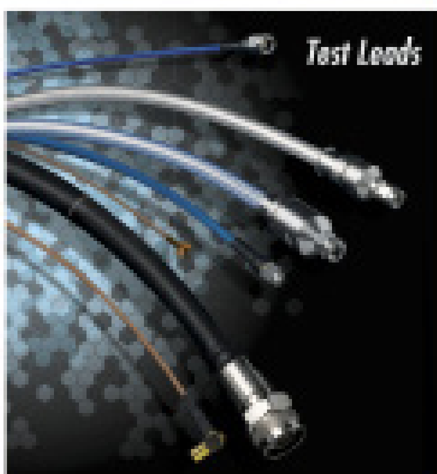
Harbour
INDUSTRIES

RF Microwave Coaxial Cable





Harbour
INDUSTRIES
High Performance Wire & Cable

Harbour Industries LLC is the preeminent manufacturer of high temperature and high performance coaxial cables for the military, aerospace, commercial, and industrial markets. Design and process engineering expertise ensure high quality and uniform products in accordance with customer specifications. Harbour Industries has a wide range of manufacturing processes with large scale production operations and "First-in-Class" customer service.

Harbour manufactures QPL approved MIL-DTL-17 Coax cables swept for VSWR to ensure product uniformity. For many years, Harbour has also been manufacturing special versions of MIL-DTL-17 cables such as HS High Strength and TRX Triaxial constructions to meet demanding customer requirements.

In the 1980's and 1990's, Harbour developed a series of LL Low Loss, SB Strip Braid, and SS Spiral Strip series of coaxial cables for the RF and Microwave markets. Techniques such as composite strip braid configurations and proprietary expanded PTFE tape dielectrics were developed, thereby creating a cost effective viable source of supply for assembly houses and OEMs.

Moving into the 21st century, through the use of special materials and innovative construction techniques, Harbour continues to enhance their product offering with coaxial cables that are lighter weight, more flexible, and have higher levels of shielding effectiveness. Explore Harbour's catalog for just a few of the cables offered.

Harbour is an ISO 9001-2008 manufacturer with facilities that are fully compliant to the directives of RoHS, REACH, DFARS, WEEE, ELV and BFR.

Harbour Industries Facility in Shelburne, Vermont.

ISO 9001 QMI REGISTERED QUALITY SYSTEM

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COAXIAL CABLES

LL (Low Loss) Coaxial Cable
-solid center conductors

Construction:
Center Conductor: Solid silver plated copper
Dielectric: Expanded PTFE tape
Inner Braid: Flat silver plated copper strip
Inter layer: Aluminum polyester or polyimide tape
Outer Braid: Round silver plated copper
Jacket: FEP, translucent colors, solid colors or clear

Operating temperature -55 +200° C
Velocity of Propagation 80%-83%
Impedence 50 Ohms
Capacitance 25.0 pF/ft
Shielding Effectiveness <-95 dB

	LL120	LL160	LL142	LL235	LL335	LL335i
Center conductor diameter	.0285″	.0403"	.051″	.057″	.089″	.089″
Dielectric diameter	.080″	.110"	.145″	.160″	.250″	.250″
Diameter over inner braid	.086″	.116"	.152″	.170″	.255″	.255″
Diameter over interlayer	.092″	.122"	.158″	.175″	.261″	.261″
Diameter over outer braid	.108″	.140"	.178″	.191″	.280″	.277″
Overall diameter	.120″	.160"	.195″	.235″	.335″	.300″
Weight(lbs/mft)	17	21	44	48	100	76
Bend radius	0.6″	0.8"	1.0″	1.2″	1.7″	1.5″
Attenuation (dB/100ft) @	**Typ / Max**	**Typ / Max**	**Typ / Max**	**Typ / Max**	**Typ / Max**	**Typ / Max**
400 MHz	8.3 / 12.0	6.4 / 7.1	4.5 / 6.5	4.2 / 5.0	2.9 / 3.5	2.9 / 3.5
1 GHz	13.1 / 18.0	10.2 / 11.2	7.2 / 10.0	6.7 / 8.0	4.6 / 5.5	4.6 / 5.5
2 GHz	18.7 / 25.0	14.6 / 16.0	10.3 / 14.0	9.6 / 11.4	6.6 / 7.8	6.6 / 7.8
3 GHz	23.0 / 30.0	18.0 / 19.6	12.7 / 17.0	11.9 / 14.0	8.2 / 9.5	8.2 / 9.5
5 GHz	29.9 / 38.0	23.4 / 25.7	16.6 / 21.0	15.5 / 18.0	10.8 / 12.5	10.8 / 12.5
10 GHz	42.8 / 54.0	33.6 / 36.9	24.0 / 30.0	22.5 / 27.0	15.8 / 19.0	15.8 / 19.0
18 GHz	58.2 / 74.0	45.9 / 50.4	33.0 / 40.0	31.0 / 37.0	21.9 / 26.00	21.9 / 26.0
Cut-off frequency (GHz)	64.0	42.0	32.9	23.0	18.0	18.0

Although higher cut-off frequencies are referenced, attenuation is tested only up to 18 Ghz. If a higher frequency performance is required, please contact the factory.

LL (Low Loss) Coaxial Cable
-solid center conductors

Unique cable design
The braid configuration and the expanded PTFE dielectrics of the LL cable constructions contribute to lower attenuation levels at higher frequencies, while providing shielding effectiveness levels that exceed those of flexible MIL-DTL-17 cables. Flat strips of silver plated copper are braided over the dielectric core with an intermediate metallized polyester or polyimide layer, and an outer round wire braid.

Excellent electrical characteristics
All of Harbour's LL cables with expanded PTFE dielectrics exhibit low coefficients of expansion over the entire operating temperature range from -55° C to +200° C. Impedance discontinuities are minimized at the cable-to-connector interface. Higher levels of power can be transmitted because higher temperatures do not affect the cable due to the thermal stability of the tape. Where phase versus temperature requirements are critical, Harbour's LL cables allow for an approximately 75% lower phase shift and change in propagation time delay due to temperature. Temperature cycling tests have been performed on a number of Harbour's cables with positive results.

Lowest attenuation for any given size
Harbour's LL coaxial cables, with expanded PTFE dielectrics and strip braid composite configurations, offer attenuation from 20 to 35% below other mil spec cables of comparable size. When size and weight are considerations, Harbour's LL cables should be specified.

Attenuation Calculation and K Factors
Although typical and maximum attenuation values are given for discrete frequencies, typical attenuation values may be calculated by using K1 and K2 factors for each construction. The K1 factor is calculated by taking into consideration the type, strand factor, and diameter of the center conductor, and the impedance of the cable. The K2 factor is calculated by taking into consideration the velocity of propagation and the dissipation factor of the dielectric.

Formula for Calculating Attenuation using K Factors:

Attenuation (dB/100 ft) at any frequency (**MHz**) =
$$(K1 \times \sqrt{\text{frequency}}) + (K2 \times \text{frequency})$$

	LL120	LL160	LL142	LL235	LL335/LL335i
K1	.410	.318	.222	.207	.141
K2	.0001785	.0001785	.0001785	.0001785	.0001674

LL (Low Loss) Coaxial Cable
-stranded center conductors

Construction:
Center Conductor: Stranded silver plated copper
Dielectric: Expanded PTFE tape
Inner Braid: Flat silver plated copper strip
Inter layer: Aluminum polyester or polyimide tape
Outer Braid: Round silver plated copper
Jacket: FEP, translucent colors, solid colors or clear

Operating temperature -55 +200° C
Velocity of Propagation 80%-83%
Impedence 50 Ohms
Capacitance 25.0 pF/ft
Shielding Effectiveness <-95 dB

	LL142STR	LL270STR	LL450STR	LL480STR
Center conductor diameter	.051″ (7/.017")	.068" (7/.023")	.133″ (7/.048")	.160" (7/.054")
Dielectric diameter	.138″	.185″	.360″	.420"
Diameter over inner braid	.146″	.195″	.368″	.432"
Diameter over interlayer	.151″	.200″	.374″	--
Diameter over outer braid	.167″	.220″	.394″	.452"
Overall diameter	.195″	.270″	.450″	.480"
Weight(lbs/mft)	44	70	165	197
Bend radius	1.0″	1.4″	2.2″	2.4"
Attenuation (dB/100ft) @	**Typ / Max**	**Typ / Max**	**Typ / Max**	**Typ / Max**
400 MHz	6.0 / 7.0	4.3 / 4.5	2.2 / 2.3	1.9 / 2.2
1 GHz	9.5 / 11.1	6.9 / 7.3	3.5 / 3.7	3.0 / 3.3
2 GHz	13.5 / 15.6	9.8 / 10.6	5.0 / 5.6	4.4 / 4.9
3 GHz	16.6 / 19.0	12.1 / 13.4	6.3 / 7.1	5.5 / 6.0
5 GHz	21.7 / 24.0	15.9 / 18.0	8.3 / 10.0	7.3 / 8.1
10 GHz	31.2 / 35.0	23.0 / 26.0	12.2 / 13.3	10.8 / 11.8
18 GHz	42.7 / 43.0	31.7 / 36.0	- / -	- / -
Cut-off frequency (GHz)	32.0	24.0	12.8	11.0

Although higher cut-off frequencies are referenced, attenuation is tested only up to 18 Ghz. If a higher frequency performance is required, please contact the factory.

LL (Low Loss) Coaxial Cable
-stranded center conductors

Flexibility with stranded center conductors
Harbour's Low Loss coax designs with stranded center conductors are more flexible than similar designs with solid center conductors. Low loss cables with stranded center conductors exhibit attenuation slightly higher than comparable solid center conductor designs; however, unique composite braid configurations and expanded PTFE dielectrics result in attenuation lower than MIL-DTL-17 cables of comparable size. Shielding effectiveness levels also exceed those of flexible MIL-DTL-17 constructions.

Excellent electrical characteristics
All of Harbour's LL cables with expanded PTFE dielectrics exhibit low coefficients of expansion over the entire operating temperature range from -55° C to +200° C. Impedance discontinuities are minimized at the cable-to-connector interface. Higher levels of power can be transmitted because higher temperatures do not affect the cable due to the thermal stability of the tape. Where phase versus temperature requirements are critical, Harbour's LL cables allow for an approximately 75% lower phase shift and change in propagation time delay due to temperature. Temperature cycling tests have been performed on a number of Harbour's cables with positive results.

Attenuation Calculation and K Factors
Although typical and maximum attenuation values are given for discrete frequencies, typical attenuation values may be calculated by using K1 and K2 factors for each construction. The K1 factor is calculated by taking into consideration the type, strand factor, and diameter of the center conductor, and the impedance of the cable. The K2 factor is calculated by taking into consideration the velocity of propagation and the dissipation factor of the dielectric.

Formula for Calculating Attenuation using K Factors:

Attenuation (dB/100 ft) at any frequency (**MHz**) =
$$(K1 \times \sqrt{\text{frequency}}) + (K2 \times \text{frequency})$$

	LL142STR	LL270STR	LL450STR	LL480STR
K1	.294	.212	.105	.091
K2	.0001785	.0001785	.0001674	.0001674

SB (Strip Braid) Coaxial Cable

Construction:
Dielectric: solid PTFE
Inner braid: flat silver plated copper strip
Interlayer: aluminum polimide polyester tape
Outer braid: round silver plated copper
Jacket: FEP, translucent colors, solid colors or clear

Operating temperature: -55 +200° C
Velocity of Propagation: 70%
Impedence: 50 Ohms
Capacitance: 29.4 pF/ft
Shielding Effectiveness: <-95 dB

	SB316	SB142	SB142i	SB400	SB304	SB393
Center conductor	SCCS	SCCS	SCCS	SPC	SCCS	SPC
Center conductor diameter	.020″ (7/.0067″)	.037″ Solid	.037″ Solid	.0385″ (19/.008″)	.059″ Solid	.094″ (7/.031″)
Dielectric diameter	.060″	.117″	.117″	.116″	.185″	.285″
Diameter over inner braid	.067″	.128″	.128″	.126″	.195″	.295″
Diameter over interlayer	.072″	.133″	.133″	.132″	.201″	.301″
Diameter over outer braid	.088″	.152″	.149″	.152″	.221″	.325″
Overall diameter	.098″	.195″	.172″	.195″	.280″	.390″
Weight (lbs/mft)	12	40	40	47	77	155
Bend radius	0.5″	1.0″	0.9″	1.0″	1.4″	2.0″
Attenuation (dB/100 ft) @	**Typ/Max**	**Typ/Max**	**Typ/Max**	**Typ/Max**	**Typ/Max**	**Typ/Max**
400 MHz	14.5 / 18.0	6.4 / 8.0	6.4 / 8.0	6.8 / 8.5	5.0 / 5.8	3.3 / 3.8
1 GHz	23.3 / 29.0	10.5 / 13.0	10.5 / 13.0	11.1 / 13.8	8.3 / 9.8	5.6 / 6.5
2 GHz	33.5 / 40.0	15.5 / 18.0	15.5 / 18.0	16.2 / 20.0	12.3 / 15.0	8.5 / 10.0
3 GHz	41.6 / 51.0	19.5 / 23.3	19.5 / 23.3	20.4 / 24.9	15.6 / 18.9	10.9 / 13.0
5 GHz	54.8 / 68.0	26.3 / 30.0	26.3 / 30.0	27.5 / 33.0	21.3 / 26.2	15.2 / 18.0
10 GHz	80.4 / 100.0	40.1 / 45.0	40.1 / 45.0	41.8 / 50.0	33.0 / 41.5	24.4 / 30.0
18 GHz	112.4 / 150.0	58.3 / 64.0	58.3 / 64.0	60.6 / 70.0	48.8 / 58.3	- / -
Cut-off frequency (Ghz)	57.0	34.2	34.2	29.0	21.6	13.9

Although higher cut-off frequencies are referenced, attenuation is tested only up to 18 Ghz. If a higher frequency performance is required, please contact the factory.

SB (Strip Braid) Coaxial Cable

Harbour's SB coaxial cables have been designed for low attenuation at high frequencies, while using similar dimensions to MIL-DTL-17 constructions. Standard connectors may frequently be used, thereby avoiding tooling charges.

Solid PTFE dielectrics are manufactured with tight tolerances to ensure impedance uniformity and to effect VSWR levels that meet or exceed MIL-DTL-17 specifications for cables of comparable size. The strip braid configuration is by far the most effective means of lowering attenuation levels of coaxial cable at high frequencies while providing shielding effectiveness levels that exceed those of flexible MIL-DTL-17 cables. Flat strips of silver plated copper are braided over the dielectric core, frequently with an intermediate metallized mylar or kapton layer, and an outer round wire braid. This shielding technique provides superior shielding effectiveness and lower transfer impedance than any standard double braided mil-spec construction.

FEP jackets are typically used, but alternate designs are available such as flame retardant PVC and abrasion resistant overall braids. Marker tapes or surface printing are used for positive identification.

The chart on the following page outlines just a few designs Harbour manufactures. Some of the more popular constructions are standard stock items, and many additional cables are available for prototype assemblies. Many cables not referenced have been designed to meet specific customer requirements.

Attenuation Calculation and K Factors

Although typical and maximum attenuation values are given for discrete frequencies, typical attenuation values may be calculated by using K1 and K2 factors for each construction. The K1 factor is calculated by taking into consideration the type, strand factor, and diameter of the center conductor, and the impedance of the cable. The K2 factor is calculated by taking into consideration the velocity of propogation and the dissipation factor of the dielectric.

Formula for Calculating Attenuation using K Factors:

Attenuation (dB/100 ft) at any frequency (**MHz**) =

$$(K1 \times \sqrt{\text{frequency}}) + (K2 \times \text{frequency})$$

	SB316	SB142/SB142i	SB400	SB304	SB393
K1	.705	.302	.319	.231	.145
K2	.00099	.00099	.00099	.00099	.00099

SS (Spiral Strip) Coaxial Cable

Construction:
Center conductor: Solid silver plated copperweld
Dielectric: Solid PTFE
Inner shield: Spiral strip of silver plated copper
Outer braid: Round silver plated copper
Jacket: Solid blue FEP

Operating temperature: -55 +200° C
Velocity of Propagation: 70%
Shielding Effectiveness: <-110 dB

	SS402	**SS405**	**SS75086**
Center conductor diameter	.037″	.0201″	.0113″
Dielectric diameter	.117″	.064″	.064″
Diameter over inner shield	.125″	.071″	.074″
Diameter over outer braid	.138″	.086″	.082″
Overall diameter	.163″	.104″	.102″
Weight (lbs/mft)	32	14	14
Bend radius	0.8″	0.5″	0.5″
Impedance (Ohms)	50	50	75
Capacitance (pF/ft)	29.4	29.4	19.5
Attenuation (dB/100ft) @	**Typ/Max**	**Typ/Max**	**Typ/Max**
400 MHz	6.4 / 8.0	11.9 / 14.0	12.4 / 13.6
1 GHz	10.5 / 13.0	19.2 / 23.0	19.9 / 21.9
2 GHz	15.5 / 18.5	27.7 / 32.0	28.8 / 31.6
2.4 GHz	17.2 / 20.0	30.6 / 35.0	31.7 / 34.9
3 GHz	19.5 / 23.0	34.5 / 39.0	35.8 / 39.4
5 GHz	26.3 / 30.0	45.7 / 52.0	-
10 GHz	40.1 / 45.0	67.5 / 80.0	-
18 GHz	58.3 / 64.0	95.1 / 110.0	-
Cut-off frequency (GHz)	34.0	63.0	72.0

Although higher cut-off frequencies are referenced, attenuation is tested only up to 18 Ghz. If a higher frequency performance is required, please contact the factory.

SS (Spiral Strip) Coaxial Cable

Harbour's SS coaxial cables are flexible alternatives to semi-rigid coax, and the unique shielding configuration offers a cost effective, low attenuation option. The use of strip/round braid composite shields results in low transfer impedance levels. The 50 ohm constructions exhibit the same attenuation characteristics as the M17/130-RG402 and M17/133-RG405 cables. All SS cables have VSWR characteristics that meet or exceed similar size flexible constructions. SS402 and SS405 have been designed with diameters over the outer braids of .141" and 086" respectively, so standard SMA connectors may be used.

An overall FEP jacket is resistant to oil and chemicals. The cable is either unmarked or surface printed eliminating a marker tape that may cause problems in termination. Without the marker tape, an improved level of adhesion exists between the braided core and the jacket that allows ease of termination with short length assemblies.

Attenuation Calculation and K Factors

Although typical and maximum attenuation values are given for discrete frequencies, typical attenuation values may be calculated by using K1 and K2 factors for each construction. The K1 factor is calculated by taking into consideration the type, strand factor, and diameter of the center conductor, and the impedance of the cable. The K2 factor is calculated by taking into consideration the velocity of propogation and the dissipation factor of the dielectric.

Formula for Calculating Attenuation using K Factors:

Attenuation (dB/100 ft) at any frequency (**MHz**) =
$(K1 \times \sqrt{\text{frequency}}) + (K2 \times \text{frequency})$

	SS402	SS405	SS75086
K1	.302	.576	.599
K2	.00099	.00099	.00099

SBF (Strip Braid Flex™) Coaxial Cable

Construction:
Center conductor: Stranded silver plated copper
Dielectric: Solid PTFE
Inner braid: Flat silver plated copper strip
Outer braid: Round silver plated copper
Jacket: Solid light blue specially formulated
compound (-105Flex) or translucent blue FEP
Velocity of Propagation: 70%
Shielding Effectiveness: <-90 dB

	SBF402-105Flex	**SBF402FEP**	**SBF405-105Flex**	**SBF405FEP**
Center conductor	SPC	SPC	SPC	SPC
Center conductor diameter	.0376″ (7/28)	.0376" (7/28)	.0210″ (7/33)	.0210" (7/33)
Dielectric diameter	.117″	.117"	.063″	.063"
Diameter over inner braid	.124″	.124"	.071″	.071"
Diameter over outer braid	.138″	.138"	.085″	.085"
Overall diameter	.180″	.158"	.115″	.105"
Jacket	-105Flex	FEP	-105Flex	FEP
Weight (lbs/mft)	29	29	14	14
Bend radius	0.9″	0.9"	0.6″	0.6"
Impedance (Ohms)	50	50	50	50
Capacitance (pF/ft)	29.4	29.4	29.4	29.4
Operating Temperature	-55ºC +105ºC	-55ºC +200ºC	-55ºC +105ºC	-55ºC +200ºC
Attenuation (dB/100ft)@	**Typ/Max**	**Typ/Max**	**Typ/Max**	**Typ/Max**
400 MHz	7.0 / 9.0	7.0 / 9.0	13.6 / 14.8	13.6 / 14.8
1 GHz	11.5 / 14.5	11.5 / 14.5	21.8 / 23.7	21.8 / 23.7
2 GHz	16.8 / 21.9	16.8 / 21.9	31.4 / 35.4	31.4 / 35.4
2.4 GHz	18.6 / 23.3	18.6 / 23.3	34.6 / 39.1	34.6 / 39.1
3 GHz	21.1 / 24.1	21.1 / 24.1	39.0 / 47.9	39.0 / 47.9
5 GHz	28.4 / 32.8	28.4 / 32.8	51.5 / 58.2	51.5 / 58.2
10 GHz	43.0 / 50.0	43.0 / 50.0	75.7 / 86.4	75.7 / 86.4
18 GHz	62.2 / 73.5	62.2 / 73.5	106.1 / 113.9	106.1 / 113.9
Cut-off frequency GHz	34.0	34.0	63.0	63.0

SBF (Strip Braid Flex™) Coaxial Cable

Harbour's SBF Strip Braid Flex™ coaxial cables, more flexible and supple versions of the industry standard SS Spiral Strip constructions, have been designed with a specially formulated 105ºC jacket compound and stranded silver plated copper center conductors. These 50 ohm versions exhibit VSWR levels that meet or exceed similar size flexible constructions, and just like their SS cable counterparts, offer excellent shielding effectiveness with readily available connectors.

Although the insertion loss is slightly higher than their SS cable counterparts, SBF attenuation levels through 18 GHz are substantially lower than comparable MIL-DTL-17 constructions.

SBF Strip Braid cables have also been designed with FEP jackets if a higher 200ºC temperature is required.

Attenuation Calculation and K Factors

Although typical and maximum attenuation values are given for discrete frequencies, typical attenuation values may be calculated by using K1 and K2 factors for each construction. The K1 factor is calculated by taking into consideration the type, strand factor, and diameter of the center conductor, and the impedance of the cable. The K2 factor is calculated by taking into consideration the velocity of propogation and the dissipation factor of the dielectric.

Formula for Calculating Attenuation using K Factors:

Attenuation (dB/100 ft) at any frequency (**MHz**) =
$$(K1 \times \sqrt{\text{frequency}}) + (K2 \times \text{frequency})$$

	SBF402-105Flex SBF402FEP	SBF405-105Flex SBF405FEP
K1	.331	.658
K2	.00099	.00099

MIL-DTL-17 Coaxial Cables
- including M17/176-00002 Twinaxial Data Bus Cable

Harbour Industries is a QPL approved manufacturer of high temperature, high performance coaxial cables supplied in exact accordance with the MIL-DTL-17 specification. The information referenced has been taken from the MIL-DTL-17 "slant sheets" which define complete physical and electrical characteristics for each MIL-DTL-17 part number including dimensional parameters, dielectric materials, shield constructions, VSWR, and maximum attenuation over various frequency ranges. For complete individual slant sheets, see the Defense Supply Center Columbus (DSCC) link in the Industry Links section of Harbour's website.

The Importance of VSWR Sweep Testing
When selecting a 50 ohm coaxial cable, constructions with VSWR requirements are highly recommended. Manufacturing and sweep testing cables with concern for VSWR ensures a quality cable free of spikes over the frequency range referenced on the slant sheet.

Precision PTFE Dielectrics Used
All of the PTFE dielectric coax cables listed are high temperature, high performance constructions exhibiting high dielectric strength and low capacitance in proportion to the cable's dielectric constant. Harbour manufactures all PTFE dielectric cable constructions with tolerances tighter than the MIL-DTL-17 specification to ensure uniformity of electrical characteristics, especially impedance, attenuation, and VSWR.

Constructions with PTFE Tape Wrapped Jackets
Harbour manufactures PTFE tape wrapped cables - specifically RG187 A/U, RG188 A/U, RG195 A/U, and RG196 A/U - in accordance with a previous revision of the MIL-DTL-17 specification. These constructions can withstand operating temperatures up to 250 º versus 200º C for FEP jacketed cables. PTFE tape wrapped cables are generally more flexible than their FEP jacketed counterpart. Alternative 250º constructions are also available with PFA jackets.

M17 Part	Center Conductor	Dielectric Diameter	Shield	Shield Diameter	Jacket	Overall Diameter	Bend Radius	Weight (lbs/mft)	Comments
M17/60-RG142	.037" SCCS	.116"	SPC (2)	.160"	FEP	.195"	1.0"	43.0	
M17/93-RG178	.0120" (7/.004")SCCS	.033"	SPC	.051"	FEP	.071"	0.4"	6.3	
M17/94-RG179	.0120" (7/.004")SCCS	.063"	SPC	.080"	FEP	.100"	0.4"	10.8	
M17/95-RG180	.0120" (7/.004")SCCS	.102"	SPC	.118"	FEP	.141"	0.7"	19.8	
M17/111-RG303	.037" SCCS	.116"	SPC	.136"	FEP	.170"	0.9"	31.0	
M17/112-RG304	.059" SCCS	.185"	SPC (2)	.240"	FEP	.280"	1.4"	94.0	
M17/113-RG316	.0201" (7/.0067")SCCS	.060"	SPC	.075"	FEP	.098"	0.5"	12.2	
M17/127-RG393	.094" (7/.0312") SPC	.285"	SPC (2)	.314"	FEP	.390"	2.0"	165.0	
M17/128-RG400	.0384" (19/.008") SPC	.116"	SPC (2)	.156"	FEP	.195"	1.0"	50.0	
M17/131-RG403	.0120" (7/.004")SCCS	.033"	SPC (2)	.090"	FEP (2)	.116"	0.6"	15.0	Triaxial RG-178
M17/152-00001	.0201" (7/.0067")SCCS	.060"	SPC (2)	.091"	FEP	.114"	0.6"	18.5	Double Shield RG-316
M17/176-00002	.0235" (19/.005")SPA(2)	.042"	SPA	.100"	PFA	.129"	0.6"	18.0	Twinax
RG187 A/U	.0120" (7/.004")SCCS	.063"	SPC	.079"	PTFE	.100"	0.5"	10.0	Tape Wrapped Jacket
RG188 A/U	.0201" (7/.0067")SCCS	.060"	SPC	.080"	PTFE	.100"	0.5"	11.0	Tape Wrapped Jacket
RG195 A/U	.0129" (7/.004")SCCS	.102"	SPC	.117"	PTFE	.141"	0.7"	18.0	Tape Wrapped Jacket
RG196 A/U	.0120" (7/.004")SCCS	.034"	SPC	.050"	PTFE	.067"	0.4"	6.0	Tape Wrapped Jacket

MIL-DTL-17 Coaxial Cables

- including M17/176-00002 Twinaxial Data Bus Cable

				Attenuation (dB/100 ft)						
M17 Part	Impedance (ohms)	Capacitance (pF/ft)	Max Voltage	100 MHz Typ/Max	400 MHz Typ/Max	1 GHz Typ/Max	2.4 GHz Typ/Max	5 GHz Typ/Max	10 GHz Typ/Max	Max Frequency (GHz)
M17/60-RG142	50 +/-2	29.4	1900	3.8 / 4.4	8.1 / 9.3	13.7 / 15.3	23.3 / 25.0	37.4 / 41.8	60.0 / 70.7	12.4
M17/93-RG178	50 +/-2	29.4	1000	14.7 / 16.0	30.2 / 33.0	48.9 / 52.0	78.7 / 83.3			
M17/94-RG179	75 +/-3	19.4	1200		15.8 / 21.0					
M17/95-RG180	95 +/-5	17.4	1500	5.7 / 6.6	11.7 / 17.4	19.2 / 23.0				
M17/111-RG303	50 +/-2	29.4	1900	4.0 / 4.4	8.1 / 9.3	13.4 / 15.3				
M17/112-RG304	50 +/-2	29.4	3000	2.4 / 2.7	5.8 / 6.4	10.0 / 11.1	17.6 / 19.6	25.4 / 28.2		8.0
M17/113-RG316	50 +/-2	29.4	1200	7.8 / 11.0	16.0 / 21.0	26.3 / 38.0	43.0 / 55.4			3.0
M17/127-RG393	50 +/-2	29.4	1500	2.2 / 2.5	4.6 / 5.0	7.9 / 9.2	13.5 / 14.2	21.9 / 26.8	35.5 / 37.9	11.0
M17/128-RG400	50 +/-2	29.4	1900	4.1 / 4.5	8.6 / 10.5	14.2 / 18.1	23.6 / 30.2	37.0 / 52.1	57.8 / 78.0	12.4
M17/131-RG403	50 +/-2	29.4	1000		33.3 / 37.0					
M17/152-00001	50 +/-2	29.4	1200	7.6 / 11.0	16.0 / 21.0	26.2 / 38.0	41.2 / 55.4	61.3 / 110.0	90.0 / 170.0	12.4
M17/176-00002	77 +/-7	19.0	1000							
RG187 A/U	75 +/-3	19.4	1200		15.5 / 21.0					
RG188 A/U	50 +/-2	29.4	1200	7.6 / 11.0	16.0 / 21.0	26.2 / 38.0	41.2 / 55.4			3.0
RG195 A/U	95 +/-5	17.4	1500		11.7 / 17.4					
RG196 A/U	50 +/-2	29.4	1000	13.0 / 16.0	27.2 / 33.0	41.7 / 52.0	64.0 / 80.0			3.0

° UL approvals for many of the MIL-DTL-17 cables listed are available upon request.

° Maximum frequencies are those referenced on individual slant sheets of the MIL-DTL-17 specification. No values are given above 400MHz for unswept constructions because MIL-DTL-17 specification recommends these cables should not be used above this frequency.

° The MIL-DTL-17 specification references maximum attenuation values as shown in the above chart, however typical values are substantially lower. For the more popular constructions, the following K factors may be used to calculate typical attenuation at any specific frequency.

	M17/60-RG142	**M17/93-RG178**	**M17/94-RG179**	**M17/113-RG316**	**M17/128-RG400**	**M17/127-RG393**
K1	.355	1.420	.766	.750	.390	.200
K2	0.00245	0.0034	0.00119	0.0026	0.00188	0.00155

HS (High Strength) Coaxial Cable

Construction:

Center Conductor: stranded, silver plated copper clad steel (alloys optional)
Dielectric: solid PTFE
Braid: silver plated copper clad steel (alloys optional)
Jacket: FEP

Part Number	Center conductor diameter	Dielectric diameter	Diameter over inner braid	Overall diameter	Impedance (ohms)	Capacitance (pF/ft)
HS 178	.0120″ (7/.0040″)	.033″	.049"	.071″	50	32
HS 179	.0120″ (7/.0040″)	.063″	.080"	.100″	75	23
HS 180	.0120″ (7/.0040″)	.102″	.118"	.141″	95	17
HS 316	.0201″ (7/.0067″)	.060″	.076"	.098″	50	32

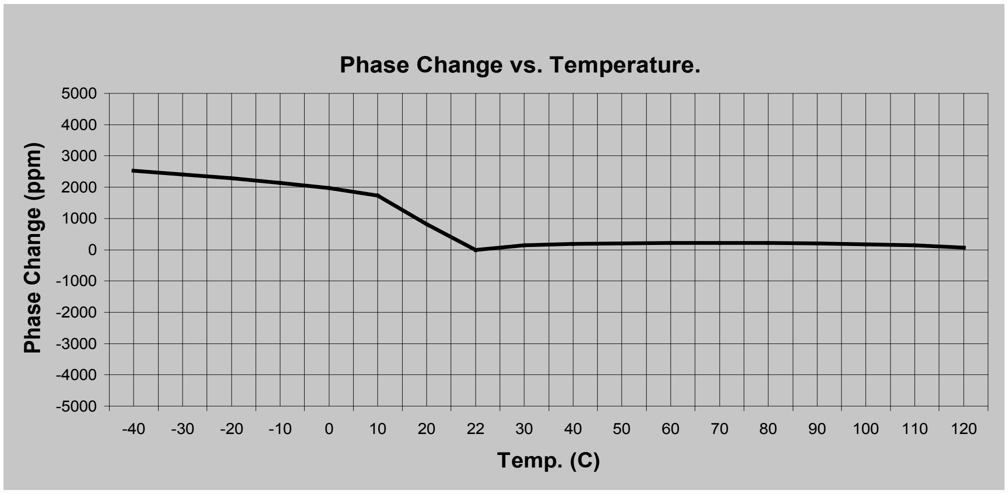
TRX (Triaxial) Cable

Construction:

Center Conductor: silver plated copper or copper clad steel
Dielectric: solid PTFE
Inner braid: silver plated copper
Interlayer: FEP
Outer Braid: silver plated copper
Jacket: FEP

Part Number	Center conductor diameter	Dielectric diameter	Diameter over inner braid	Diameter over interlayer	Diameter over outer braid	Overall diameter	Impedance (ohms)
M17/131-RG403	.0120″(7/.0040″)	.033″	.049″	.074″	.090″	.116″	50
TRX316	.0201″(7/.0067″)	.060″	.076″	.096″	.112″	.140″	50
TRX142	.037″ Solid	.116″	.136″	.166″	.186″	.215″	50
TRX400	.0384″(19/.008″)	.116″	.136″	.166″	.186″	.215″	50
TRX179	.0120″(7/.0040″)	.063″	.079″	.099″	.115″	.141″	75
TRX180	.0120″(7/.0040″)	.102″	.118″	.138″	.154″	.180″	95

Phase Stability over Temperature



Phase Change:
The electrical length for a given frequency will "shift" as a result of environmental changes. The ***degree*** of change is based on mechanical stresses, connector torque and thermal conditions.

The ***degree*** of phase shift as a result of temperature variation can be calculated by using the following formula:

$$\Delta\varphi = \varphi^* \left(\frac{ppm}{10^6}\right)$$

Before calculating the excepted phase shift there are a few additional questions that need to be answered.
→ What is the mecyhanical length of the assembly (ft)
→ What is the frequency of interest (Ghz)
→ What is the electrical length at the frequency of interest (φ)
→ What is the dielectric constant of the insulation (E)
→ What is the temperature of interest (°C)
Once these questions are answered the phase shift can be calculated.

For example, what would be the change in phase for a 10 ft of cable assembly of LL142 at 80°C at 18 Ghz?

Step 1: Calculate the electrical length using the following formula:

$$\varphi = 365.7 * \sqrt{E} * (ft) \text{ x } (Ghz)$$

$$\varphi = 365.7 * \sqrt{L478} * 10 \text{ x } 18 = 80{,}032°$$

Step 2: Using the chart above determine the parts per million (ppm) at 80°C

Step 3: Now solve

$$\Delta\varphi = \varphi^* \left(\frac{ppm}{10^6}\right)$$

$$\Delta\varphi = 80{,}032° * \left(\frac{212}{10^6}\right) = 16.97°$$

The cable assembly will become 16.97° longer at 80°C at 18 Ghz

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Power Handling Capability of Coaxial Cable

The power handling capability of coaxial cable is dependent either on its maximum voltage-withstanding capability for the transmission of peak power or on its thermal dissipation ability for average power transmission, which is the more common problem for RF applications. The thermal dissipation of cable depends upon its thermal resistance. For a cable in air, the thermal resistance of the surrounding air is related to the condition and radiation losses and dependent upon the surface area of the cable, the temperature of the surfaces, the ambient temperature, emissivity of the surface, and the flow of air.

The amount of heat which flows radially from the line will depend upon the composite thermal resistivity of the dielectric and insulating material of the cable, and the temperature gradients therein. The heat generated within a cable is given by the ratio of temperature rise between the inner conductor and the ambient temperature to its thermal resistance, which is equal to the difference of the input power and the output power in a matched system. The ratio of these powers is a function of the attenuation per unit length, which is directly proportional to the heat generated in the cable.

For any particular cable construction, the average power rating will depend on the permissible temperature rise above a stated ambient which is limited by the maximum operating temperature that the dielectric can withstand. The generally accepted maximum operating temperature for polyethylene is 80°C and for PTFE is 250°C. Simply stated, power handling of a coaxial cable is a function of attenuation and the temperature of the dielectric. The higher the operating frequency, the lower the power handling capability.

The chart references the maximum power handling capability at various frequencies for MIL-DTL-17 cables and Harbour's special cable constructions.

Maximum Power Handling Capability of Coaxial Cable (In Watts)

	Dielectric Diameter	Overall Diameter	@ Frequency				
			400MHz	1GHz	3Ghz	5GHz	10GHz
M17/RG178, CN178SC, CN178TC, RG196 A/U	.033"	.071"	123	78	41	28	14
M17/131-RG403	.033"	.116"	123	78	41	28	14
M17/113-RG316, CN316SC, CN316TC, RG188 A/U, SB316	.060"	.098"	240	160	80	57	30
M17/152-00001, CN316SCSC, CN316TCTC	.060"	.114"	240	160	80	57	30
M17/94-RG179, CN179SC, CN179TC, RG187 A/U	.063"	.100"	310	200	110	76	41
SS405, SBF405FEP	.064"	.104"	240	160	80	57	30
SS75086	.064"	.100"	240	160	80	57	30
SB405-105Flex	.063"	.115"	200	130	65	45	25
LL120	.080"	.120"	720	460	250	190	140
M17/95-RG180, RG195 A/U	.102"	.141"	400	250	135	93	50
M17/60-RG142, CN142SCSC, CN142TCTC	.116"	.195"	1100	550	350	245	140
M17/111-RG303	.116"	.170"	1100	550	350	245	140
M17/128-RG400, SB400	.116"	.195"	1100	550	350	245	140
SS402, SBF402FEP	.117"	.163"	1100	550	350	245	140
SB402-105Flex	.117"	.180"	880	440	280	200	110
SB142	.117"	.195"	1100	550	350	245	140
LL142	.145"	.195"	1200	720	400	310	220
LL235	.160"	.235"	1500	900	540	410	300
LL393-2	.185"	.270"	1900	1100	680	510	380
M17/112-RG304	.185"	.280"	1900	1100	680	510	380
SB304	.185"	.280"	1450	870	460	330	190
LL335	.250"	.335"	2900	1800	1050	850	600
M17/127-RG393, SB393	.285"	.390"	2800	1700	880	620	350
LL450	.360"	.450"	7250	4200	2200	1600	1015

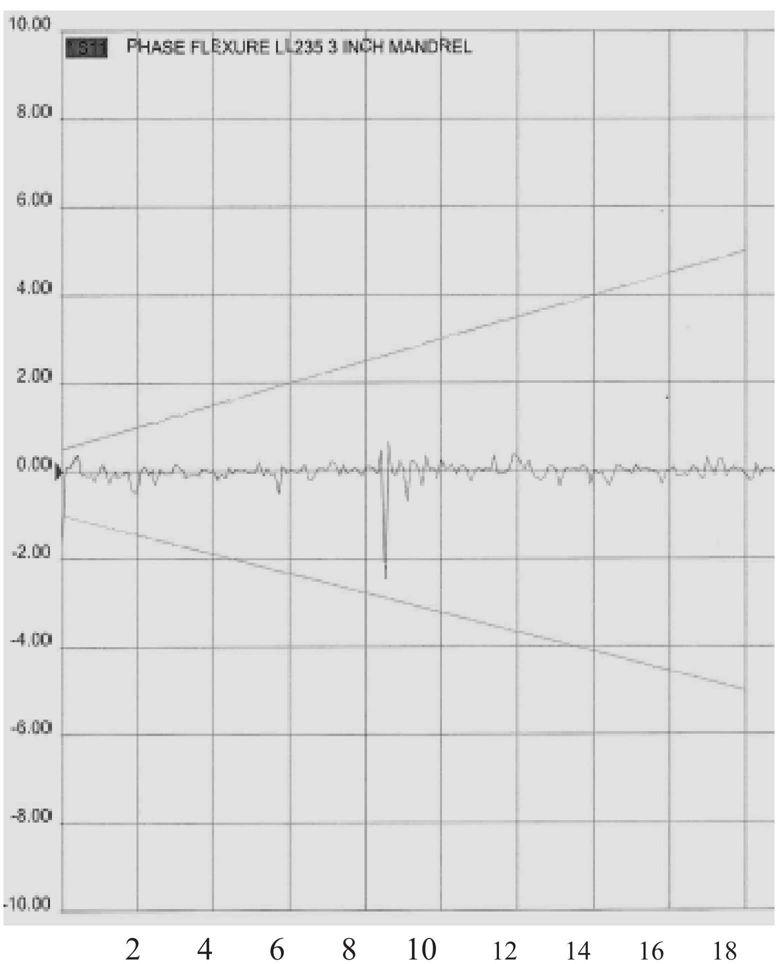
Phase Stability over Flexure

Phase stability over flexure can be significantly affected by the cable assembly technique, cable bend radius, and the length of the cable assembly. Harbour's Low Loss coax cables are typically tested for phase stability over flexure using an Agilent E8362B Network Analyzer using the following procedure:

a. Perform dynamic testing on a given length of cable (see Figure 1)
b. Record phase in the network analyzer
c. Flex cable over various size mandrels depending on the cable diameter
d. Retest cable for phase change when the cable is coiled around the mandrel
e. Record change in the network analyzer
f. Display phase change on the analyzer as degrees of change over frequency.

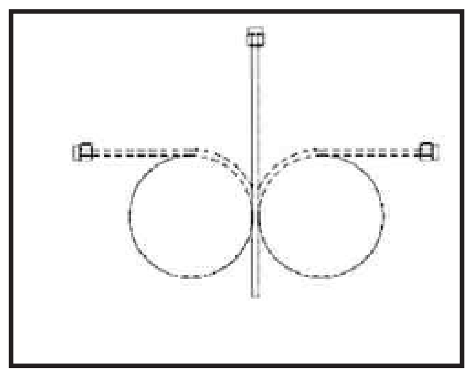
Performance - less than:
+/- 2.0º up to 4 GHz
+/- 4º from 4.01 to 8 GHz
+/- 6º from 8.01 to 18 GHz

Phase Change (degrees)



Frequency (GHz)

Dynamic Bend Test (Figure 1)



This data is representative of anticipated results. As phase stability over flexure is application dependent, please contact the factory regarding your specific cable and application.

VSWR and Return Loss of Coaxial Cables

Voltage Standing Wave Ratio (VSWR) and Structural Return Loss (SRL) are basically the same - only different. Both terms are used to characterize the uniformity of a cable's impedance along its length as it relates to reflected energy. VSWR is essentially the ratio of the input impedance to the average characteristic impedance as a result of signal losses due to reflections and is expressed as a ratio (1.xx:1). SRL is the measurement of reflected energy expressed in decibels (dB). Connectors and termination techniques are major sources of reflected energy and can significantly deteriorate system VSWR or SRL. The difference between VSWR and SRL is no more than how the reflected energy is measured.

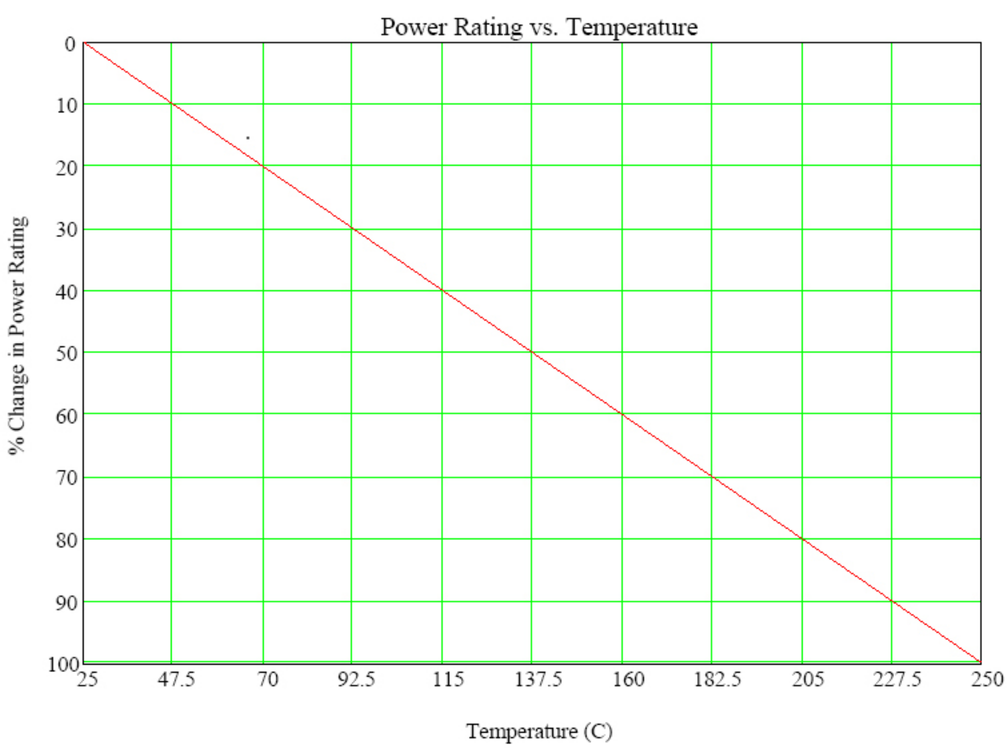
Structural Return Loss (SRL) is expressed as VSWR (Voltage Standing Wave Ratio) by the following formula:

$$\mathrm{VSWR} = \frac{1 + 10^{RL/20}}{1 - 10^{RL/20}}$$

SRL	VSWR	SRL	VSWR	SRL	VSWR
-40dB	1.0202:1	-30dB	1.0653:1	-20dB	1.2222:1
-39dB	1.0227:1	-29dB	1.0736:1	-19dB	1.2528:1
-38dB	1.0255:1	-28dB	1.0829:1	-18dB	1.2880:1
-37dB	1.0287:1	-27dB	1.0935:1	-17dB	1.3290:1
-36dB	1.0322;1	-26dB	1.1055:1	-16dB	1.3767:1
-35dB	1.0362:1	-25dB	1.1192:1	-15dB	1.4326:1
-34dB	1.0407:1	-24dB	1.1347:1	-14dB	1.4985:1
-33dB	1.0458:1	-23dB	1.1524:1	-13dB	1.5769:1
-32dB	1.0515:1	-22dB	1.1726:1	-12dB	1.6709:1
-31dB	1.0580:1	-21dB	1.1957:1	-11dB	1.7849:1
				-10dB	1.9250:1

Power vs. Temperature Derating Factors

The chart below recalculates the power handling capability of a coaxial cable at various temperatures.



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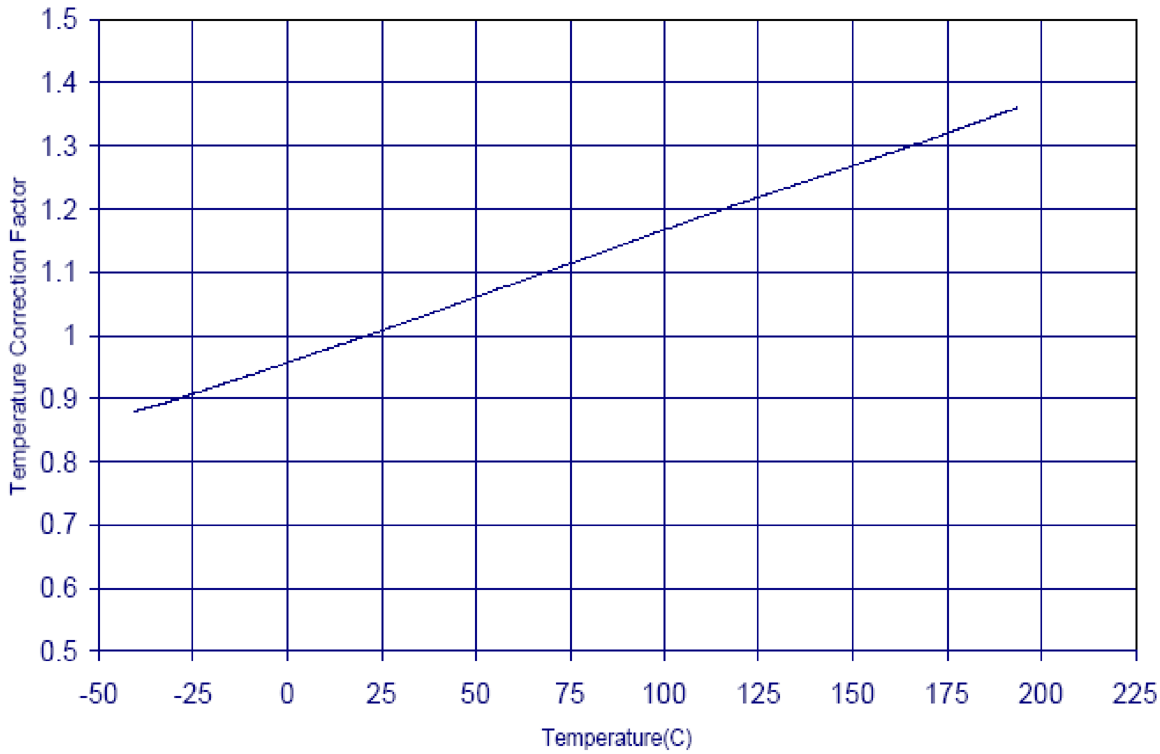
Attenuation vs. Temperature Correction Factor for Coaxial

The chart below recalculates the attenuation of a coaxial cable at various temperatures.



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Shielding Effectiveness Test Method
Harbour's LL, SB, and SS Coaxial Cables
Designs for Improved Shielding Effectiveness

Harbour Industries has been manufacturing strip braided expanded PTFE dielectric coaxial cable (LL series) and strip braided solid PTFE dielectric coaxial cable (SB series) since 1988. The strip braid design is a proven, effective shield configuration. Flat strips of silver plated copper are braided over the dielectric, then an intermediate aluminum polyester or aluminum polyimide tape is applied under a silver plated copper round wire braid.

The need for improved shielding effectiveness

High frequency cable and assemblies have been traditionally used in applications requiring a high level of shielding such as commercial and military aviation, defense systems, antenna systems and microwave test leads. Today, cellular and personal communication systems (PCS) require cable and assemblies with the same high level of shielding. Cables must provide adequate isolation to preserve the integrity of the system and to avoid interference with over-the-air communications.

Harbour supplies cable assembly houses with reliable high performance cable. Test data must be given, including impedance, attenuation, structural return loss, and shielding effectiveness. Since the strip braid composite configuration had previously been used and published data existed, there seemed to be little need for testing cables for shield effectiveness. Later, however, it was discovered that many cable manufacturers made general statements about shielding, but did not perform shielding effectiveness tests, certainly not at frequencies above 1 GHz. At best, one RF leakage number was given for a given shield configuration. Test procedures were difficult to obtain.

A new, improved shield configuration

In 1993, Harbour designed a new SS series of high frequency coaxial cables with a new shield design of silver plated copper strip spiraled around a solid PTFE dielectric. Since these cables were frequently used as flexible alternatives for semi-rigid coax, it was time to develop a reliable, repeatable test procedure for shielding effectiveness. RF leakage and transfer impedance were considered in developing a test method. Other methods, such as open field antenna sites, absorbing clamps, and TEM cells were deemed less reliable in comparing one cable to another.

Shielding effectiveness (RF leakage and transfer impedance)

Radiation, or the transformation of energy out of a coaxial cable, is known as RF leakage.
The formula for RF leakage is as follows:

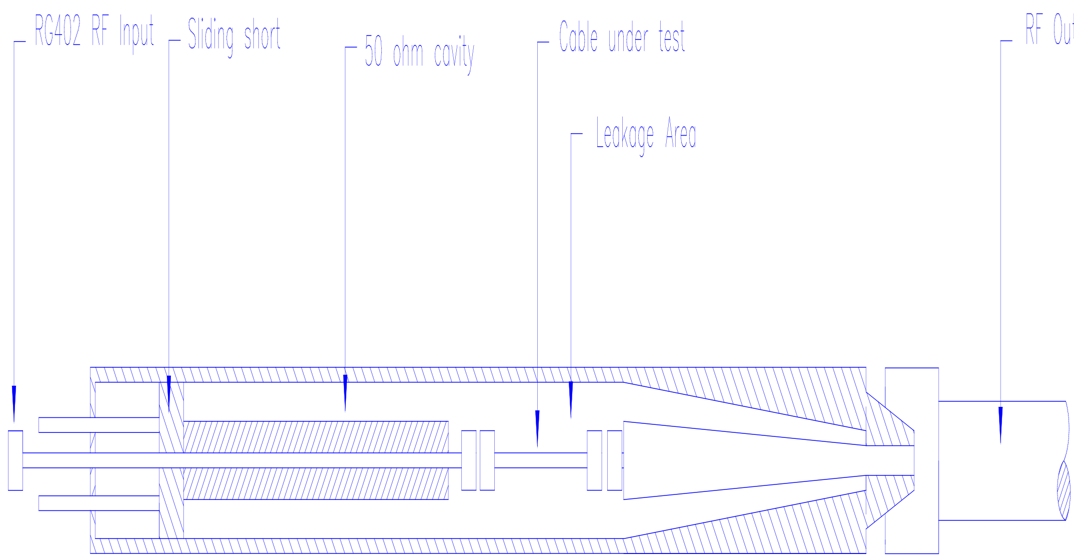
$$dB = 10 \log10 \frac{Pt}{Pi}$$

RF leakage, measured in decibels (dB), compares the input power level (Pi) to the power level propagating in the test chamber (Pt). The power in the test chamber is a function of the chamber itself and the attenuation, impedance and velocity of propagation of the cable under test. Importantly, the ability of the shield to attenuate the energy passing through it enables comparison of various shield configurations. The transfer impedance of a coaxial cable is defined as the ratio of the voltage in the disturbed circuit to the current flowing in the interfering circuit. The current on one surface of the shield is related to the voltage drop generated by this current on the opposite surface of the shield. This value depends solely on the shield construction.

Test setup

Shielding effectiveness testing was performed to evaluate the relative ratings of different cables. Testing was performed in accordance with MIL-T-81490, with actual measured values difficult to substantiate. Repeatability was questionable. Therefore, the following triaxial test assembly was constructed in accordance with MIL-C-39012C for RF leakage.

Figure 1: Triaxial test assembly



A Hewlett Packard Network Analyzer was calibrated and used with the triaxial test assembly as shown in Figure 2. To differentiate cable leakage from connector leakage, 4 and 8 inch test cables were used. For connector leakage, a test sample of 8 inches versus 4 inches will not increase the measured leakage. For a cable leakage, the longer sample will increase the measured leakage by +6 dB. Therefore, if the longer cable causes a 6 dB change in measured leakage, it can be deduced that the leakage is coming from the cable and not the connector or connector/cable interface.

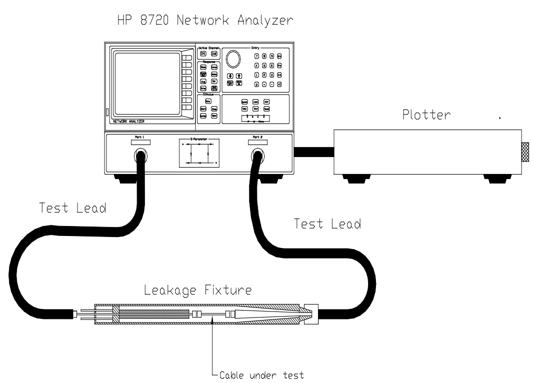


Figure 2: Shielding effectiveness test setup

The following shielding effective test procedure was developed:

1. Connect a semi-rigid calibration cable within the leakage cell into the internal matched termination.

2. Solder all connections for calibration to eliminate any leakage.

3. Connect the input side of the leakage cell to port one of the analyzer and connect the output side of the leakage cell to the analyzer with the other test cable. (The calibration measurement of the system must meet the device under test levels by at least -6 dB. For Harbour's setup, the specification was -90 dB prior to testing, with a calibration reading of - 96 dB minimum required prior to testing.)

4. Measure the insertion loss over the band of the sweep.

5. Once the required value is met for calibration, store the data to memory in the analyzer.

6. Disconnect the calibration samples within the cell.

7. Move the coaxial cable out of the cell, and insert the test sample between the calibration cable connection just separated.

8. Reconnect the test cell and re-measure the insertion loss. Adjust connections to eliminate false leakage signals from inhibiting the measurement. (Use aluminum foil to prevent connector leakage.)

9. Slide the short circuit rod within the leakage cell back and forth to cover at least one half wavelength of travel at the test frequency. This is to phase tune the leakage signals with the output connector, maximizing the signal at any variable phase. The sliding of the variable short circuit is not required when making swept frequency measurements since phase tuning will be accomplished over the band. The sliding short circuit is used for a fixed, single frequency measurement test to ensure there is not a null resonance within the cavity.

10. Once a proper measurement has been reached, and the measured leakage signal resembles that of the test cable, plot the result and store it to a disk file, similar to all other microwave test measurements. (This plot has the stored memory trace of the fixture calibration and the test cable. The intent is to notice the measurement noise level, relative to the leakage from the test cable.)

11. Disconnect the leakage cell, reconnect the calibration test cables within the cell to make sure the noise floor is still within the required levels given above.

Typically, leakage measurements over frequency can have two responses. If there is a physical gap or leak, the leakage response will show more leakage as frequency is increased. If there is a conductive, or absorptive path for leakage, the low frequency leakage may appear higher, since this path is shorter at lower frequencies and attenuating the signal more at higher frequencies. Any leakage due to a cutoff effect similar to an opening in a shield will show more leakage as the frequency is increased.

RF leakage testing was performed from 50 MHz to 18 GHz in order to compare the LL, SB, and SS cables with MIL-DTL-17 constructions. The results for the MIL-DTL-17 cables are consistent with previously reported values. Single and double braided shield configurations (even those with greater than 90% braid coverage) exhibit the highest RF leakage, at -50 and -75 dB respectively. The LL and SB cables with composite strip braid/round wire braid configurations exhibited lower RF leakage of -95 dB. Spiral strip shields (used in the SS cables) further improved the RF leakage to -110 dB. The tightly applied strip used in this shield type most closely approximates the solid copper tube of a semi-rigid cable. As a result, leakage levels down to the noise floor of the test equipment are exhibited.

Sample		Shield Configuration	RF Leakage
Number	Cable type		
1	M17/111-RG303	single round wire silver plated copper braid	- 50 dB
2	M17/60-RG142	double round wire silver plated copper braids	- 75 dB
3	LL142	silver plated copper strip braid, mylar, round wire silver plated copper braid	- 95 dB
4	SB142	silver plated copper strip braid, mylar, round wire silver plated copper braid	- 95 dB
5	SS402	spiral wrapped silver plated copper strip, round wire silver plated copper braid	-110 dB
6	SS405	spiral wrapped silver plated copper strip, round wire silver plated copper braid	-110 dB
7	M17/133-RG405	solid copper tube	-110 dB

Additional Testing for SS Cables
Additional tests were performed to evaluate the effectiveness of the SS402 and SS405 cables when bent. These tests compared samples 5 and 6 to the following samples:

Sample 8: An 8 inch test cable of SS402 with a 360° loop was bent into a tight .52″ radius to fit inside the test cell. This bend radius exceeded the .82″ minimum recommended bend radius for the cable (five times the .163″ diameter). RF leakage was measured at - 100 dB. When the spiral strip shielded SS402 cable was tightly bent, the inner tape separated just enough to cause a + 10 dB change in shielding effectiveness.

Sample 9: An 8 inch test cable of SS405 with a 360° loop and was bent with a .52″ radius, then inserted into the test cell. This bend radius was the minimum recommended bend radius of the cable (five times the .104″ diameter). The RF leakage was measured at - 110 dB, the same as the straight length of the cable and the noise floor of the equipment.

Table 2: SS402 and SS405 Test Results

Sample		Bend radius of the sample	Minimum recommended bend radius	RF Leakage
Number	Cable type			
5	SS402, straight	N/A	.82″	- 110 dB
8	SS402, 360 loop	.52”	.82″	- 100 dB
6	SS405, straight	N/A	.52″	- 110 dB
9	SS405, 360 loop	.52”	.52″	- 110 dB

The above tests show that bent lengths of Harbour’s SS cables exhibit the same shielding effectiveness level as straight lengths, if the minimum bend radius is not exceeded.

Using the shielding effectiveness test method as a design tool
Harbour’s RF leakage cell allows the convenient testing of many different cables at frequencies up to 18 GHz. It provides an effective, reliable and repeatable method not only for testing, but for the design of effective shield configurations. Physical characteristics of the braid configuration -- braid angles, picks per inch, number of carriers, braid coverage, tape widths, tape thickness, and percent overlap of metal tapes -- can be tested and modified for optimal shielding effectiveness.

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