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Analysis of S-Parameters for RF Coaxial Cables at Different Environmental Conditions

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Abstract: *RF coaxial cables are essential components in radio frequency and microwave systems. RF coaxial cables are necessary for the test and measurement systems. In spacecraft (TTC & Payload subsystem) testing, RF coaxial cables are used to uplink the signal from signal sources to spacecraft and receive the signal from spacecraft to measuring equipment. The performance of the RF coaxial cable can affect the test results of the spacecraft. The primary performance parameter for coaxial cable is the loss or attenuation. The losses are attributed to several factors and are present in all the RF Coaxial Cables. Environmental conditions affect coaxial cables, including temperature, pressure, moisture, dampness, etc. In this paper, an analysis of S-Parameters for RF coaxial cables at different environmental conditions is given. For this purpose, in the thermo vacuum chamber (TVAC), an experiment was conducted on N-type Polytetrafluoroethylene (PTFE) or Teflon coaxial cables during TVAC IST. A vector network analyzer and a computer with a LabVIEW-based application were used as a data acquisition system. All the processing of acquired data is done using the matrix laboratory (MATLAB) tool.*

Keywords: Coaxial Cables, Integrated Spacecraft Testing (IST), MATLAB, Radio Frequency, Scattering (S) Parameters, Telemetry, Tracking and Commanding (TTC), Vector Network Analyzer (VNA)

I. INTRODUCTION

The coaxial cable invented by Heaviside [1] is a transmission line composed of an inner conductor surrounded by an insulating layer and an outer conducting shield. The inner and outer conductors share the same geometrical axis, as shown in Figure 1. Nowadays, there exist several types of transmission lines, coaxial cables, hollow waveguides (rectangular, circular, elliptical, and parallel plates [2,3]), the two wires [3,4], and the channel waveguides (buried, strip-loaded, ridge, rib, diffused, and graded-dielectric index [5]). The principal constraints on a coaxial cable performance are attenuation, thermal noise, and passive intermodulation noise (PIM).

In RF applications, the wave propagates essentially in the fundamental transverse electric magnetic (TEM) mode; the electric and magnetic fields are perpendicular to the propagation direction [6]. RF coaxial cable is a robust and convenient form of feeder for various applications where radio frequency or other high-frequency signals need to be carried from one point to another. The standard coaxial cable impedance for RF power transmission is 50 ohms. Different impedance values are optimum for various parameters. Coaxial cables are used in many applications like commercial radio communication, domestic radio & television, satellite antennas, test systems, equipment, data applications, etc.

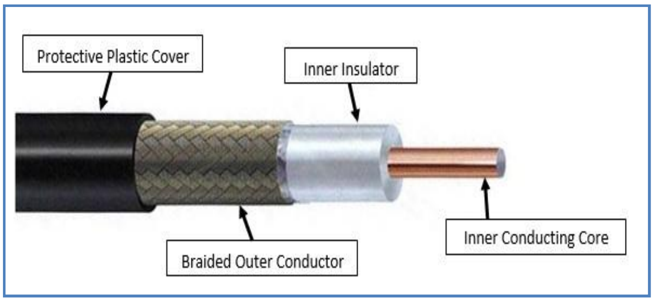

Figure 1: Cross-section of Coaxial cable [7]

During operation, a cable can be exposed to unplanned thermal stress over a short segment (Hotspots or Coldspots) or along the whole length. If the temperature increases or decreases across the entire length of the coaxial cable or a short piece, it impacts the whole cable performance [8].

Vector network analyzers (VNA) were introduced in the sixties to measure the electrical properties of microwave devices and circuits [9]. VNA is one of the essential RF and microwave measurement equipment. Vector network analyzer is the measuring instrument for analyzing passive and active components such as filters, amplifiers, mixers, and multiport modules. Vector network analyzer is used to measure all kinds of microwave network parameters. The concept of S-Parameters is a central part of RF and microwave engineering for characterizing and modeling the behavior of RF devices and networks [10]. Vector network analyzer measures the S-parameters in the frequency domain.

MATLAB is mathematics software, which is the industry leader in numerical calculation. MATLAB supports plotting functions and data, matrix operations, user interface creation, algorithm implementation, etc. It is widely used in many fields, such as image processing, engineering calculation, financial modeling design, signal processing, communication, and control design [11].

1.1 Performance Parameters for RF Coaxial Cables

The most common performance parameters for RF Coaxial cables are summarized in below table [12]:

Table 1: Performance Parameters for RF Coaxial Cable

Electrical	Mechanical	Environmental
Frequency Range	Outside Diameter	Temperature Range
Attenuation (Max Loss)	Flexibility (Min. Bend Radius)	Humidity
Power Handling	Flex Life	Vibration
RF Stability	Weight	Resistance to Solvents/UV
Shielding	Dielectric Material	Outgassing
Return Loss/VSWR	Connector Series	Altitude

RF Stability depends on several factors, including whether the cable will be subject to regular handling and bending (in the lab) or fixed in place. Most cables include manufacturer ratings on the minimum bend radius and the total number of flex cycles before RF performance starts to degrade. RF stability is also affected by environmental factors such as temperature, which becomes important when cables are used in temperature chambers for high temperature operating life (HTOL) testing or in assembled systems where extreme temperatures are expected.

1.2 S-Parameters

The abbreviation S has been derived from the word scattering. It is convenient for high frequencies to describe a given network in terms of waves rather than voltages or currents [13]. S-Parameters are used to characterize the reflective and transmissive behavior of a device upon the impact of a high-frequency electromagnetic signal. Figure 2 schematically represents a system for a 2-port device with input signals applied to both ports.

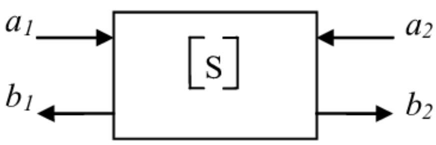

Figure 2: Two-Port Network

If the device is linear, the output signals can be defined in terms of the input signals. Thus,

$$b_1 = S_{11}a_1 + S_{12}a_2 \quad (1)$$

$$b_2 = S_{21}a_1 + S_{22}a_2 \quad (2)$$

Where a_1, a_2= Signal amplitude of input signals

b_1, b_2= Signal amplitude of output signals

S_{11}= Forward reflection coefficient (input match)

S_{12} = Reverse transmission coefficient (isolation)

S_{21} = Forward transmission (gain or loss)

S_{22}= Reverse reflection coefficient (output match)

The units of S-Parameters measured by VNA is in dB. The scheme can be generalized to N ports, and the equations can be written more economically in matrix form:

$$\begin{bmatrix} b_1 \\ b_2 \\ . \\ . \\ b_N \end{bmatrix} = \begin{bmatrix} S_{11} S_{12} \ldots S_{1N} \\ S_{21} S_{22} \ldots S_{2N} \\ . \quad . \quad \ldots \quad . \\ . \quad . \quad \ldots \quad . \\ S_{N1} \ldots S_{NN} \end{bmatrix} . \begin{bmatrix} a_1 \\ a_2 \\ . \\ . \\ a_N \end{bmatrix} \qquad (3)$$

The S-Parameters in the scattering matrix S and the column vectors a and b have input and output signal amplitudes. In general, the S-parameters are complex and frequency-dependent. S-parameters are two-dimensional quantities either described in polar coordinates with magnitude and phase or as complex numbers with real and imaginary parts. The rest of the paper is organized as follows. In Section 2, experimental test setup and TVAC IST test profile are given. In section 3, the processing of raw data in the MATLAB tool is provided. Finally, sections 4 and 5 discuss the experimental results and conclude, respectively.

II. EXPERIMENTAL TEST SETUP AND TVAC IST TEST PROFILE

This section discusses the experimental test setup and TVAC IST test profile for a communication satellite.

2.1 Experimental Test Setup

The experimental test setup for analysis of the S-Parameters for RF coaxial cable is given in Figure 3. The measurement system consists of a two-port vector network analyzer (Rohde & Schwarz ZVA40) and a pair of 10-meter RF cables of N-type PTFE coaxial cables. These coaxial cables were offered for thermal sensors (23 nos. of thermocouple) implementation, and the same was used as dummy cable. Dummy cables are used in TVAC IST for insertion loss compensation due to temperature and pressure variation. For this reason, the S-Parameters analysis for RF coaxial cables at different environmental conditions became an important area for investigation. One end of the cables was connected to the TVAC flange ports, and the other end of the cables was joined together with an N-type female to female adaptor. The TVAC chamber has provided feed-through for the coaxial cable interface and RF pressure windows for the waveguide interface mounted on the TVAC flange. The Dummy cable set was routed along with the spacecraft RF cables in a fixed position and was not moved during the measurements. A pair of 3-meter RF cables of N-type PTFE connected from TVAC flange to VNA ports. A personal computer controls the VNA through a local area network (LAN). The scattering parameters of coaxial cables were continuously monitored during the entire TVAC IST in VNA via Labview-based application.

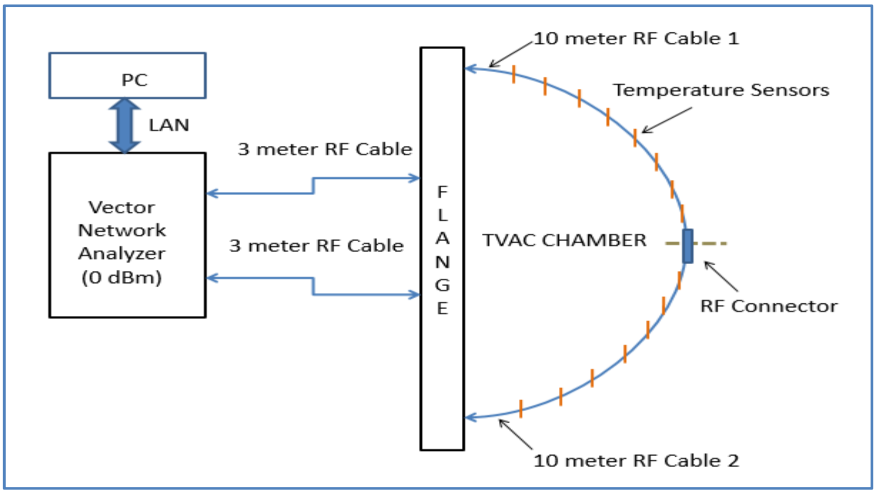

Figure 3: Experimental Test Setup

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2.2 TVAC IST Test Profile

This experiment was conducted along with the TVAC Integrated Spacecraft Testing (IST) of the typical communication spacecraft. The TVAC test profile is given in Figure 4.

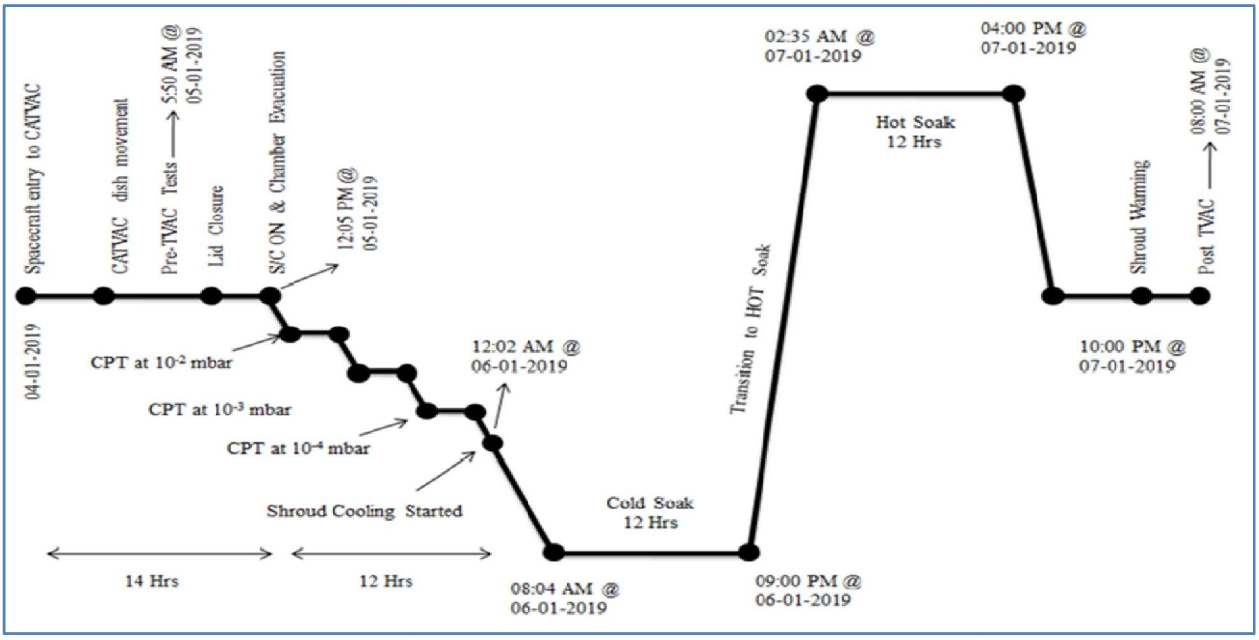

Figure 4: TVAC IST Test Profile

The temperature profile of 23 number thermocouples (TC) is given in Figure 5. The temperature units is provided in degree C. Thermocouple TC180 measured the maximum dynamic temperature range of 79.66 degrees C (from 21.34 to -58.32 degrees C). Therefore S-Parameters analysis w.r.t. Temperature is done for thermocouple TC180 data.

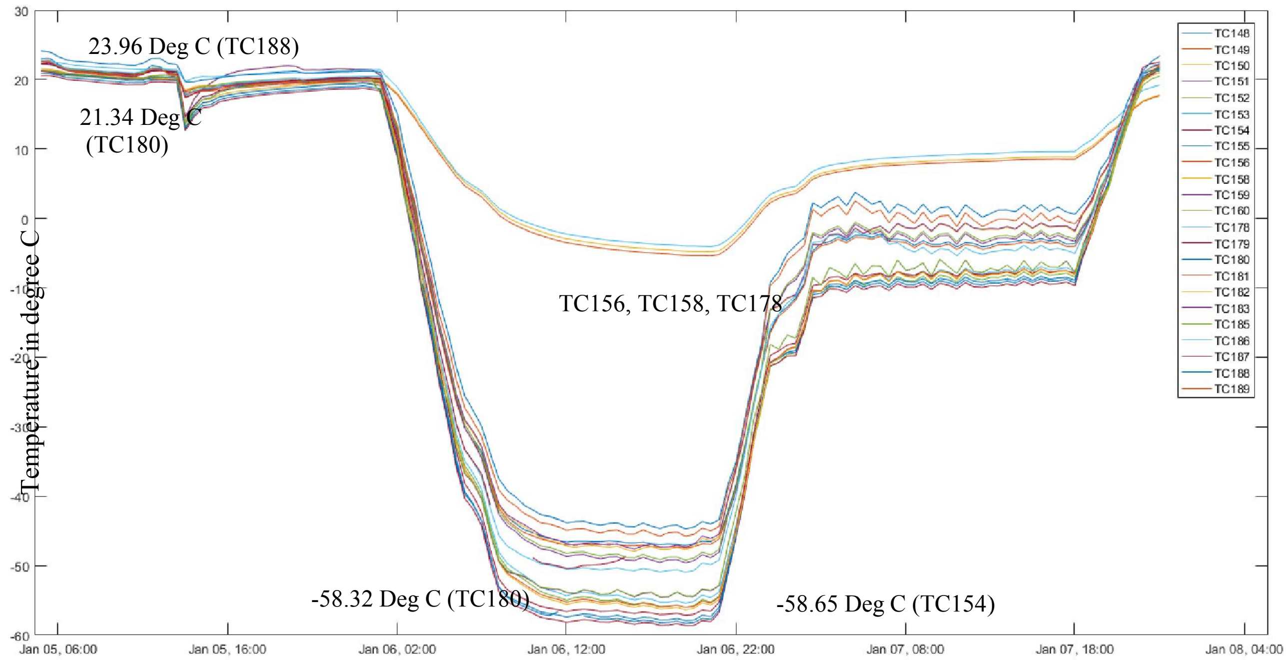

Figure 3: Temperature Profile of Thermocouple for RF Coaxial Cables in thermo vacuum chamber

The pressure profile in the thermo vacuum chamber is shown in Figure 6, and the units of pressure is given in torr, and a log scale is used for plotting. The ionization gauges measured the pressure values from 640 to 1.19E-06 torr.

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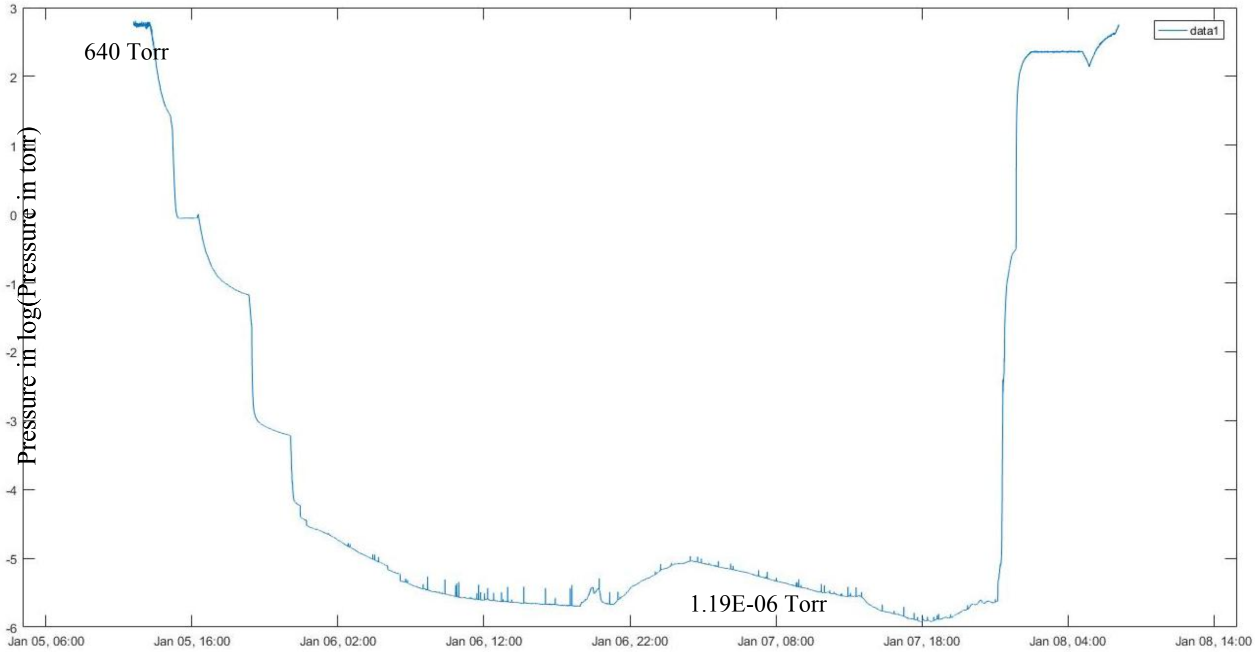

Figure 4: Pressure Profile in thermo vacuum chamber

III. EXPERIMENTAL DATA ACQUISITION, EXTRACTION, AND PROCESSING

The experimental data for S-Parameters were acquired using a two-port vector network analyzer (Rohde & Schwarz ZVA40) and Labview-based applications for 10 MHz to 18 GHz frequency range in .s2p file type format. The experimental data was stored at an interval of 24 seconds. Each trace for S-Parameters was saved with 5000 points in each file. The experimental data acquisition was started at 11:24:04 on 05-012019 and stopped at 23:06:50 on 07-01-2019. The total raw data was stored in 9221 files for the aforementioned time. In MATLAB, the required data from each file is extracted into .MAT file. The nearest sample point for the listed frequency is taken for the analysis. This paper provides detailed S-Parameters results at a specific frequency only. The variation in insertion loss for 2-18 GHz is also given at extreme temperature and pressure conditions.

The variation in insertion loss over the temperature or pressure for any frequency can be calculated as

$$\Delta S12 = (S12_{\text{TMax or PMax}}) - (S12_{\text{TMin or PMin}}) \quad (4)$$

$$\Delta S21 = (S21_{\text{TMax or PMax}}) - (S21_{\text{TMin or PMin}}) \quad (5)$$

Where TMax = Maximum temp. at an almost constant pressure
TMin = Minimum temp. at an almost constant pressure
PMax = Maximum pressure at an almost constant temp.
PMin = Minimum pressure at an almost constant temp.

In Figure 7, a flow chart of experimental data acquisition, extraction, and processing is given. The processed results for the S-Parameters are given in section-4.

IV. EXPERIMENTAL TEST RESULTS

The frequency range of N-type PTFE coaxial cables is DC-18 GHz, and analysis of S-Parameters is given for 2-18 GHz. In this paper, the test results of the S-Parameters are described in tabular and graphical forms. The test results are provided at the selected frequency only. For analysis of S-Parameters, the lowest (2 GHz), the highest frequency (18 GHz), and the arithmetic mean of the frequency range (10 GHz) are selected. Only 18 samples are chosen from the available data in the temperature range (20.27 to -57.58 0C). From the available data, only 17 samples are chosen in the pressure range (229.1064 to 3.55E-05 torr).

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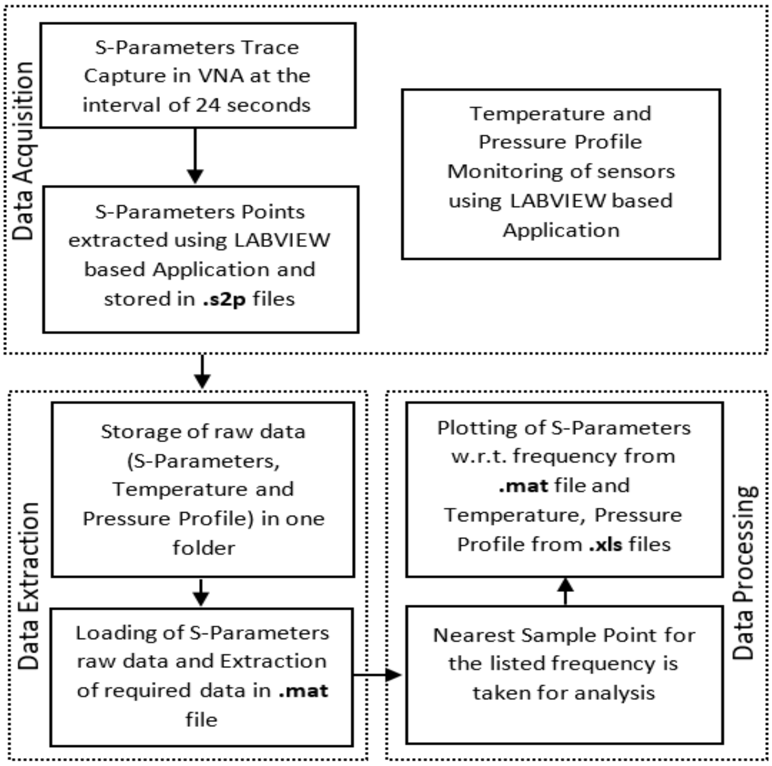

Figure 5: Flow chart of experimental data acquisition, extraction, and processing

4.1 S-Parameters w.r.t. Temperature

In table 2, S-Parameters are given w.r.t. temperature at 2, 10, 18 GHz, respectively. From table 2, it is observed that an insertion loss of coaxial cables decreases when the temperature decreases. At 2 GHz, the observed variation in insertion loss or S12 and S21 over the temperature range is 0.92 dB and 0.91 dB, respectively. The variation in the return loss or S11 and S22 over the temperature range is 1.32 dB and 0.83 dB, respectively. At 10 GHz, the observed variation in S12 and S21 over the temperature range is 2.28 dB and 2.27 dB, respectively. The variation in S11 and S22 over the temperature range is 1.88 dB and 0.73 dB, respectively. At 18 GHz, the observed variation in S12 and S21 over the temperature range is 3.37 dB and 3.32 dB, respectively. The variation in the S11 and S22 over the temperature range is 0.45 dB and 0.64 dB, respectively. The S-Parameters plot at 2, 10, and 18 GHz w.r.t. Temperature is given in Figures 8, 9, 10, respectively. From figures 8, 9, 10, insertion loss increases with increased frequency and decreases with a reduction in temperature.

V. EXPERIMENTAL TEST RESULTS

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Table 2: S-Parameters w.r.t. Temperature

Date & Time	Temp TC180	At 2 GHz				At 10 GHz				At 18 GHz			
		S11 (dB)	S12 (dB)	S21 (dB)	S22 (dB)	S11 (dB)	S12 (dB)	S21 (dB)	S22 (dB)	S11 (dB)	S12 (dB)	S21 (dB)	S22 (dB)
'05-Jan 11:24:04'	20.27	-22.13	-12.41	-12.43	-17.37	-20.45	-29.55	-29.67	-22.91	-17.35	-41.13	-41.11	-13.65
'05-Jan 14:39:51'	16.64	-21.36	-12.53	-12.57	-17.26	-20.30	-29.92	-30.01	-22.64	-17.05	-41.71	-41.65	-13.46
'05-Jan 17:54:53'	18.4	-21.49	-12.54	-12.57	-17.25	-20.16	-29.89	-30.02	-22.50	-17.11	-41.74	-41.68	-13.77
'05-Jan 19:31:58'	18.75	-21.54	-12.53	-12.57	-17.25	-20.11	-29.88	-29.99	-22.49	-17.10	-41.70	-41.65	-13.79
'05-Jan 22:46:57'	19.33	-21.59	-12.51	-12.55	-17.25	-20.03	-29.84	-29.97	-22.35	-17.15	-41.59	-41.55	-13.87
'06-Jan 02:01:44'	9.84	-21.71	-12.56	-12.59	-17.56	-20.28	-29.90	-30.06	-22.34	-17.13	-41.78	-41.70	-13.63
'06-Jan 03:40:04'	-9.44	-22.68	-12.29	-12.31	-18.08	-20.24	-29.18	-29.33	-22.18	-17.12	-40.61	-40.58	-13.56
'06-Jan 05:17:25'	-34.67	-22.34	-12.00	-12.02	-17.90	-20.27	-28.44	-28.58	-22.24	-17.07	-39.51	-39.49	-13.53
'06-Jan 06:55:41'	-43.56	-21.94	-11.81	-11.85	-17.71	-20.38	-27.96	-28.09	-22.39	-17.02	-38.83	-38.79	-13.52
'06-Jan 08:33:00'	-54.57	-21.66	-11.72	-11.75	-17.45	-21.62	-27.83	-27.95	-22.53	-16.99	-38.61	-38.57	-13.39
'06-Jan 19:59:03'	-57.58	-21.47	-11.64	-11.68	-17.40	-21.71	-27.65	-27.81	-22.51	-16.92	-38.41	-38.41	-13.28
'06-Jan 21:36:41'	-51.16	-21.67	-11.68	-11.73	-17.48	-21.74	-27.82	-27.93	-22.58	-16.90	-38.55	-38.55	-13.33
'06-Jan 23:13:12'	-26.21	-22.31	-11.87	-11.91	-17.79	-21.91	-28.23	-28.38	-22.42	-16.94	-39.08	-39.06	-13.25
'07-Jan 00:49:37'	-20.15	-22.52	-12.07	-12.12	-17.88	-21.58	-28.69	-28.87	-22.36	-16.93	-39.84	-39.84	-13.23
'07-Jan 02:26:19'	-10.65	-22.62	-12.20	-12.24	-17.92	-21.58	-29.04	-29.21	-22.36	-16.93	-40.38	-40.32	-13.25
'07-Jan 18:29:57'	-4.69	-22.61	-12.27	-12.32	-17.96	-21.56	-29.26	-29.39	-22.36	-17.00	-40.59	-40.62	-13.31
'07-Jan 20:06:35'	5.38	-22.49	-12.42	-12.47	-17.91	-21.61	-29.64	-29.80	-22.29	-16.97	-41.21	-41.23	-13.31
'07-Jan 21:42:52'	17.5	-21.59	-12.52	-12.56	-17.38	-21.47	-29.93	-30.08	-22.29	-16.97	-41.73	-41.73	-13.33

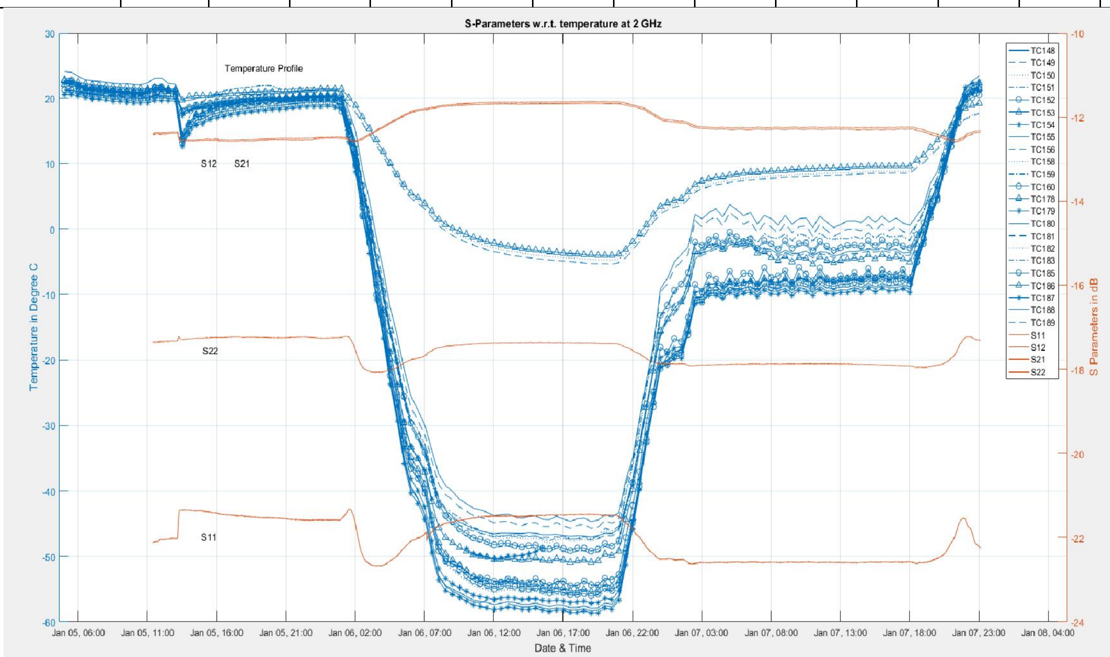

Figure 6: S-Parameters w.r.t. Temperature @ 2 GHz

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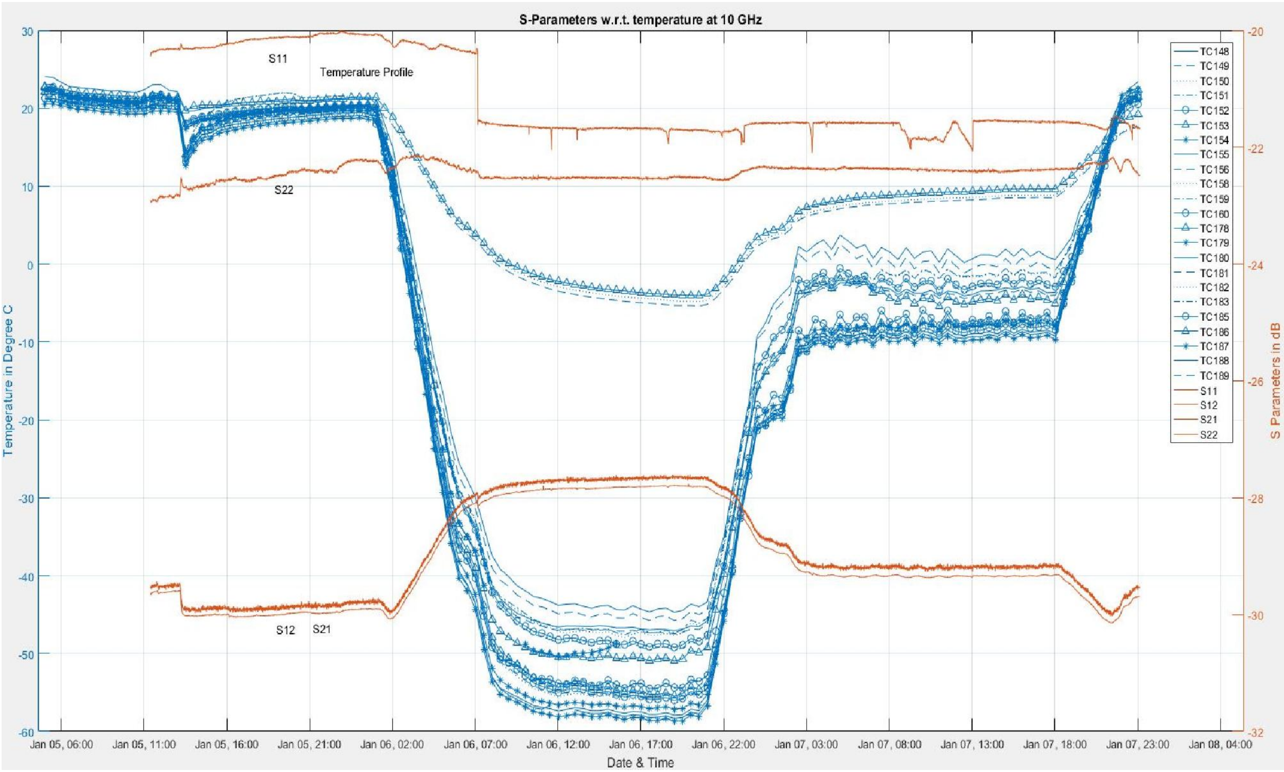

Figure 7: S-Parameters w.r.t. Temperature @ 10 GHz

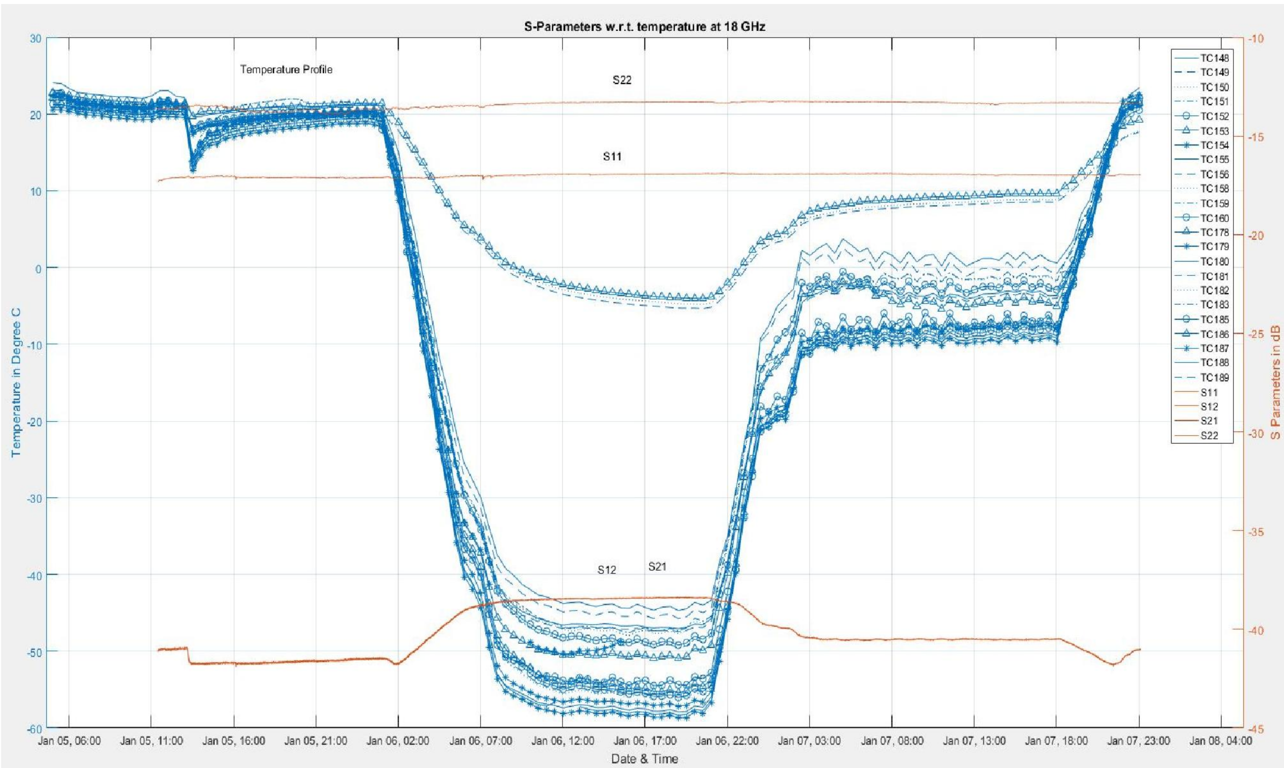

Figure 8: S-Parameters w.r.t. Temperature @ 18 GHz

The change in insertion loss due to extreme temperature variation (from 20.27 Degree C to -57.58 Degree C) is calculated using equations 4 & 5 and given in table 3.

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Table 3: **Change in Insertion Loss due to Extreme Temperature Variation at different Frequency**

Frequency (GHz)	ΔS12 (dB)	ΔS21 (dB)
2	0.77	0.75
3	0.95	0.93
4	1.09	1.08
5	1.22	1.23
6	1.40	1.39
7	1.62	1.59
8	1.72	1.75
9	1.81	1.81
10	1.91	1.86
11	2.11	2.11
12	2.11	2.08
13	2.27	2.29
14	2.40	2.46
15	2.52	2.50
16	2.63	2.59
17	2.64	2.66
18	2.72	2.70

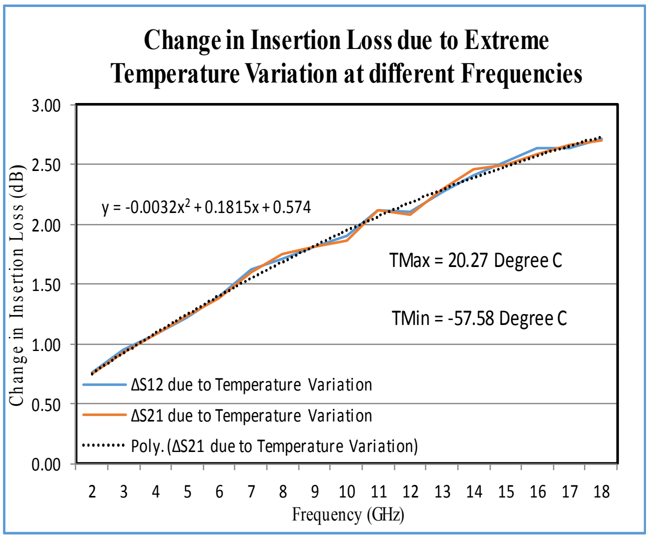

Figure 9: Change in Insertion Loss due to Extreme Temperature Variation at different Frequencies

Table 3 and figure 11 show a significant increase in ΔS12 and ΔS21 due to extreme temperature variation at different frequencies. This increase in insertion loss variation can be mapped with the second-order polynomial equation that is given below:

$$y = -0.0032x^2 + 0.1815x + 0.574 \qquad (6)$$

5.1 S-Parameters w.r.t. Pressure

In table 4, S-Parameters are given w.r.t. pressure at 2, 10, 18 GHz, respectively. From table 4, it is observed that the S-Parameters of coaxial cables remained almost constant when the pressure was decreasing. At 2 GHz, the observed variation in insertion loss over the pressure range is 0.07 dB. The variation in S11 and S22 over the pressure range is 0.25 dB and 0.05 dB, respectively. At 10 GHz, the observed variation in the insertion loss over the pressure range is 0.13 dB. The variation in S11 and S22 over the pressure range is 0.27 dB and 0.48 dB, respectively. At 18 GHz, the observed variation in S12 and S21 over the pressure range is 0.27 dB and 0.26 dB, respectively. The variation in S11 and S22 over the pressure range is 0.10 dB and 0.38 dB, respectively. The S-Parameters plot at 2, 10, and 18 GHz w.r.t.

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Pressure is given in Figures 12, 13, 14, respectively. From figures 12, 13, 14, it is observed that insertion loss increases with an increase in frequency and remains almost constant w.r.t. pressure profile. A slight increase in insertion loss variation over the pressure profile is observed at a higher frequency. The variation in return loss over the pressure profile is within 0.5 dB. This variation is within measurement uncertainty, which is negligible for the return loss. The Return Loss and VSWR can be defined as:

$$RL(dB) = -20 \log(|\text{Reflection Coefficient } (\Gamma)|) \quad (7)$$

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (8)$$

If Return Loss (RL) = 20 dB, Γ = 0.1 and VSWR = 1.22

Table 4: S-Parameters w.r.t. Pressure

Time	Pressure		At 2 GHz				At 10 GHz				At 18 GHz			
	Torr	Log Scale	S11 (dB)	S12 (dB)	S21 (dB)	S22 (dB)	S11 (dB)	S12 (dB)	S21 (dB)	S22 (dB)	S11 (dB)	S12 (dB)	S21 (dB)	S22 (dB)
13:24:53	229.1064	2.36	-21.34	-12.54	-12.57	-17.29	-20.31	-29.89	-30.00	-22.68	-17.11	-41.78	-41.67	-13.50
14:03:42	43.51301	1.64	-21.36	-12.55	-12.57	-17.28	-20.30	-29.93	-30.02	-22.69	-17.09	-41.76	-41.73	-13.46
14:43:02	7.478092	0.87	-21.36	-12.54	-12.57	-17.27	-20.30	-29.90	-30.00	-22.62	-17.06	-41.76	-41.70	-13.49
15:22:37	0.872026	-0.06	-21.39	-12.53	-12.57	-17.26	-20.27	-29.87	-30.00	-22.58	-17.07	-41.73	-41.67	-13.53
16:01:27	0.872999	-0.06	-21.42	-12.53	-12.57	-17.25	-20.24	-29.92	-30.00	-22.56	-17.05	-41.72	-41.69	-13.56
16:40:23	0.490148	-0.31	-21.46	-12.55	-12.58	-17.24	-20.21	-29.93	-30.04	-22.56	-17.09	-41.76	-41.72	-13.70
17:19:20	0.176893	-0.75	-21.48	-12.54	-12.59	-17.24	-20.15	-29.90	-30.03	-22.55	-17.11	-41.76	-41.75	-13.79
17:57:56	0.112062	-0.95	-21.49	-12.54	-12.57	-17.24	-20.16	-29.93	-30.02	-22.54	-17.10	-41.72	-41.69	-13.76
18:36:49	0.088281	-1.05	-21.51	-12.54	-12.57	-17.24	-20.13	-29.93	-30.02	-22.52	-17.13	-41.73	-41.68	-13.80
19:15:40	0.074755	-1.13	-21.52	-12.53	-12.57	-17.25	-20.13	-29.86	-29.99	-22.47	-17.11	-41.68	-41.65	-13.80
19:54:43	0.063307	-1.20	-21.53	-12.52	-12.55	-17.26	-20.11	-29.83	-29.98	-22.43	-17.08	-41.65	-41.58	-13.71
20:33:39	0.000961	-3.02	-21.53	-12.51	-12.54	-17.26	-20.12	-29.84	-29.96	-22.38	-17.09	-41.63	-41.59	-13.68
21:12:50	0.000785	-3.10	-21.57	-12.52	-12.55	-17.25	-20.11	-29.88	-29.97	-22.40	-17.11	-41.62	-41.61	-13.77
21:51:39	0.000690	-3.16	-21.57	-12.51	-12.55	-17.24	-20.06	-29.84	-29.97	-22.42	-17.09	-41.60	-41.56	-13.84
22:30:31	0.00062	-3.20	-21.59	-12.51	-12.55	-17.24	-20.05	-29.80	-29.96	-22.42	-17.08	-41.61	-41.56	-13.83
23:09:31	6.29E-05	-4.20	-21.58	-12.49	-12.52	-17.26	-20.04	-29.84	-29.92	-22.27	-17.15	-41.53	-41.49	-13.74
23:48:15	3.55E-05	-4.45	-21.58	-12.48	-12.52	-17.27	-20.08	-29.80	-29.91	-22.21	-17.12	-41.51	-41.50	-13.66

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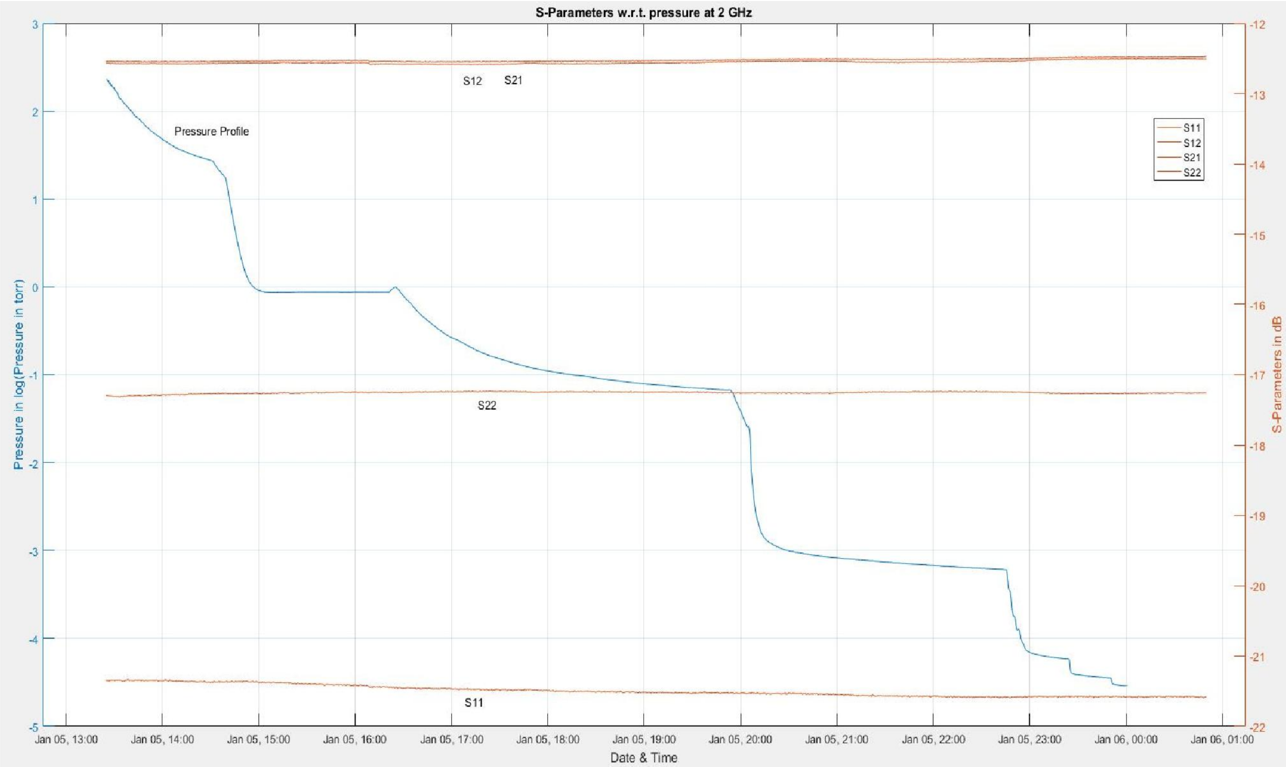

Figure 10: S-Parameters w.r.t. Pressure @ 2 GHz

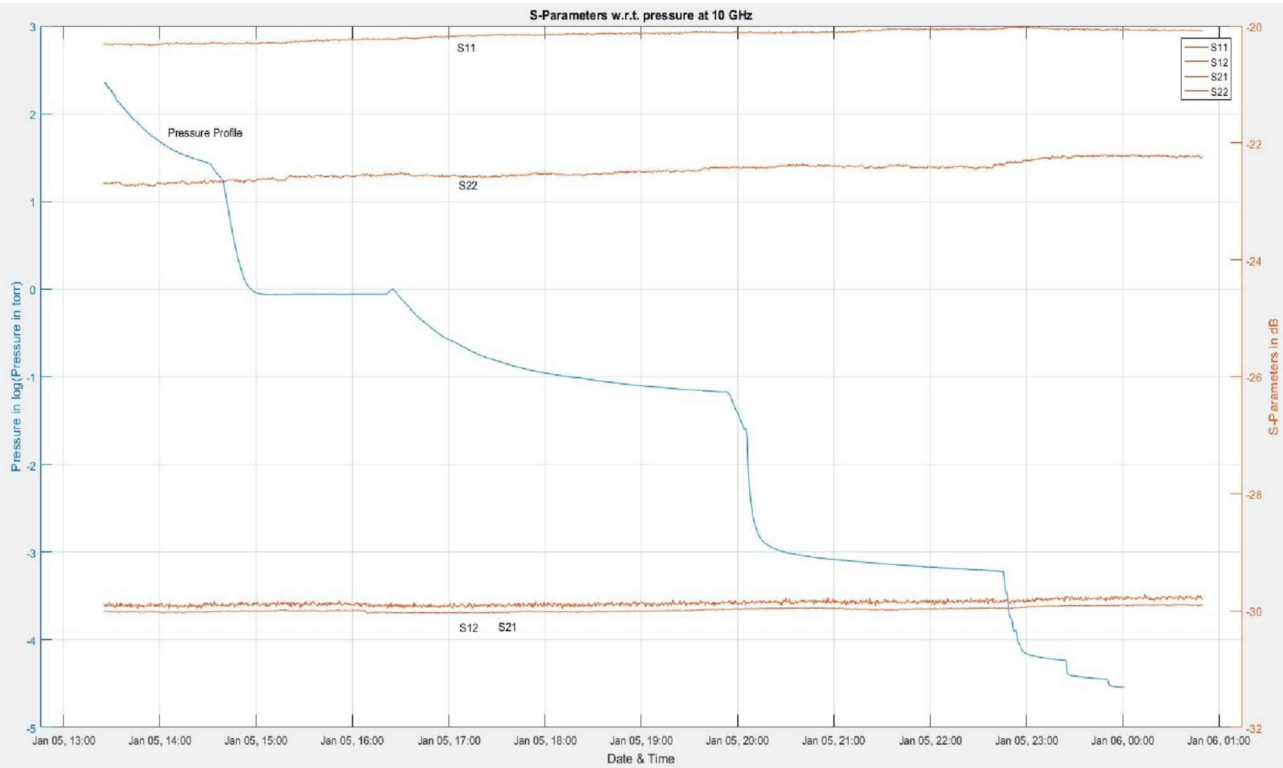

Figure 11: S-Parameters w.r.t. Pressure @ 10 GHz

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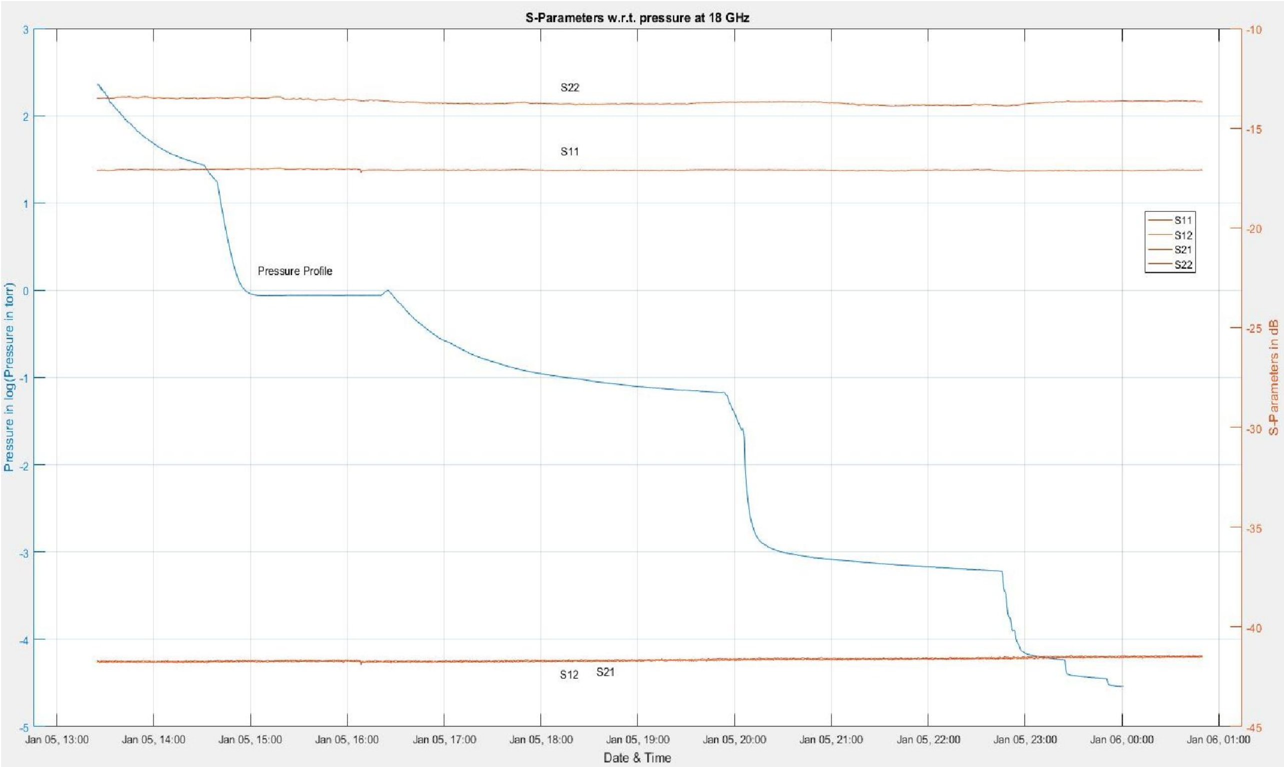

Figure 14: S-Parameters w.r.t. Pressure @ 18 GHz

The change in insertion loss due to extreme pressure variation (from 229.1064 torr to 3.55E-05 torr) at different frequencies is calculated using equations 4 & 5 and given in table 5.

Table 5: Change in Insertion Loss due to extreme Pressure Variation at different Frequencies

Frequency (GHz)	ΔS12 (dB)	ΔS21 (dB)
2	0.05	0.05
3	0.10	0.09
4	0.10	0.12
5	0.11	0.11
6	0.13	0.07
7	0.14	0.08
8	0.13	0.07
9	0.14	0.11
10	0.09	0.09
11	0.22	0.22
12	0.13	0.12
13	0.16	0.16
14	0.18	0.17
15	0.17	0.22
16	0.22	0.18
17	0.21	0.17
18	0.27	0.18

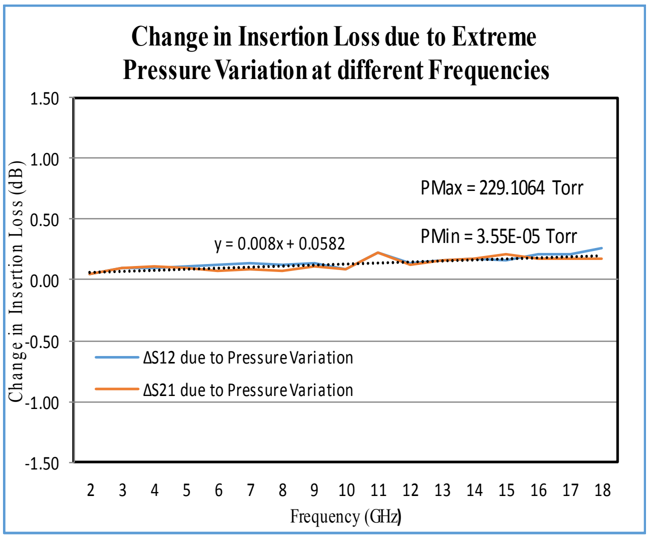

Figure 15: Change in Insertion Loss due to Extreme Pressure Variation at different Frequencies

Table 5 and figure 15 above show a slight increase in ΔS12 and ΔS21 due to extreme pressure variation at different frequencies. This slight increase in insertion loss variation can be mapped with the linear equation that is given below:

$$y = 0.008x + 0.0582 \qquad (9)$$

VI. CONCLUSION AND DISCUSSION

This paper describes the S-Parameters analysis in the frequency range of 2-18 GHz at different environmental conditions for PTFE RF Coaxial Cables in detail. From this experiment and analysis of S-Parameters, we can conclude the following points:

- The insertion loss is mainly affected by temperature profile and decreases with a reduction in temperature.
- The insertion loss is negligibly affected by the pressure profile, and a slight decrease with pressure reduction is observed.
- At different frequencies (2-18 GHz), the change in insertion loss due to extreme temperature variation increases significantly; a slight increase in insertion loss variation due to extreme pressure variation is observed.
- The variation in return loss or ΔS11 & ΔS22 is within 2 dB for temperature and pressure profiles. This variation is within measurement uncertainty, which means that the return loss variation is negligible, and both ports of cables are perfectly matched.
- The change in VSWR over temperature for ~2dB variation (-20 dB to -18 dB) in return loss is 0.066 that is negligible. Table 8 describes the approximate change in VSWR over temperature, pressure, and frequency (data tabulated from Tables 2, 4).
- Based on this S-Parameters analysis, we can compute the change in insertion loss due to temperature or pressure profile at different frequencies (2-18 GHz) for PTFE RF coaxial cable during TVAC IST. All the absolute RF measurements carried out during TVAC IST can be compensated by the computed values based on Temperature, Pressure, and Frequency.

Table 6: Insertion Loss Variation

Frequency (GHz)	Insertion Loss Variation (dB)			
	Over Temperature		Over Pressure	
	ΔS12	ΔS21	ΔS12	ΔS21
2	0.92	0.91	0.07	0.07
10	2.28	2.27	0.13	0.13
18	3.37	3.32	0.27	0.26

Table 7: Return Loss Variation

Frequency (GHz)	Return Loss Variation (dB)			
	Over Temperature		Over Pressure	
	ΔS11	ΔS22	ΔS11	ΔS22
2	1.32	0.83	0.25	0.05
10	1.88	0.73	0.27	0.48
18	0.45	0.64	0.1	0.38

Table 8: Change in VSWR

Condition		Return Loss (dB)	Reflection Coefficient (Γ)	VSWR	ΔVSWR
Over Temp.	At 2 GHz	-21	0.089	1.196	0.038
		-19.6	0.105	1.234	
	At 10 GHz	-20	0.100	1.222	0.066
		-18	0.126	1.288	
	At 18 GHz	-13	0.224	1.577	0.064
		-12.3	0.243	1.641	
Over Pres.	At 2 GHz	-21	0.089	1.196	0.007
		-20.7	0.092	1.203	
	At 10 GHz	-22	0.079	1.173	0.011
		-21.5	0.084	1.184	
	At 18 GHz	-13	0.224	1.577	0.035
		-12.6	0.234	1.612	

VII. ACKNOWLEDGMENT

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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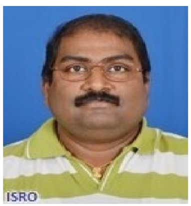

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