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75 Ω Transmission System

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Abstract. This report represents the measurements to evaluate the performance of 75 Ω RG-6 cables and F-type RF connectors. Measurements include magnitude and phase stability, connector repeatability, sensitivity to temperature and relative humidity. The impedance matching modules, developed to match with 50 Ω system, are also described in the report.

1. Introduction

The next generation of low frequency interferometer for radio astronomy will require phasing together a relative large number of antennas in order to provide a reasonable collecting area. Due to a large number of elements and significant path lengths, the coaxial cable transmission system could be a significant cost driver. An inexpensive alternative to conventional coaxial cable is to use coaxial cable developed for the broadcast television industry such as RG-6/U. The impedance of RG-6/U cable is 75 Ω and it is more lossy than the common low loss cable such as Belden 9913. However, the cost of such cable and corresponding F-type connectors are much lower than that of conventional cable and connectors. The manufacturing quality and ruggedness of such inexpensive cable must be studied carefully so that a sound engineering decision can be made regarding its use in radio astronomy.

This report describes the testing of 75 Ω RG-6 cable fitted with F-type RF connectors.

2. Construction Details

2.1. RG-6 75 Ω Coaxial Cable

The RG-6/U coaxial cables described in this report are manufactured by CommScope for CATV and Satellite receiver applications. The dielectric material is polyethylene (PE) foam yielding a nominal capacitance of 53.1 pF/m (16.2 pF/ft) with $\epsilon_r = 1.48$. The corresponding velocity factor is 82 % and a nominal attenuation is 6.72 dB/100 meter. Figure 1 shows the construction details of RG-6 cable. The center conductor is made of Copper Covered Steel (CCS).

A foamed dielectric helps to have a better velocity of propagation. The shield includes aluminum foil, where aluminum is bonded to sides of polypropylene to provide 100% coverage and braid, where flexible wire is woven around the dielectric. The jacket material is polyethylene (PE). The Quad-Shield type cable has an extra layer of aluminum foil and braid. Figure 2 shows the types of cables from CommScope.

Figure 1. RG-6 Cable Construction

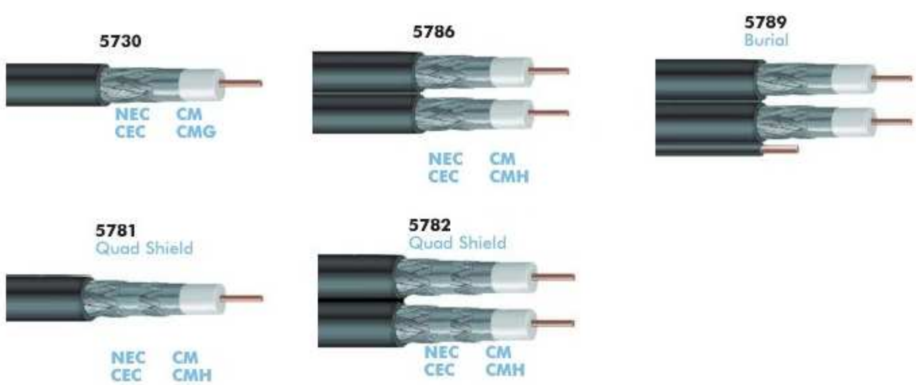

Figure 2. Types of 75Ω RG-6 Cables from CommScope

2.2. Compression F-Connectors for RG-6/U Cable

The F-type connectors are shown in Figure 3. These connectors are environmentally sealed to protect drops from harsh environments and offer superior corrosion resistance and RF integrity. The connectors offer signal leakage protection through a unique 360^0 compression process. The connector design makes it easy visually to ensure that the cable dielectric is flush with the post face prior to compression. All the connectors use commonly available compression tools and standard trim dimensions which make the connector installation process easy and quick.

Figure 3. F-Connectors for RG-6/U Cable : a) Thomas & Betts RG-6 Snap n Seal Compression Connectors b) PPC Coax Compression Connectors c) Gilbert Engineering Compression Connectors

3. Performance Measurement

The 75 Ω cable and F-connectors were tested using the HP 8753D VNA. A set of calibration standards were developed for use with 75 Ω RG-6 cable fitted with F-type RF connectors. A detailed information on the standards is given in [].

3.1. Magnitude and Phase Stability

It is necessary to test the cable performance in mechanical stresses such as bending, twisting, mechanical vibrations etc. The cable fitted with F-connectors was bent and twisted in several ways to check its stability to mechanical stresses. The magnitude and phase variation observed on the network analyzer were less than 0.05 dB and 0.5^0 respectively.

The coupling between the dual cables was also measured which is around -90 dB.

3.2. Connector Repeatability Test

In addition to the stability, it is necessary that the connectors produce the same results if the measurement is repeated under the same environmental conditions. Three pieces of RG-6 5730 cable, each fitted with a different type of connectors, were prepared . To check the connector repeatability, each piece of cable was connected and disconnected several times and the S-parameter measurements

(S_{11} and S_{21}) were taken at several frequencies over the 50-500 MHz range. The graphs showing the repeatability measure of each type of connectors are shown in Figure 4. The average standard deviation in the readings of S_{11} and S_{21} are shown in Table.1. Overall all the connectors show a good measure of repeatability with SNS6 having the highest of all.

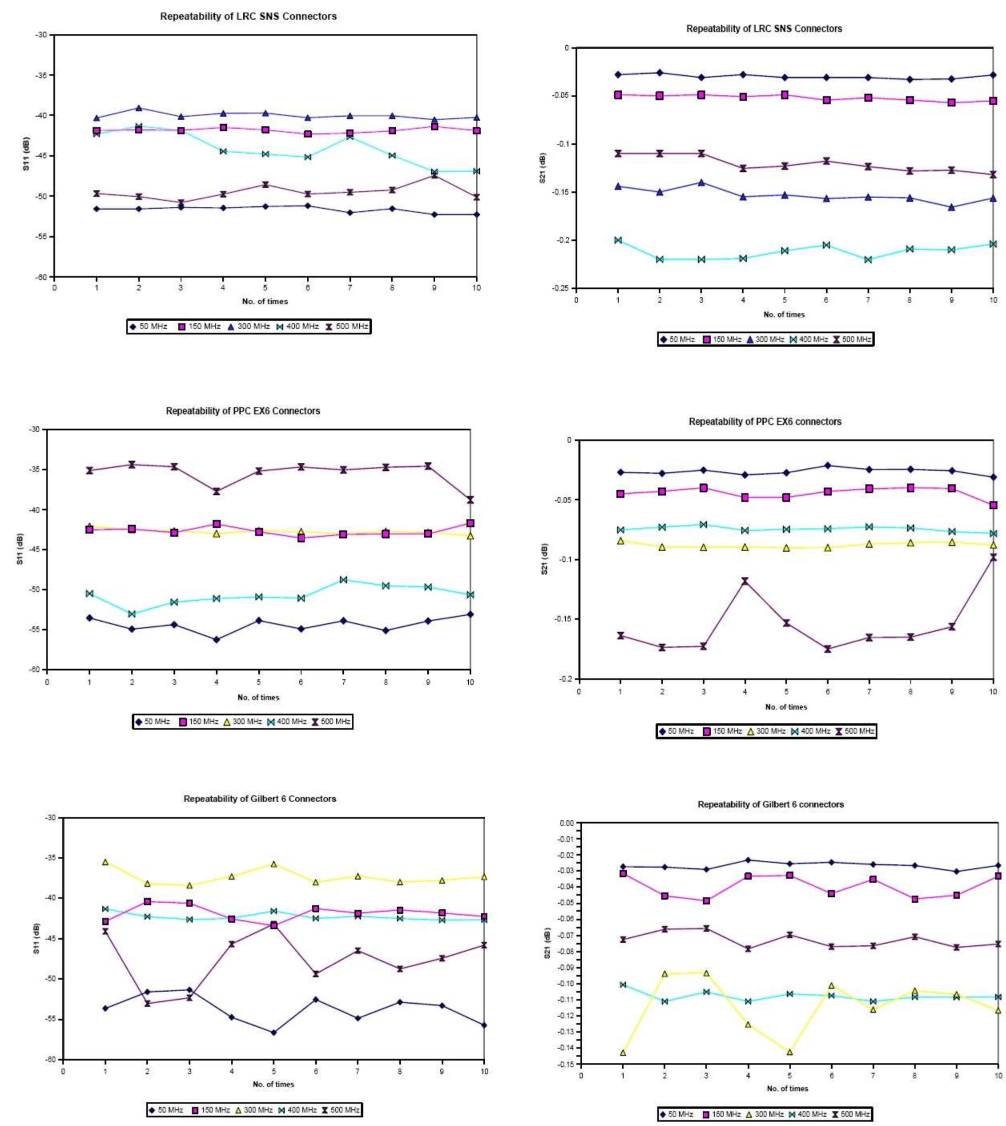

Figure 4. F-Connectors Repeatability: a) S_{11} and S_{21} of Thomas & Betts RG-6 SNS Connectors b) S_{11} and S_{21} of PPC Coax Compression Connectors c) S_{11} and S_{21} of Gilbert Engineering Compression Connectors

Table 1. Connector Repeatability: Standard Deviation in S-parameters

Connector	STD DEV in S11 [dB]	STD DEV in S21 [dB]
SNS	0.8	0.006
Gilbert	1.48	0.007
PPC EX6	0.8	0.006

3.3. Sensitivity to Temperature and Humidity

The sensitivity to temperature and humidity measurements were conducted using an environmentally controlled chamber (Thunder Scientific Corp. Model 2500S). This is a self contained facility capable of producing known humidity and temperature values in the test chamber.

Connectors Sensitivity to Temperature and Humidity The three pieces of coaxial cable RG-6 5730, each fitted with a different type connectors, were kept inside the test chamber. The relative humidity was set at a different value each time. Three sets of readings were taken at humidity values of 10%, 40% and 80%. For each humidity value, the temperature was varied from 0^0C to 50^0C in steps of 5^0C. After completion of the temperature cycle, the cables were taken out of the chamber and tested on the network analyzer in terms of S_{11} and S_{21}. The performance of the connectors was found to be insensitive to the change in temperature and relative humidity.

In addition to this measurement, a long term test was conducted. The three pieces of cable, each fitted with a different type of connectors, were kept inside the test chamber for 5 days continuously. For the first half of the time the temperature and humidity values were set at 0^0C and 10% respectively and later at 40^0C and 80% respectively. This also did not show any significant change in the performance of the connectors.

Cable Delay Vs Temperature Measurement It is important to study the change in cable delay with changing temperature for a good understanding of the overall system performance. To evaluate the cable performance versus temperature, a 10 m coaxial cable RG-6 5789 was tested over the temperature range 0-50^0C in steps of 5^0C allowing 2 hours between readings to ensure thermal equilibrium. The insertion loss and delay of the cable over the temperature range were measured on the network analyzer. A plot of cable insertion loss Vs temperature at several frequencies is shown in Figure 5. The temperature coefficient of insertion loss at 150 MHz is 0.0019 dB/^0C.

Figure 6 shows the cable delay Vs temperature. It can be seen that the cable delay is decreasing as the temperature increases. The temperature coefficient of delay at 150 MHz is -0.0013 nS/^0C. This can be explained as follows. As the temperature increases, the center conductor undergoes thermal expansion changing the electrical length in proportion to the physical length. The individual conductors of the braid are wrapped around the circumference of the dielectric core due to which a certain amount of force is applied on the dielectric

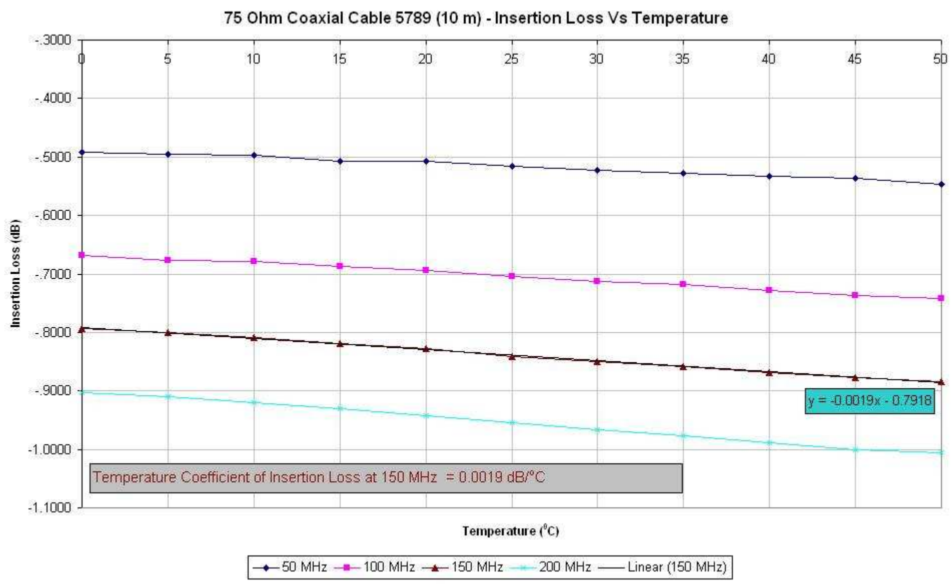

Figure 5. 10 m Coaxial cable (RG-6 5789) - Insertion Loss Vs Temperature

Figure 6. 10 m Coaxial cable (RG-6 5789) - Delay Vs Temperature

core. As the temperature changes the length of the braid conductors changes which in turn increases or decreases the amount of force applied by the braid on the dielectric. This causes the relative density of the dielectric to change which in turn changes the net dielectric constant.

Thus in this case when the temperature is increasing the physical length of center conductor is increasing. The physical length of the braids are increasing as well causing the relative density of the dielectric to decrease which in turn decreases the dielectric constant. The effects due to the change in dielectric constant are much greater than the effects of the physical length changes and hence the electric length decreases. Therefore the delay in the cable, which is given by $Delay = \frac{\sqrt{\epsilon_r}}{c} \times length$, decreases as the temperature increases.

The temperature coefficient of delay of 10 m cable at 150 MHz is -0.0013 nS/$^{\circ}C$.

The change in delay per$^{\circ}C$ for 1 m cable (Δt_d) = -0.132 pS/$^{\circ}C$.

The change in phase ($\Delta\Phi$) per $^{\circ}C$ for 1 m cable $= 2\pi \times f \times \Delta t_d = -0.0071^{\circ}/^{\circ}C$

The coefficient of change in length per $^{\circ}C$ can be calculated as,

$$t_d = \frac{\sqrt{\epsilon_r}}{c} \times L$$

where, t_d = delay in the cable,
L = physical length of the cable

Therefore, $\Delta t_d = \frac{\sqrt{\epsilon_r}}{c} \times \Delta L$

Thus, the change in length per $^{\circ}C$ for 1 m cable is,

$$\Delta L = \frac{c}{\sqrt{\epsilon_r}} \times \Delta t_d = -0.0325 mm/^{\circ}C$$

and the change in length per $^{\circ}C$ for a 150 m cable is $0.0325 \times 150 = 4.88 mm/^{\circ}C$

4. Impedance Transformation Networks

50-75 Ω and 75-50 Ω impedance transformation networks, working in the frequency range of 100-200 MHz, were developed to make use of the 75 Ω RG-6 coaxial cable with 50 Ω system.

4.1. Design Details

The matching modules were designed using Agilent Advanced Design System (ADS). The design criteria was to achieve a return loss below 25 dB over the frequency range of 100-200 MHz. Since the RG-6 75Ω cable is more lossy than the conventional cables, an amplifier (designed at NRAO-DSL) with a gain of 8 dB was included in each module for line-loss compensation. Figure 7 and Figure 8 illustrate the schematics of 50-75 Ω impedance transformation module and 75-50 Ω impedance transformation module respectively. The 50-75Ω design includes an amplifier stage followed by the matching network. The 75-50Ω design includes the matching network followed by an amplifier stage. The inductors are constructed by winding a 28 AWG magnet wire with the air core diameter of 0.064 inch.

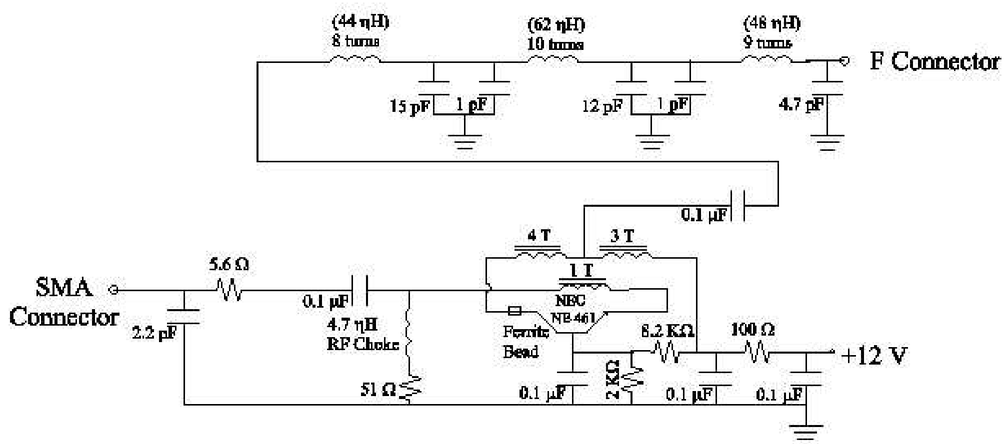

Figure 7. Schematic of 50-75 Ω Impedance Transformation Design

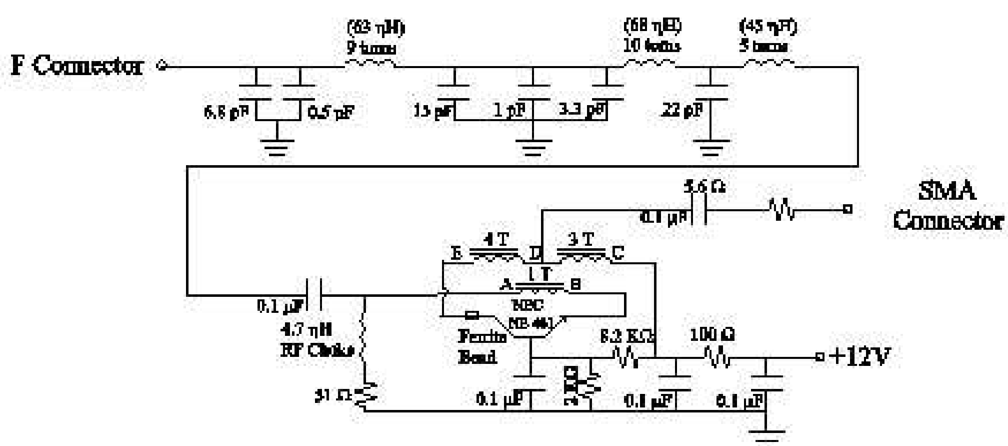

Figure 8. Schematic of 75-50 Ω Impedance Transformation Design

Figure 9 shows photographs of dual-polarization impedance transformation modules. A photograph showing the assembly of dual-polarization impedance matching modules in a box of 2 × 2 inch is also shown in Figure 9.

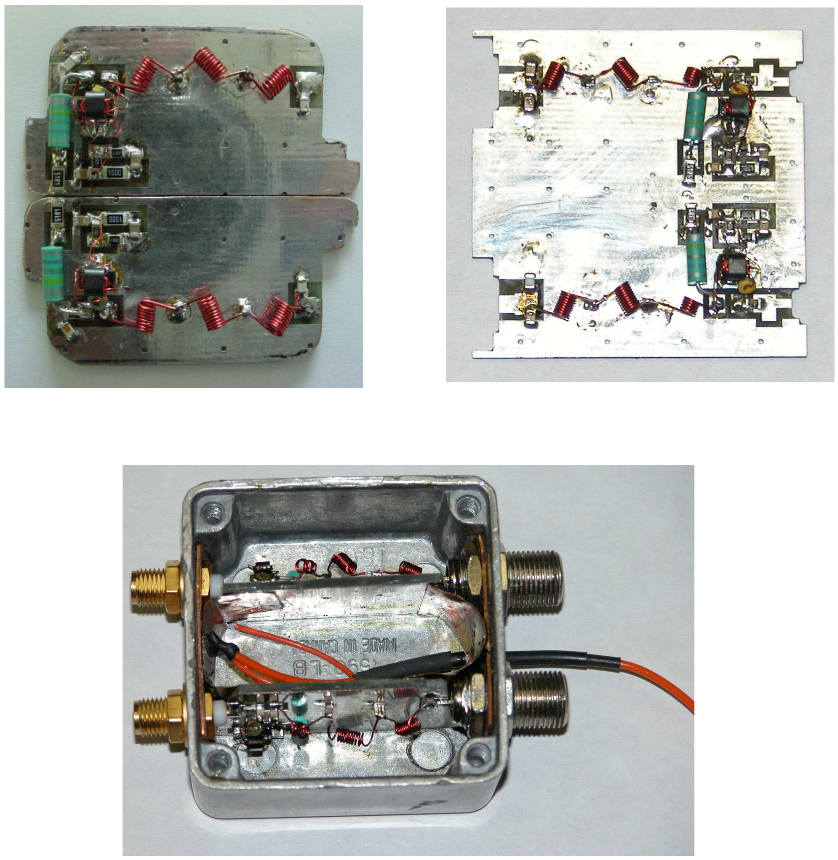

Figure 9. Photographs showing a) Dual-polarization 50-75 Ω Impedance Transformation Module b)Dual-polarization 75-50 Ω Impedance Transformation Module c) The Assembly in a 2 × 2 inch box.

4.2. Measurement Results

The 75 Ω transmission system consisting of a 25 cm RG-6 (5789) and impedance transformation modules was tested on the HP 8753D VNA. The S-parameter measurement results are shown in Figure 10. The amplifier stages in the impedance transformation modules have a total gain of 15 dB. The input and output return losses (S_{11} and S_{22}) are below 20 dB over the frequency band of 100-200 MHz. The inductors in the networks can be tuned to achieve better return losses (below 25 dB). Thus the modules show a good level of input and output match.

Figure 11 shows the S_{21} plot of the transmission system consisting of a 150 m RG-6 (5789) and the impedance transformation modules. Due to the gain of the amplifier stages in the impedance matching modules (total 15 dB) and the cable loss (6.72dB/100 meter), the overall gain of the transmission system

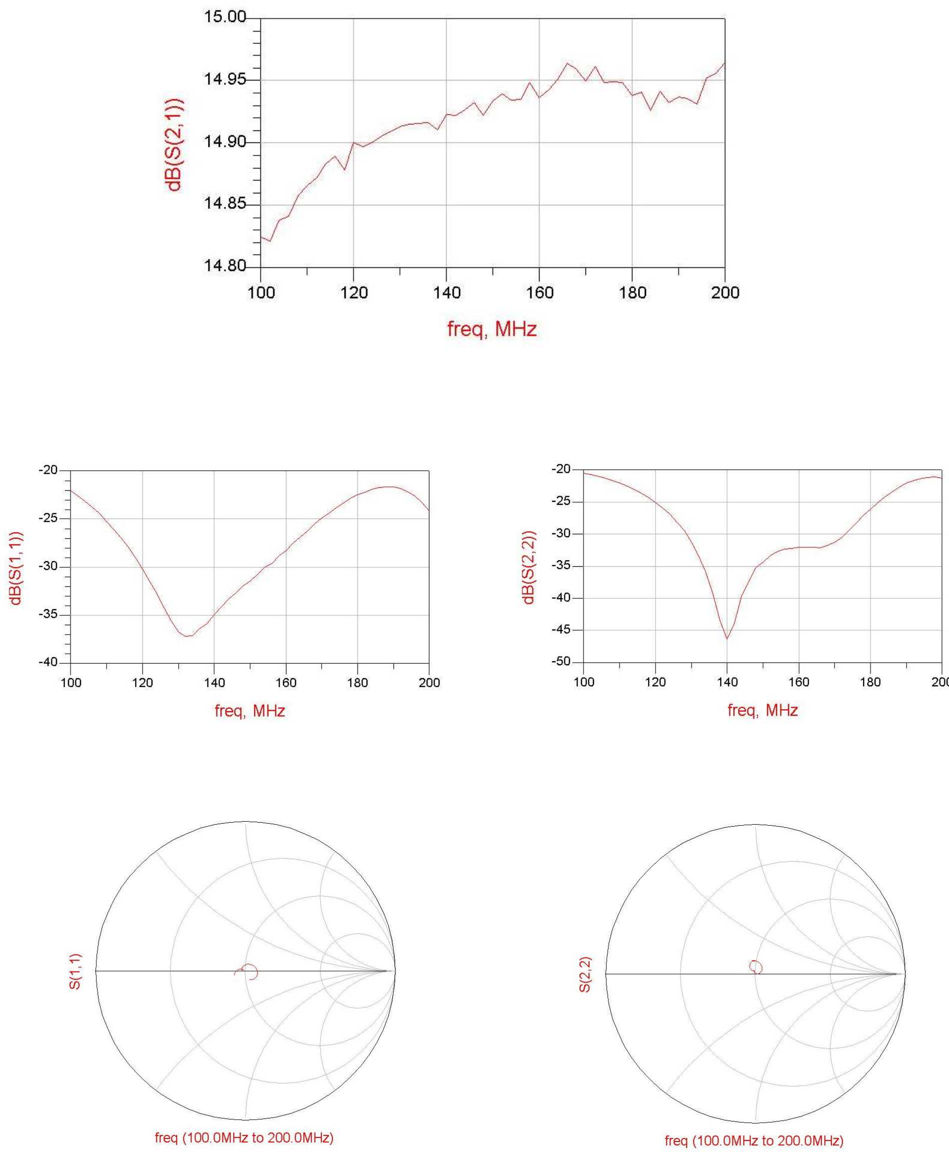

Figure 10. S-parameter Measurement Plots of the 75 Ω Transmission System Consisting a 25 cm RG-6 (5789) and Impedance Matching Modules)

becomes ∼4 dB with a slope of -0.034 dB/MHz over the frequency band of 100-200 MHz.

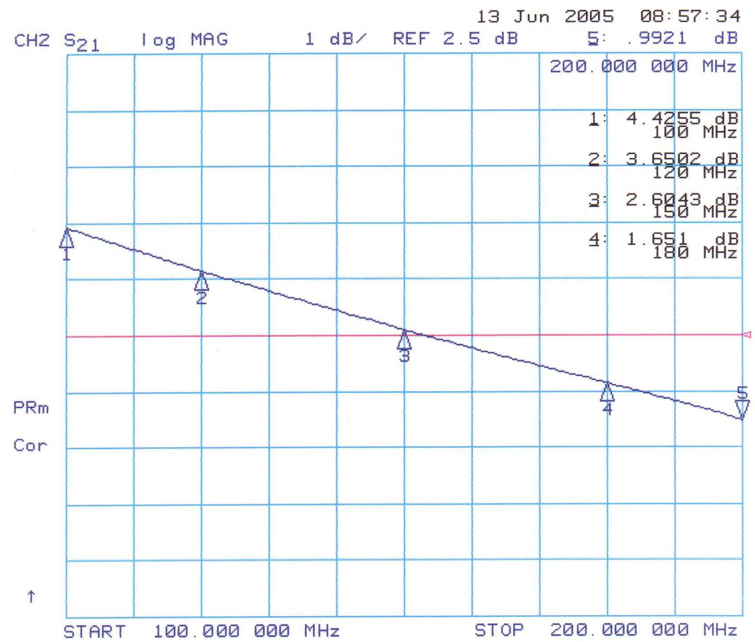

Figure 11. S_{21} Plot of the 75 Ω Transmission System Consisting a 150 m RG-6 (5789) and Impedance Matching Modules with the overall gain of the transmission system 4 dB with a slope of -0.034 dB/MHz over the frequency band of 100-200 MHz

4.3. Temperature Stability Test

The gain of the transmission system versus temperature was measured using the HP 8753D VNA with the 75 Ω transmission system kept inside the environmentally controlled chamber (Thunder Scientific Corp., Model 2500S). The the 75 Ω transmission system includes a 25 cm 75 Ω RG-6 cable and the impedance matching modules. The temperature was varied over the range of 0-35^0C in steps of 5^0C allowing 2 hours between gain readings to ensure thermal equilibrium. A plot of the gain versus temperature at several operating frequencies is shown in Figure 12. The gain sensitivity with temperature is approximately -0.091 dB/^0C.

The electrical delay though the entire system was also measured during this test and found to be insensitive to temperature over the 0-35^0C range. Figure 13 shows a plot of the delay versus temperature at several operating frequencies. Since the cable length is significantly small (25 cm), the change in cable delay due to changing temperature does not have any significant effect on the results. Hence, the plot reflects the delay sensitivity of the impedance transformation networks only.

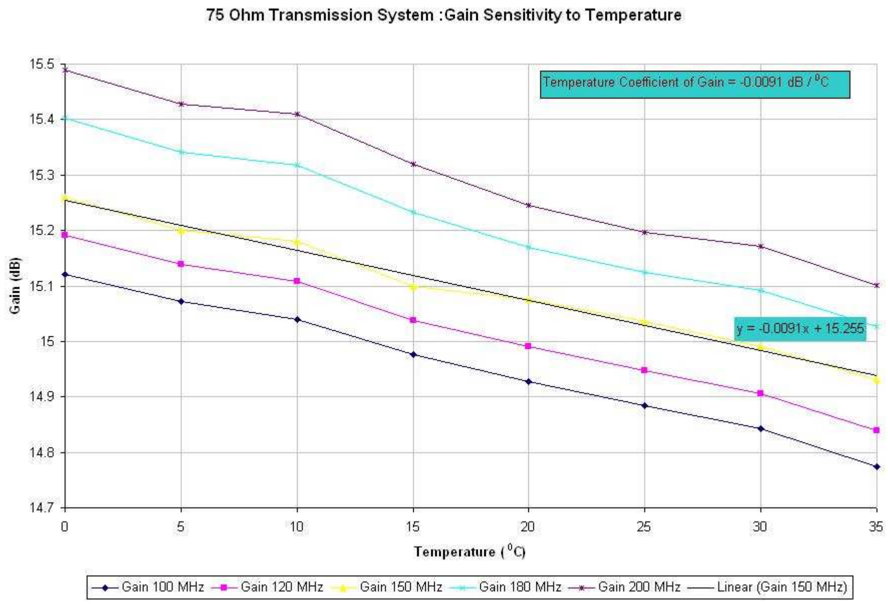

Figure 12. Graph showing the gain of the transmission system including impedance transformation networks with 25 cm cable as a function of ambient temperature at several operating frequencies

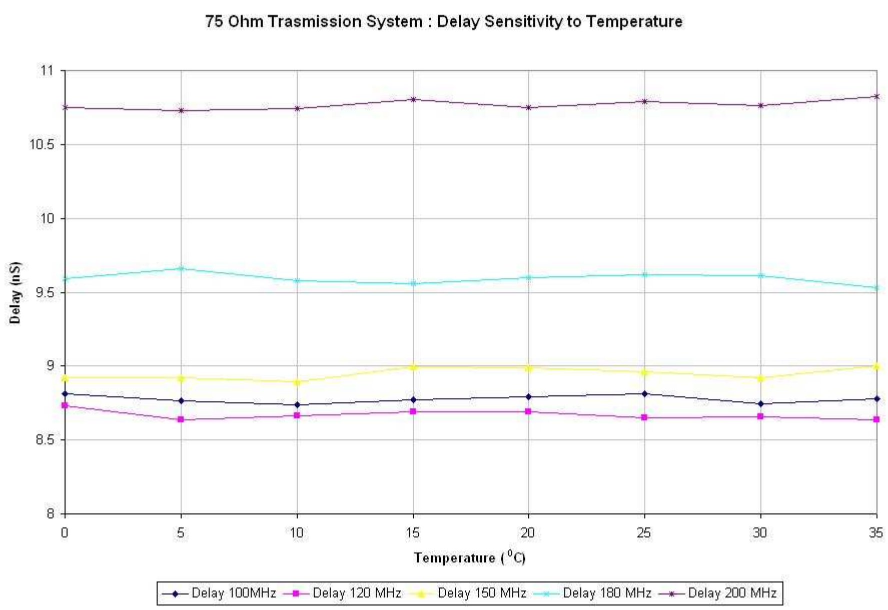

Figure 13. Graph showing the delay of the impedance transformation networks as a function of ambient temperature at several operating frequencies