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Report on Completion of Tasks 1.1.2 and 1.1.3

LONG TERM STABILITY OF THE NBS DESIGN
DEBYE DIELECTRIC COAXIAL LINE WAVESHAPING FILTER

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Jan. 5, 1994

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LONG TERM STABILITY OF THE NBS DESIGN

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Norris S. Nahman

Abstract

By means of analysis of NBS laboratory notebooks for the period of 1976 - 1982 in conjunction with recent LANL P14 measurements it is shown that the Model 100-1, S/N 1 Debye Coaxial Line is stable. From the date of its inception in July 1977 to the present, at a temperature of 30 C the transition duration of the filter insertion step response has remained a 125.8 ps while the relative dielectric constant has remained at 2.7. Also, capacitance measurements on the NBS - held Model 100-2, S/N 2 have demonstrated that the capacitance has remained at 32.3 pF since 1979.

LONG TERM STABILITY OF THE NBS DESIGN

DEBYE DIELECTRIC COAXIAL LINE WAVE SHAPING FILTER

1. Introduction.

The objective of the work reported in this report was to compare the 1977 NBS measurements on the wave shaping filter Model 100-1, S/N 1 and those made in 1993. The parameters to be compared are (1) the transition duration of the insertion transmission step response, and (2) the low frequency relative dielectric constant of the Debye liquid solution inside of wave shaping filter. Also, at the behest of LANL P14 NIST capacitance measurements were made on the NIST - held Model 100-2, S/N 2 in 1990 and compared by LANL P14 with those made in 1979.

To accomplish the objective required a thorough review of the NBS laboratory notebooks and reports covering the research, development, and calibration of all of the wave shaping filters produced by NBS. The work was done during the period of 1976 through 1982 with a total of 17 units being built and calibrated.

The Model 100-1, serial No. 1, was built in 1977. It was an engineering prototype whose performance did not meet the predicted values, thus it served to define the necessary future research on the properties of the Debye liquid which were needed for the accurate design of the filters. Model 100-1, Serial No. 1. was kept at NBS with its original Debye liquid solution filling intact. The conclusion that the solution was in fact intact was not established until the 1993 measurements were made, and the review of the 1976 - 1982 NBS laboratory notebooks was completed. Hindsight use of the 1978 notebook graphs versus molal concentration M for (1) the relative dielectric constant ϵ_r and (2) the insertion transmission step response transition duration t_d then allowed the calculation of the desired parameters. To correct for the temperature dependence of the NBS 1977 parameters, data obtained from the 1993 measurements was used.

This report is divided into six chapters and seven appendices as described below.

Chapter 1. Introduction.

Chapter 2. 1977 NBS Measurements on the Filter, Model 100-1, S/N 1.

Chapter 3. 1978 NBS Measurements of the Dielectric Parameters versus Molal Concentration.

Chapter 4. 1993 LANL/PSPL Measurements on the Filter, Model 100-1, S/N 1.

1. Introduction (cont.).

Chapter 5. 1993 LANL Analysis to Determine the 1977 Dielectric Parameters and Molal Concentration of the Filter, Model 100-1, S/N 1.

Chapter 6. LANL/NIST November 30, 1990 Capacitance Measurements of the Model 100-2, S/N 2.

Appendix 1. NBS June 10, 1977, Lab. notebook pages (8).

Appendix 2. NBS October 28, 1976, Lab. notebook pages (1).

Appendix 3. NBS July 25, 1977, Lab. notebook pages (4).

Appendix 4. NBS July 7, 1978, Lab. notebook pages (3).

Appendix 5. NBS August 21, 1978, Lab. notebook pages (3).

Appendix 6. LANL/PSPL July 9, 1993, Lab. notebook pages (7).

Appendix 7. LANL/NIST 1990, Capacitance Measurements (3).

Chapter 2.

1977 NBS Measurements on the Filter.

The Model 100-1, S/N 1 was the prototype for the wave shaping filters. It was designed and built in 1977 by Dr. James R. Andrews (JRA). On June 10, 1977 using the NBS Automatic Pulse Measurement System (APMS) with the tunnel diode Model HP1106A, S/N 732-00869 as a signal source he made the first measurements of the performance of a filter having the same structure as the Model 100-1, S/N 1. The structure consisted of a 30 cm coaxial line having liquid sealing dielectric supports at each end, and a filling valve and expansion bellows mounted on the exterior of the coaxial line outer conductor. The coaxial line inner conductor OD was 0.081 inches while the outer conductor was a 7mm precision line outer conductor (ID 0.276 inches, 7mm). The connectors mounted on the line were APC 7 precision connectors with modified (sealing) dielectric support beads.

The results of the June 10, 1977 measurements were recorded in his laboratory looseleaf notebook. His laboratory notebook contains the following information: (1) a single page containing the descriptions of the measurement setup and the Debye line, (2) the APMS print out for the observed transition duration, (3) three APMS plots for the transmission waveform, and (4) three APMS plots for the reflection (TDR) measurements.

For the transmission measurements the vertical sensitivity was 50.00 mV/Div. while those for the TDR measurements were 50 mV/Div. and 5 mV/Div.. The timebases employed for the transmission measurements were 0.998 ns/Div. and 0.048 ns/Div. while those for the reflection measurements were 0.998 ns/Div. and 0.198 ns/Div.. The 0% and 100% percent levels were determined by the vertical axis histogram method over a time window of 9.98 ns. The measurements were made at room temperature. See Appendix 1 for a copy of the June 10, 1977 laboratory notebook pages.

The Debye line was filled with a solution believed to be a 1.225 molal concentration solution of the solute 2-Heptanone in the solvent n-Heptane. The solution was made up by Mr. Edward Risley in November 12, 1976. Based on his theoretical work Risley predicted that the 1.225 molal solution would have a relative dielectric constant ϵ_r equal to 2.57 which in turn would give a transmission step response having a transition duration t_d of 100 ps. Also, for the Debye line to have a characteristic impedance Z_0 of 50 Ohms the inner conductor diameter would have to be 0.081 inches because the inner diameter of the precision 7 mm air line outer conductor was 0.276 inches (7.0E-3 meters). See Appendix 2 for a copy of the summary of Mr. Risley's predictions.

Both ϵ_r and t_d were not known quantities as they were predicted values based upon Risley's theoretical work. Thus, the experiment was designed to yield the actual values of the solution dielectric constant ϵ_r and the transmission transition duration t_d .

Chapter 2 (cont.).

On July 25, 1977 Dr. Andrews made measurements on the Model 100-1, S/N 1 and recorded the transmission waveforms. He labeled them as "NBS Time Xfer Std, Model 100-1, S/N 1" (Also, inside of the filter enclosure written on the coaxial line is " NBS XFR Standard Model 100-1, S/N 1"). There was no APMS print out of the observed transition duration accompanying the waveforms, and the timebases were 49.951 and 99.902 ps . Also, his notebook contains one page of calculations using the equation for the characteristic impedance Z_0 of a coaxial line in which he used Risley's predicted value for ϵ_r (2.57). He adjusted the value of the center conductor OD to match the observed Z_0 of 44.9 Ohms. His last calculated value for the OD was 0.80 inches which gave $Z_0 = 46.23$. This result demonstrated that Mr. Risley's prediction for the dielectric constant was incorrect. See Appendix 3 for a copy of the July 25, 1977 laboratory notes.

Chapter 3.

1978 NBS Measurements of the Dielectric Parameters versus Molal Concentration.

With the results of the June & July 1977 measurements in hand Dr. Andrews concluded that the behavior of the dielectric parameters versus molal concentration had to be experimentally determined. The parameters to be determined were the engineering design parameters $\epsilon_r(0,M,T)$ and $t_d(M,T)$ which are the low frequency limit (DC) relative dielectric constant and the transmission transition duration, respectively, as functions of the molal concentration M and the temperature T . The dielectric constant of the solution has a Debye form which is frequency, temperature, and concentration dependent and is given by

$$\epsilon_r(j\omega, M, T) := \epsilon_r(\infty, M, T) - \frac{[\epsilon_r(\infty, M, T) - \epsilon_r(0, M, T)]}{1 + j\omega\tau(M, T)} \quad (3.1)$$

where $\epsilon_r(\infty, M, T)$ and $\tau(M, T)$ are the high frequency limit relative dielectric constant and the dielectric relaxation time, respectively. When the angular frequency ω ($2\pi f$) approaches zero (DC) $\epsilon_r(j\omega, M, T)$ becomes $\epsilon_r(0, M, T)$; in the other extreme, for infinite frequency $\epsilon_r(j\omega, M, T)$ reduces to $\epsilon_r(\infty, M, T)$.

The polar molecule polarization contribution from the solute 2-Heptanone makes $\epsilon_r(0, M, T)$ greater than $\epsilon_r(\infty, M, T)$. Because the polar molecules can not follow the reversals of the electric field at high frequencies, their contribution diminishes at high frequencies, and $\epsilon_r(j\omega, M, T)$ ultimately decreases to $\epsilon_r(\infty, M, T)$ which is dependent upon the electronic polarization contribution from both the solvent n-Heptane and the solute 2-Heptanone.

The two engineering design parameters sought by Dr. Andrews, $\epsilon_r(0, M, T)$ and $t_d(M, T)$ can be determined by a series of time domain measurements on solutions of solute 2-Heptanone and solvent n-Heptane with M as the parametric variable. $\epsilon_r(0, M, T)$ can be calculated from the characteristic impedance measured by TDR, while $t_d(M, T)$ can be calculated from the insertion time domain transmission measurements. He performed the measurements with the APMS and the tunnel diode Model HP1106A, S/N 732-00870 using the wave shaping filter Model 100-1, S/N 2. The graphs of $\epsilon_r(0, M, 30)$ and $t_d(M, 30)$ are shown in Appendix 4. Model 100-1, S/N 2 differed from Model 100-1, S/N 1 in that its center conductor ID was 0.073 in. rather than 0.081 in.. Note that the temperature T is 30 C (deg. Celsius).

Chapter 4.

1993 LANL/PSPL Measurements

After the Model 100-1, S/N 1 was modified to include a temperature controlling system, the temperature was set to 30 C, and the unit was run for several months to age the electronic components. On July 9, 1993 pulse measurements were made on the unit which consisted of the following:

- 4.1. Step response transmission at 23.3 and 30.0 C.
- 4.2. TDR responses for the input port at 23.3 and 30.0 C.
- 4.3. TDR response for the output port at 30.0 C.

Refer to pages A.4-1 through A.4-5 for copies of the laboratory notebook pages covering these measurements.

The results of these measurements were as follows:

Measurement	Input Port	Temperature	Value
4.1	F1	23.3 C	129.8 ps
4.1	F2	30.0 C	125.8 ps
4.2	F1	23.3 C	44.4 Ohms
4.2	F1	30.0 C	44.7 Ohms
4.3	F2	30.0 C	44.6 Ohms

Chapter 5.

1993 LANL Analysis to Determination the 1977 Dielectric
Parameters and Molal Concentration of the Filter.

5.1. The Filter Transition Duration Based on the NBS measurements of the
Model 100-1, S/N 1, July 25, 1977.

To estimate the transition duration of the waveform filter itself, the system transition duration must be known. The system transition duration is that produced by the tunnel diode generator operating directly into the APMS. Because the APMS step response may be considered to be constant (within statistical limits), the system transition duration depends upon the particular tunnel diode employed.

The June 10, 1977 measurements employed the tunnel diode HP1106A, S/N 732-00869. For the transmission transition duration measurement of the Model 100-1, S/N 1 on July 25, 1977 there was no record of the tunnel diode used in the measurement nor was the temperature of the coaxial structure recorded. However, the tunnel diode HP1106A, S/N 732-00870 was used beginning on July 7, 1978 for the series of measurements to determine $\epsilon_r(0, M, T)$ and $t_d(M, T)$ with T being 30 C, and the system response was recorded, pages A.4-1 through A.4-3. Comparing the transmission waveforms, pages A.3-2 and A.4-3, indicates that the Model HP1106A, S/N 732-00870 was used for the measurements on the Model 100-1, S/N 1 wave filter; consequently, we can conclude that the system transition duration t_{ds} was 30.89 ps.

Regarding the operating temperature of the coaxial structure we will assume it to have been 24.4 C. This was the value of the case temperature for the calibration measurement of the Model 100-1, S/N 3 which was delivered to Tektronix, January 24, 1978. This unit did not have a temperature controlling system attached to it. The calibration was done in the temperature controlled laboratory housing the NBS APMS which was used for the calibration measurements. Since the Model 100-1, S/N 1 was calibrated in the same laboratory using the NBS APMS, we have assumed that the temperature was the same, i.e., 24.4 C.

Using the observed transition durations from pages A.3-3 and A.3-4 we then have the following:

Temperature assumed to be 24.4 C.

For the timebase of 99.902 ps/div. we have:

$t_{d01} := 132.4$ ps.

$t_{ds} := 30.89$ ps.

The filter transition duration is then

$$t_{df1} := \sqrt{t_{d01}^2 - t_{ds}^2} \quad t_{df1} = 128.7461 \text{ ps.}$$

5.1. (cont.).

For the timebase of 49.951 ps/div. we have:

$$tdo2 := 134.8 \quad tds := 30.89 \text{ ps.}$$

which gives a filter transition duration tdf2 of

$$tdf2 := \sqrt{tdo2^2 - tds^2} \quad tdf2 = 131.213 \text{ ps.}$$

The average transition duration tdf is

$$tdf := \frac{tdf1 + tdf2}{2} \quad tdf = 129.9796 \text{ ps.}$$

5.2. LANL/Picosecond Pulse Labs, Boulder, Co. Measurements on Model 100-1, S/N 1, July 9, 1993.

Using the data for the transition duration of the filter vs temperature we have

$$T1 := 23.3 \quad td1 := 130.6 \quad ; \quad T2 := 30 \quad td2 := 125.8$$

The temperature coefficient for the filter transition duration $\$td$ is then

$$\$td := \frac{td2 - td1}{T2 - T1} \quad \$td = -0.7164$$

Assuming that the 1977 NBS laboratory temperature was 24.4 C. the temperature coefficient of -0.716 ps/C gives the transition duration td2

$$T1 := 23.3 \quad T2 := 24.4 \quad \$td := -0.716 \text{ ps/C}$$

$$td2 := td1 + (T2 - T1) \cdot \$td \quad td2 = 129.8124 \text{ ps}$$

which is very close to the average value tdf = 129.98 ps computed above in Section 5.1.

5.3. Comparison of LANL/PSPL 1993 Measurements with Those of NBS 1978.

From JRA's (Aug. 21, 1978) curves for transmission transition duration τ_d vs. molal concentration M , page A.5-2, we have that for 30 C and a transition duration of 125.8 ps

125.8 ps corresponds to $M = 1.50$.

This in turn gives from the ϵ_r vs M curve, page A.5-3, that

$\epsilon_r = 2.68$ corresponds to $M = 1.50$.

The LANL/PSPL TDR measurement at 30 C gave an average reflection coefficient ρ of

$$\begin{aligned}\rho_1 &:= -5.552 \cdot 10^{-2} & \rho_2 &:= -5.627 \cdot 10^{-2} \\ \rho &:= \frac{\rho_1 + \rho_2}{2} & \rho &= -0.0559\end{aligned}$$

$$K := \frac{50.03}{50} \quad Z := \frac{1 + \rho}{1 - \rho} \cdot 50$$

$$Z = 44.7064$$

$$Z_1 := Z \cdot K \quad Z_1 = 44.7332$$

$$\epsilon_r := \left[\left[\frac{376.99}{2 \cdot \pi \cdot Z_1} \right] \cdot \ln \left[\frac{7}{2.057} \right] \right]^2 \quad \epsilon_r = 2.6982$$

which is very close to the value measured at NBS 1978, $\epsilon_r = 2.68$.

At a temperature of 23.3 deg.C the reflection coefficient ρ was

$$\begin{aligned}\rho &:= -5.857 \cdot 10^{-2} \\ Z &:= \frac{1 + \rho}{1 - \rho} \cdot 50 & Z &= 44.4671 \\ Z_1 &:= Z \cdot K & Z_1 &= 44.4937\end{aligned}$$

5.3. (cont.)

thus we have for ϵ_r at $T = 23.3$ deg.C,

$$\epsilon_r := \left[\left[\frac{376.99}{2 \cdot \pi \cdot Z1} \right] \cdot \ln \left[\frac{7}{2.057} \right] \right]^2 \quad \epsilon_r = 2.7273$$

5.4. Summary.

TABLE 5.4.1

Meas./Calc.	Yr./Lab.	Temp.,C.	Molal.	td, ps.	ϵ_r .
Measured	1977 NBS	24.4	-	129.98	-
Calculated	1993 LANL	24.4	-	129.8	-
Measured	1978 NBS	30.0	1.50	125.8	2.68
Measured	1993 LANL	30.0	-	125.8	2.70
Measured	1993 LANL	23.3	-	130.6	2.73

Inspection of Table 5.4.1 leads us to the conclusions that (1) the liquid dielectric has been stable during the period 1977 through 1993 with a 30.0 C. relative dielectric constant of $\epsilon_r = 2.7$ and (2) that the filter step response transition duration has remained as 125.8 ps for a temperature of 30.0 C.

Chapter 6.

LANL/NIST November 30, 1990 Capacitance Measurements

Model 100-2, S/N 2.

George Free of NIST 723 Capacitance Standards Group calibrated the capacitance of the Model 100-2, S/N 2 while it was operating under temperature control by its temperature controller at 30 C. Using three runs of ten successive capacitance measurements he obtained the following mean values for each run, Appendix 7.

Run	Mean Value, pF.
1	32.2945
2	32.3038
3	32.3121

which yields the mean value of the means of

$$\frac{32.2945 + 32.3038 + 32.3121}{3} = 32.3035 \quad \text{pF.}$$

At NBS in 1979 at 30 C the capacitance had a measured value of 32.3678 pF, refer to Appendix 7. Consequently, we conclude that the capacitance of the filter is stable.

10 June 77 JRA

(1)

\$400 ps line Test with old solution of 1.225 molal 2 heptanone in heptane made 11/12/76 by Risley. Line mounted in new box with bellows. Filled by vacuum techniques.

Test Set-up for Transmission

For TDR

APPENDIX - 1

Page A.1-1 of 8 Pages.

10 June 77
[Signature]

NUMBER OF OCCURRENCES= 69 ,ZERO= 0.330599E 4
NUMBER OF OCCURRENCES= 90 ,HUND= 0.119379E 5

CALCULATION METHOD FOR 100% POINT?

0=LAST WAVEFORM POINT

1=WAVEFORM MAXIMUM VALUE

2=HISTOGRAM UPPER MODE

3=HP-1106A/B TUNNEL DIODE

4=TEKTRONIX METHOD

METHOD DESIRED=2

NEXT COMES FAST WAVEFORM ACQUISITION.

TYPE OF MEASUREMENT? (1=FALLTIME, 0=RISETIME)0

NUMBER OF WAVEFORM MEASUREMENTS=?10

NUMBER OF SWEEP AVERAGES PER WAVEFORM=?10

VERTICAL SCALE IN MV/CM?50

TIME SCALE IN NSEC/CM?0.050

PULSE RISETIME= 139.640 PICOSECONDS

RISETIME STD. DEVIATION= 1.586 PICOSECONDS

PULSE AMPLITUDE (0%-100%)= 263.427 MILLIVOLTS

STOP 999

SLOW WAVEFORM PLOT---VERTICAL SCALE= 50.000 MU/DIV

HORIZONTAL SCALE= 0.998 NSEC/DIV

[illegible]

Page A.1-4 of 8 Pages

FAST WAVEFORM PLOT---VERTICAL SCALE= 50.000 MU/DIU

Page A.1-5 of 8 Pages

HORIZONTAL SCALE= 0.049 NSEC/DIU

Transition (10-90)%
Duration

208 mm time base
(10-90)% 59 mm
 $\frac{59}{208} \times 480 \mu s = 131.5 \mu s$
WJL
7/10/93

100% 51mm x $\frac{50mV}{10mm} = 255mV$

52 x 5 = 260

Amplitude should be 52.7mm $\Rightarrow$ 263.5mV
10-90% should be 60.51mm $\Rightarrow$ 139.4405
Then don't agree with Paint tool
Graphics are not accurate !!
t

TDR output

SLOW WAVEFORM PLOT-----VERTICAL SCALE= 50.000 MU/DIV

HORIZONTAL SCALE= 0.998 NSEC/DIV

$$\Gamma = \frac{50-53}{53} = \frac{3}{53} = -0.0566$$

7/10/93

$$Z = \frac{1-0.0566}{1+0.0566} \times 50 = \frac{0.9434}{1.0566} \times 50 = 44.6$$

W.S.W.

i.e. 44.6

APC-7
interface

TD R 1/1/1

SLOW WAVEFORM PLOT---VERTICAL SCALE= 5.000 MV/DIV

HORIZONTAL SCALE= 0.198 NSEC/DIV

TD R output

SLOW WAVEFORM PLOT---VERTICAL SCALE= 5.000 MV/DIV

HORIZONTAL SCALE= 0.198 NSEC/DIV

Ref. Wave Gen Design Ed Risley
28 Oct 76

Values of first transition time (t_r), molal
concentration, dielectric constant (ϵ_r) and
center conductor dia. for 50 Ω 1' RWG

t_r	molal conc.	ϵ_r	dia.
50 μs	0.35	2.13	.080"
100 μs	1.225	2.57	.072"
200 μs	4.0	4.09	.052"

APPENDIX -2

Page A.2-1 of 1 page.

25 July 77

WRA

$$Z_0 = \frac{\eta}{2\pi} \ln\left(\frac{r_o}{r_i}\right) \quad \eta = \sqrt{\mu/\epsilon}$$

$$\eta_0 = \sqrt{\mu_0/\epsilon_0} = 376.7 \Omega \quad \eta = \frac{1}{\sqrt{\epsilon_r}} \eta_0$$

for APC-7 7mm line

$$O.D. = 0.2756" \pm 0.0002"$$

$$I.D. = 0.1197" \pm 0.0001"$$

$$Z_0 = 49.996 \Omega$$

$$\text{if use 1.225 molal sol. } \epsilon_r = 2.57 \quad Z_0 = 31.2 \Omega$$

for $Z_0 = 50 \Omega$ find I.D.

$$\ln(r_o/r_i) = \frac{2\pi Z_0 \sqrt{\epsilon_r}}{\eta_0} = \frac{2\pi \times 50 \sqrt{2.57}}{376.7} = 1.33697 \dots$$

$$\frac{r_o}{r_i} = 3.8075 \dots ; \text{ I.D.} = 0.07238"$$

what if I.D. = 0.080" find Z_0

$$Z_0 = \frac{\eta_0}{2\pi \sqrt{\epsilon_r}} \ln\left(\frac{0.2756}{0.080}\right) = 46.23 \Omega$$

observed 44.9 Ω

APPENDIX 3

Page A.3-1 of 4 Pages

42,381 50 SHEETS 5 SQUARE
23,382 100 SHEETS 5 SQUARE
23,383 200 SHEETS 5 SQUARE

NO OF PTS = 1024 START AT 1, XMIN = 0.000000E 0
YMAX = 0.500000E 3

YMIN = 0.000000E 0 MU/DIV NS/DIV
VERT SC = 50.000
CASE OF : NBS TRANS. TIME XFER STD, MODEL 100-1, 8/N 1

$$0 \text{ to } 100\% : (90.5 - 28.5) \text{ mm} = 62.0 \text{ mm} \leftrightarrow \frac{500 \times 62}{127.5} = 243.14 \text{ mV}$$

Full Scale
127.5 mm /
500 mV

7/10/93

90.5 mm

28.5 mm

7/10/93

NO OF PTS = 1024 START AT 1, XMIN = 0.000000E 0
 YMAX = 0.500000E 3

YMIN = 0.000000E 0
 VERT SC = 50.000 MU/DIU
 CASE OF : NBS TRANS. TIME XFER STD, MODEL 100-1, S/N 1
 HORIZ SC = 0.99902E -1 NS/DIU

(10-90)% : $\frac{27.5 \text{ mm}}{207.5 \text{ mm}} \times 999 = 132.4 \text{ ps.}$
added 9/10/93

NO OF PTS = 1024 START AT 1 ; XMIN = 0.000000E 0

YMAX = 0.500000E 3

YMIN = 0.000000E 0 MU/DIU
VERT SC = 50.000
CASE OF : NBS TRANS. TIME XFER STD, MODEL 100-1, S/N 1

HORIZ SC = 0.49951E -1 NS/DIU
Time Window 207.5 min, 500ps/207.5 min
(10-90) % Trans Duration = 499.51 $\frac{56}{207.5}$ ps. = 134.8 ps
W. S. J. 7/10/93

NEXT COMES FAST WAVEFORM ACQUISITION.
TYPE OF MEASUREMENT? (1=FALLTIME, 0=RISETIME)0
NUMBER OF WAVEFORM MEASUREMENTS=?10
NUMBER OF SWEEP AVERAGES PER WAVEFORM=?10
VERTICAL SCALE IN MU/CM?50
TIME SCALE IN NSEC/CM?0.052347

PULSE RISETIME= 30.894 PICOSECONDS

RISETIME STD. DEVIATION= 0.355 PICOSECONDS

PULSE AMPLITUDE (0%-100%)= 225.341 MILLIVOLTS
STOP 999

Driving pulse gen HP 1106 A

S/O - 732-00870

2 July 78 JRA

SLOW WAVEFORM PLOT---VERTICAL SCALE= 50.000 MV/DIV

0-100% 45.5mm
FS: 101mm $\leftrightarrow$ 500mV

HORIZONTAL SCALE= 0.998 NSEC/DIV

$$\frac{45.5}{101} \times 500 \text{ mV} = 225.248 \text{ mV}$$

which checks with print-out. (225.341mV)

WJW 12/93.

FAST WAVEFORM PLOT---VERTICAL SCALE= 50.000 MV/DIV

HORIZONTAL SCALE= 0.051 NSEC/DIV (0 - 100) % 45.5mm ; Overshoot = 3.5 mm

% Overshoot: $\frac{3.5}{45.5} \times 100 = 7.69\%$
cf. Bul 12/93

1 Aug 78

JRA

Summary of recent results

<u>Date</u>	<u>Molal</u>	<u>Z rise</u> <u>ps</u>	<u>E</u>	<u>Z_o</u> <u>Ω</u>
21 Aug	4.0	222	3.95	40.4
16 Aug	3.0	188	3.43	43.8
15 Aug	2.0	153	2.93	46.6
11 Aug	1.85	143	2.84	47.4
7 Aug	0.91	100	2.41	51.4
4 Aug	0.73	87	2.28	52.7
4 Aug	0.40	62.6	2.14	54.2
3 Aug	0.21	50.4	2.03	55.6
3 Aug	0.12	39.8	1.98	56.1
1 Aug	0.08	36.1	1.95	56.3
31 July	0.0	26.7	1.90	57.2
22 Aug	3.35	202	3.77	41.1
23 Aug	3.30	203	3.66	41.8

APPENDIX 5

Page A.5-1 of 3 Pages.

2-Heptanone in Heptane @ 30°C

Page A.5-2 of 3 Pages.

21 Aug 78 JRA

1. Insertion 30°C

7/9/93

Cursor

37.7720 ns 38.7720 ns 39.7720 ns

Timebase	=	200 ps/div	Delay	=	37.7720 ns
Memory 2	=	1.486 Volts/div	Offset	=	-4.498 Volts
Timebase	=	200 ps/div	Delay	=	37.7720 ns
Delta V	=	8.9193 Volts	Vmarker2	=	-46.455 mVolts
Vmarker1	=	-8.9658 Volts	Stop	=	38.1556 ns
Delta T	=	125.8 ps			
Start	=	38.0298 ns			

Trigger on External at Pos. Edge at 500.0 mVolts

INVERTED

37.7720 ns 38.7720 ns 39.7720 ns

Function2	=	1.486 Volts/div	Offset	=	4.498 Volts
Timebase	=	200 ps/div	Delay	=	37.7720 ns

Trigger on External at Pos. Edge at 500.0 mVolts

7/9/93

Input Connector
30 ps Normalized TDR

Timebase = 250 ps/div
 Memory 1 = 5.000 mVolts/div
 Timebase = 250 ps/div
 Cursor on Memory 1 at 1.7975 ns from reference plane
 Ref Plane = 19.3025 ns
 o = -5.552 % Cursor

Delay = 18.7800 ns
 Offset = 200.7 mVolts
 Delay = 18.7800 ns
 Distance = 269.4 mmeters
 Impedance = 44.7 Ohms Cursor

Trigger on External at Pos. Edge at 500.0 mVolts

	Time	Rho	Z
① SHA/APC	-22 ps	-0.71%	49.2
② "	+37.5 ps	+0.56%	50.5
③ "	92.5 ps	-0.55%	49.4
④ "	132 ps	0.85%	50.8
⑤	227 ps	-9.13%	41.6
⑥	307	+3.0%	53.0
⑦	363	0.75	50.7
⑧	412	3.59%	53.7
⑨	492	1.04%	51.0

$$\Delta t_{\text{to 9}} = 492 - 363 = 129 \text{ ps}$$

$$\Delta t_{\text{to 8}} = 412 - 307 = 105 \text{ ps}$$

Output Connector F2

Analysis NSN

9/9/93.

CWD

Timebase = 250 ps/div
 Memory 1 = 5.000 mVolts/div
 Timebase = 250 ps/div

Delay = 18.8850 ns
 Offset = 200.7 mVolts
 Delay = 18.8850 ns

Trigger on External at Pos. Edge at 500.0 mVolts

250 ps / 14.2 mm.

$$\frac{250}{14.2} = \frac{2t_4}{36}; 2t_4 = \frac{150 \times 36}{14.2} = 633.8 \text{ ps}; t_4 = 316.9 \text{ ps}$$

Reference Termination = 50.03 Ω

Corrected Reflection Impedances: : Correction Factor : $K = 50.03/50 = 1.0006$

$$Z = 50K \frac{1+\Gamma}{1-\Gamma}$$

$$Z_4 = 51.3 \times 1.0006 = 51.33; Z_5 = 44.6 \times 1.0006 = 44.63$$

Relative Dielectric Constant of liquid from Γ_5 section of line:

$$Z_o = \frac{\eta}{2\pi\sqrt{\epsilon_r}} \ln(7/2.057); \epsilon_r = \left[\frac{\eta}{2\pi Z_5} \ln(7/2.057) \right]^2 = \left[\frac{376.99}{2\pi Z_5} \ln(7/2.057) \right]^2$$

$$\epsilon_r = 2.711; \sqrt{\epsilon_r} = 1.6464$$

$$T_5 = \sqrt{\epsilon_r} T = 1.6464 \times \frac{10}{3} \times 10^{-9} \text{ s/m} = 5.488 \times 10^{-9} \text{ s/m}$$

$$\text{Length of } \Gamma_4 \text{ section: } X_4 = t_4/T_5 = 316.9 \times 10^{-12} / 5.488 \times 10^{-9} = 57.744 \times 10^{-3} = 57.744 \text{ mm} = 2.273''$$

Outer Diameter Γ_4 section:

$$d_o = d_i \ln' \left(\frac{2\pi\sqrt{\epsilon_r} Z_4}{\eta} \right) = 2.057 \ln'(1.4085) = 2.057 \times 10^{-3} \times 4.0893 = 8.4127 \text{ mm}$$

Page A.6-3 of 5 Pages.

$\therefore$ Section Γ_4 has 1.412 mm greater OD than Precision 7mm line.

7/9/93 JAU

23.3°C

3

Ch. 4	= 1.486 Volts/div = Raw data	Offset	= -4.498 Volts
Timebase	= 50.0 ps/div	Delay	= 37.8690 ns
Memory 2	= 1.486 Volts/div = Normalized	Offset	= -4.498 Volts
Timebase	= 50.0 ps/div	Delay	= 37.8690 ns

Trigger is Freerunning at 10.0 kHz with Step on

"Normalized"
13 ps input

identical
results!

Timebase	= 50.0 ps/div	Delay	= 37.8690 ns
Memory 2	= 1.486 Volts/div	Offset	= -4.498 Volts
Timebase	= 50.0 ps/div	Delay	= 37.8690 ns
Mem 2 Parameters		P-P Volts	= 9.3374 Volts
ll Time	= 129.8 ps	Overshoot	= 0.000 %
reshoot	= 0.000 %		

Trigger on External at Pos. Edge at 500.0 mVolts

23.3 °C

18.7800 ns 20.0300 ns 21.2800 ns

Timebase = 250 ps/div	Delay = 18.7800 ns
Memory 1 = 5.000 mVolts/div	Offset = 200.7 mVolts
Timebase = 250 ps/div	Delay = 18.7800 ns
Cursor on Memory 1 at 1.8225 ns from reference plane	
Ref Plane = 19.3025 ns	Distance = 273.1 mmeters
Δ = -5.857 %	Impedance = 44.4 Ohms

Trigger on External at Pos. Edge at 500.0 mVolts

30 ps TDR of F1 connector

APPENDIX-7

Page A.7-1 of 3 Pages

CALIBRATION OF VARIABLE CAPACITOR
PROGRAM USED IS VARIABLECAL

TEMPERATURE- 23.9 C
ATMOSPHERIC PRESSURE 23.7 mmHg
RELATIVE HUMIDITY 37 %
TIME 11:09:00
DATE 3 Dec 1990
CIB CAPACITANCE 0 pF

Room Temperature

12/3/90
George Free
NIST 723

MODEL 100-2

S/N 2

CAPACITANCE * CONDUCTANCE *
(pF) (nanoS)

4.45590075	1.645000E-04
4.45590108	1.671000E-04
4.45590075	1.652000E-04
4.45590060	1.658000E-04
4.45590049	1.627000E-04
4.45590054	1.647000E-04
4.45590075	1.676000E-04
4.45590004	1.673000E-04
4.45590035	1.669000E-04
4.45590030	1.660000E-04

4.45590057	1.657800E-04
.0000000917	4.664383E-07
4.45590057	
0.000000000	

MEAN OF MEASURED VALUES
S.D. OF MEASURED VALUES
ACTUAL VALUE (pF) OF VARIABLE
NOMINAL VALUE (pF) OF VARIABLE

CAPACITANCE * CONDUCTANCE *
(pF) (nanoS)

36.74833600	2.828000E-02
36.74880400	2.827000E-02
36.74927000	2.827000E-02
36.74972900	2.827000E-02
36.75018600	2.826000E-02
36.75064000	2.824000E-02
36.75109100	2.824000E-02
36.75156400	2.822000E-02
36.75201100	2.822000E-02
36.75245300	2.821000E-02

36.75040840	2.824800E-02
.0004381736	8.000000E-06
36.75040840	
100.00000000	

32.2945 pF

MEAN OF MEASURED VALUES
S.D. OF MEASURED VALUES
ACTUAL VALUE (pF) OF VARIABLE
NOMINAL VALUE (pF) OF VARIABLE

CAPACITANCE CONDUCTANCE
(pF) (nanoS)

36.75781900	2.815000E-02
36.75826300	2.815000E-02
36.75868600	2.814000E-02

Measurements made with
controller temperature set
at 30 C.

36.75952300
36.75994900
36.76036900
36.76078500
36.76120100
36.76161500

2.810000E-02
2.812000E-02
2.812000E-02
2.812000E-02
2.812000E-02
2.810000E-02

36.75973300
.0004028156
36.75973300
100.00000000

2.813000E-02
5.163978E-06

32.3038 μF

MEAN OF MEASURED VALUES
S.D. OF MEASURED VALUES
ACTUAL VALUE (pF) OF VARIABLE
NOMINAL VALUE (pF) OF VARIABLE

12/3/90
George Free
NIST 723

CAPACITANCE *
(pF)

CONDUCTANCE *
(nanoS)

36.76626700
36.76666000
36.76705400
36.76744400
36.76783400
36.76822100
36.76860900
36.76899200
36.76937400
36.76975700

2.809000E-02
2.809000E-02
2.809000E-02
2.807000E-02
2.807000E-02
2.807000E-02
2.807000E-02
2.807000E-02
2.807000E-02
2.807000E-02

36.76802120
.0003712548
36.76802120
100.00000000

2.807600E-02
3.055050E-06

32.3121 μF

MEAN OF MEASURED VALUES
S.D. OF MEASURED VALUES
ACTUAL VALUE (pF) OF VARIABLE
NOMINAL VALUE (pF) OF VARIABLE

Measurements made with controller
temperature set at 30 C.

32.2945

32.3038

32.3121

$\frac{96.9104}{3} = 32.3035 \text{ pF.}$

Model	S/N	C_{meas} (empty)	C_{STD} (empty) $= C_{meas} - C_{setup}$	C_{cell} (empty) (calculated)	C_{ends} $= C_{STD} - C_{cell}$	C_{meas} (full)	C_{STD} (full)	C_{cell} (full) $= C_{STD} - C_{ends}$	E_r (30°C) $= \frac{C_{cell}(full)}{C_{cell}(empty)}$	was
50-1	1	24,5483	15,5397	14,0272	1,5125	38,8844	29,8758	28,3633	2,02202	was 2.024
50-1	2	24,5383	15,5297	14,0272	1,5025	38,9437	29,9351	28,4326	2,02449 (mean)	was 2.024
100-2	1	23,5000	14,4914	12,9017	1,5897	not at temp	—	—	—	—
100-2	2	23,44266	14,4346	12,9017	1,53236	41,3764	32,3678	30,8354	2,3900	was 2.390
200-1	1	21,4882	12,4796	10,9469	1,5327	not at temp	—	—	—	—
200-1	2	21,4679	12,4593	10,9469	1,5124	48,9172	39,9086	38,3962	3,50749	was 3.507

Cap. of meas. setup was 9.0086 PF

7 May 79

7 May 79

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