

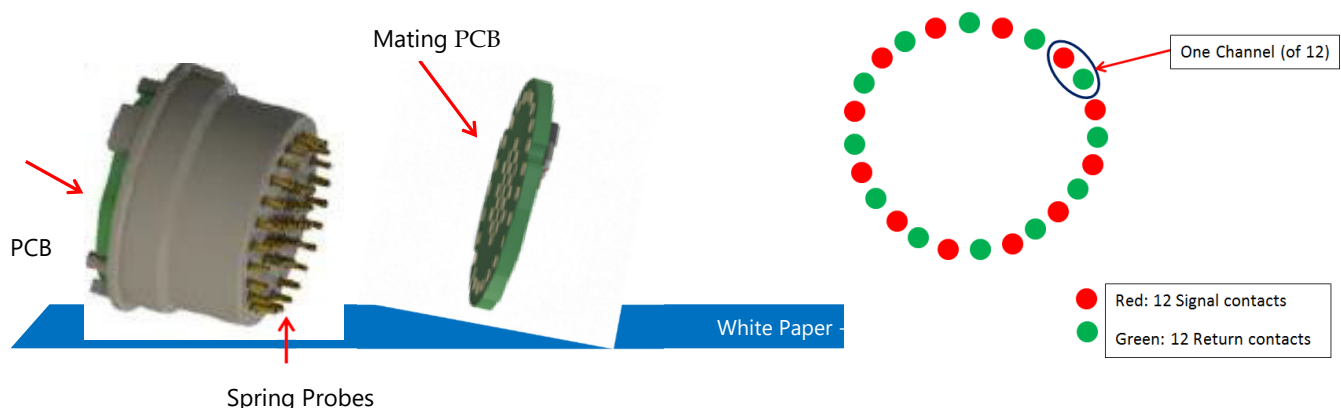
Typical Interconnect Requirements for RF MRI Connectors:

- Relative Magnetic Permeability
 - Less than $0.00005\mu_r$
- Insertion Loss
 - Greater than -0.2dB up to 12.5MHz
 - Greater than -0.3dB up to 135MHz
- Return Loss
 - Less than -33dB up to 12.5MHz
 - Less than -20dB up to 300MHz
- Crosstalk Ratio
 - Less than -45dB up to 12.5MHz
- Low Level Circuit Resistance (LLCR)
 - Less than $20m\Omega$ per contact (before and after mating cycle life)
- Mating Cycle Life
 - 60k mating cycles

Validation Testing:

To validate the interconnect technology of spring probes in a PGA pattern, the following configuration was tested. As has been mentioned, each RF channel was connected with one spring probe for the signal and an adjacent contact in the connector for return.

- The configuration tested was a circular connector with a ring array of 24 equally spaced spring probes carrying 12 channels (see pattern in Figure 4, below)
 - Each channel is carried by 2 adjacent spring probe contacts, one signal and one return per channel
 - The spring probes are terminated to a PCB on the back of the connector and mate to pads on an identical PCB in the mating connector



- Testing Performed:

TEST NO.	TEST DESCRIPTION	TEST SPECIFICATION
All Samples 1/		
1	Visual and Mechanical Inspection	N/A – Company specific
2	Magnetic Permeability	N/A – Company specific
3	Insertion Loss and Return Loss	EIA-364-108
4	Cross Talk Ratio	EIA-364-90
5	Low-Level Contact Resistance	EIA-364-23
6	Connector Durability/Contact Life	EIA-364-09
7	Low-Level Contact Resistance	EIA-364-23
8	Insertion Loss and Return Loss	EIA-364-108

Table 1: Validation test List

- Test Results:

- Relative Magnetic Permeability:
 - Components in close proximity of the imaging volume within an MRI system, must have a very low magnetic permeability to minimize any “artifacts” which could distort or obscure the resulting image.
 - Test Scope: Measure the magnetic permeability of the plug and receptacle connectors
 - Result: Passed
 - Connectors were found to have a relative magnetic permeability of less than $0.00005\mu_r$
- Insertion Loss:
 - Insertion loss is the loss of signal power resulting from a device, a connector in this case, in a transmission line. It is desirable for the insertion loss to be as close to zero as possible.
 - Test Scope: Determine the insertion loss caused by the connector (only) in a pair of coaxial cable assemblies.
 - Result: Passed
 - The insertion loss of the connector only (not including the termination or cable losses), was found to be greater than -0.2dB, up to 12.5MHz, and greater than -0.3dB, up to 135MHz (see Figure 5 below)

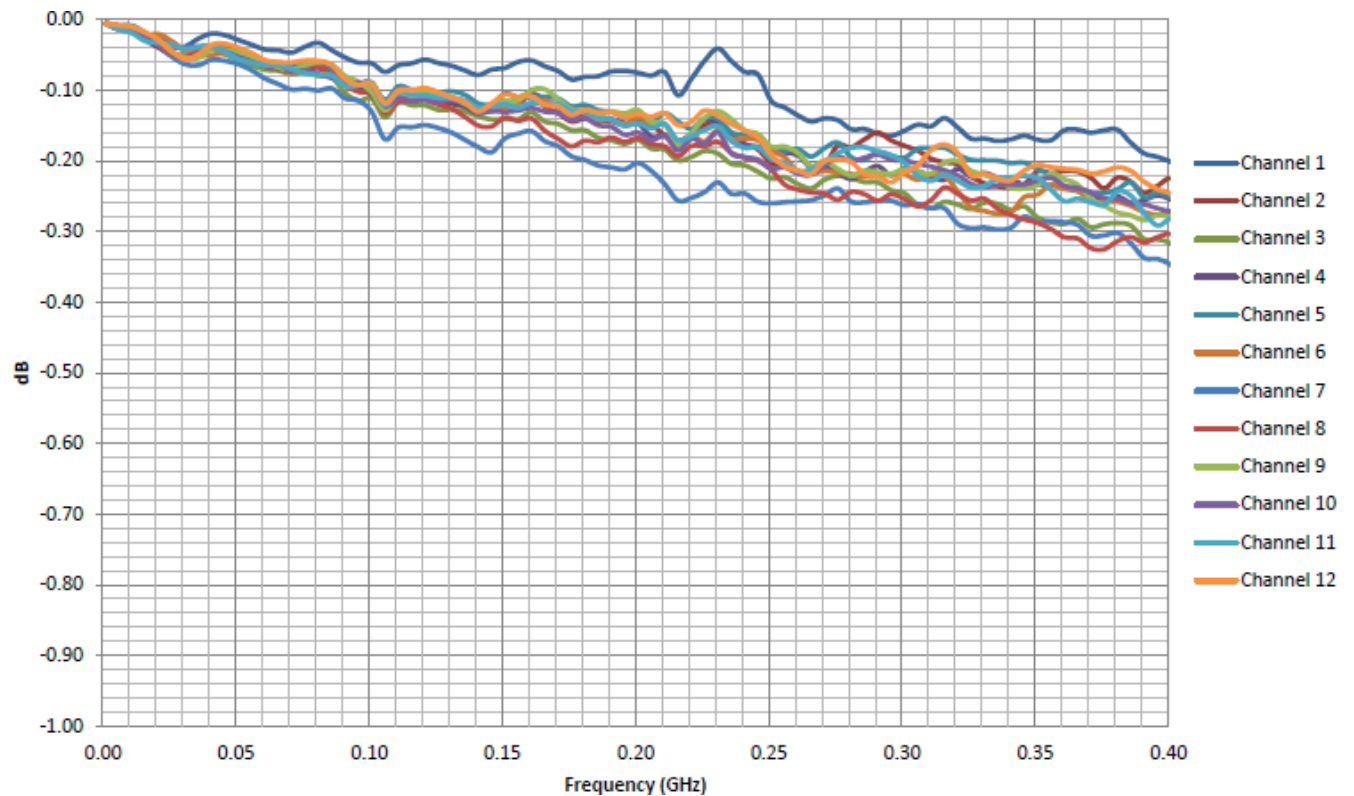


Figure 5: Insertion Loss vs. Frequency

- Return Loss:
 - The reflection of the electrical signal through the circuit, or the return loss, and the connector's effect on this, should be minimized so as not to affect the image signal.
 - Test Scope: Determine the return loss caused by the connector (only) in a pair of coaxial cable assemblies.
 - Result: Passed
 - The return loss of the connector only (not including termination or cable losses), was found to be less than -33dB up to 12.5MHz, & less than -20dB, up to 300MHz (see Figure 6 below)

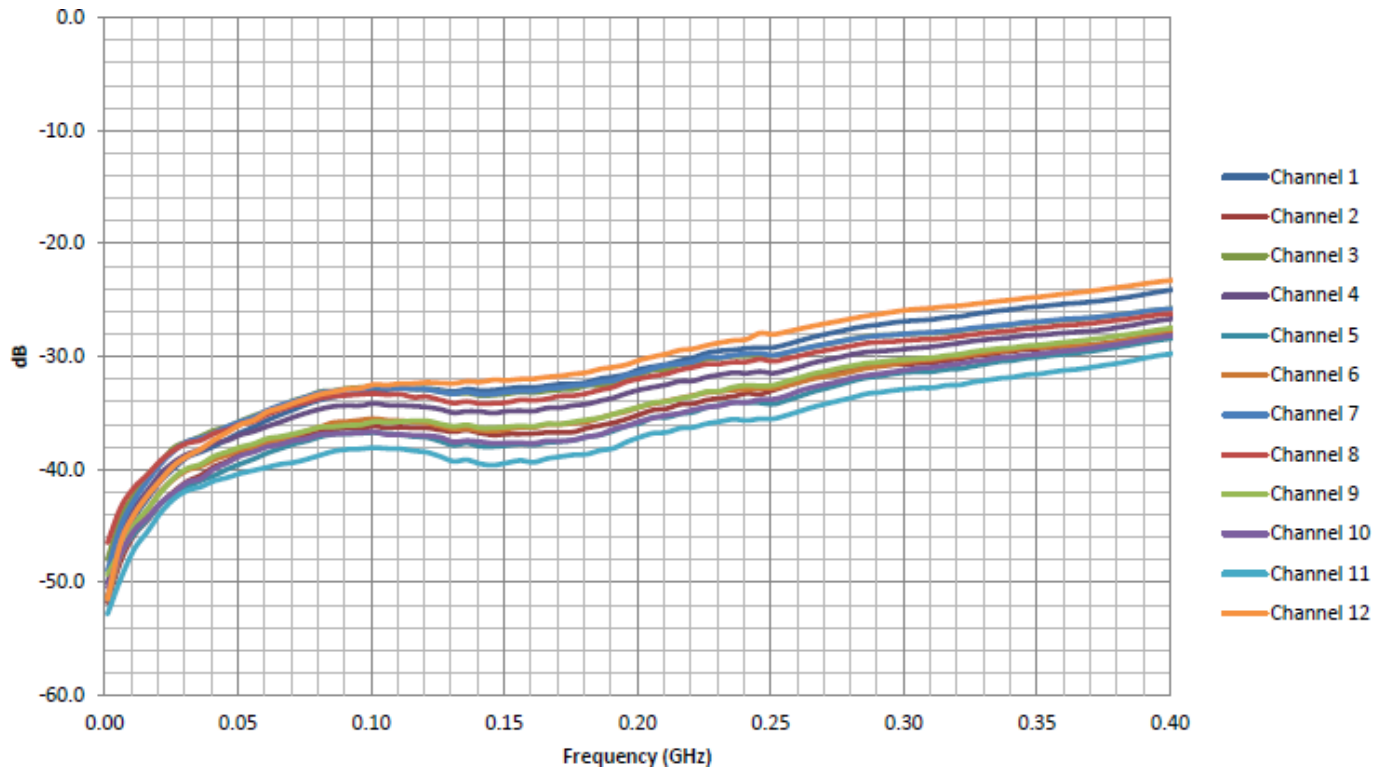
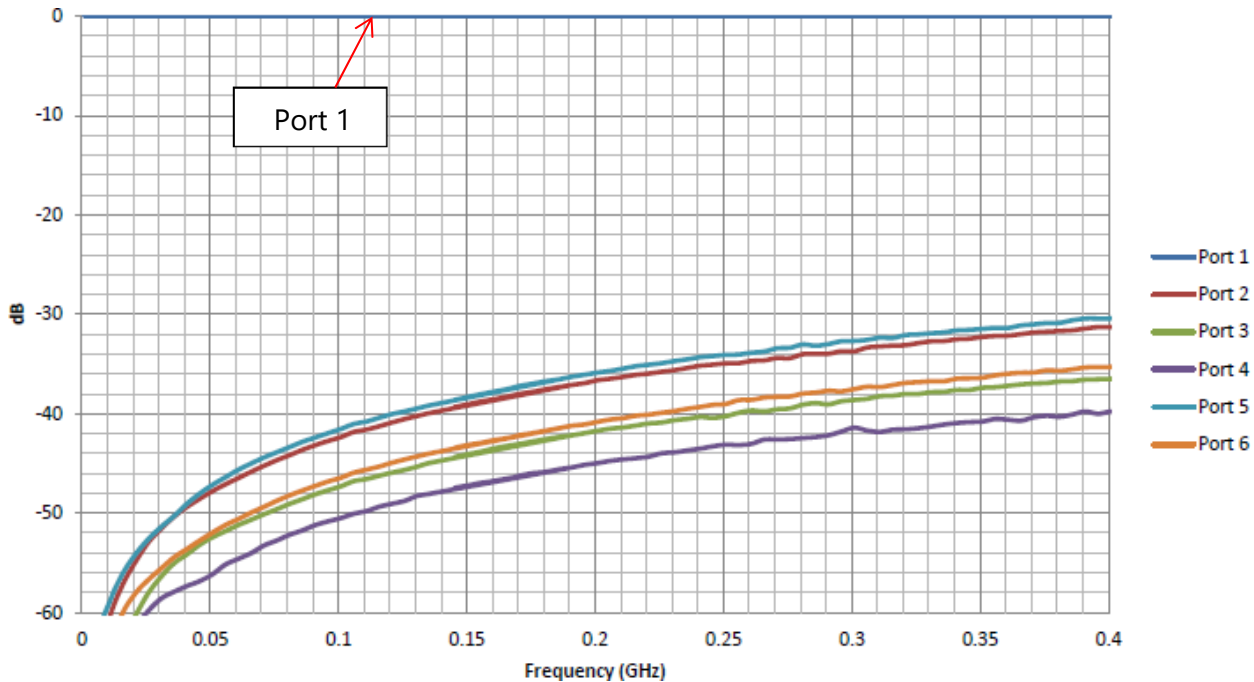


Figure 6: Return Loss vs.

- Cross Talk Ratio
 - The EMI fields radiating around parallel RF signal lines can interfere with the signal in adjacent lines, and this “cross talk” should be minimal.
 - Test Scope: Determine the cross talk ratio of the connector assembly by measuring the magnitude of the electromagnetic coupling between driven and quiet lines in the interconnect assembly.
 - Result: Passed:
 - Cross Talk Ratio was found to be less than -45dB up to 12.5MHz
 - See Figures 7a through 7e below (cross talk was measured between one port and each of the other 5 ports)
 - Note: Due to the symmetric nature of the connector contact layout in this test, only channels 1 through 6 were measured. The use of the same PCB on both sides of the connection ensures that channels 7 through 12 are also represented (as the signal must pass through them at the far side of the connection). Port 6 is not shown in a separate table since the cross talk values between port 6 and each of the channels 1 through 5



are represented in the values from those channels.

Figure 7a: Far End Cross Talk, Port 1, vs.

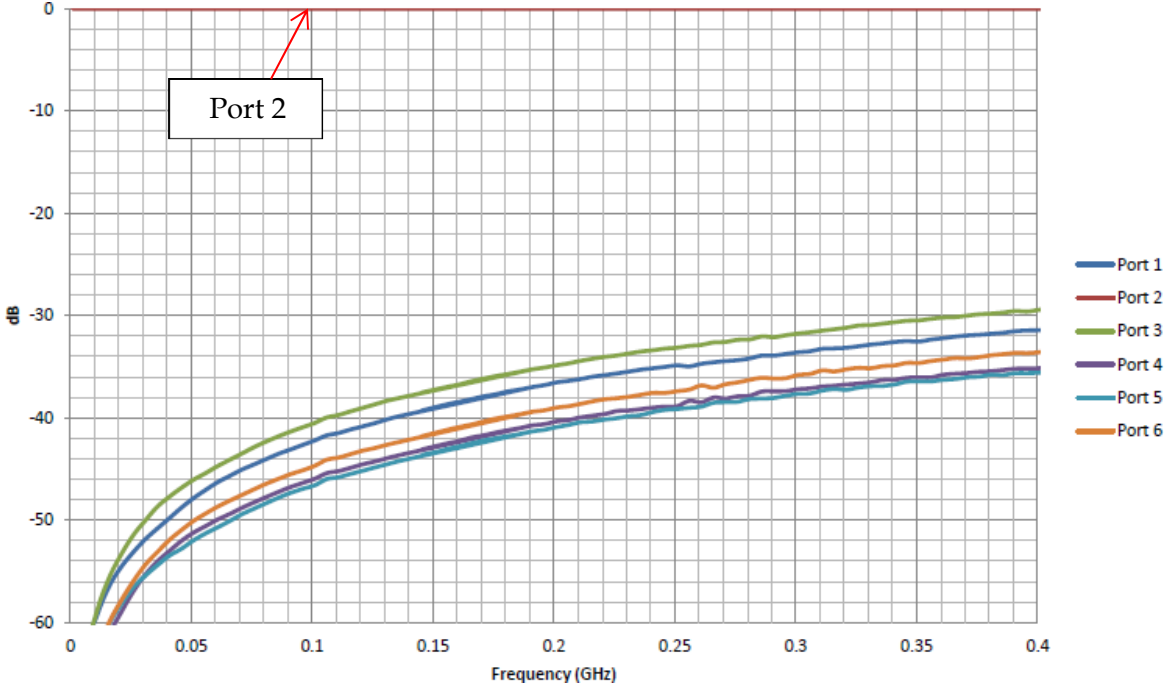


Figure 7b: Far End Cross Talk, Port 2, vs. Frequency

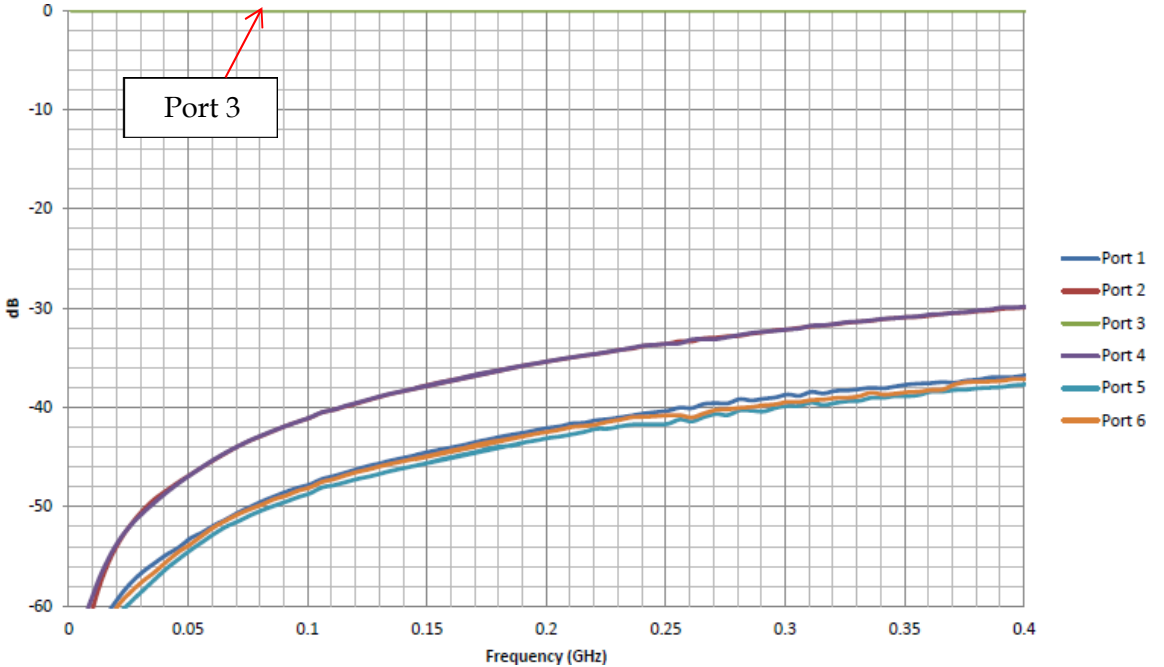


Figure 7c: Far End Cross Talk, Port 3, vs. Frequency

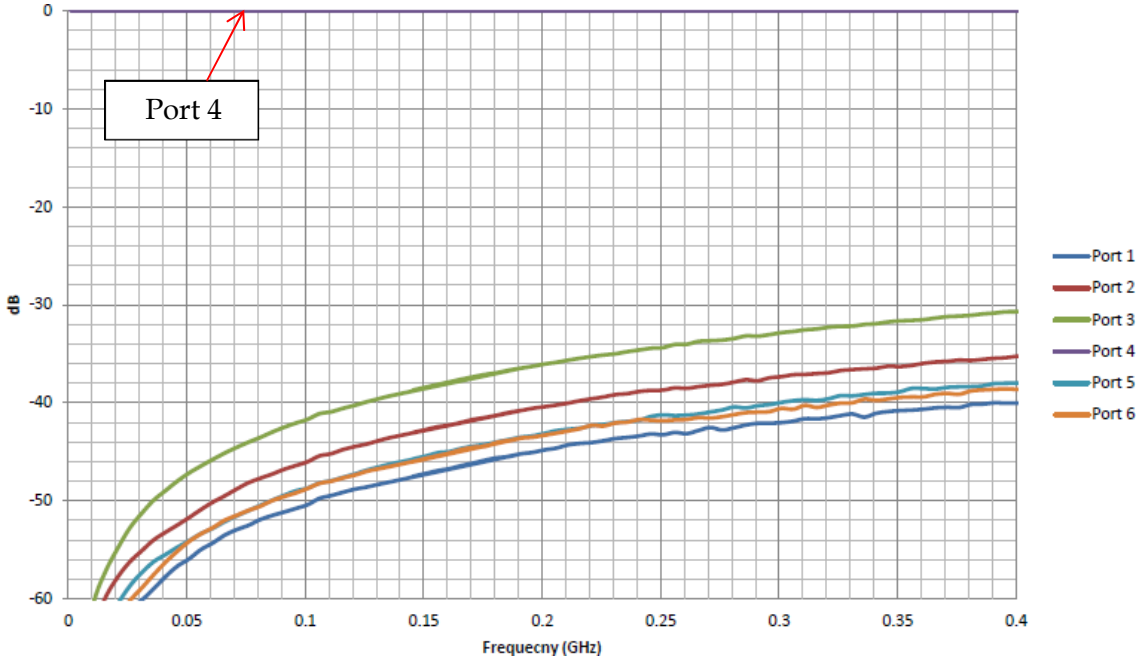


Figure 7d: Far End Cross Talk, Port 4, vs. Frequency

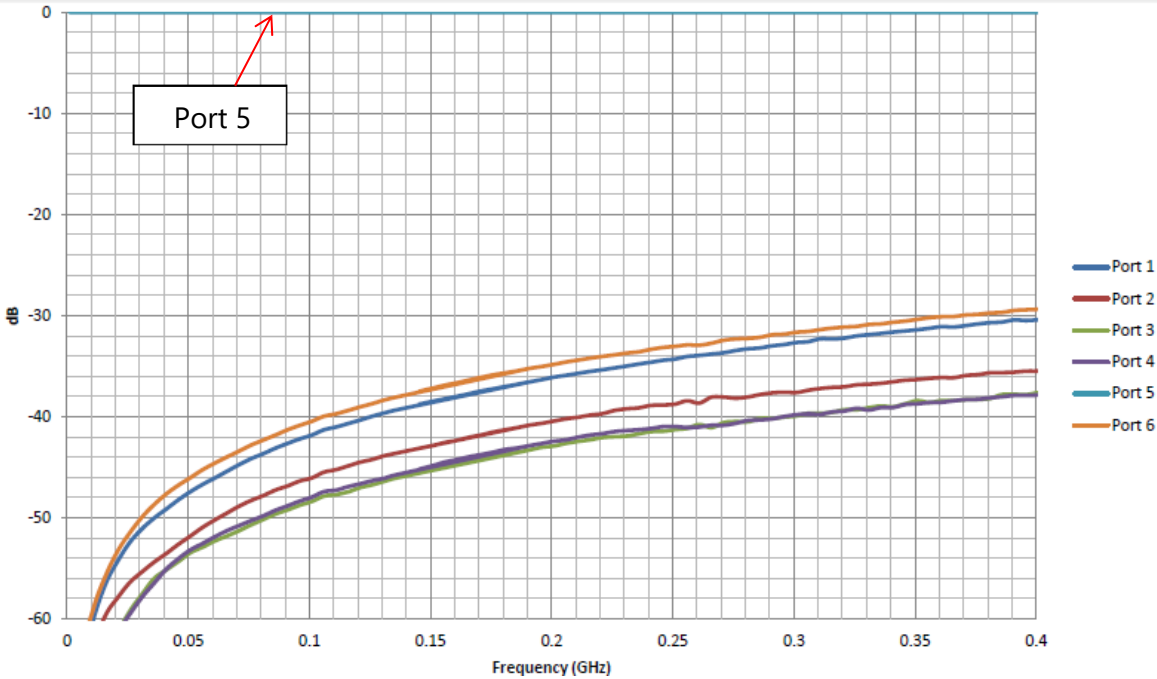


Figure 7e: Far End Cross Talk, Port 5, vs. Frequency

- Low Level Circuit Resistance (LLCR)
 - Lower contact resistance uses less power in the system, creating less heat at the contact interface, and has less impact on signal integrity.
 - Test Scope: Determine the contact resistance between the spring probe and the pc board in the mating connector, when subjected to a continuous electrical signal.
 - Result: Passed
 - Resistance was less than 20mΩ per contact: See Figure 8 below
- Mating Cycle Life
 - A connector system is suitable over a high number of mating cycles, without need of repair or replacement, if the contact resistance does not change significantly during repeated mating and unmating.
 - Test Scope: Determine the effects of mating and unmating the connectors on the contact resistance
 - Result: Passed
 - Contacts were cycled between 0 and 60k mating cycles. The LLCR was monitored throughout the process and remained less than 20mΩ per contact: See Figure 8 below

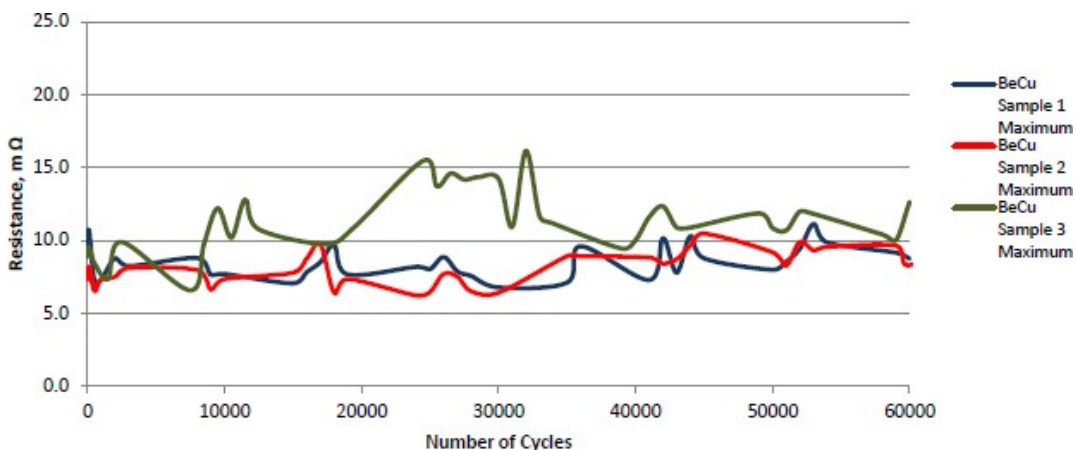


Figure 8: Maximum Contact Resistance vs. Number of mating cycles

- Test Results Summary:
 - The preceding tests show that the RF connector system with Spring Probe contacts arranged in a pin circle met the typical performance targets. A summary of these tests is shown below in Table 2:

Test Results Summary			
Test	Requirement	Status	Result
Visual and Dimensional Inspection	Meet drawing requirements	Complete	Pass
Magnetic Permeability	Relative magnetic permeability less than or equal to 0.0005 μ r	Complete	Pass
Insertion Loss and Return Loss	<u>Insertion Loss</u> : greater than -0.2 dB up to 12.5 MHz greater than -0.3 dB up to 135 MHz <u>Return Loss</u> : less than -33 dB up to 12.5 MHz less than or equal to -20 dB up to 300 MHz	Complete	Pass
Cross Talk Ratio	Far End Cross Talk up to 12.5 MHz shall be less than or equal to -45 dB	Complete	Pass
Low Level Circuit Resistance	The low level contact resistance must be less than 20m Ω per contact	Complete	Pass
Connector Durability/Cycle Life	Confirm the electrical and mechanical performance targets at the end of the connectors service life: 30,000 and 60,000 cycles	Complete	Pass

Table 2: Summary of Test Results

6. Rectangular Grid Array Testing:

- Supplemental testing was performed on similar connectors with Spring Probes arranged in a rectangular PGA pattern, for a 16 Channel Pin Grid Array Connector
- Rectangular connector with a rectangular grid array of 32 equally spaced spring probes, in 4 rows of 8, carrying 16 channels (see pattern in Figure 9 below)
 - Again, each channel is carried by 2 adjacent spring probe contacts, one signal and one return per channel
 - This connector pair includes spring probes in one half, mating to discrete target contacts in the other side
- The results of this testing are shown in the graphs below

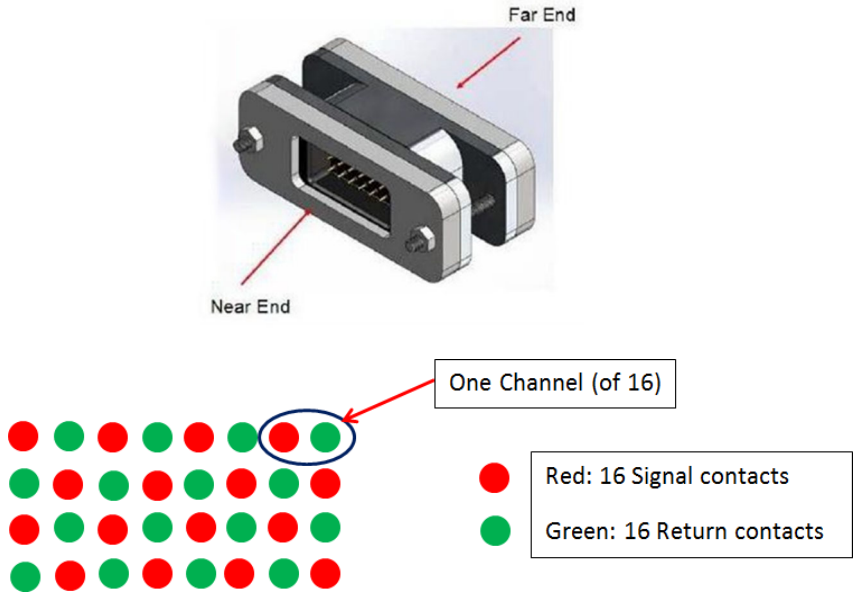


Figure 9: 16 Channel Test connector

- Insertion Loss

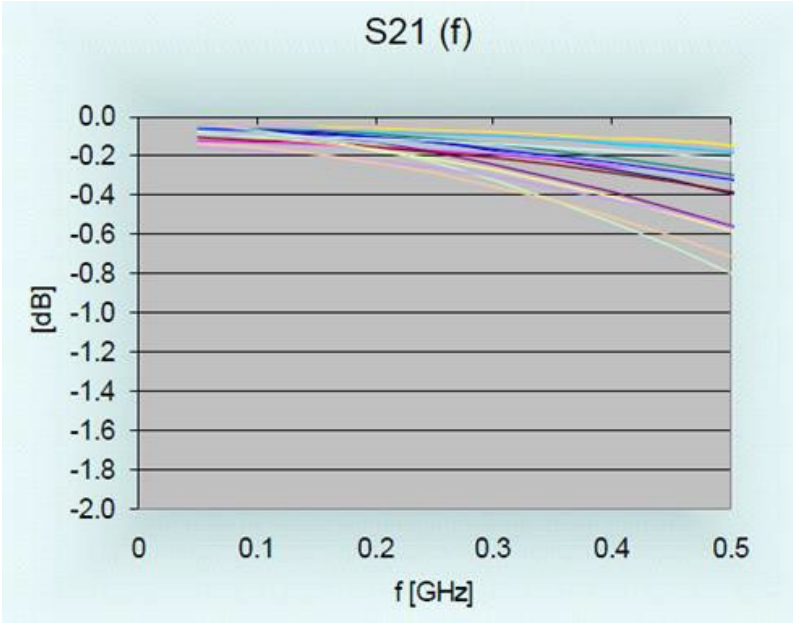


Figure 10: 16 Channel Test: Insertion Loss / Mated

- Return Loss

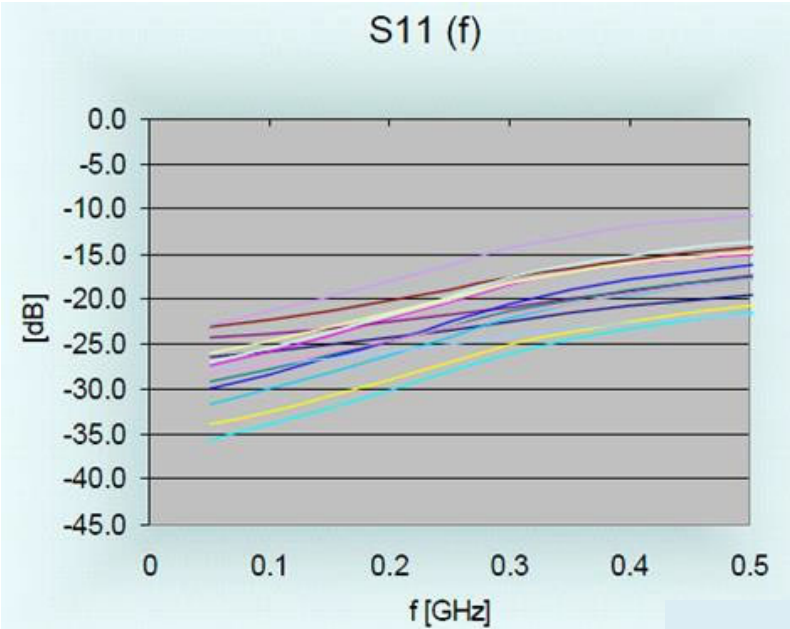


Figure 11: 16 Channel Test: Return Loss / Mated Connector

- Cross Talk (FEXT – Far End Cross Talk)

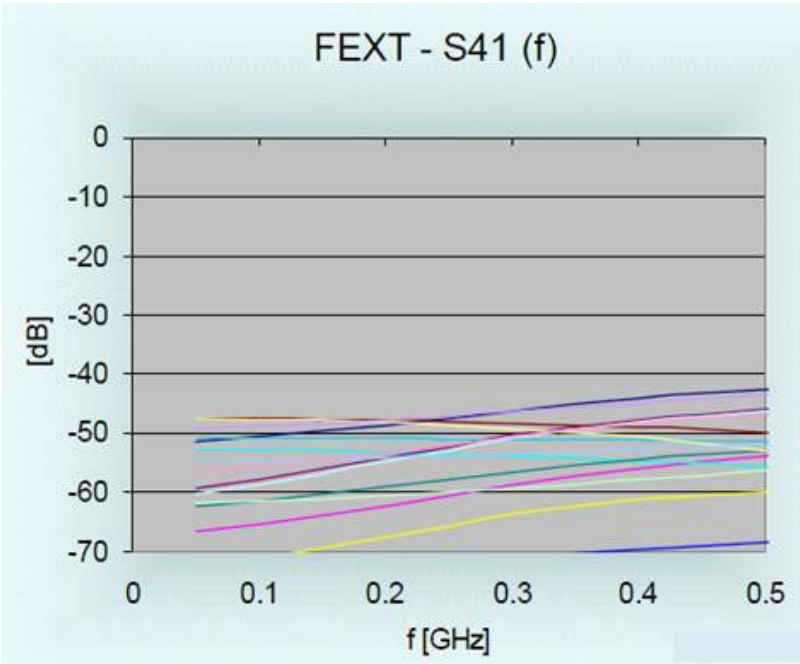


Figure 12: 16 Channel Test: Cross Talk / Mated Connector

7. Specially Optimized PGA Design & Testing:

- Specially designed spring probe PGA Test Kits were tested in a D-Series connector profile, to showcase our ability to design for Ethernet, analog, digital, and power signals (see Figures 13 & 14) simultaneously with higher spring probe density than normal.
- Each case where signal integrity is necessary, the grid array was specifically designed to optimize impedance control, return loss, and cross talk in the connector.
- Four sections of arrays of pins are represented in this design (see Figure 14).
 - Ethernet is made up of four differential pairs and the four pairs were specifically designed in such a way to optimize impedance control and crosstalk from the nearest transmission lines.
 - The 2A pattern array section (8 channels) is made up of contacts configured with a return signal return or GSG pattern. This allows a certain level of crosstalk from the other transmission lines that would be better than the 1A configurations as performed above, which were not shown for Near End Cross Talk.
 - The 4B pattern array section (9 channels) is made up of contacts configured with a signal pin surrounded by four return pins. This allows a certain level of crosstalk from the other transmission lines that would be better than the 1A and 2A configurations as discussed above.
 - Power is made up of a collection of contacts to ensure a certain level of power through the connector as the contacts are being used in parallel as each contact may only have a current carrying capability of 1 to 2 Amps. In this case, we designed the the connector for at most 40 Amps of current.
- The results of signal integrity testing are shown in the graphs below. All testing includes the impedance discontinuities of the cables, terminations, and fixtures, unless otherwise stated in the captions as "DUT Only". The measurements with that designation were de-embedded to get more accurate measurements of just the connector without the entire test setup. Maximum length of attached cables were ~ 2ft total for each channel.

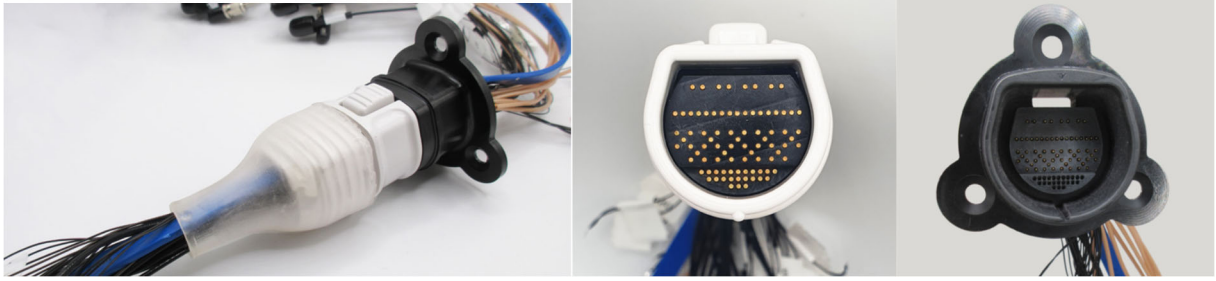


Figure 13: Test Kits: Mated Connector Only

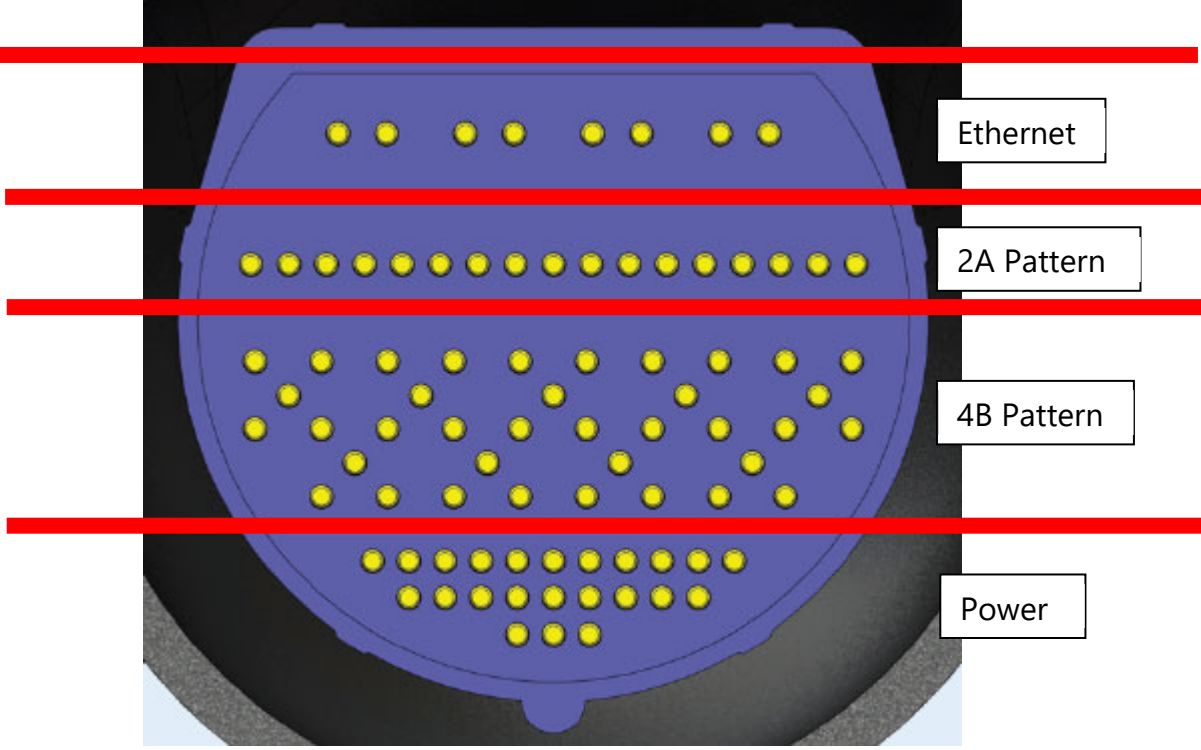


Figure 14: : Array Sections

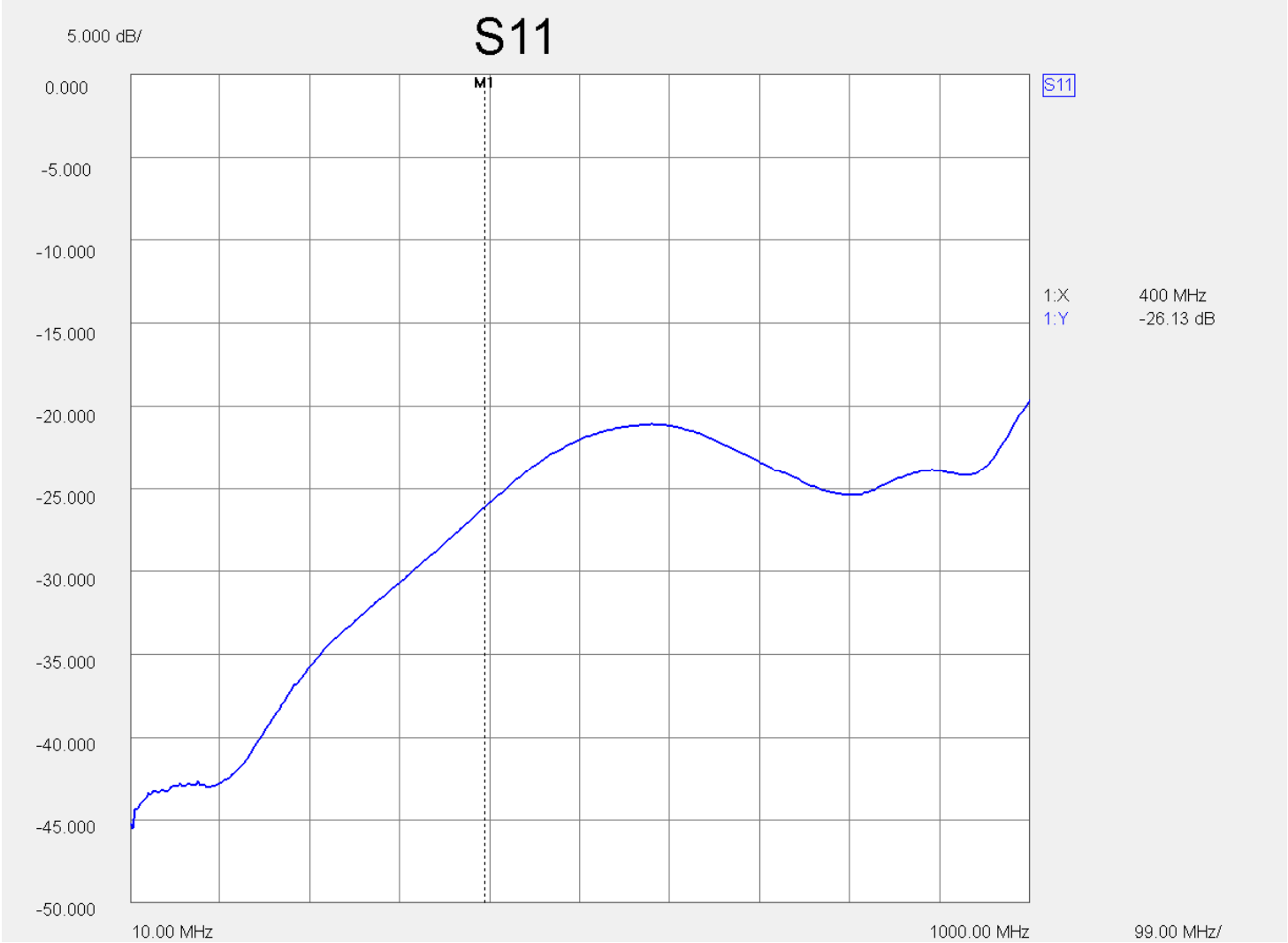


Figure 15: General Return Loss of 4B Connector Configuration / DUT Only

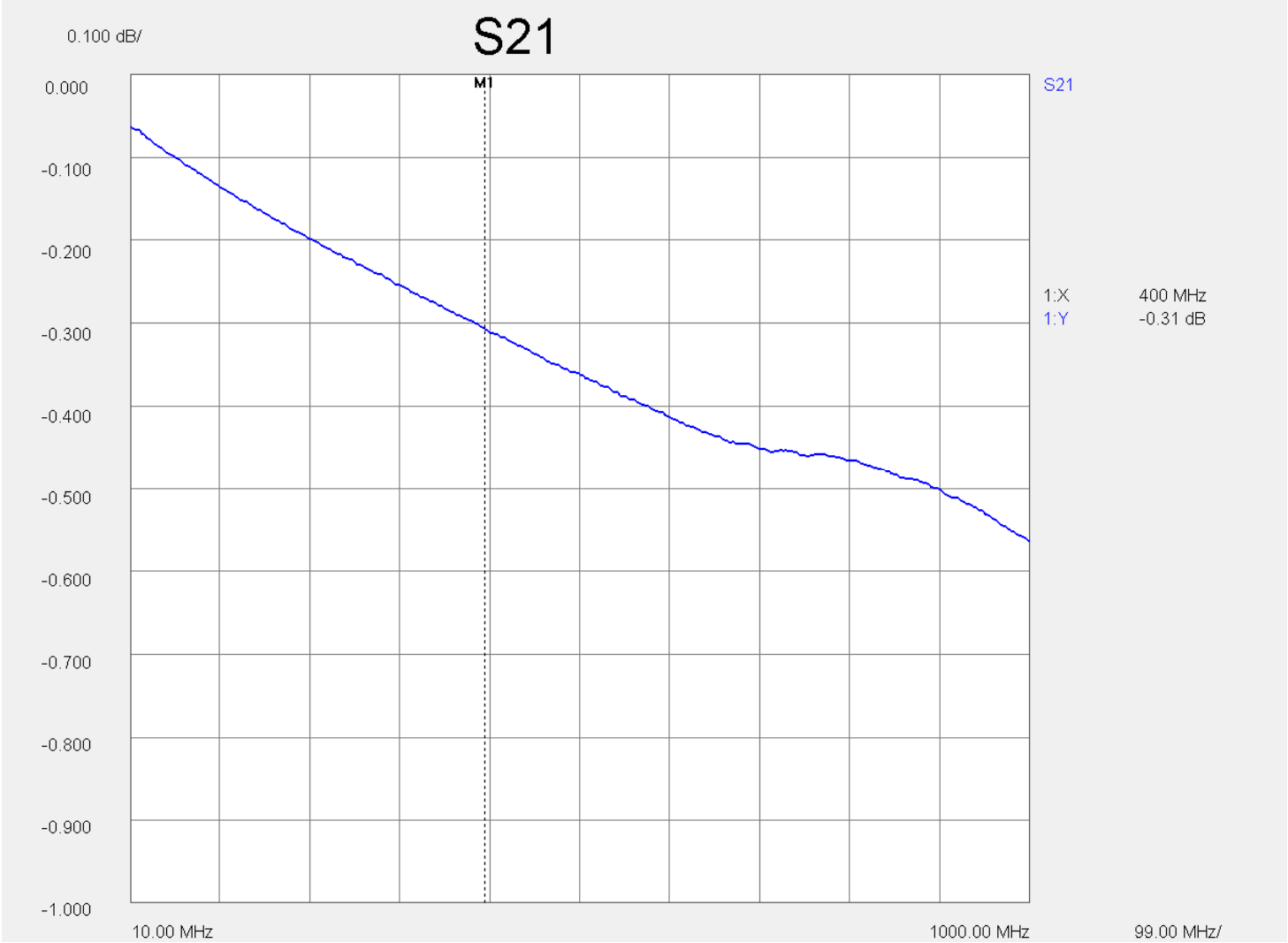


Figure 16: General Insertion Loss of 4B Connector configuration / DUT Only

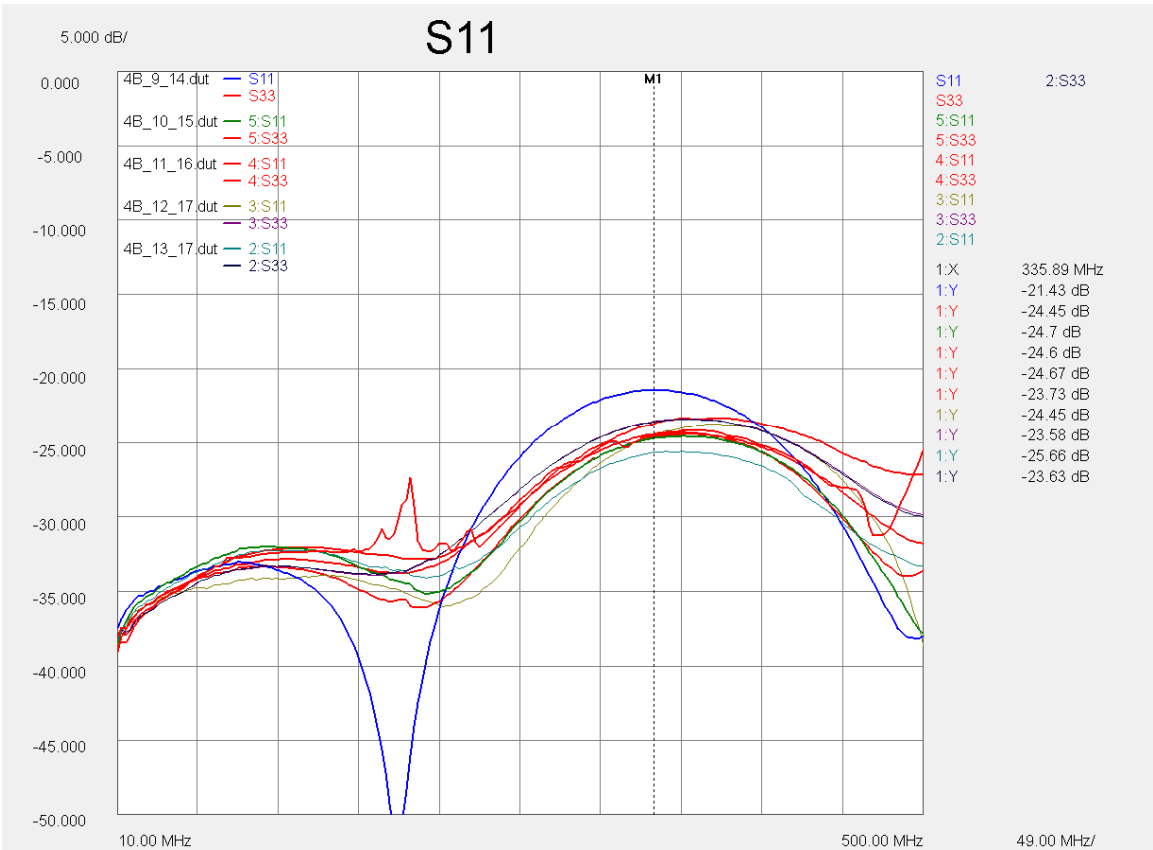


Figure 16: Return Loss VS Frequency Overlays Measurements of 4B Configurations with Entire Test Setup

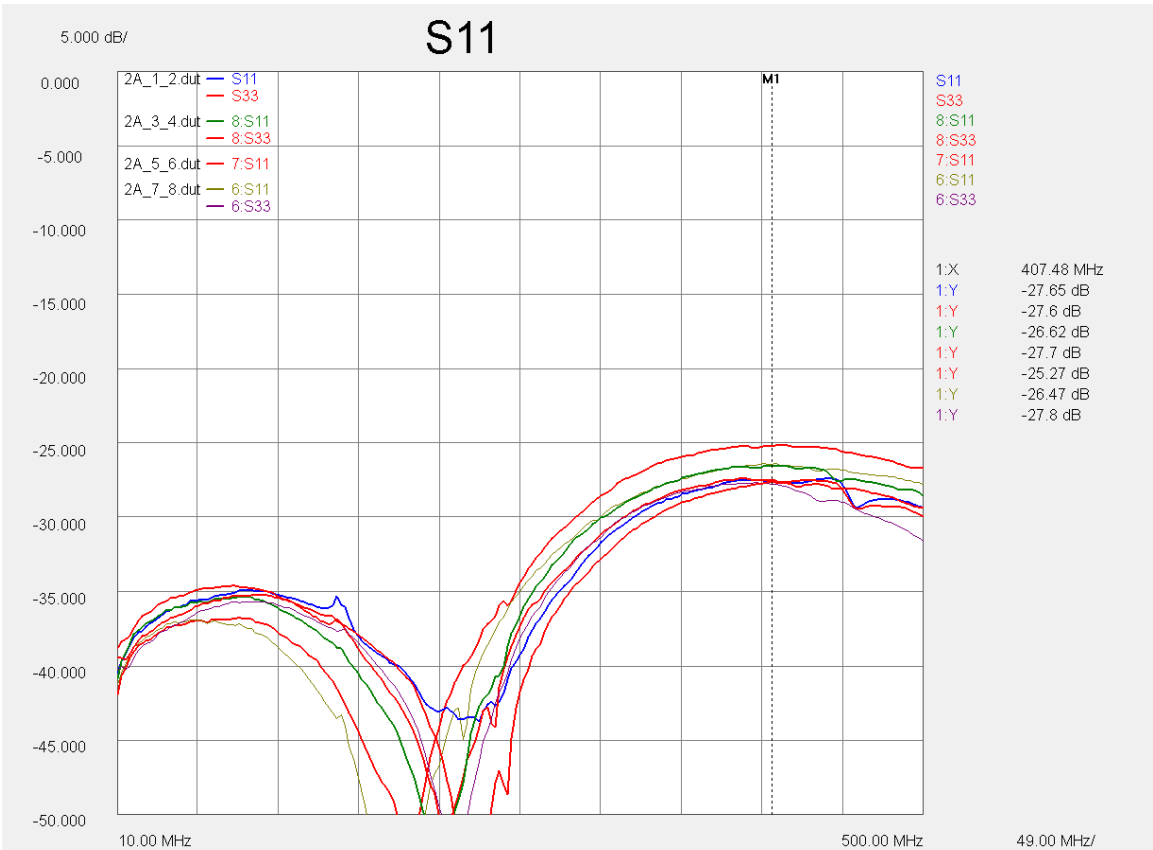


Figure 17: Return Loss VS Frequency Overlays Measurements of 2A Configurations with Entire Test Setup

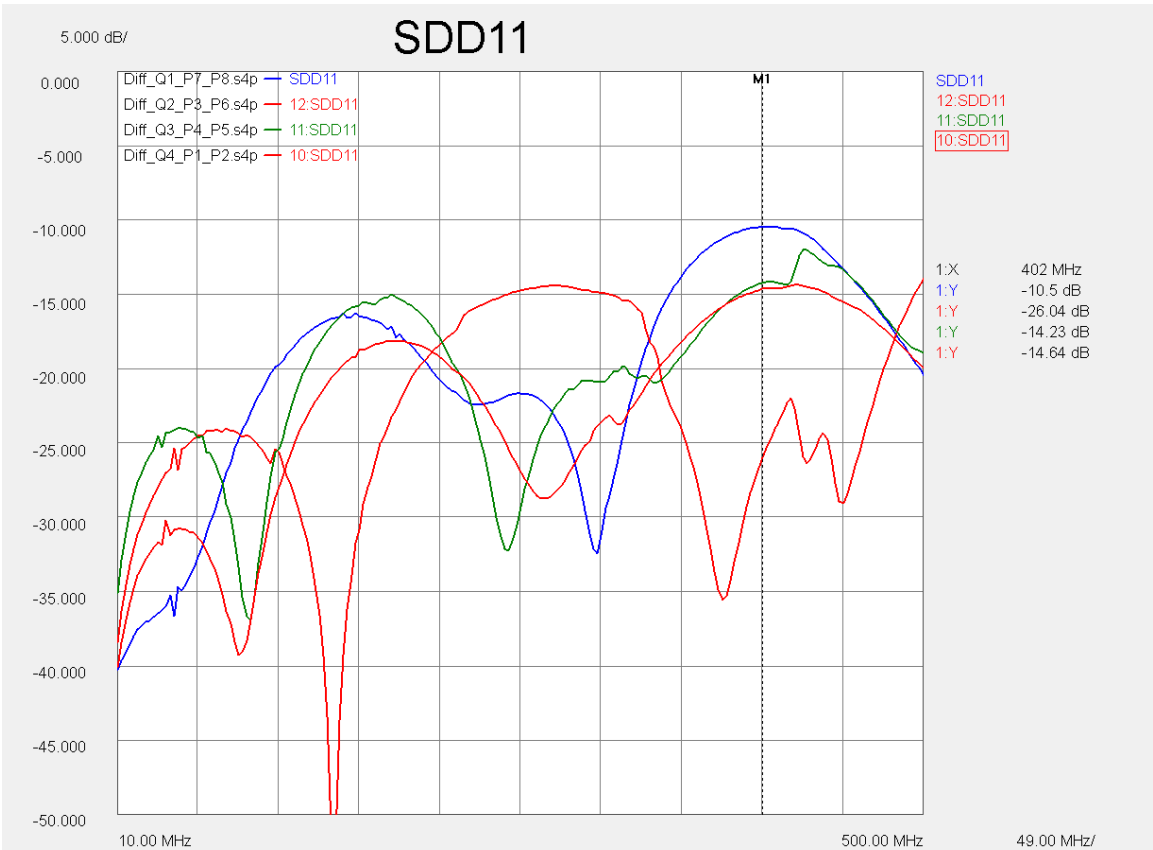


Figure 18: Return Loss VS Frequency Overlays Measurements of Ethernet Configurations with Entire Test Setup



Figure 19: Insertion Loss VS Frequency Overlays Measurements of 4B Configurations with Entire Test Setup

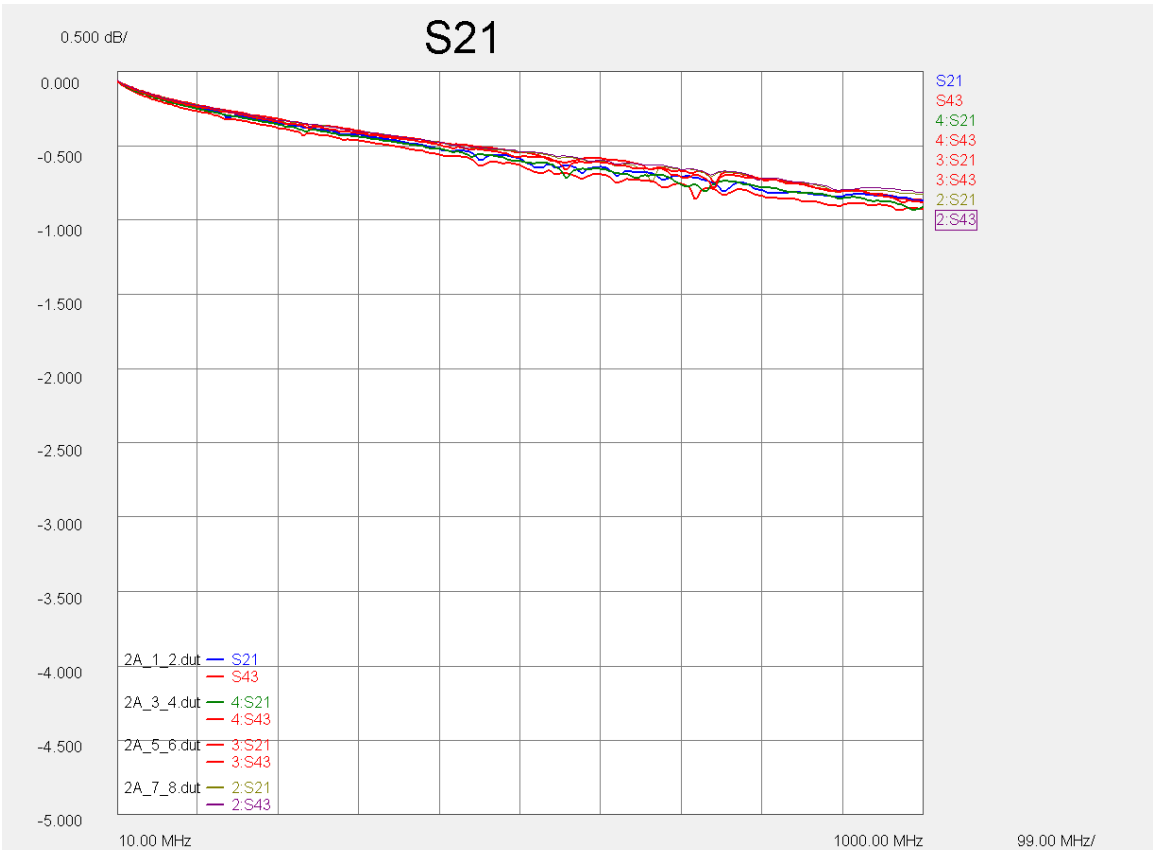


Figure 20: Insertion Loss VS Frequency Overlays Measurements of 2A Configurations with Entire Test Setup

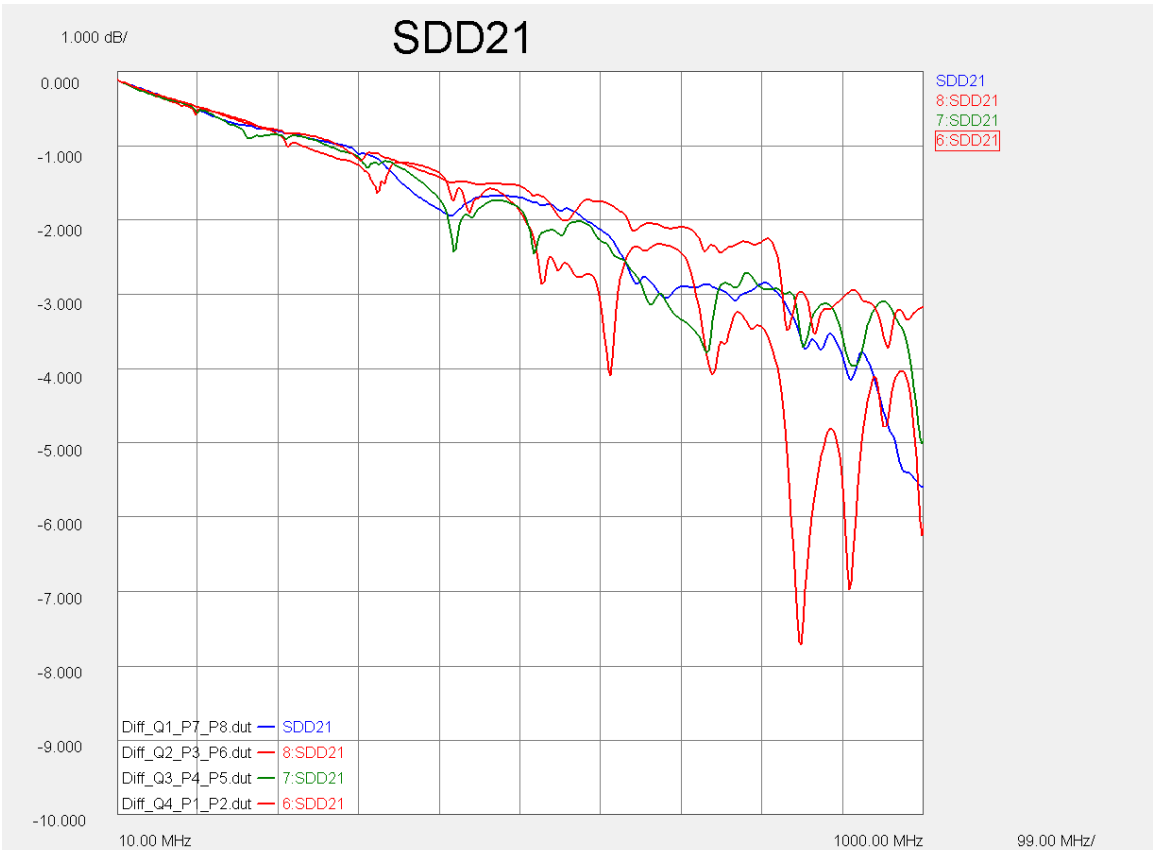


Figure 21: Insertion Loss VS Frequency Overlays for Measurements of Ethernet Configurations with Entire Test Setup

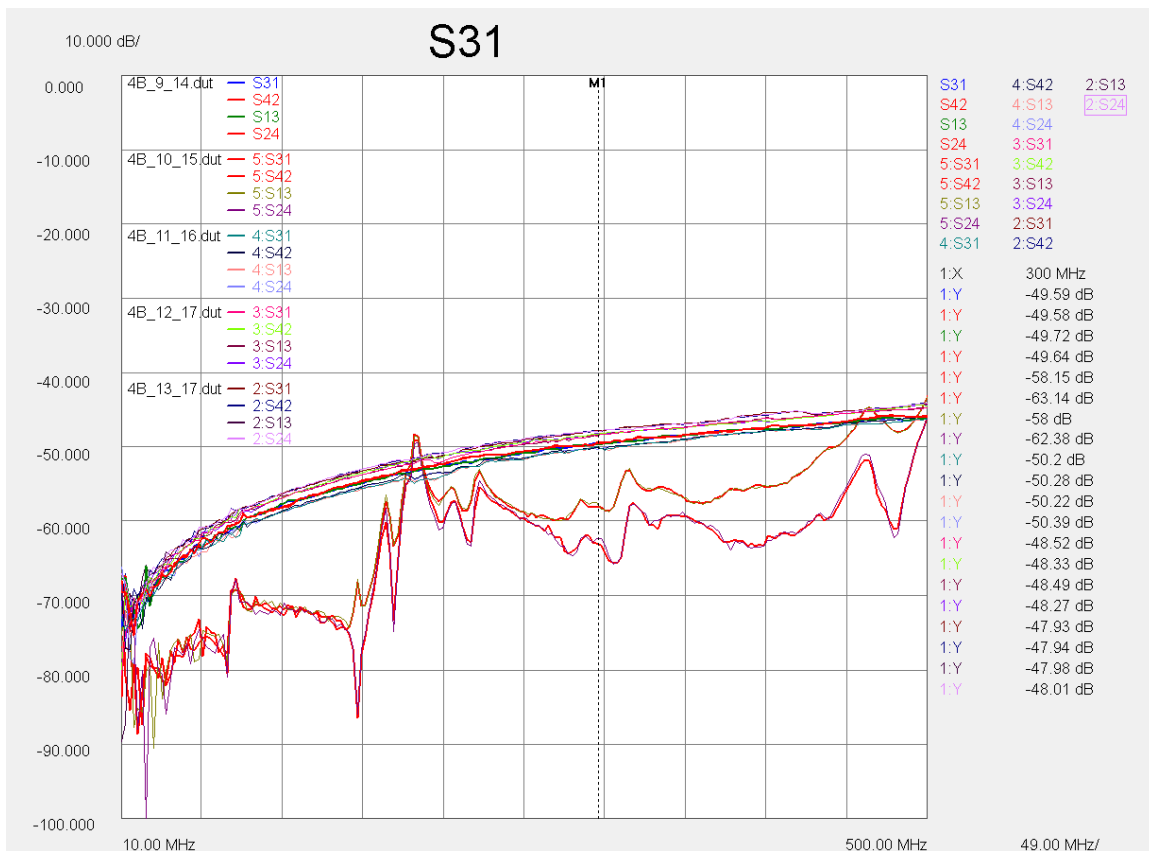


Figure 22: Near Ended Cross Talk VS Frequency Overlays for Measurements of 4B Configurations with Entire Test Setup

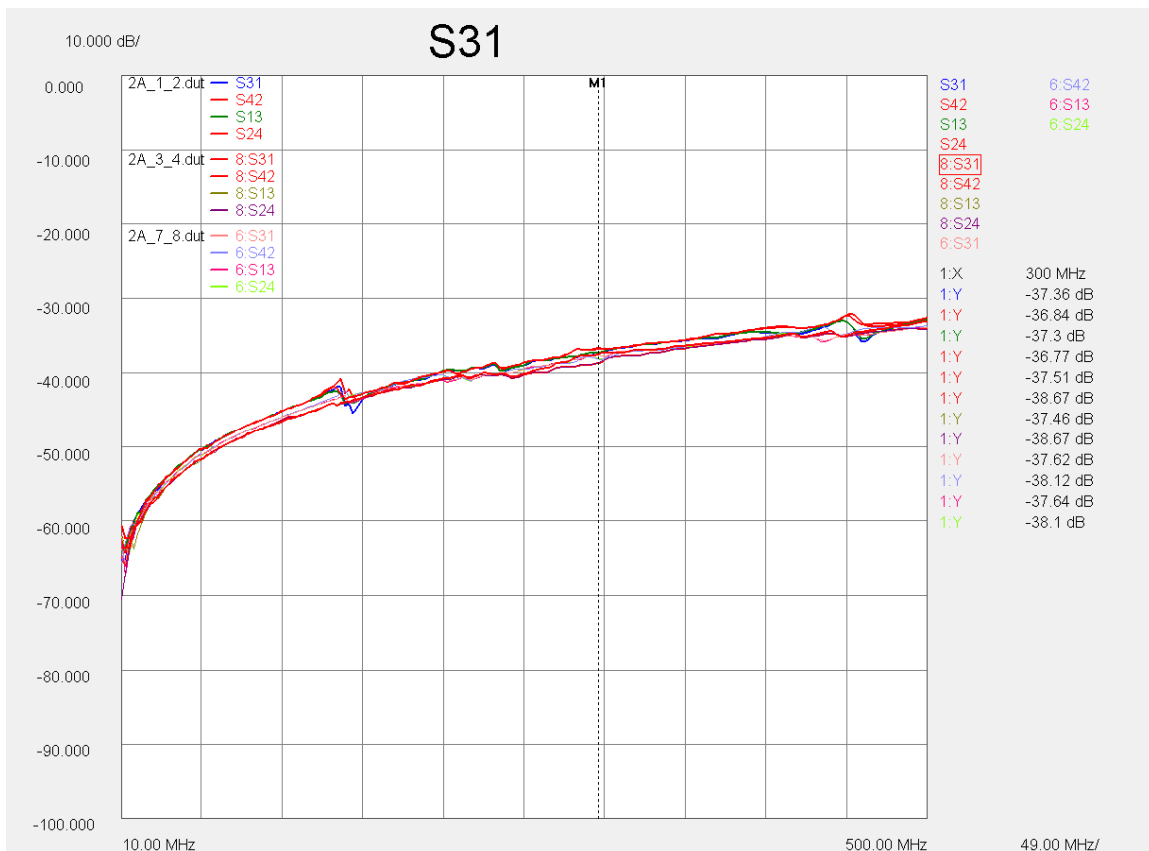


Figure 23: Near Ended Cross Talk VS Frequency Overlays for Measurements of 2A Configurations with Entire Test Setup

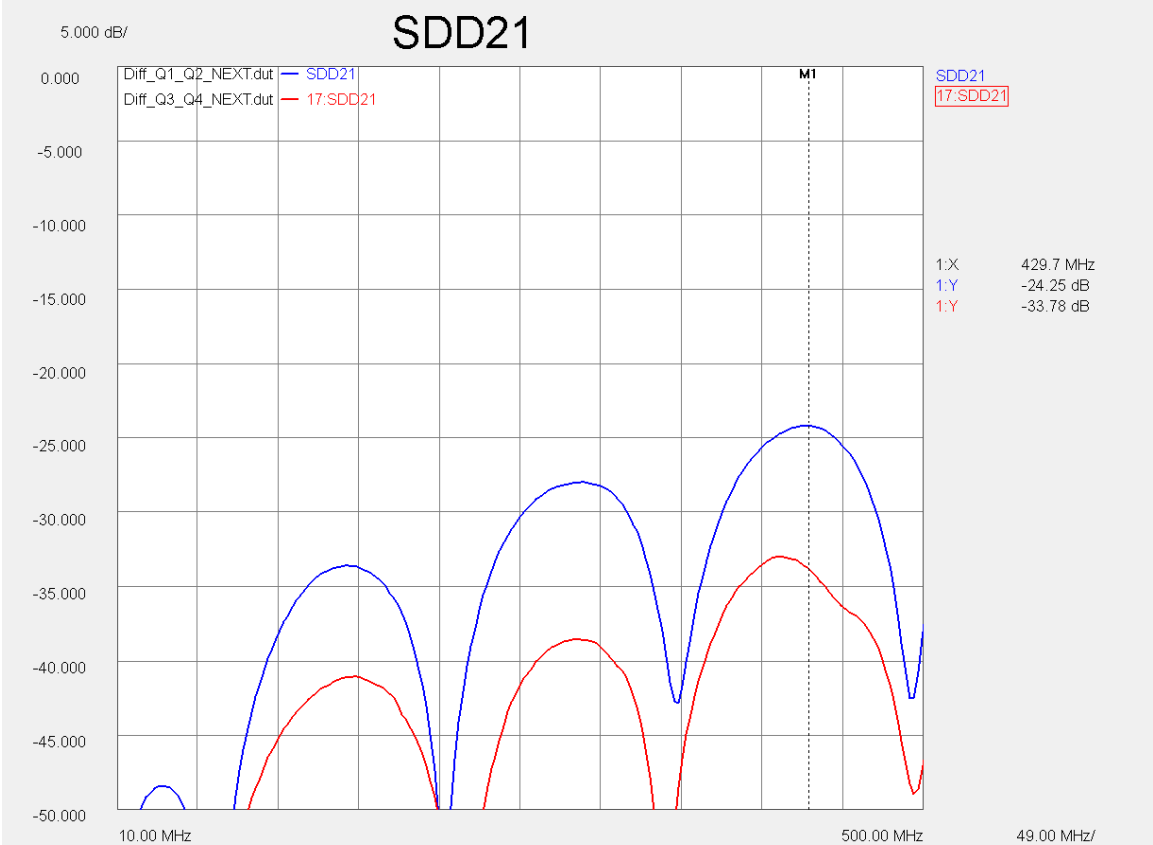


Figure 24: Near Ended Cross Talk VS Frequency Overlays for Measurements of Ethernet Configurations with Entire Test Setup

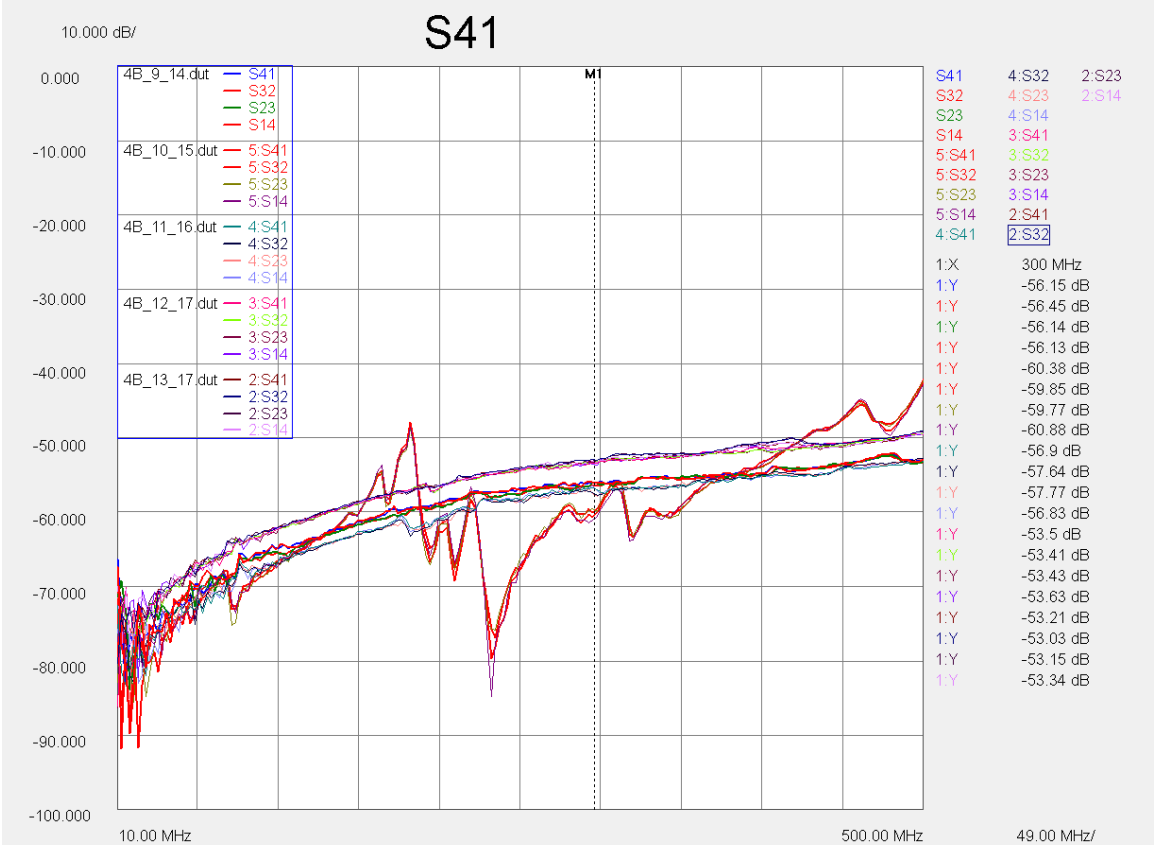


Figure 25: Far Ended Cross Talk VS Frequency Overlays for Measurements of 4B Configurations with Entire Test Setup

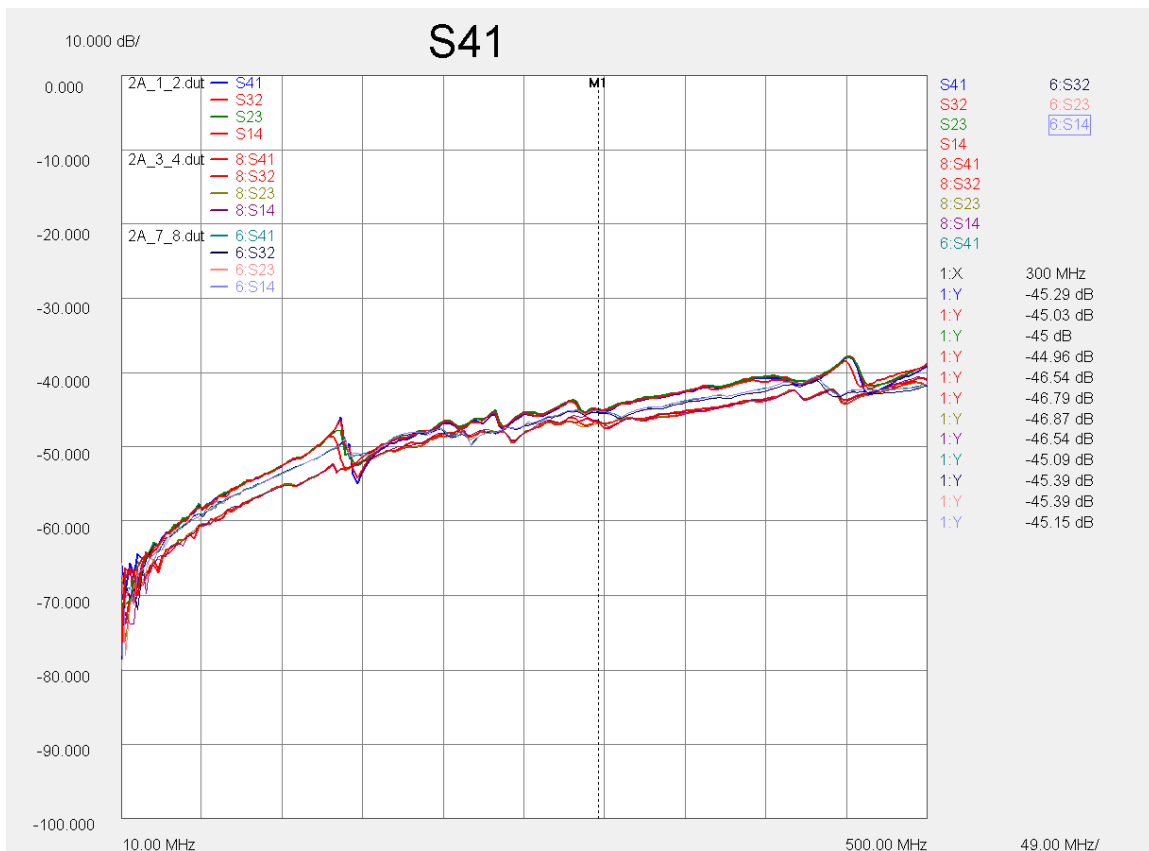


Figure 26: Far Ended Cross Talk VS Frequency Overlays for Measurements of 2A Configurations with Entire Test Setup

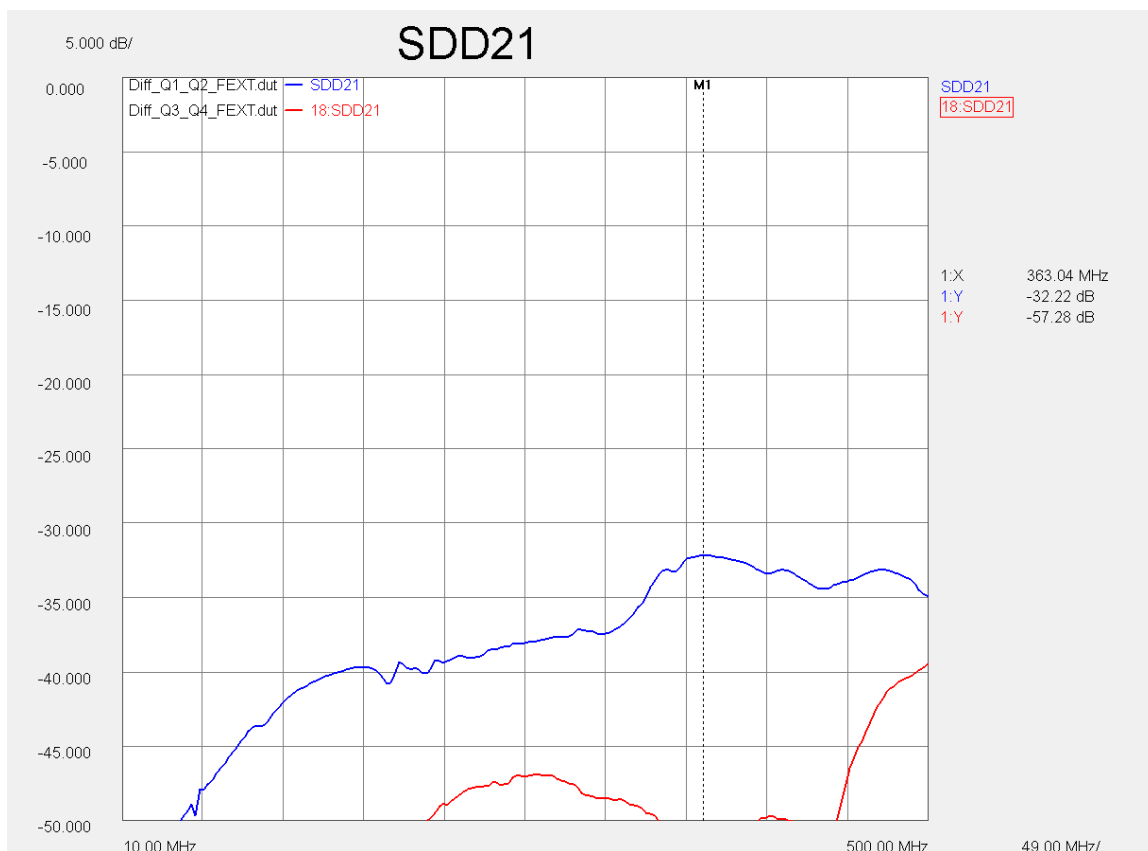


Figure 27: Far Ended Cross Talk VS Frequency Overlays for Measurements of Ethernet Configurations with Entire Test Setup

8. Conclusion:

The testing exercise clearly shows that spring probe grid array connectors provide the mechanical, electrical, and optimizable performance required for a typical MRI coil interconnect system, as well as internal connections within the system. This technology provides a non-magnetic interface, reliable mating upto 60,000 cycles, with insertion/return loss, cross talk, and contact resistance levels required by MRI system designers.

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