NATIONAL RADIO ASTRONOMY OBSERVATORY
GREEN BANK, WEST VIRGINIA

ELECTRONICS DIVISION TECHNICAL NOTE NO. 168

Title: **MEASUREMENTS OF OPTICAL FIBER TEMPERATURE COEFFICIENT OF DELAY**

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Date: January 25, 1993

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(August 1992 Update)

Measurements of Optical Fiber
Temperature Coefficient of Delay

Roger D. Norrod
January 25, 1993

Summary

The purpose of this note is to document some measurements of delay temperature coefficient recently made on several types of optical fiber. These measurements were undertaken in order to better understand the causes of delay temperature sensitivity in analog optical fiber microwave links. A discrepancy was noted between published data and results measured with a round-trip phase measurement system operating on an antenna in Green Bank. It was found that one type of "tight-buffered" single-mode fiber has a temperature coefficient of approximately 60 ppm, while samples of other types of single-mode fiber and "loose-tube" optical cable have coefficients of less than 10 ppm. Since temperature coefficient data is not usually available from the cable manufacturer, for applications where the delay (phase) stability is important, users should select the type of fiber carefully, or measure the temperature coefficient of a sample.

Interferometer Round-Trip Measurement System

In 1988, as part of the installation of new receivers on the 85-foot Interferometer antennas in Green Bank, analog optical fiber microwave links were installed to transmit LO reference signals from the control room to the front-end boxes (FEB) and to transmit IF signals from the FEB to the control room. On the 85-3 antenna, used in the USNO VLBI network, a round-trip phase measurement system was implemented to measure changes in the delay between the control room and the FEB. Basically, this system sends a 500 MHz signal (used as a LO reference signal) to the FEB over an analog fiber link. A sample of this signal is returned over a second fiber link (multiplexed with the IF signals) to the control room. A HP vector voltmeter is used to compare the phases of the outgoing and returned 500 MHz signals and this data is recorded by the antenna control computer. The systems were further described by Jim Coe in EDIR 287 and EDTN 149.

Plots of the resulting data are routinely produced, scaled to one-way delay in picoseconds. Figure 1 shows three representative plots of the delay (*), overlaid by the measured outdoor air temperature (T) scaled at 20 ps/°C. It is obvious that the delay variations are highly correlated with the outdoor temperature, and one would suspect that this is due to changes in the effective length of the fibers running from the base of the telescope to the FEB, since the majority of the cable length is buried 18 inches deep. EDTN 149 states that the aerial cable is 65 meters long, and delay through single-mode optical fiber is commonly quoted in the literature at 5 μs/km. If we believe these values, the empirical T_c of 20 ps/°C indicates the fiber delay is changing approximately 60 ppm/°C. However, JPL and other researchers have commonly quoted standard single-mode optical fiber T_c at 10 ppm/°C. Since we plan to use analog optical fiber links on the GBT for IF and LO reference distribution, it was important to understand the causes of this discrepency.

Laboratory Measurements

Modern low-loss single-mode optical fibers consist of a silicate glass core (approximately 8 μm diameter), covered with a silicate glass layer (approximately 125 μm diameter and called the cladding) having a slightly lower index of refraction. The vast majority of the optical energy propagates in the core. Some manufacturers dope the core to elevate the core index (called "matched-cladding fibers" meaning the cladding index is that of silica), others dope the cladding (called "depressed-cladding fibers") to reduce the cladding index. The cladding is coated with an opaque substance to help protect the glass and to prevent crosstalk. All fibers we tested used a color-coded, ultraviolet-cured acrylate coating of 250 μm diameter. Figure 2 illustrates the standard fiber construction.

The delay temperature coefficient of three optical cable samples were measured in the laboratory:

> Sample 1 was an Optical Cable Co. four fiber cable, 130 meters long, similar to the aerial cables installed on the 85-foot antennas. Figure 3 is an excerpt from the OCC catalog, showing the cable construction. The acrylate coated fiber is covered with a 900 μm diameter tight buffer layer, followed by a kelvar strength layer, and finally a 2.5 mm diameter elastomeric jacket. These fiber subcables are laid together with an overall PVC jacket. Two fibers in this cable were tested independently and then two fibers spliced in series, giving a total length of 260 meters, were tested. During the tests, a jumper of tight-buffered fiber 2.5 meters long with a Radiall low-reflection connector was fusion spliced on each end of the fiber tested.
>
> Sample 2 was a spool of matched-cladding acrylate coated fiber 2930 meters long, supplied by Litespec, Inc. A jumper of tight-buffered fiber 2.5 meters long with a Radiall low-reflection connector was fusion spliced on each end.
>
> Sample 3 was a 210 meter length of a six fiber, loose-tube, optical cable supplied by Sumitomo Electric Fiber Optics Co. Figures 4a and 4b are excerpts from the Sumitomo catalog. The fibers used in the Sumitomo cable were manufactured by Litespec (a corporation formed as a joint venture by AT&T and Sumitomo), and are similar to the fibers of sample 2. A jumper of tight-buffered fiber 2.5 meters long with a Radiall low-reflection connector was fusion spliced on each end of one fiber.

The test setup used to measure the temperature coefficient is shown in Figure 5. The network analyzer was used to measure the change in insertion phase near 1 GHz as the chamber holding the optical cable sample was changed in 5°C steps. The change in delay was calculated from the phase change using the equation:

$$\Delta\tau = \Delta\phi \ / \ 360 \ / \ f$$

where $\Delta\phi$ is the phase change in degrees and f is the measurement frequency.

Table 1 and Figure 6 summarizes results for the 260 meter length of Sample 1. The average measured coefficient of 63 ppm/°C is consistent with the data obtained by the Interferometer round-trip phase measurement system.

Table 2 and Figure 7 summarizes results for Sample 2. The average coefficient of 8 ppm/°C is consistent with coefficients reported in the literature for standard single-mode fiber.

Table 3 and Figure 8 summarizes results for Sample 3.

Discussion of Results

It has been recognized for many years that the phase delay through optical fibers is sensitive to temperature, pressure, strain, and other physical stimuli [1], [2]. These effects have even been utilized to fabricate optical fiber sensors for physical quantities. There are several mechanisms by which the stimuli act on the delay: by changing the refractive index and/or the physical dimensions of the fiber, both diameter and length [3]. Each mechanism contributes to the total delay change, some with positive coefficients, others negative. The magnitude of the various contributions are affected by many things, including the thickness and composition of coatings or jackets on the fiber [4]. It has been suggested that the temperature sensitivity could be controlled by proper selection of coating materials [5]. Sumitomo has produced special low temperature coefficient fibers by using special coatings to control the balance of the temperature coefficient contributions. (The Sumitomo fibers tested here were not of the low-Tc type.) Researchers at SAO presented data at the January 1993 URSI meeting also showing that fiber coatings or jackets effect the temperature coefficient.

Conclusions

It appears certain that the tight-buffered fiber selected originally for the Interferometer has a temperature coefficient seven or eight times higher than that obtainable with standard loose-tube fiber. We have had loose-tube fiber on the 140-foot for a couple of years with no obvious problems, but I hope we can install loose-tube fiber on 85-3 in the near future where routine phase measurements can be obtained. This will allow us to look for unforeseen effects that could be harmful to future applications.

Acknowledgements

Brian Crouse did the laboratory measurements and Frank Ghigo supplied the Interferometer phase measurement data.

TABLE 1
Optical Cable Co. Cable Test Results

Cable Length : 260 m (approximate)

Measured Delay : 1.26 μs (4.8 $\mu s/km$)

Measured Loss : 21 dB (includes Tx/Rx)

T (°C)	ϕ (°)
30	-79.4
25	-6.3
20	140.9
15	286.8
10	454.8
5	621.0

Slope of Linear Fit: -28.8 °/°C
$\Delta\tau$: -79.9 ps/°C

Delay Temp Coeff = -79.9 ps/°C / 1.26 μs = -63 ppm/°C

TABLE 2
LiteSpec Cable Test Results

Cable Length : 2965 m

Measured Delay : 14.4 μs (4.9 $\mu s/km$)

Measured Loss : 24 dB (includes Tx/Rx)

T (°C)	ϕ (°)
30	-11.7
25	179.2
20	378.9
15	588.1
10	790.2
5	1004.9

Slope of Linear Fit: -40.7 °/°C
$\Delta\tau$: -119 ps/°C

Delay Temp Coeff = -119 ps/°C / 14.4 μs = -8.3 ppm/°C

TABLE 3
Sumitomo Loose-Tube Cable Test Results

Cable Length : 215 m

Measured Delay : 1.09 μs (5.1 $\mu s/km$)

Measured Loss : 20 dB (includes Tx/Rx)

T (°C)	ϕ (°)
-10	120.0
5	86.4
10	71.5
15	55.3
20	44.9
25	32.2
30	5.8

Slope of Linear Fit: -2.76 °/°C
$\Delta\tau$: -7.9 ps/°C

Delay Temp Coeff = -7.9 ps/°C / 1.09 μs = -7.3 ppm/°C

References

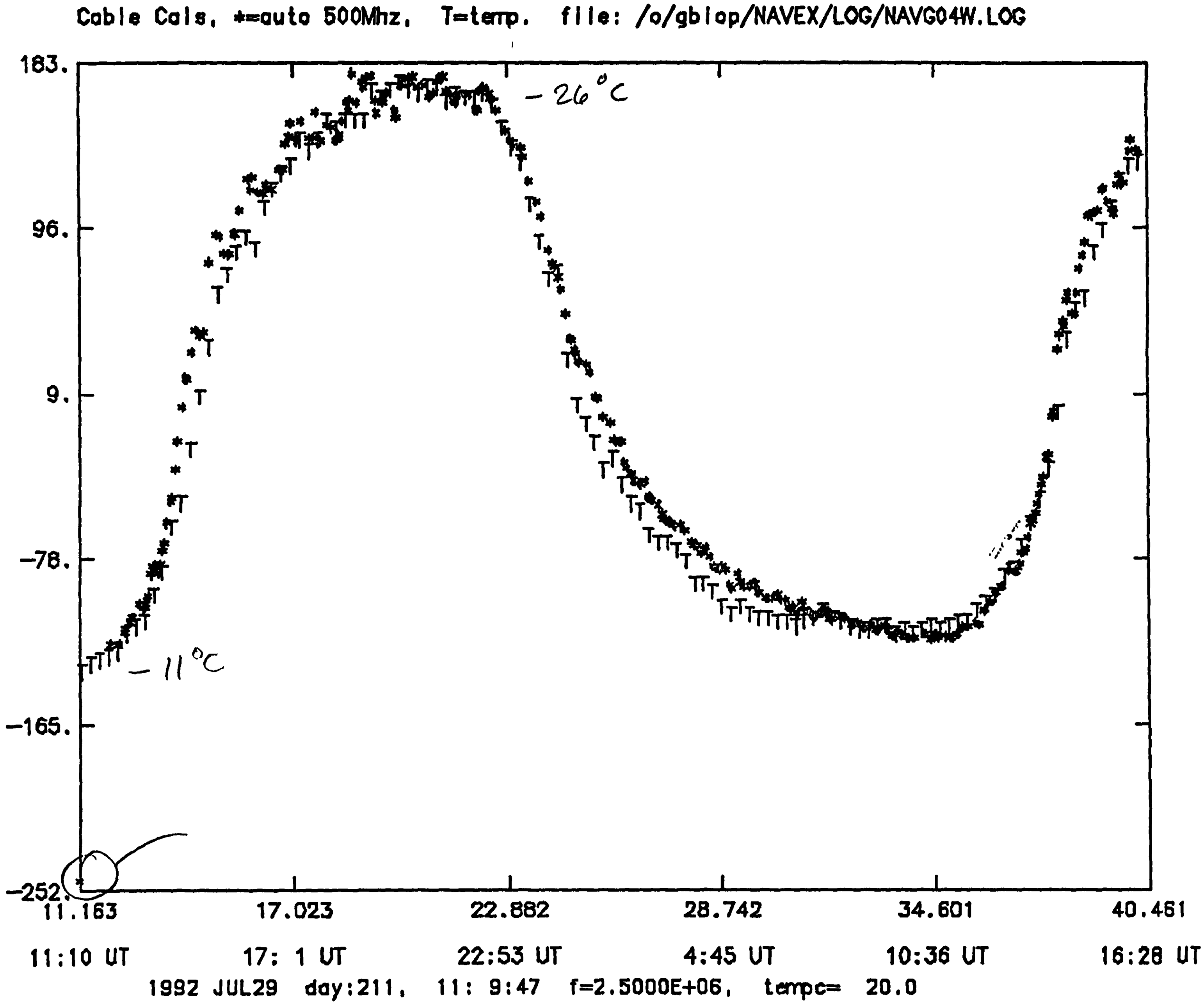
[1] Single-Mode Optical Fiber Measurement,
G. Cancellieri, ed. Artech House, 1993
Chapter 5.

[2] Optical Fiber Sensors: Principles and Components,
J. Dakin and B. Culshaw, Aertech House, 1988

[3] "Fiber Optic Sensing of Pressure and Temperature",
G. B. Hocker, Applied Optics, V. 18, No. 9, May 1979
pp 1445-1448.

[4] "Temperature-induced Optical Phase Shifts in Fibers",
N. Lagakos, J. Bucano, J. Jarzynsld,
Applied Optics, V. 20, No. 13, July 1981,
pp 2305-2308.

[5] "Minimizing Temperature Sensitivity of Optical Fibers",
N. Lagakos and J. Bucano,
Applied Optics, V. 20, No. 19, October 1981,
pp 3276-3278.



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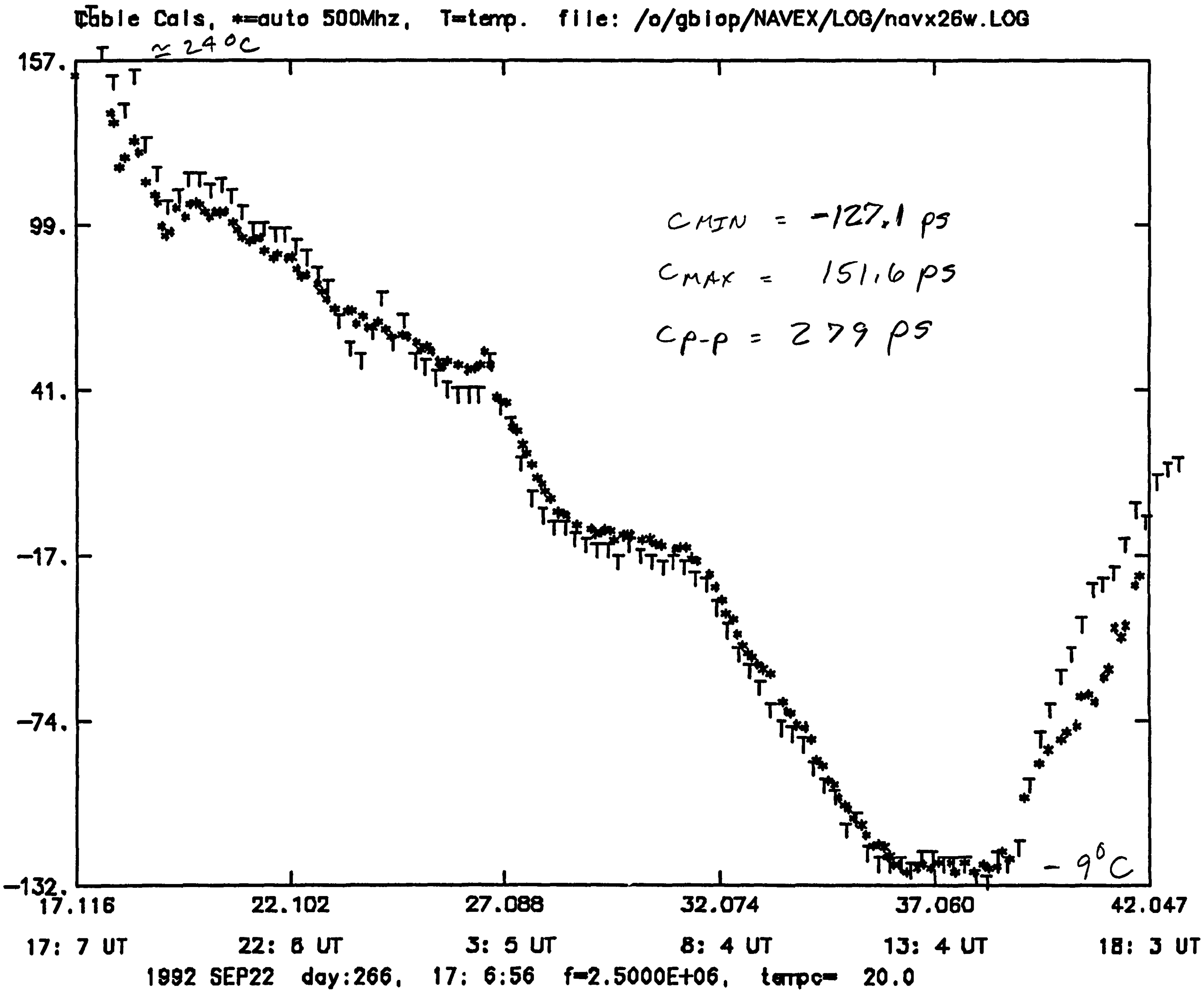
183.
96.
9.
-78.
-165.
-252.
11.163
17.023
22.882
28.742
34.601
40.461
11:10 UT
17: 1 UT
22:53 UT
4:45 UT
10:36 UT
16:28 UT
1992 JUL29 day:211, 11: 9:47 f=2.5000E+06, tempc= 20.0
-26°C
-11°C

Figure 1 (a)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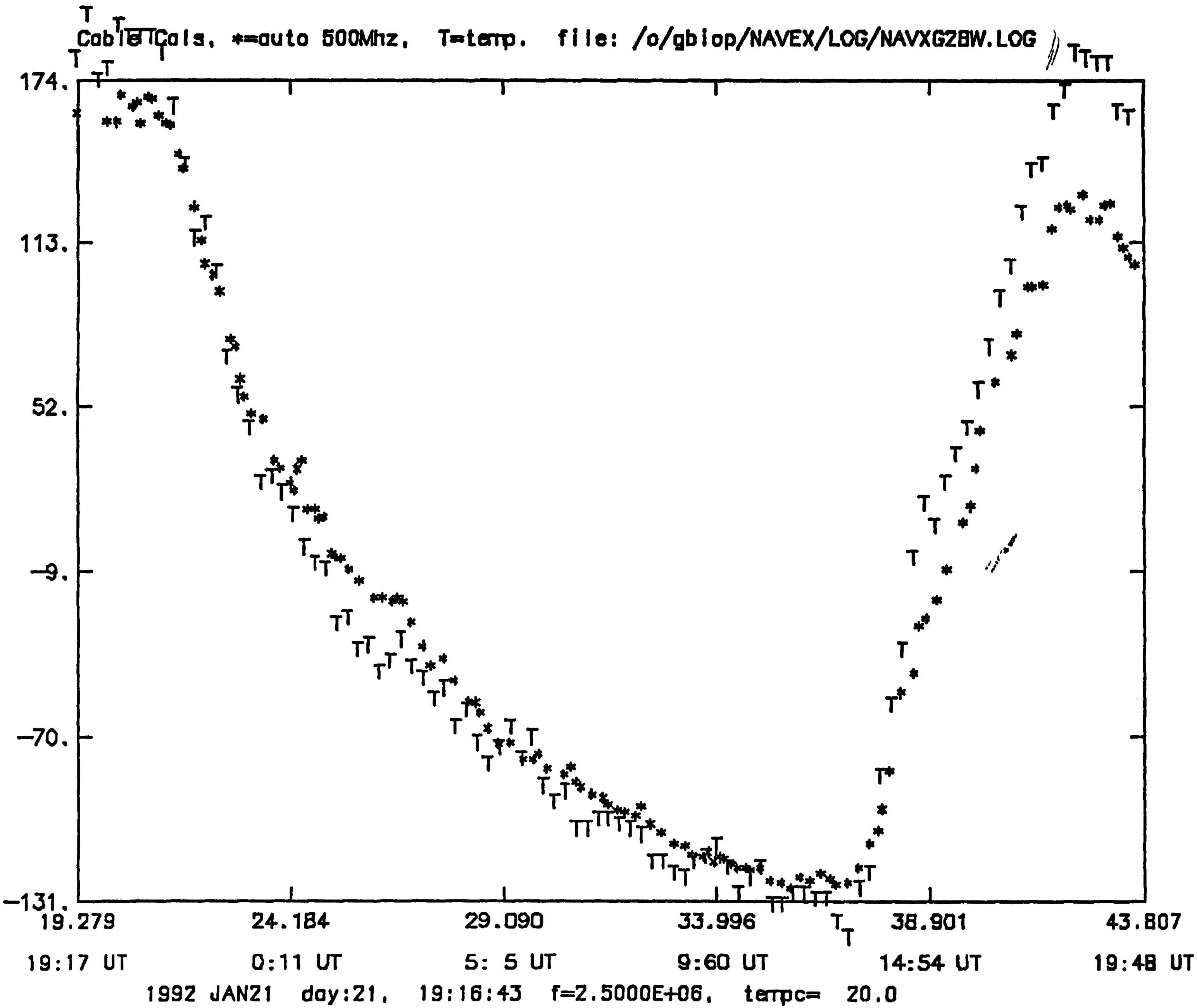
≃ 24 °C
C MIN = -127.1 ps
C MAX = 151.6 ps
C p-p = 279 ps
- 9 °C
157.
99.
41.
-17.
-74.
-132.
17.116
22.102
27.088
32.074
37.060
42.047
17: 7 UT
22: 6 UT
3: 5 UT
8: 4 UT
13: 4 UT
18: 3 UT
1992 SEP22 day:266, 17: 6:56 f=2.5000E+06, tempc= 20.0

Figure 1 (b)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174.
113.
52.
-9.
-70.
-131.
19.279
24.184
29.090
33.996
38.901
43.807
19:17 UT
0:11 UT
5: 5 UT
9:60 UT
14:54 UT
19:48 UT
1992 JAN21 day:21, 19:16:43 f=2.5000E+06, tempc= 20.0

Figure 1 (c)

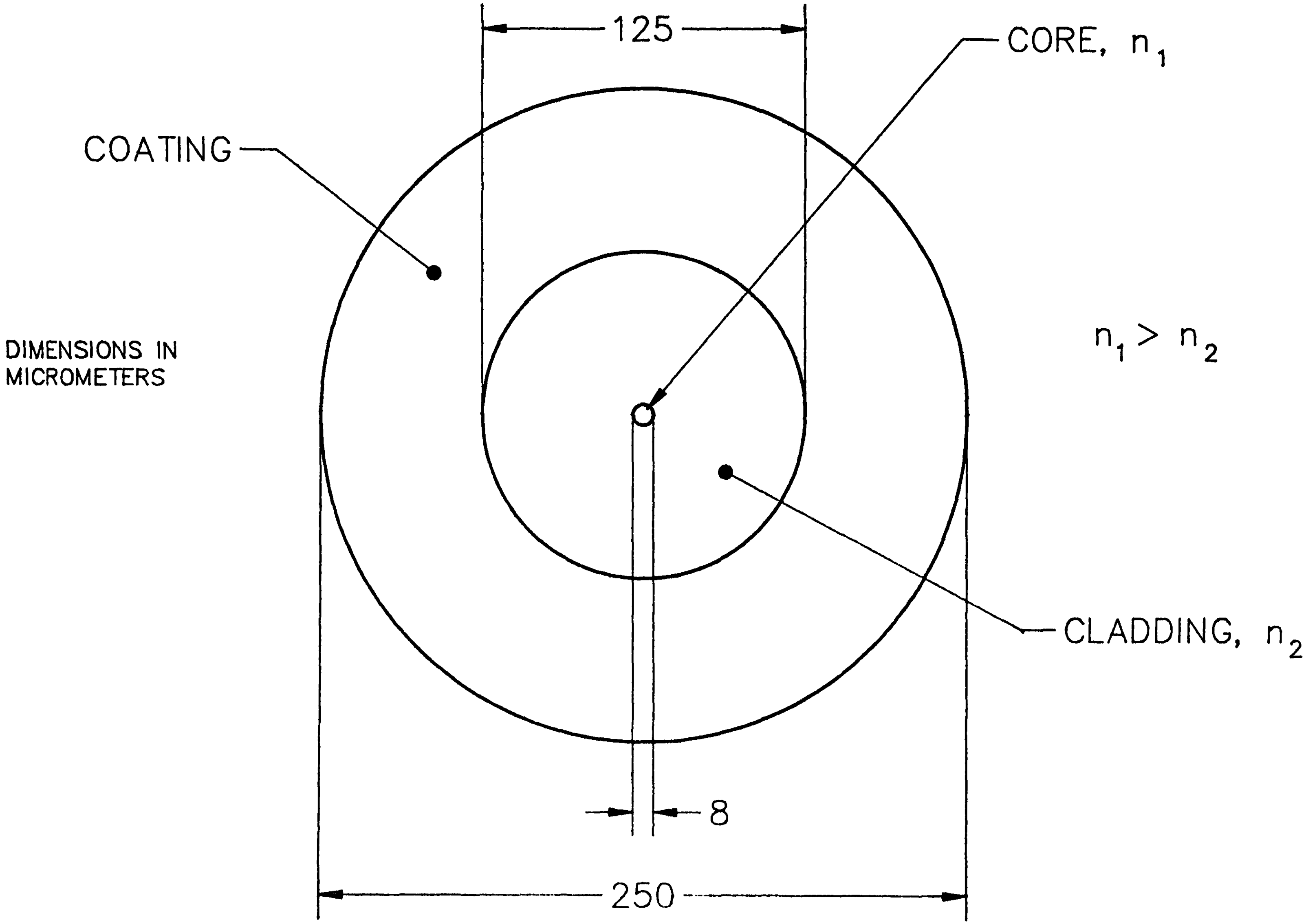
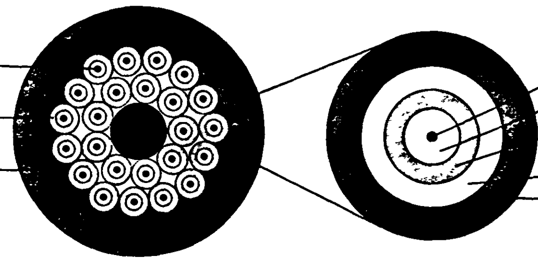


FIGURE 2
STANDARD SINGLE-MODE OPTICAL FIBER

FROM optical Cable Corporation Catalog

Figure 3

SPECIFICATION GUIDE
B-SERIES BREAKOUT CABLES



(DRAWINGS NOT TO SCALE)

	STANDARD (2.5 mm Subcable)				MINI (2.0 mm Subcable)				MICRO (1.5 mm Subcable)			
			Tensile Load Rating (N)*				Tensile Load Rating (N)*				Tensile Load Rating (N)*	
FIBER COUNT	Dia. (mm)	Wt. (kg/km)	Short Term	Long Term	Dia. (mm)	Wt. (kg/km)	Short Term	Long Term	Dia. (mm)	Wt. (kg/km)	Short Term	Long Term
2	7.0	50	1,200	500	6.0	38	800	200	5.0	27	800	200
4	8.0	65	2,000	800	7.0	50	1,600	400	6.0	37	1,600	400
6	9.5	82	3,000	1,200	8.0	64	2,400	600	6.5	39	2,400	600
6	11.0	111	4,000	1,700	9.5	83	3,200	800	7.5	52	3,200	800
10	13.0	152	5,000	1,900	10.5	102	4,000	1,000	8.5	67	4,000	1,000
12	12.5	148	6,000	2,500	10.0	96	4,800	1,200	8.0	64	4,800	1,200
18	14.5	186	8,000	3,500	12.0	121	6,000	1,500	9.5	85	6,000	1,500
24	17.5	237	10,000	3,800	14.0	178	7,200	1,800	11.0	108	7,200	1,800
30	19.5	285	12,000	5,000	15.5	203	8,400	2,100	12.5	132	8,400	2,100
36	20.5	305	14,000	6,000	16.5	208	9,600	2,400	13.0	137	9,600	2,400
48	23.5	393	18,000	7,500	19.5	288	12,000	3,000	14.5	178	12,000	3,000
60	25.0	426	22,000	8,800	20.5	305	14,400	3,600	15.5	194	14,400	3,600
72	27.5	516	26,000	11,000	22.5	366	16,800	4,200	17.5	223	16,800	4,200
84					24.5	433	19,200	4,800	19.0	254	19,200	4,800
96					26.5	506	21,600	5,400	20.5	296	21,600	5,400
108					27.0	509	24,000	6,000	21.0	301	24,000	6,000
120									22.5	346	26,400	6,600
132									23.5	377	28,800	7,200
144									24.5	410	31,200	7,800
156									26.0	463	33,600	8,400

*Installation loads in excess of 2,700 N (600 lbs.) are not recommended.

Part Number example: B12-125D-W3SB/1UC/900

SEE FIBER SPECIFICATION AND CABLE ORDERING GUIDE FOR FURTHER DETAILS

SPECIFICATIONS COMMON TO ALL B-SERIES BREAKOUT CABLES

Minimum Bend Radius	
Under Installation Tensile Load:	20 x Outside Diameter
Under Long Term Tensile Load:	10 x Outside Diameter
Operating Temperature:	-40°C to +85°C
Storage Temperature:	-55°C to +85°C
Crush Resistance:	2200 N/cm
Impact Resistance:	2500 Impacts
Flex Resistance:	2000 Cycles

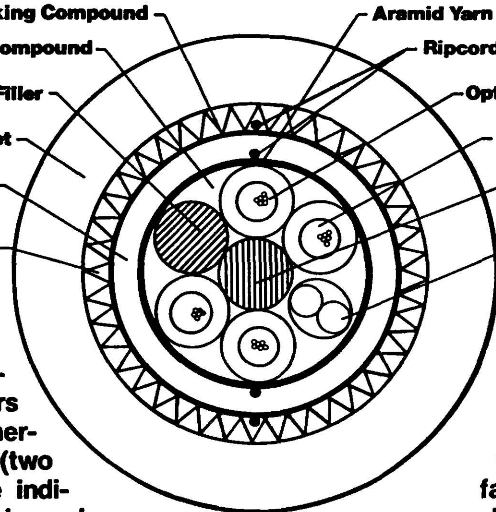
These specifications are subject to change without prior notification.

Meets or exceeds BellCore requirements for intrabuilding fiber optic cables as outlined in TR-TSY-000409 and TR-TSY-000020.

Figure 4a

Loose Tube Cable Construction

► *Typical Sumiguide Cable Construction*



► *Core*

Sumitomo Electric's Loose Tube cable construction consists of acrylate coated fibers placed loosely in a gel-filled thermoplastic tube. The fibers (two through twelve per tube) are individually color coded within a tube and the required number of loose tubes are stranded around a fiber reinforced plastic (FRP) or metallic center member, followed by a plastic binder. A water blocking jelly fills the interstices of the cable core. For some cables with an FRP center member (depending upon the number of tube positions), aramid fiber is served over the core followed by another polyester binder.

► *PE Sheath*

For aerial or duct applications, a 1.5 mm thick black polyethylene sheath is extruded over the cable core. Two ripcords are placed (180° opposed) under the sheath to facilitate jacket removal during splicing.

► *Armor Sheath*

For direct buried applications, the sheath consists of an inner jacket of black polyethylene. Two ripcords are placed 180° opposed under the inner jacket. A copolymer coated steel tape armor is longitudinally wrapped over the inner jacket for rodent resistance. This is followed by a black polyethylene outer jacket. A floodant is under the armor to prohibit water migration. Two ripcords are also placed (180° opposed) under the armor to facilitate jacket removal during splicing.

► *Cable Diameter and Weights (Polyethylene Sheath)*

# of fibers	# of tube positions	# of fibers per tube	Metallic Center Member				Dielectric Center Member			
			Nominal Outer Dia.		Nominal Weight		Nominal Outer Dia.		Nominal Weight	
			(mm)	(in)	(kg/km)	(lb/kft)	(mm)	(in)	(kg/km)	(lb/kft)
2-36	6	6	10.8	0.425	125	85	11.9	0.470	120	80
37-48	8	6	12.5	0.490	160	110	13.2	0.520	155	105
37-72	6	12	12.5	0.490	160	110	13.2	0.520	155	105
73-96	8	12	14.5	0.570	210	145	15.3	0.600	200	135
97-120	10	12	16.4	0.645	255	170	16.8	0.660	245	165
121-144	12	12	18.4	0.725	315	215	19.0	0.750	305	205

► *Cable Diameter and Weights (Steel Armor Sheath)*

# of fibers	# of tube positions	# of fibers per tube	Metallic Center Member				Dielectric Center Member			
			Nominal Outer Dia.		Nominal Weight		Nominal Outer Dia.		Nominal Weight	
			(mm)	(in)	(kg/km)	(lb/kft)	(mm)	(in)	(kg/km)	(lb/kft)
2-36	6	6	13.8	0.540	260	175	14.6	0.575	260	175
37-48	8	6	15.5	0.610	315	215	16.1	0.631	310	210
37-72	6	12	15.5	0.610	315	215	16.1	0.634	310	210
73-96	8	12	17.5	0.690	380	255	18.0	0.709	375	255
97-120	10	12	19.4	0.764	455	305	19.4	0.764	430	290
121-144	12	12	21.4	0.840	530	355	21.7	0.854	520	350

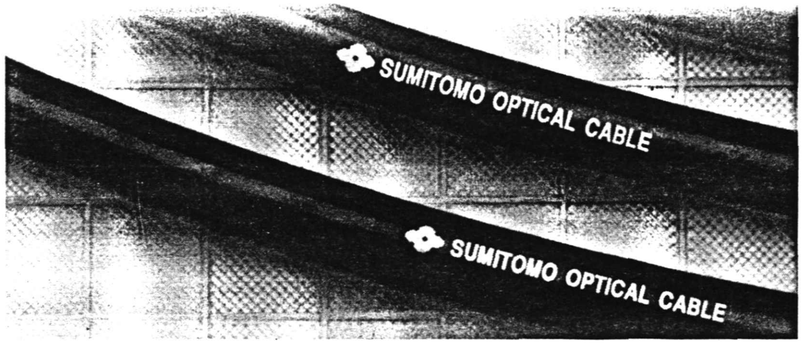


Figure 4b

SUMIGUIDE LOOSE TUBE OPTICAL CABLES are state-of-the-art optical fiber cables for use in long and short haul telecommunications systems. The cable offering may contain as many as 144 singlemode or multimode optical fibers, and a variety of sheath configurations for effective use in duct, direct buried or aerial environments.

Sumitomo Electric Fiber Optics Corp. has developed and produced optical fiber products in the United States since 1985. Our parent company, Sumitomo Electric Industries, Ltd., is an international leader in the fiber optics industry since 1974 and, together, we have built a worldwide reputation of excellence by supplying superior quality and reliable products offering long life.

Sumitomo's dedicated and innovative personnel are committed to excellence, and our state-of-the-art facility in North Carolina enables research and manufacture of the finest fiber optic communications products in the world.

Exacting standards, rigorous quality assurance and leading edge technologies are evidence of Sumitomo's commitment to our customers.

Loose Tube Cable Mechanical/ Environmental Design Specifications

Loose Tube		
Maximum Tensile Load During Installation (EIA RS-455-33)	5400N (1200 lb) 2700N (600 lb)	Optional Standard
Maximum Recommended Service Load (EIA RS-455-33)	1200N (270 lb) 600N (135 lb)	Optional Standard
Minimum Bend Radius During Installation After Installation	 20 times cable diameter 10 times cable diameter	
Crush (EIA RS-455-41)	220N/cm for PE sheath 440N/cm for armor sheath	
Impact (EIA RS-455-25)	25 impacts	
Maximum Vertical Rise	< 50 meters	
Compound Flow Drip Temperature	65°C	

Fiber Characteristics

SingleMode		MultiMode		
Core			**50/125**	**62.5/125**
Mode Field Diameter	8.8 or 9.5μm (Nominal)	Core Diameter	50 ± 3μm	62.5 ± 3μm
Mode Field Tolerance	± 6%	Numerical Aperture	0.20 ± 0.02	0.275 ± 0.02
Core/Cladding Offset	≤ 1.0μm	Core Non- Circularity	≤ 6%	≤ 6%
Optical		Core Eccentricity	≤ 6%	≤ 6%
Zero Dispersion Slope (So)	< 0.095 ps/nm^2-km			
Zero Dispersion Wavelength	1300nm-1322nm			
Maximum Dispersion @ 1310nm/1550nm	3.2/17 ps/nm/km			
Cutoff (cable)	< 1250nm			

Common Characteristics					
Cladding		**Coating**		**Mechanical**	
Cladding Diameter	125 ± 2μm	Coating Diameter	250 ± 15μm	Fiber Proof Test	50 KPSI
Cladding Non-Circularity	≤ 2%	Material	UV Acrylate	Min. Short Term Bend Radius	20mm
				Min. Long Term Bend Radius	37.5mm

Transmission Characteristics

Single Mode		Multimode		
Maximum Attenuation (dB/km)		Maximum Attenuation (dB/km)		
Grade	**@ 1310/1550 nm**	**Attenuation Ranges**	**50/125**	**62.5/125**
SA	0.35/0.25	@ 850nm	3.0	4.0
SB	0.40/0.30	@ 1310nm	1.0-1.5	1.0-1.5
SC	0.45/0.35	**Bandwidth Ranges (MHz-km)**		
SD	0.5/0.4	@ 850nm	200–400	160–200
SE	0.5/—	@ 1310nm	400–1000	200–500

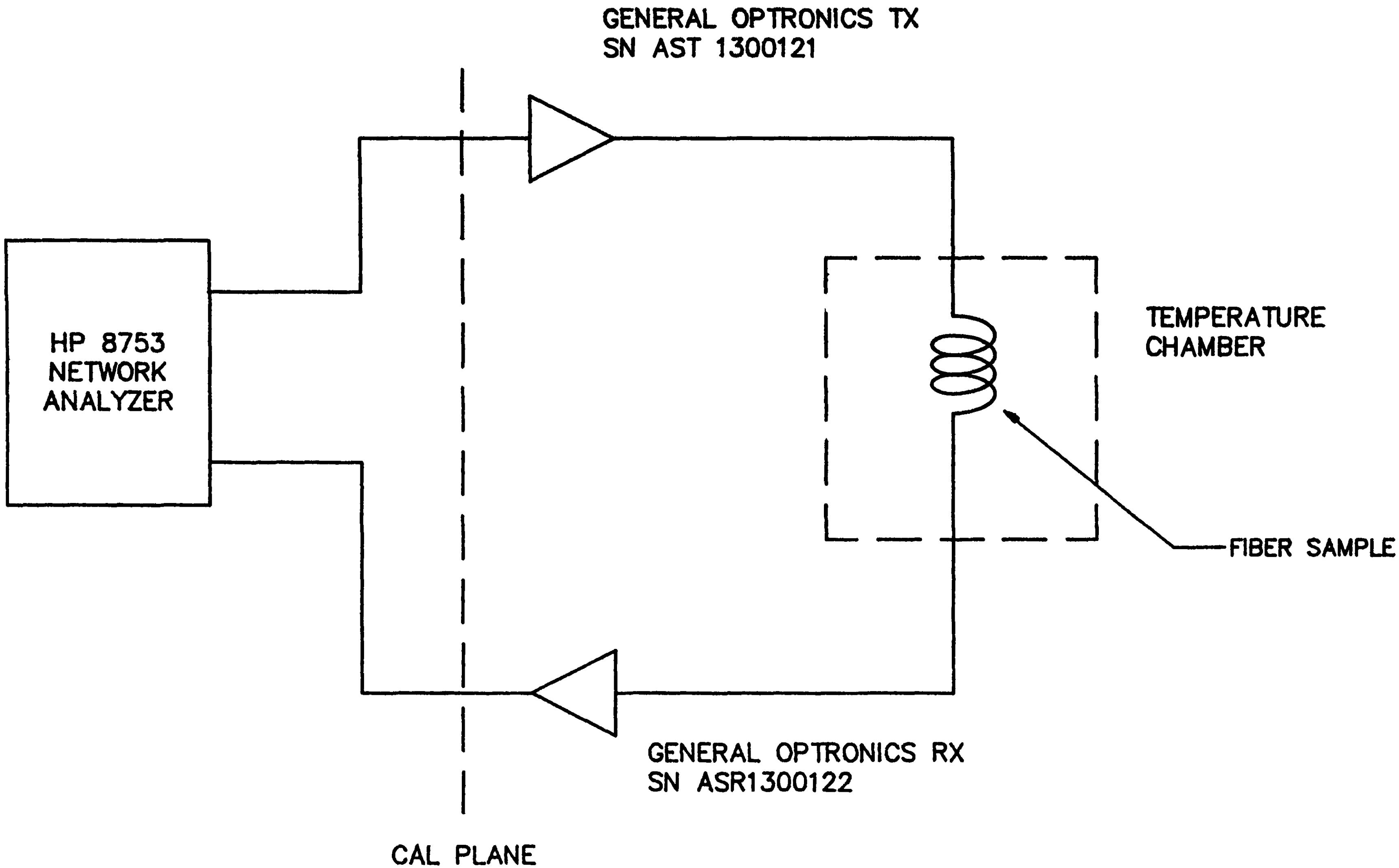
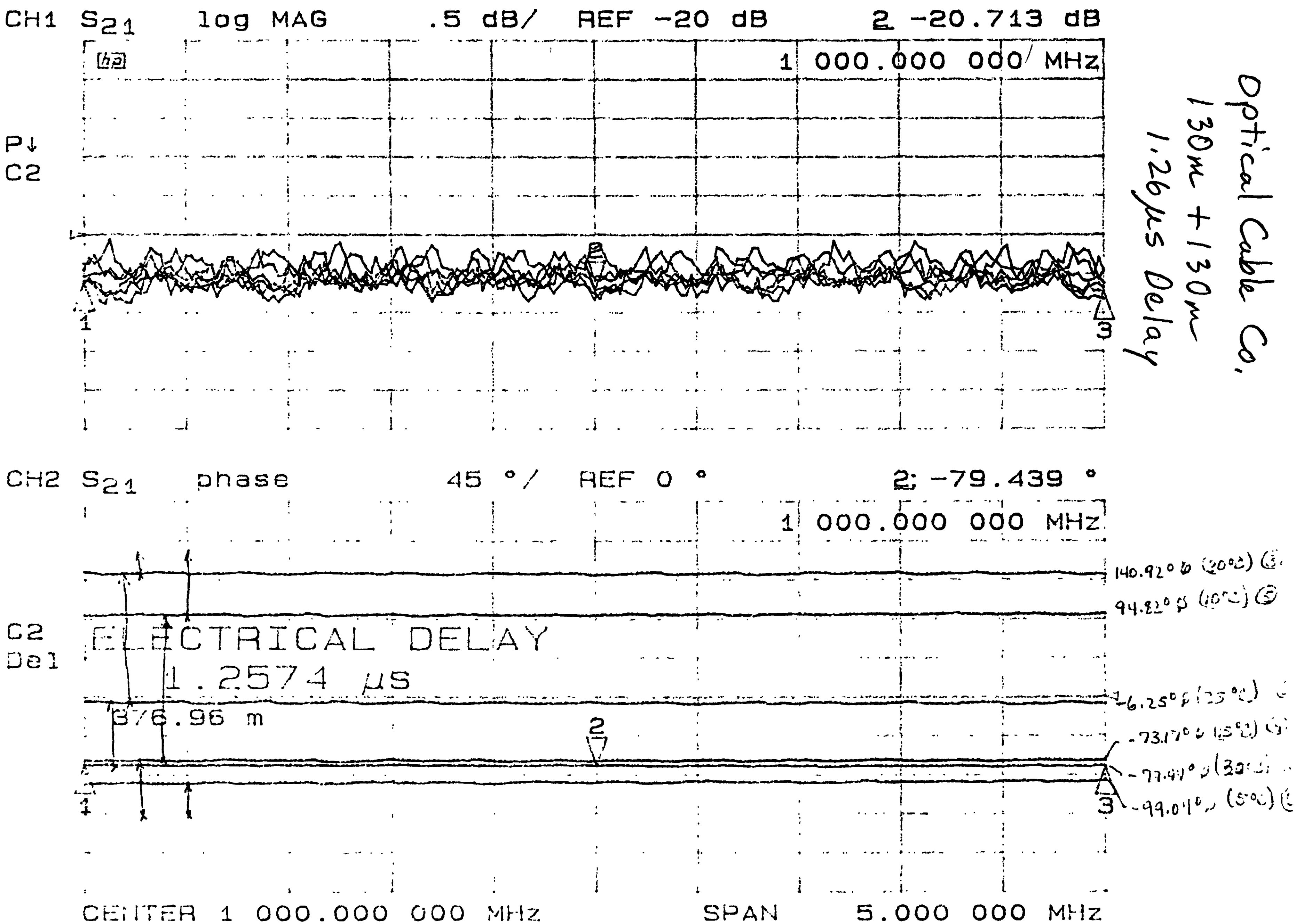


FIGURE 5
OPTICAL FIBER TEST SETUP



CH1 S21 log MAG .5 dB/ REF -20 dB 2 -20.713 dB
1 000.000 000 MHz
P↓
C2
1
3
Optical Cable Co.
130m + 130m
1.26µs Delay
CH2 S21 phase 45 °/ REF 0 ° 2: -79.439 °
1 000.000 000 MHz
C2
Del
ELECTRICAL DELAY
1.2574 µs
376.96 m
2
1
3
140.92°
94.82°
-6.25°
-73.17°
-99.01°
CENTER 1 000.000 000 MHz SPAN 5.000 000 MHz

Figure 6 (a)

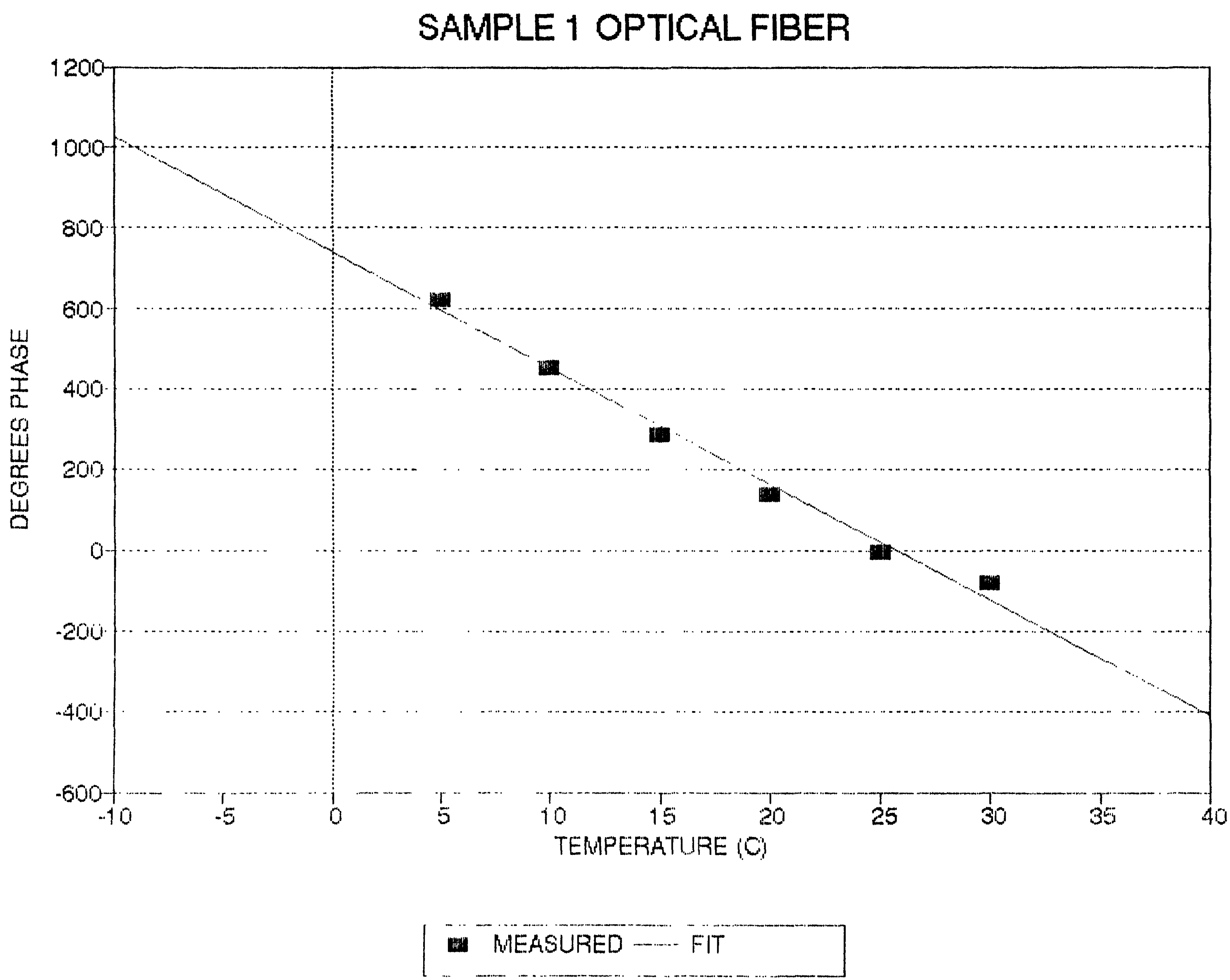

SAMPLE 1 OPTICAL FIBER
DEGREES PHASE
1200
1000
800
600
400
200
0
-200
-400
-600
-10
-5
0
5
10
15
20
25
30
35
40
TEMPERATURE (C)
MEASURED
FIT

Figure 6 (b)

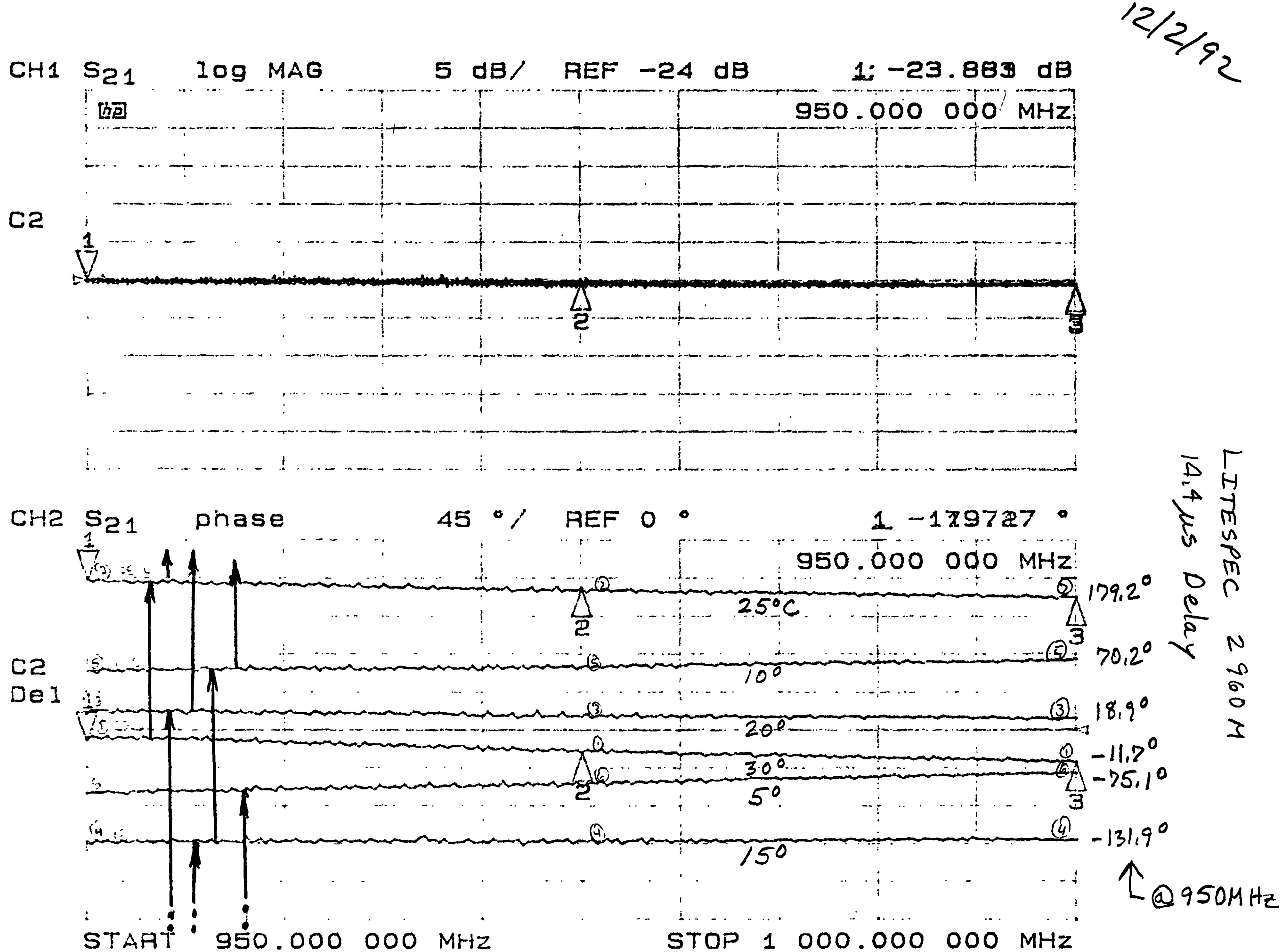

12/2/92
CH1 S21 log MAG 5 dB/ REF -24 dB 1: -23.883 dB
950.000 000 MHz
C2
CH2 S21 phase 45 °/ REF 0 ° 1 -179.27 °
950.000 000 MHz
C2
Del
25°C
10°
20°
30°
5°
15°
179.2°
70.2°
18.9°
-11.7°
-75.1°
-131.9°
@950MHz
LITESPEC 2960M
14.4 μs Delay
START 950.000 000 MHz
STOP 1 000.000 000 MHz

Figure 7 (a)

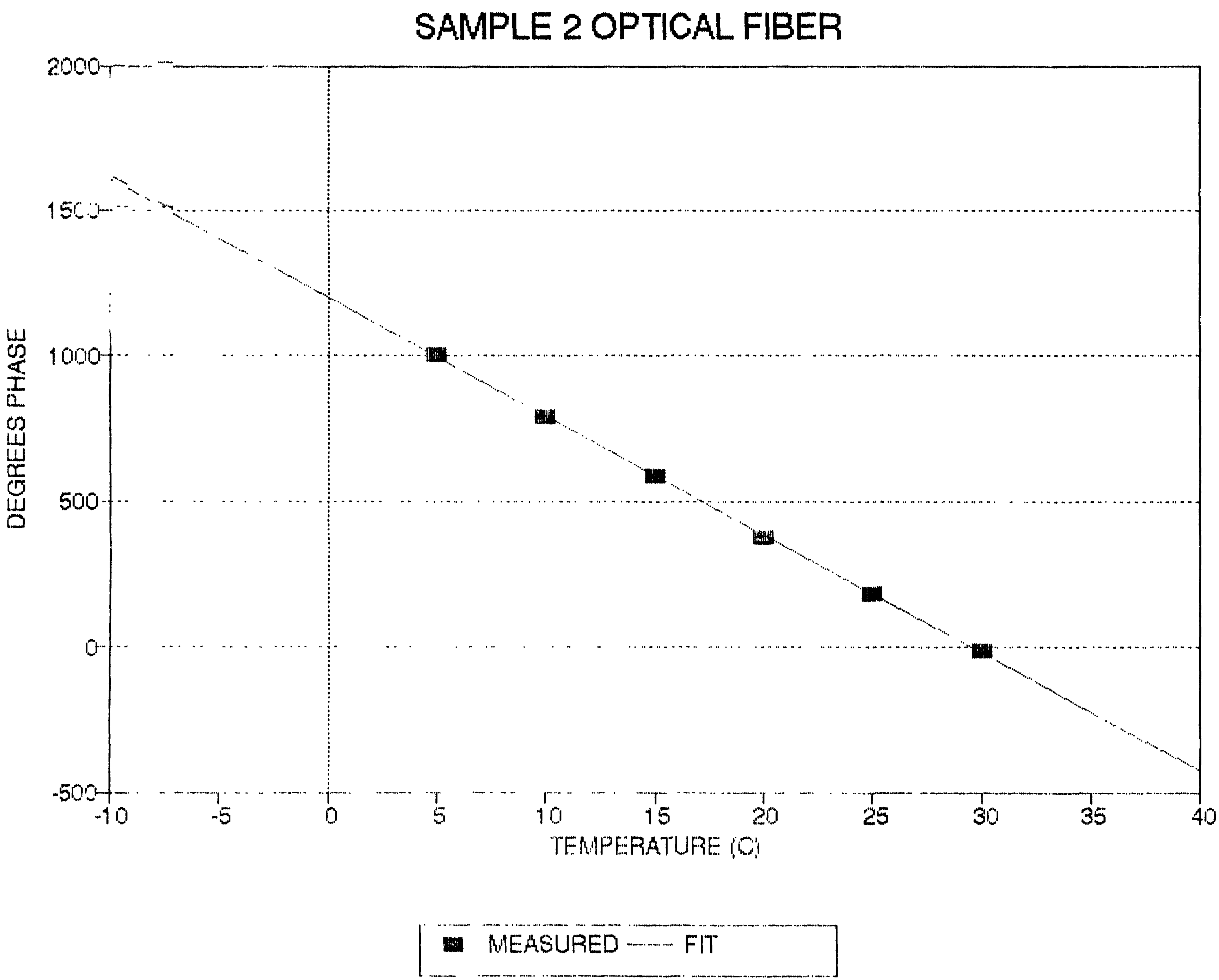

SAMPLE 2 OPTICAL FIBER
DEGREES PHASE
2000
1500
1000
500
0
-500
-10
-5
0
5
10
15
20
25
30
35
40
TEMPERATURE (C)
MEASURED
FIT

Figure 7 (b)

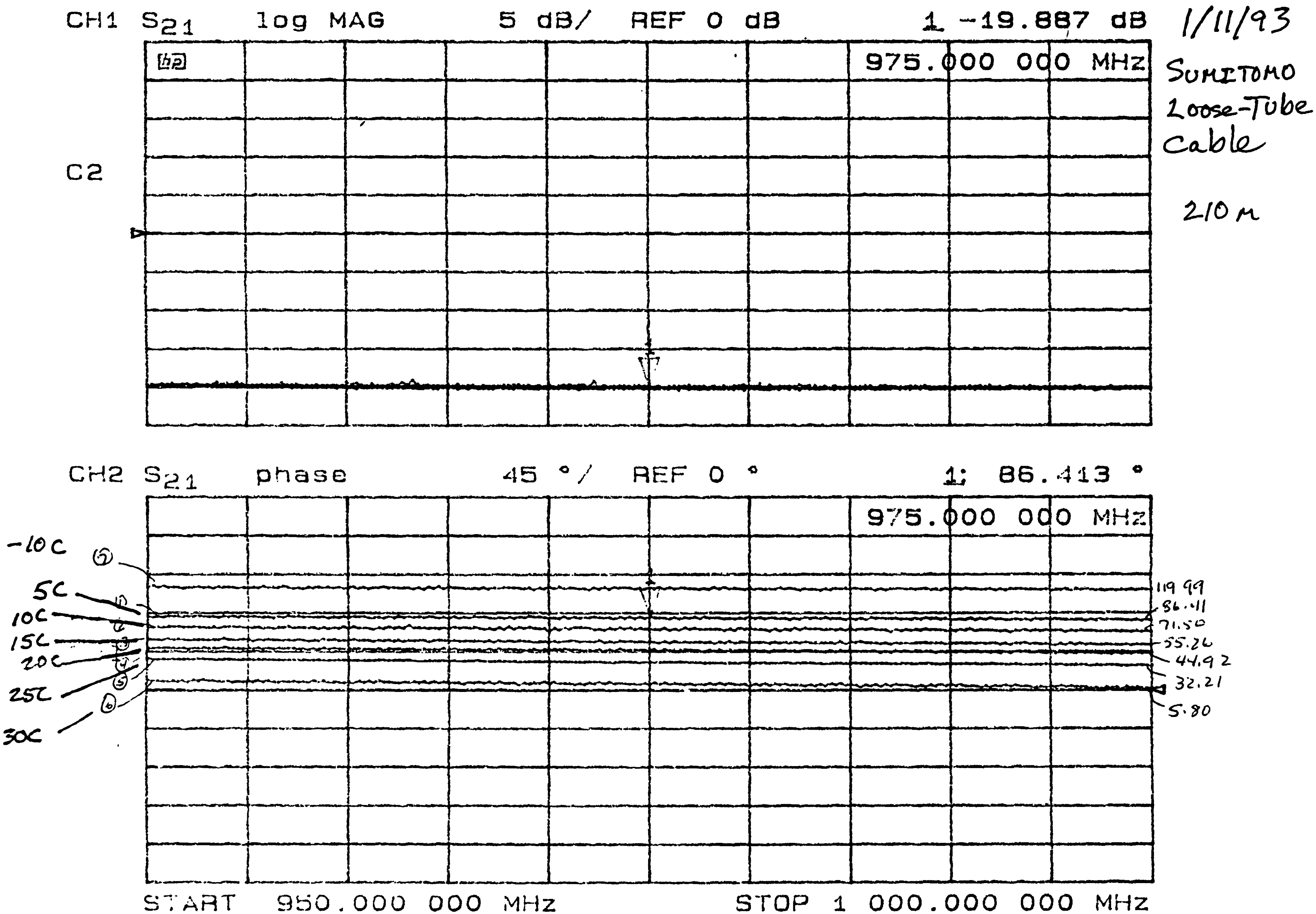

CH1 S21 log MAG 5 dB/ REF 0 dB 1 -19.887 dB
1/11/93
975.000 000 MHz
Sumitomo
Loose-Tube
Cable
C2
210 m
CH2 S21 phase 45 °/ REF 0 ° 1: 86.413 °
975.000 000 MHz
-10C
5C
10C
15C
20C
25C
30C
119.99
86.41
71.50
55.26
44.92
32.21
5.80
START 950.000 000 MHz
STOP 1 000.000 000 MHz

Figure 8 (a)

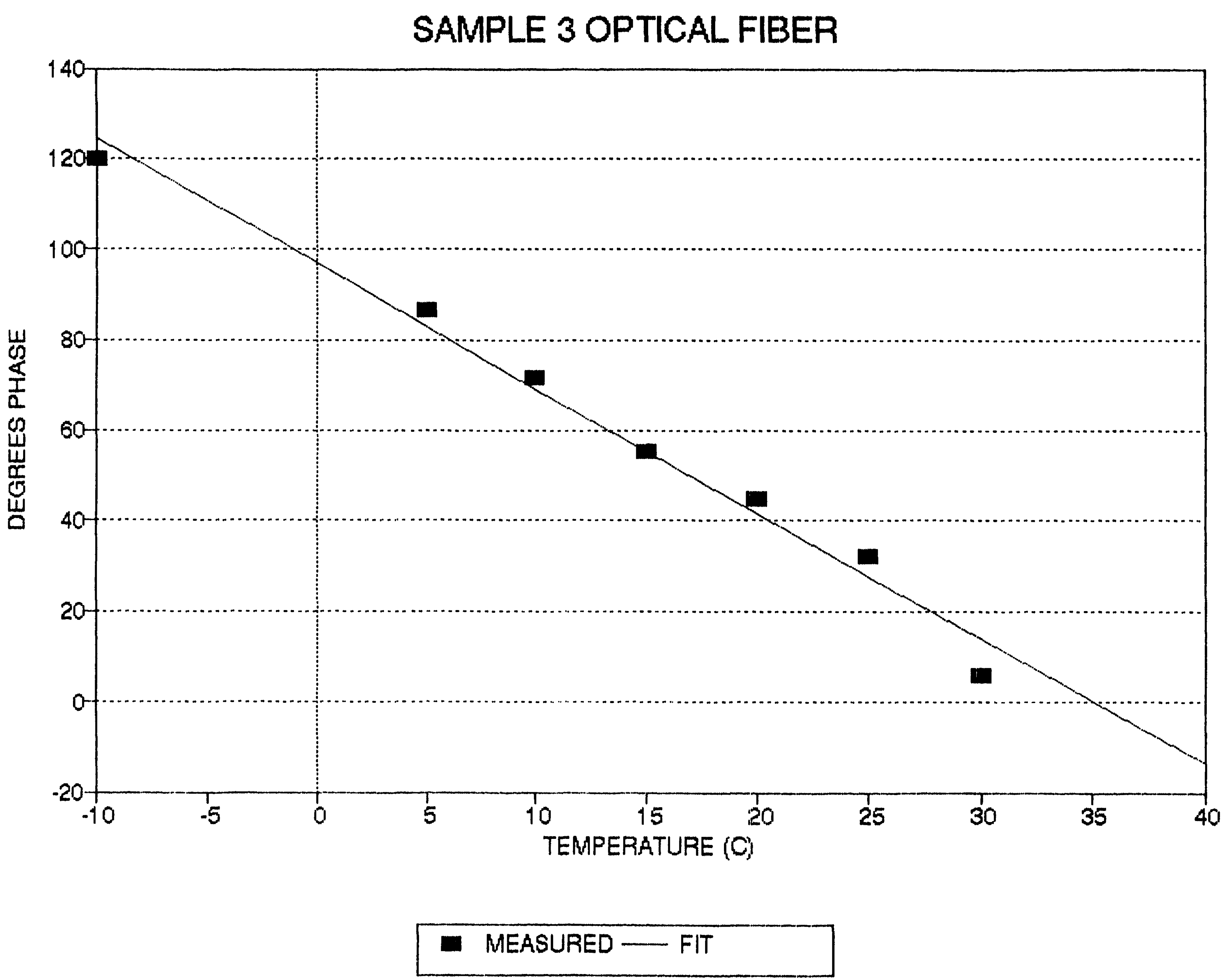

SAMPLE 3 OPTICAL FIBER
140
120
100
80
60
40
20
0
-20
DEGREES PHASE
-10
-5
0
5
10
15
20
25
30
35
40
TEMPERATURE (C)
MEASURED
FIT

Figure 8 (b)