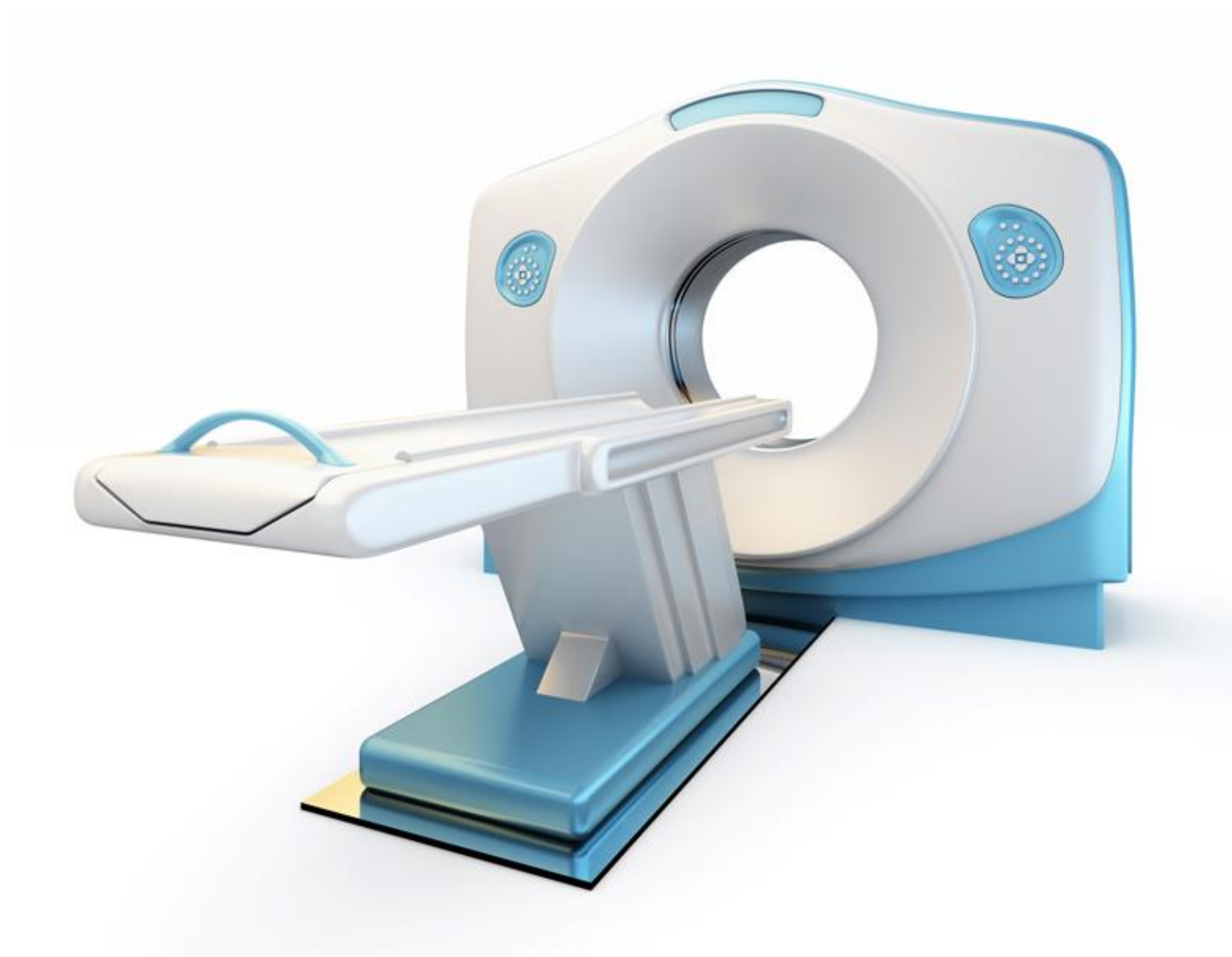
White Paper

Spring Probe PGA Technology

Spring Probe based Pin Grid Arrays (PGAs) for MRI Applications



1. OVERVIEW

MRI (Magnetic Resonance Imaging) systems are used to obtain a clear view of structures inside the body, non-invasively through applying the principal of nuclear magnetic resonance within a powerful magnetic field to image those structures, without the use of potentially harmful X-rays. An RF coil is used as an antenna, around the specific body part to be imaged. It communicates with the RF gradient within the magnetic field. That coil is typically connected into the MRI system with a high frequency cable and connectors.

Since components comprised of magnetic materials hold the potential to interfere with the image, these coil cables and connectors must be non-magnetic. Additionally, the signal, power, and RF contacts used in these connectors must be highly reliable for tens of thousands of mating cycles. However coaxial RF contacts can be large, costly, and fragile. As such, there is pressing need for smaller, more robust, and more cost efficient interconnect systems.

Coils are often in direct contact with the patient, so patient comfort is a priority design concern. Wherever it is possible, these coils are made of lightweight materials so that excessive pressure is not applied to the patient being imaged. The size and weight of the cable and connector is also a consideration for the same reason.

Each RF channel in an MRI coil normally requires one coaxial connection and by replacing coaxial contacts with a contact grid array can reduce the size, weight, and cost of the connector. However, by replacing pin and socket contacts with spring probes, cleaning the cable connector can be faster and easier since flat target contacts are simpler to clean than coaxial sockets, thus improving throughput in an MRI suite.

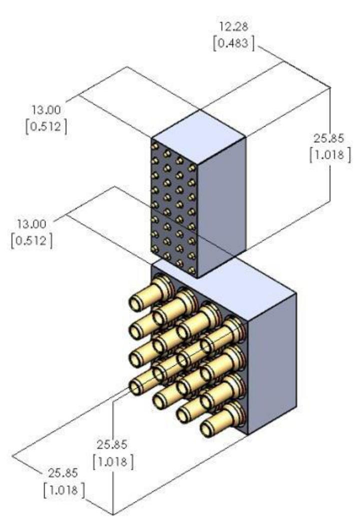
There may also be the desire to incorporate a connector at the coil end of the cable to facilitate replacing the cable if it becomes damaged, without need of sending the entire coil out for repair. This dictates the use of a very small connector since it is in even closer proximity to the patient, and connectors that feature an array of contacts make this possible.

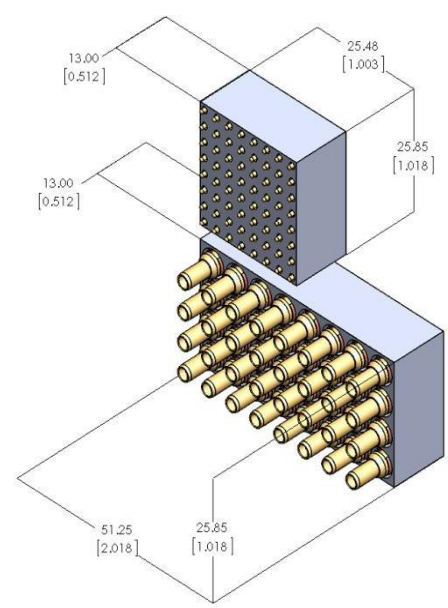
2. Spring Probe PGA Technology

Spring probes have a very high mating cycle life, often higher than traditional pin & socket contact systems, and this is needed to keep very expensive MRI systems operating to their full capacity and patient throughput to a maximum. Smiths Interconnect, the leader in spring probe technology, has developed non-magnetic spring probes with mating cycles exceeding 60,000, specifically for MRI applications.

Using a spring probe grid array allows for the designer to customize the number of ground pins used to optimize the performance of the connector for specific frequencies/coil designs, saving size, weight, and cost while maintaining the performance of a coax channel where needed. Spring probe grid arrays also simplify cable termination activities by allowing mass solder termination to printed circuit boards.

Comparing the relative size of the PGA and coaxial contact connectors in select applications, the PGA contacts occupy only about ½ the space of traditional coaxial contacts as shown in the examples below for 16 and 32 channel connector pin fields (see Figures 1 & 2)





Dimensions: mm [inch]

Figure 1: 16 channel

Figure 2: 32 channel

A typical 16 channel PGA layout, shown in Figure 3 below, incorporates 32 probe contacts, in which 16 are signal and 16 are returns. Each RF channel utilizes 1 signal contact and an adjacent contact for the return:

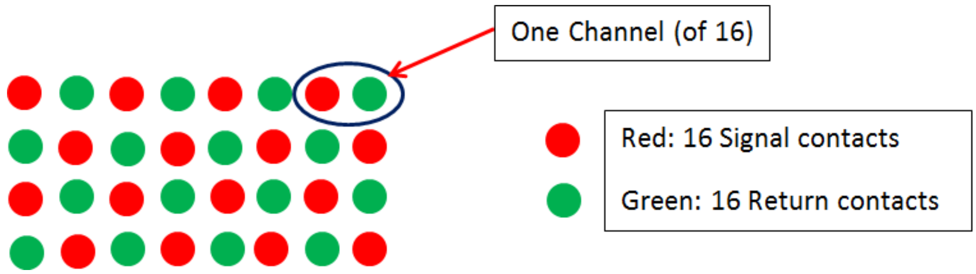


Figure 3: 16 channel PGA

The analysis of testing commissioned by Smiths Interconnect on pin grid array spring probe connectors, below, shows that this technology is a very viable next step in MRI coil interconnections.

3. Features & Benefits of Spring Probe PGA (Pin Grid Array) Connectors for typical MRI System Applications:

FEATURES:	BENEFITS:
- High Density	- Smaller Footprint for patient comfort
- 60K Mating Cycles	- Increase in MTBF
- Stable Contact Resistance	- Consistent Image Quality
- Damage Resistant Target Contacts	- Increase in MTBF
- Sealed Target Contacts	- Cleanable Interface / Increase in MTBF
- Non-Magnetic Components	- Prevent “artifacts” that could distort the image

4. Typical Interconnect Requirements for RF MRI Connectors:

- Relative Magnetic Permeability
    - Less than 0.00005μ_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 20mΩ per contact (before and after mating cycle life)
- Mating Cycle Life
    - 60k mating cycles

5. 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

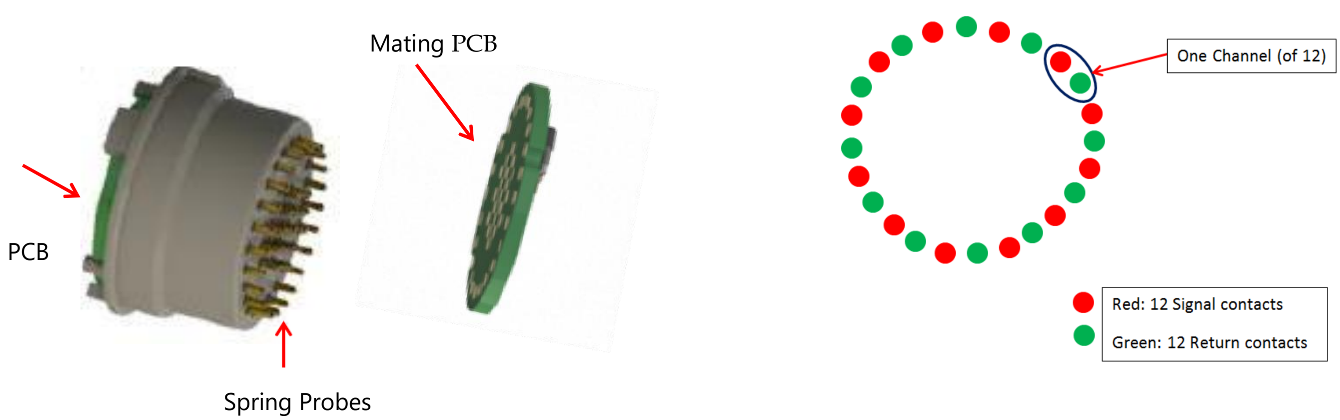


Figure 4: Test connector configuration

- 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 permeablity to minimize any “artifacts” whichcould distort or obscure the resulting image.
    - Test Scope: Measure the magnetic permeablity of the plug and receptacleconnctors
    - Result: Passed
      - Connectors were found to have a relative magnetic permeability of lessthan 0.00005μ_r
  - Insertion Loss:
    - Insertion loss is the loss of signal power resulting from a device, a connector inthis 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 pairof coaxial cable assemblies.
    - Result: Passed
      - The insertion loss of the connector only (not including the terminationor 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)

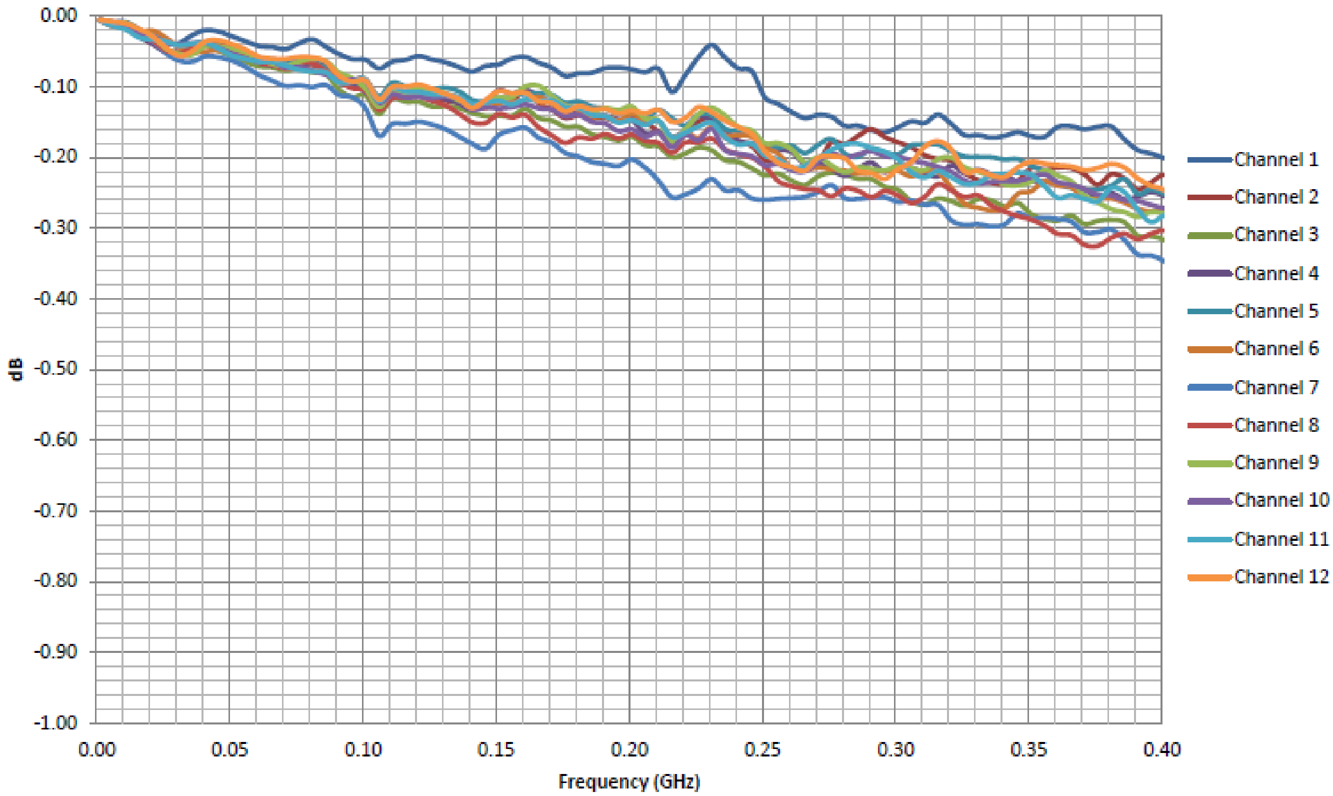


Figure 5: Insertion Loss vs. Frequency

- 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 ofcoaxial 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)

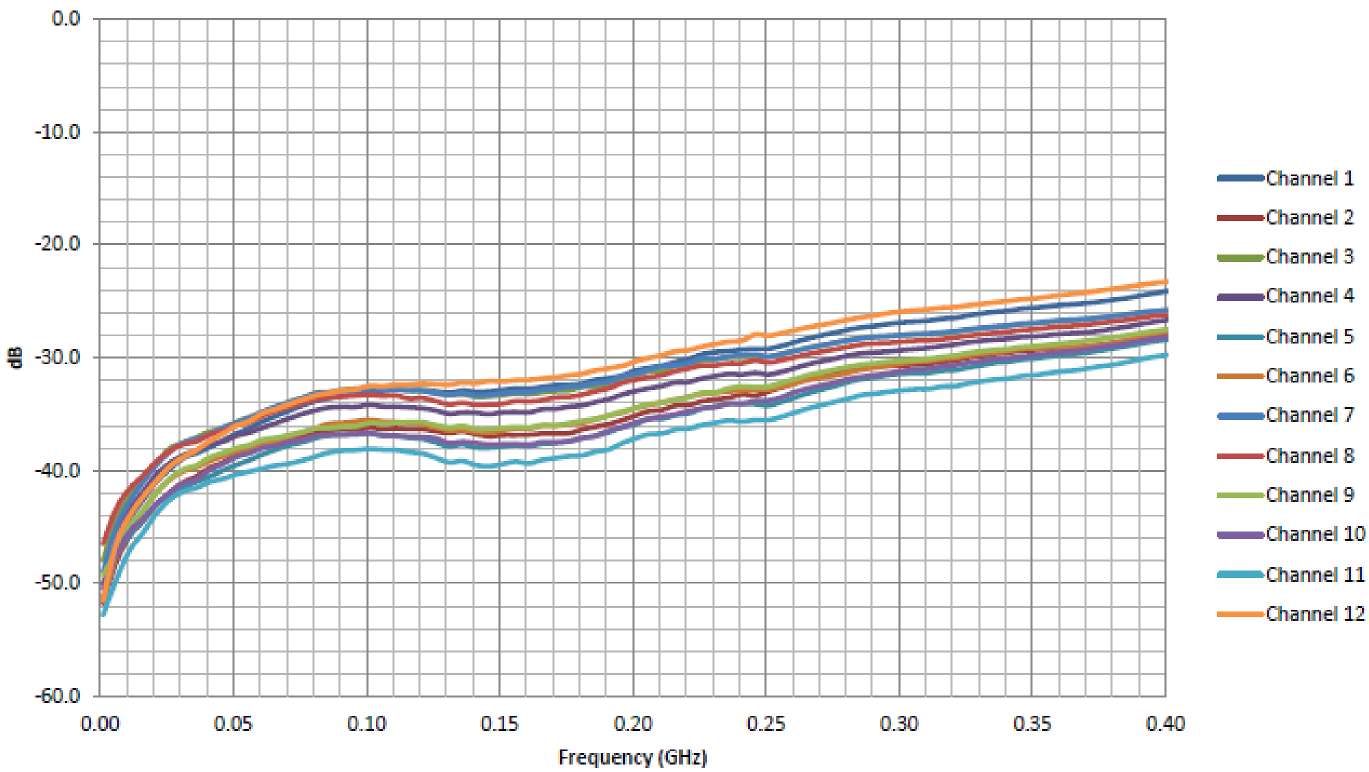
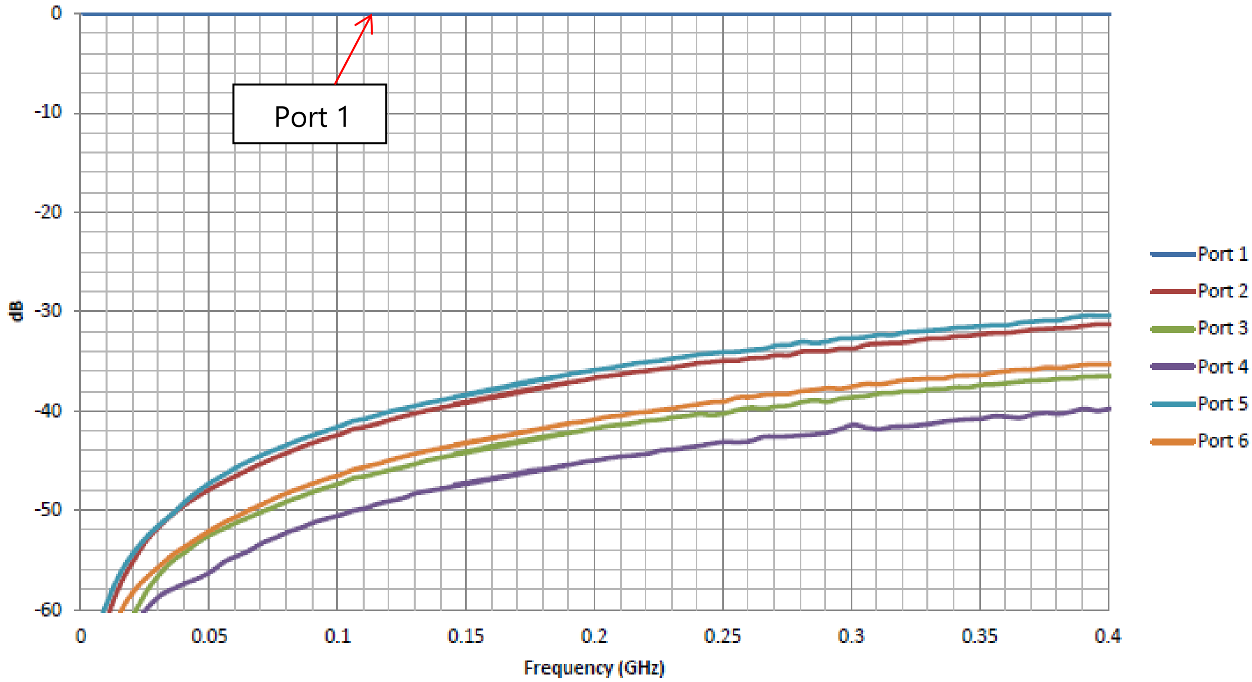


Figure 6: Return Loss vs.

- 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.

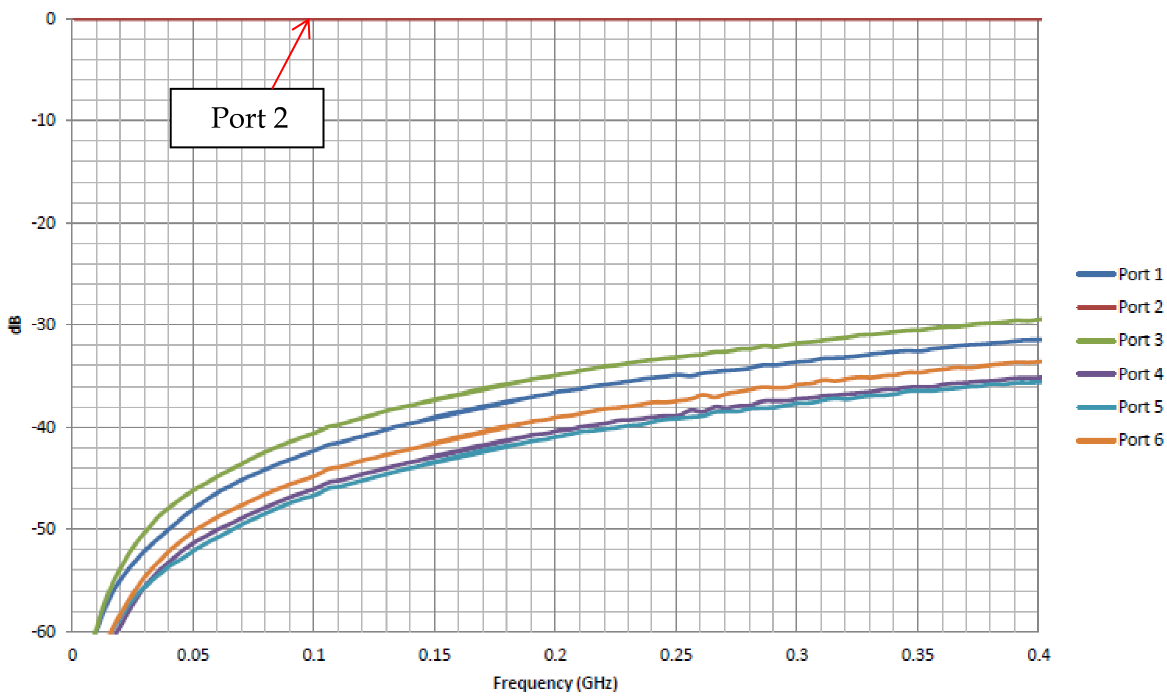


Figure 7b: Far End Cross Talk, Port 2, vs. Frequency

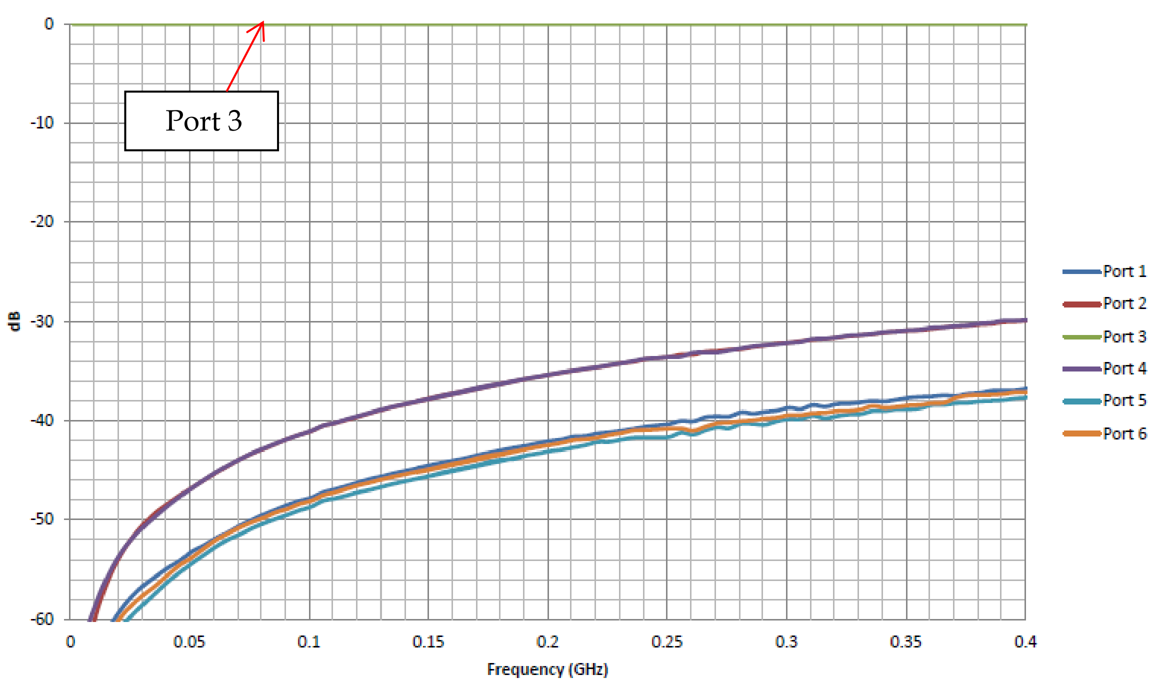


Figure 7c: Far End Cross Talk, Port 3, vs. Frequency

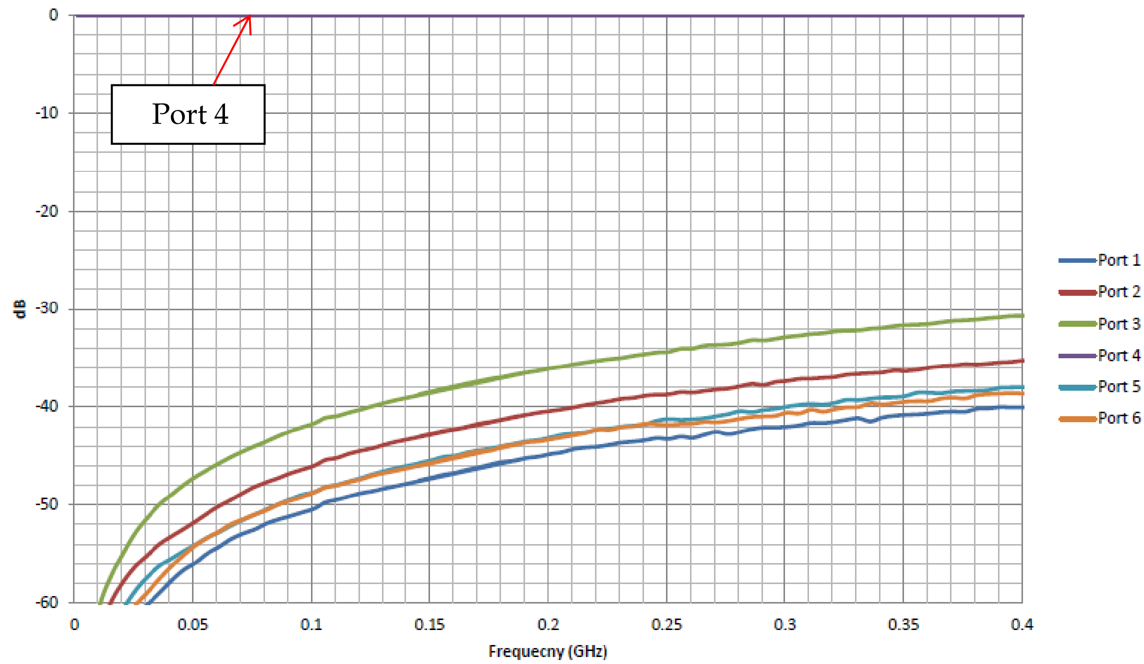


Figure 7d: Far End Cross Talk, Port 4, vs. Frequency

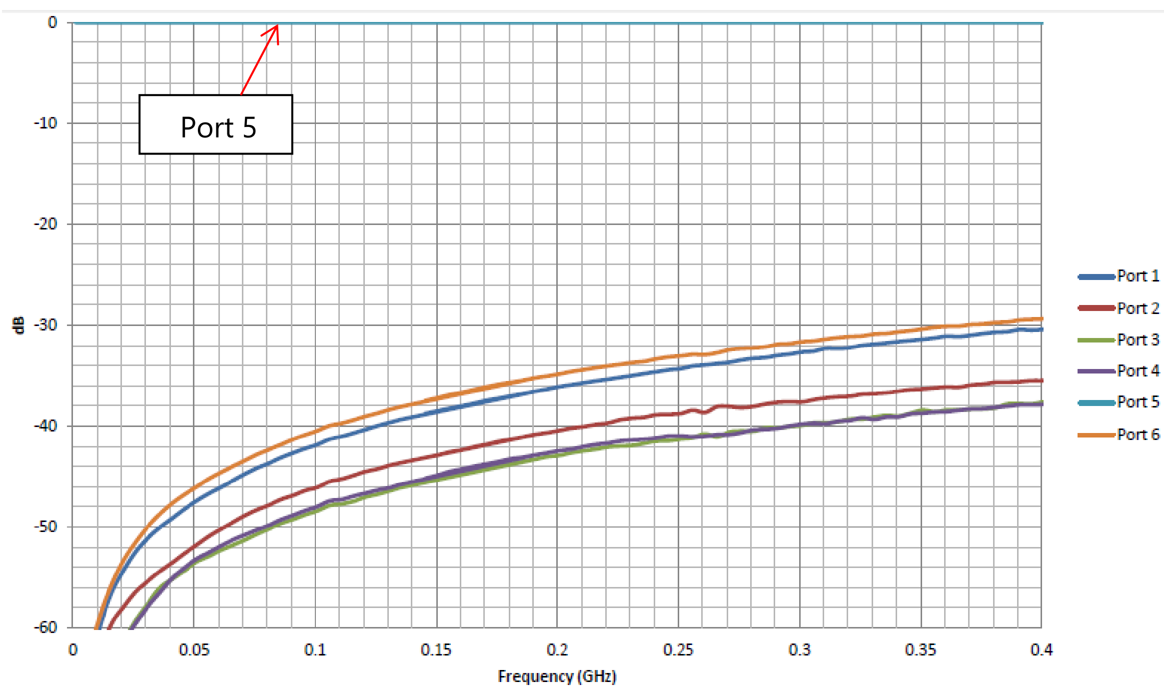


Figure 7e: Far End Cross Talk, Port 5, vs. Frequency

- Low Level Circuit Resistance (LLCR)
    - Lower contact resistance uses less power in the system, creating less heat at thecontact 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 thecontact resistance
    - Result: Passed
        - Contacts were cycled between 0 and 60k mating cycles. The LLCR wasmonitored throughout the process and remained less than 20mΩ per contact: See Figure 8 below

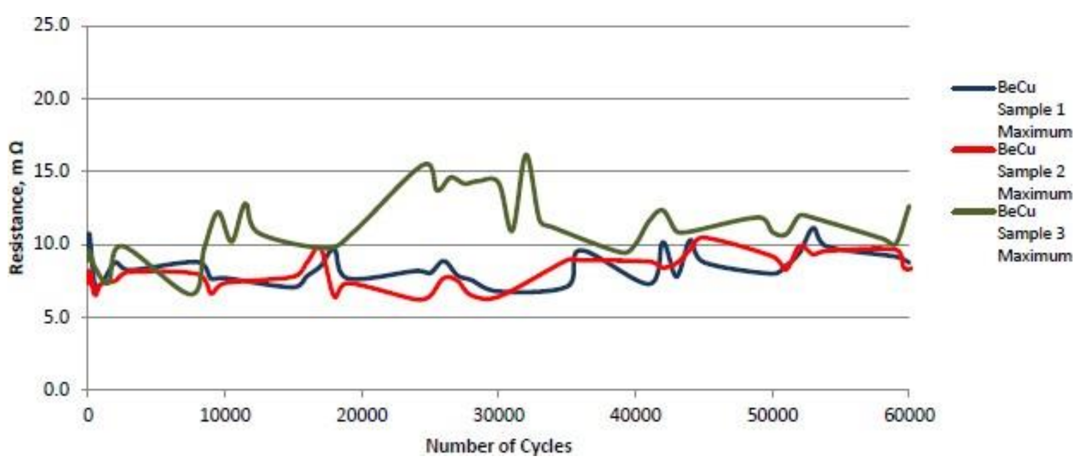


Figure 8: Maximum Contact Resistance vs. Number of mating cycles

- 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 testsis 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 μr	Complete	Pass
Insertion Loss and Return Loss	Insertion Loss: greater than -0.2 dB up to 12.5 MHz greater than -0.3 dB up to 135 MHz Return Loss: 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 20mΩ 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

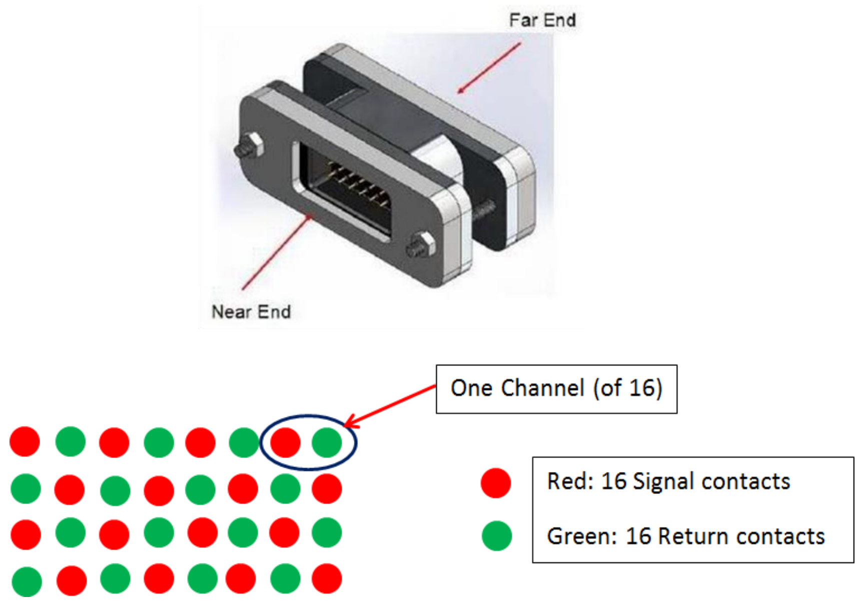


Figure 9: 16 Channel Test connector

- Insertion Loss

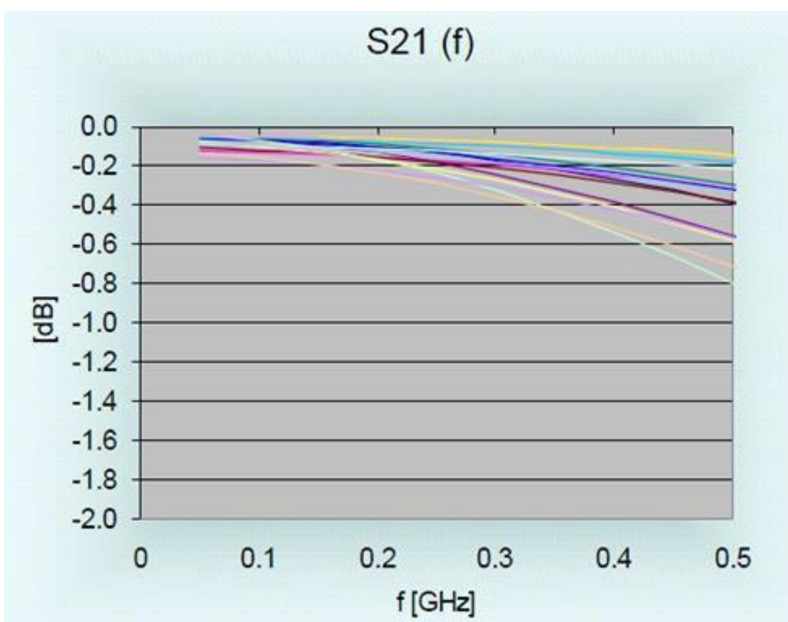


Figure 10: 16 Channel Test: Insertion Loss / Mated

- Return Loss

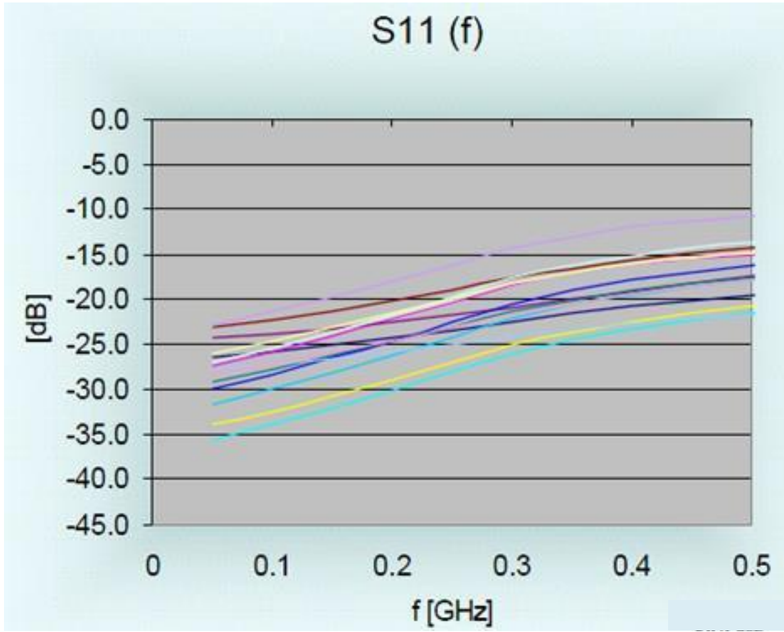


Figure 11: 16 Channel Test: Return Loss / Mated Connector

- Cross Talk (FEXT – Far End Cross Talk)

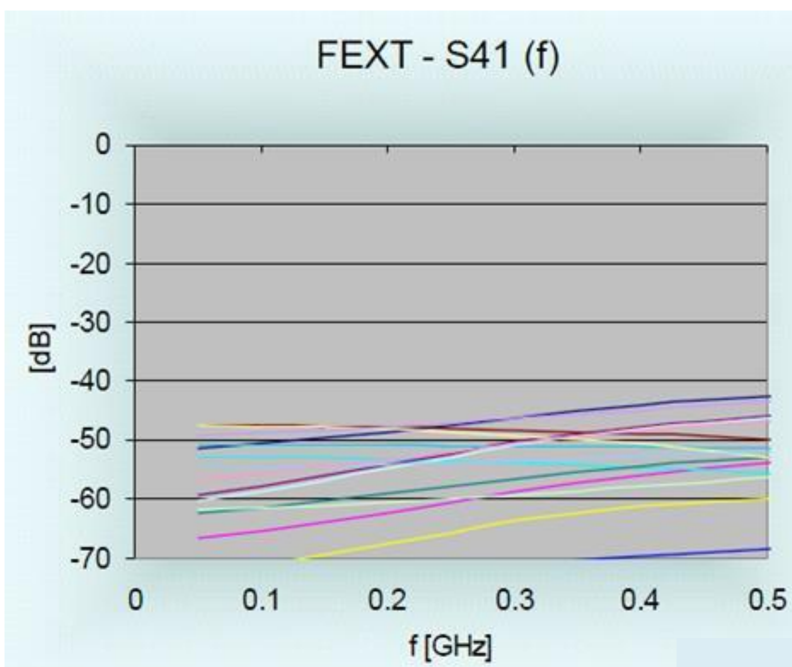


Figure 12: 16 Channel Test: Cross Talk / Mated Connector

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.

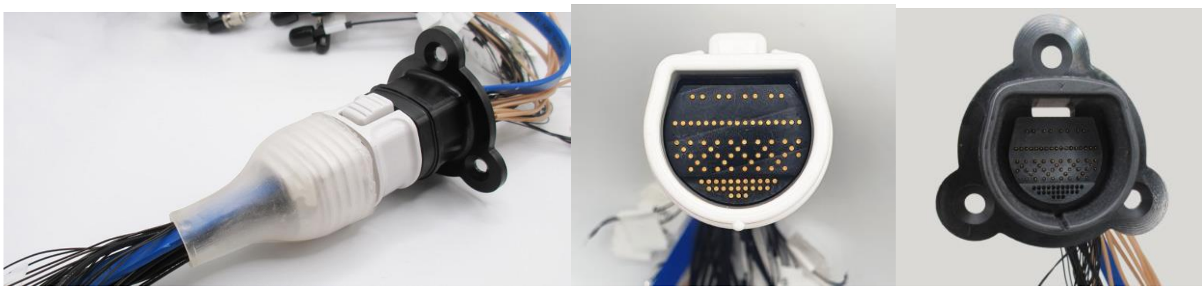


Figure 13: Test Kits: Mated Connector Only

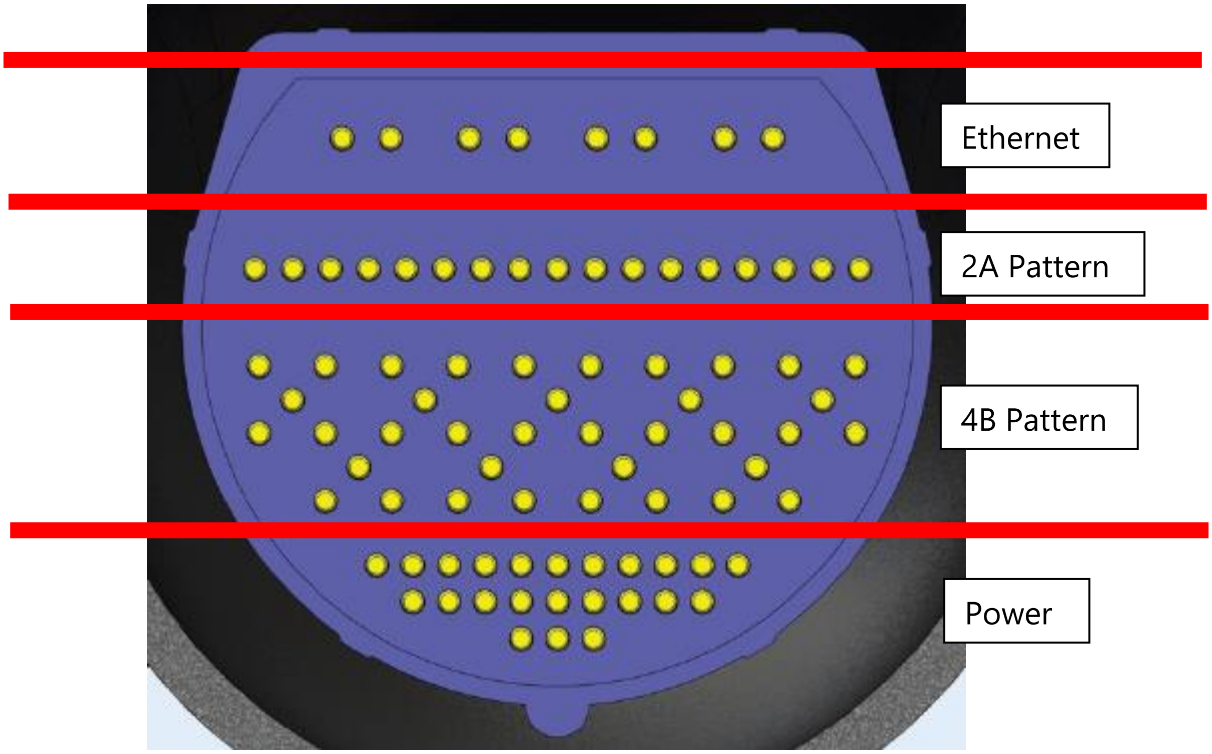


Figure 14: : Array Sections

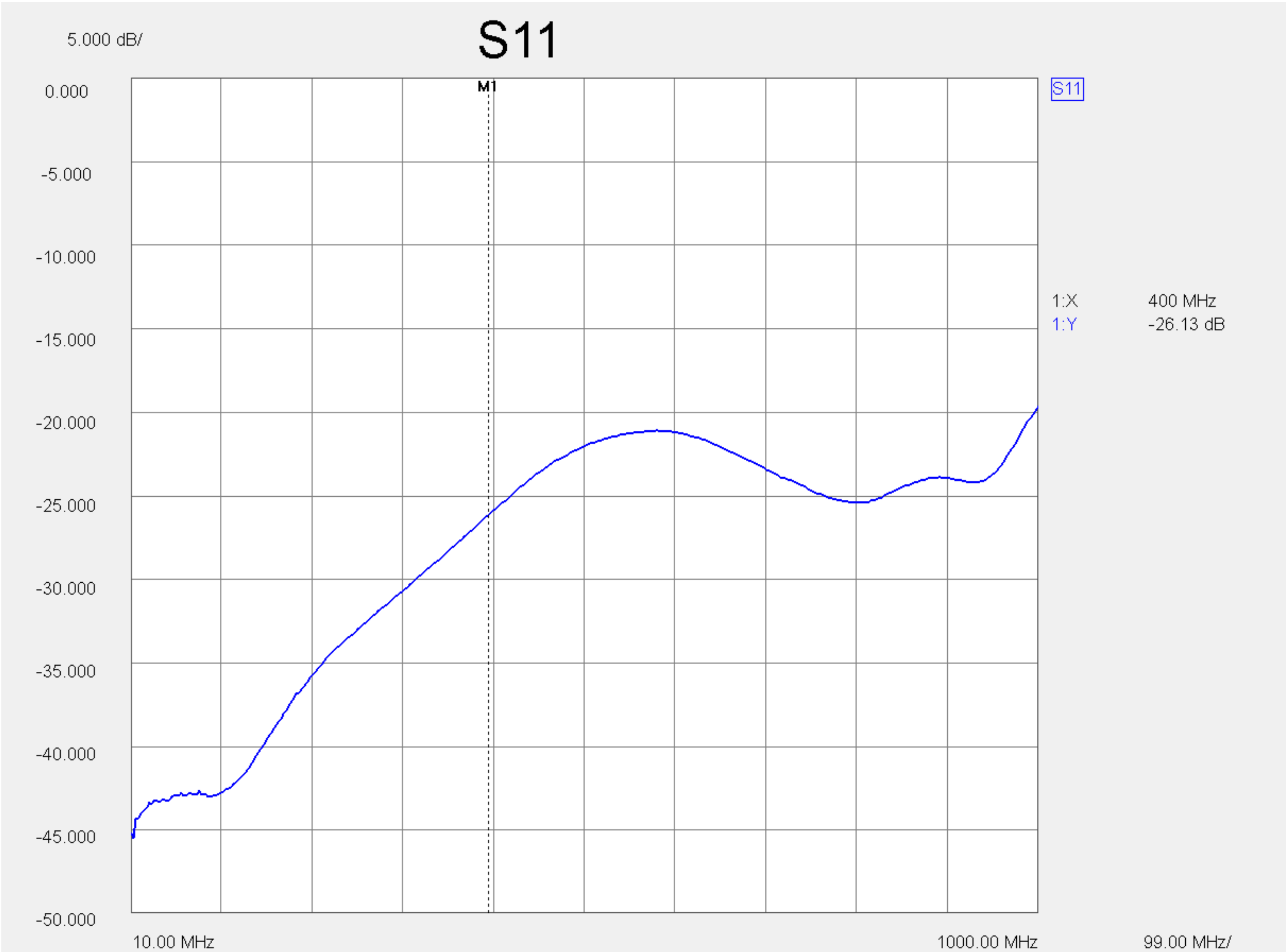


Figure 15: General Return Loss of 4B Connector Configuration / DUT Only

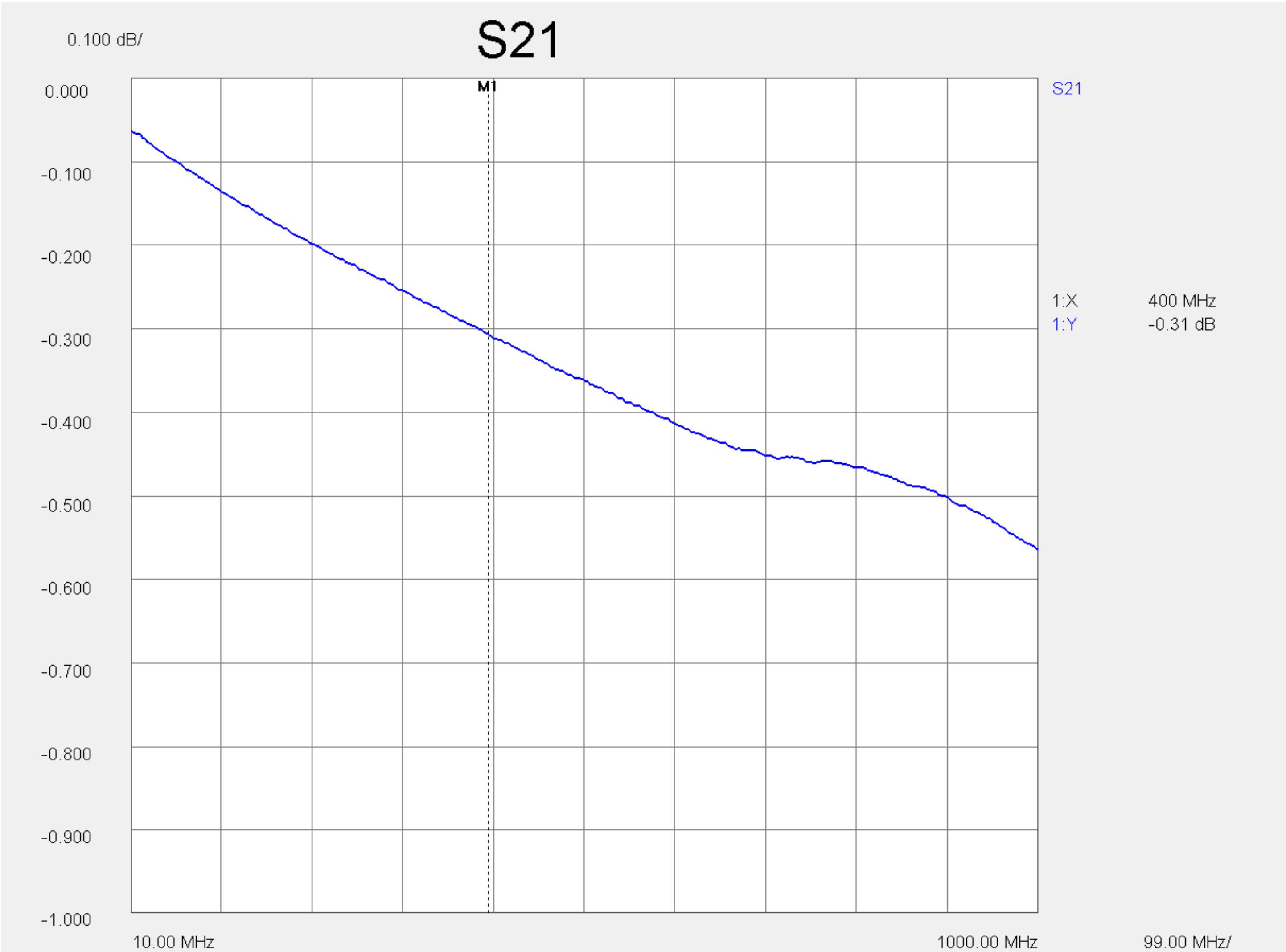


Figure 16: General Insertion Loss of 4B Connector configuration / DUT Only

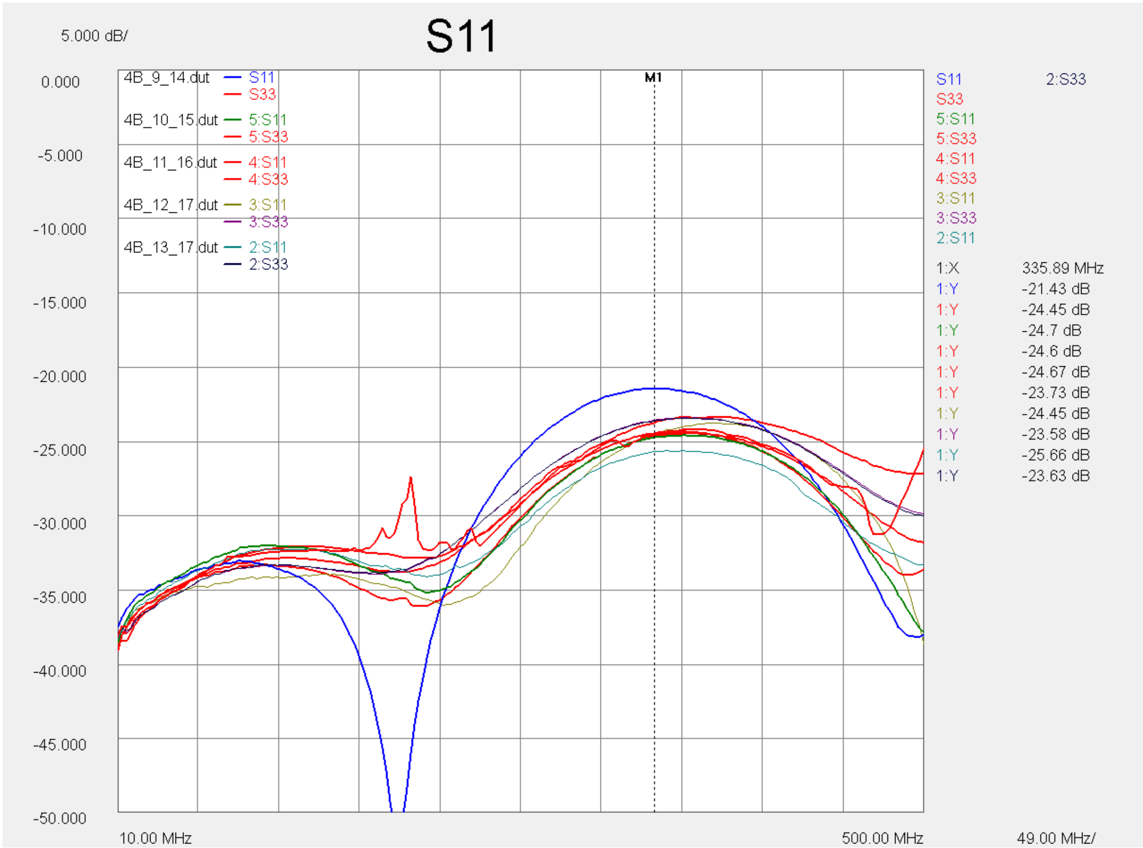


Figure 16: Return Loss VS Frequency Overlays Measurements of 4B Configurations with Entire Test Setup

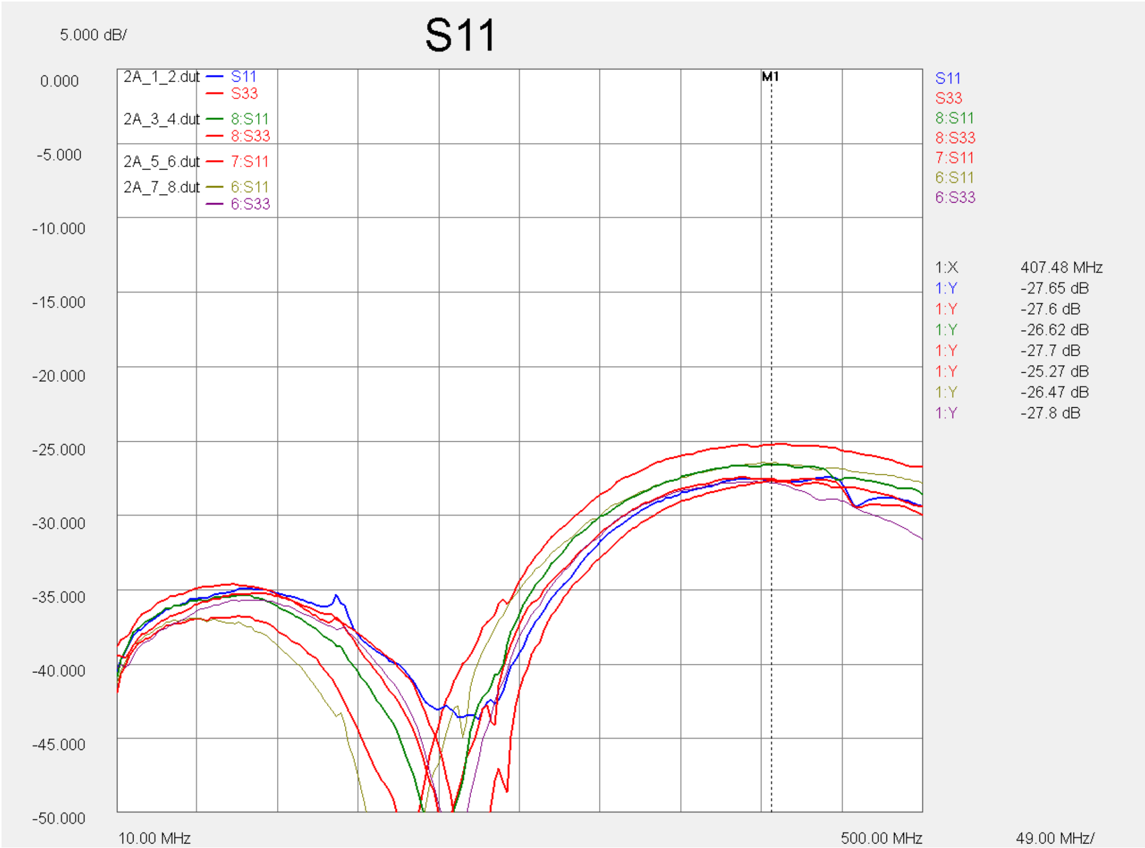


Figure 17: Return Loss VS Frequency Overlays Measurements of 2A Configurations with Entire Test Setup

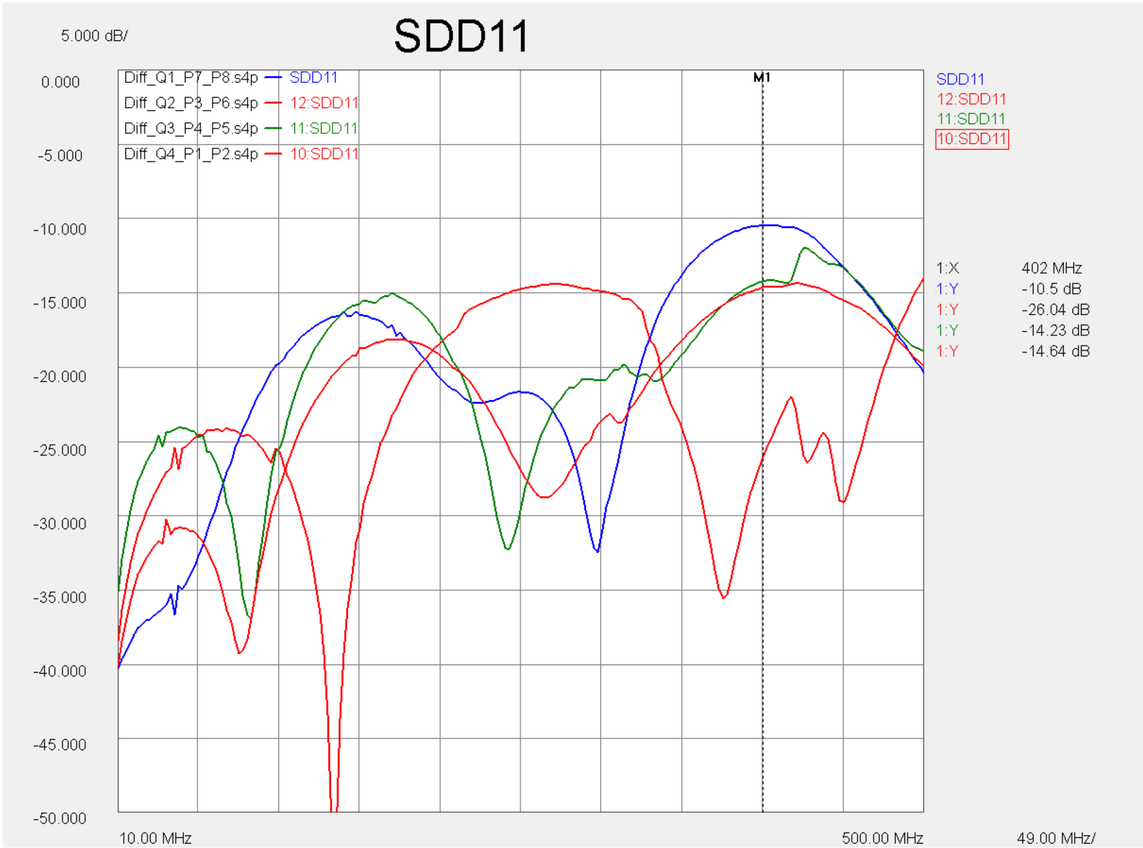


Figure 18: Return Loss VS Frequency Overlays Measurements of Ethernet Configurations with Entire Test Setup

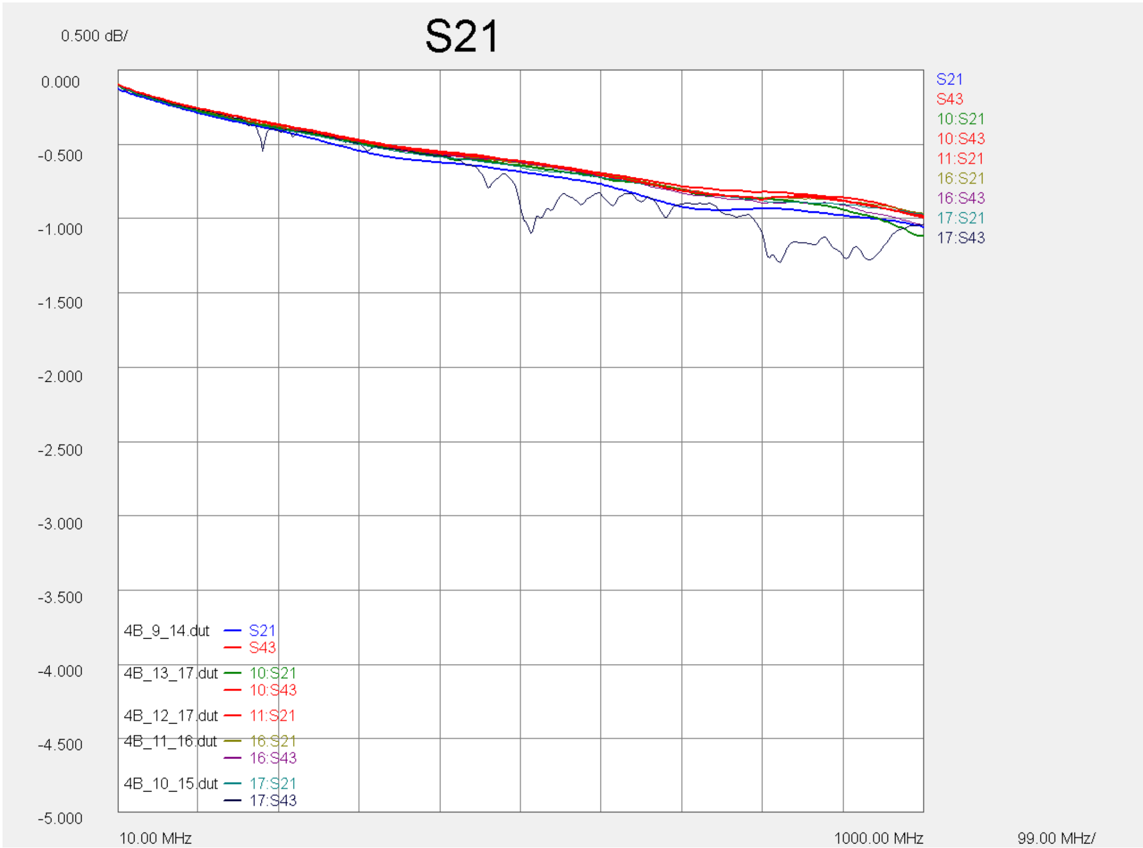


Figure 19: Insertion Loss VS Frequency Overlays Measurements of 4B Configurations with Entire Test Setup

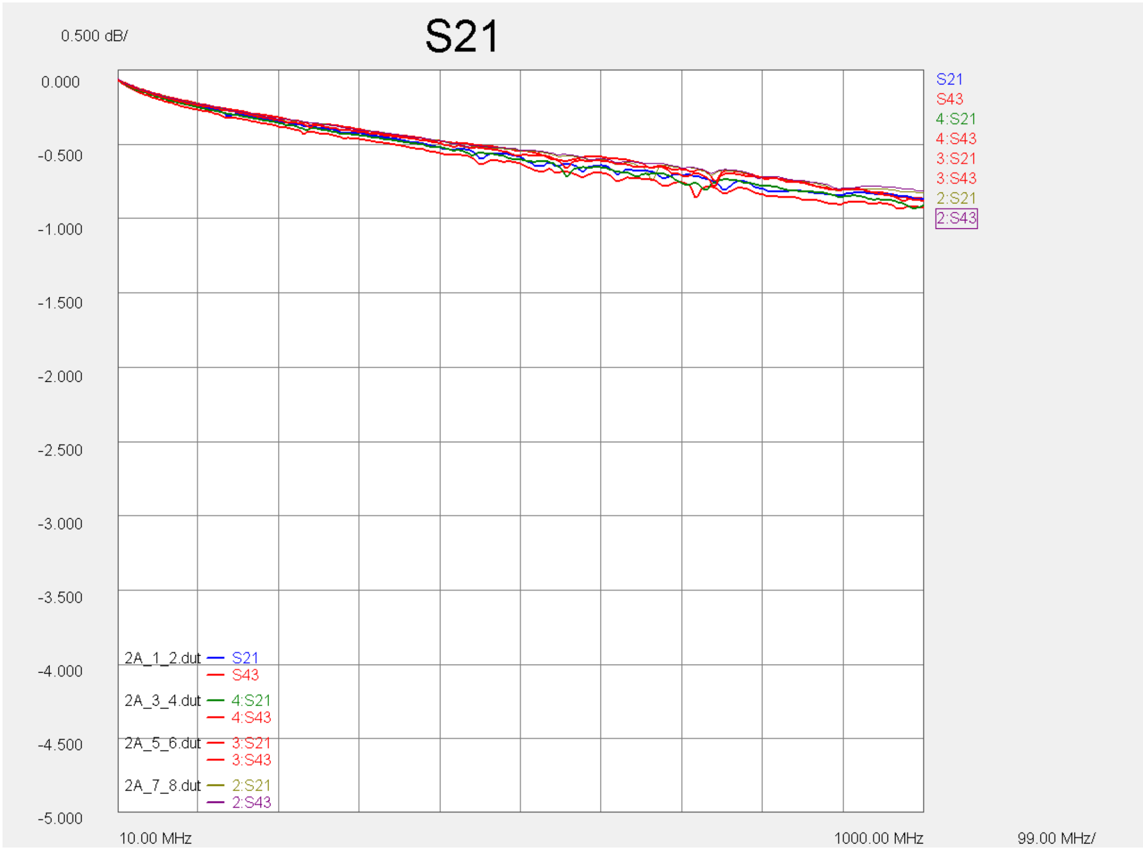


Figure 20: Insertion Loss VS Frequency Overlays Measurements of 2A Configurations with Entire Test Setup

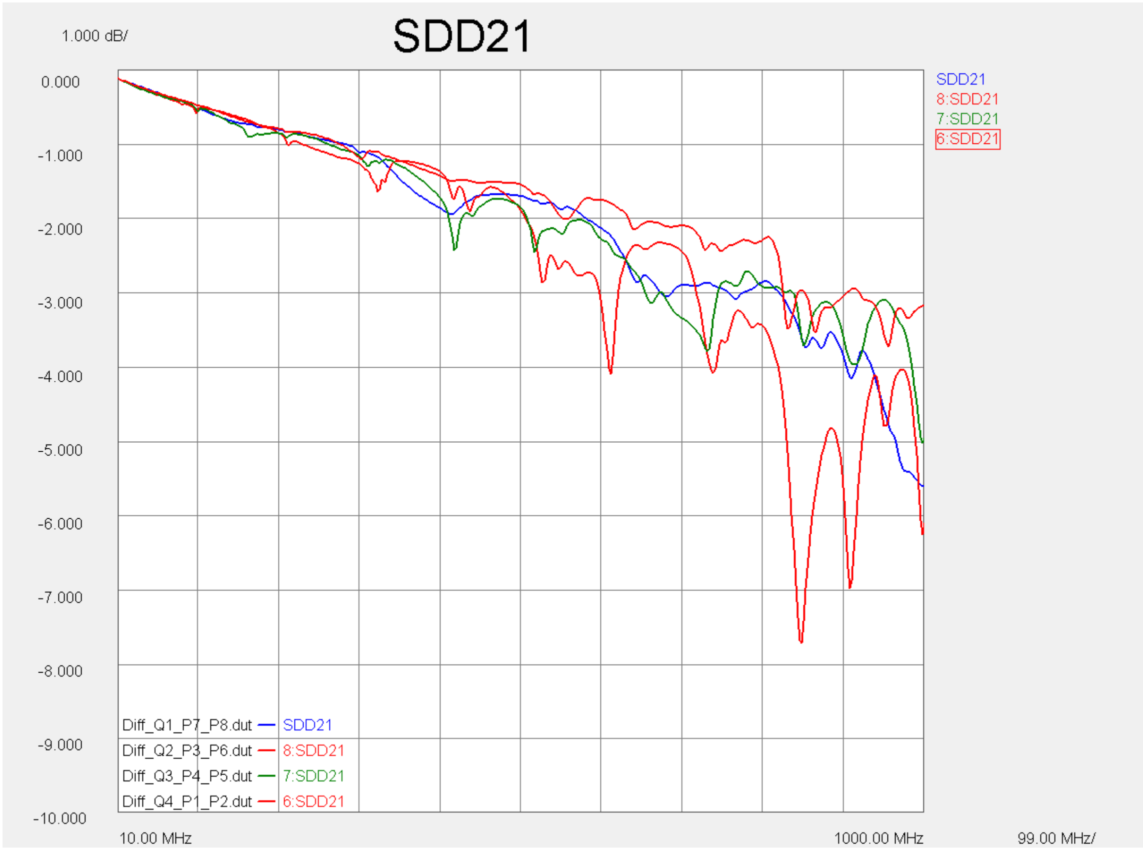


Figure 21: Insertion Loss VS Frequency Overlays for Measurements of Ethernet Configurations with Entire Test Setup

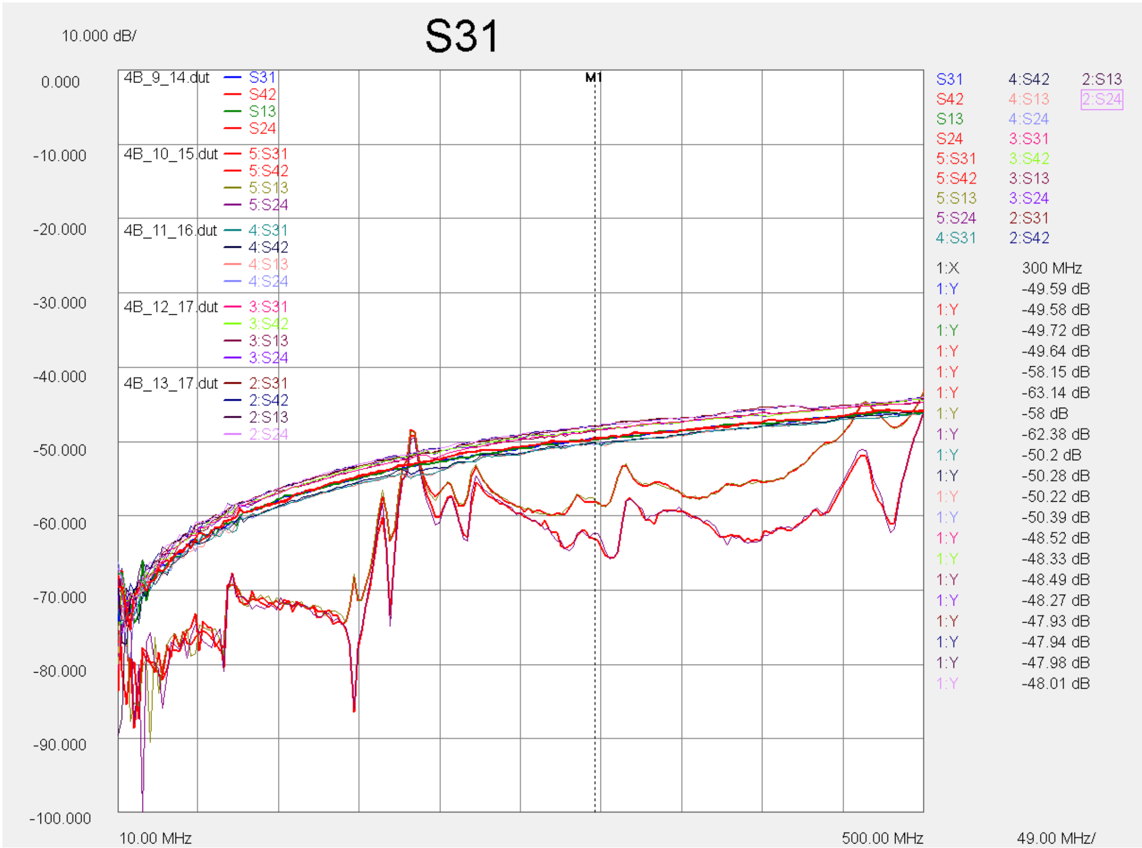


Figure 22: Near Ended Cross Talk VS Frequency Overlays for Measurements of 4B Configurations with Entire Test Setup

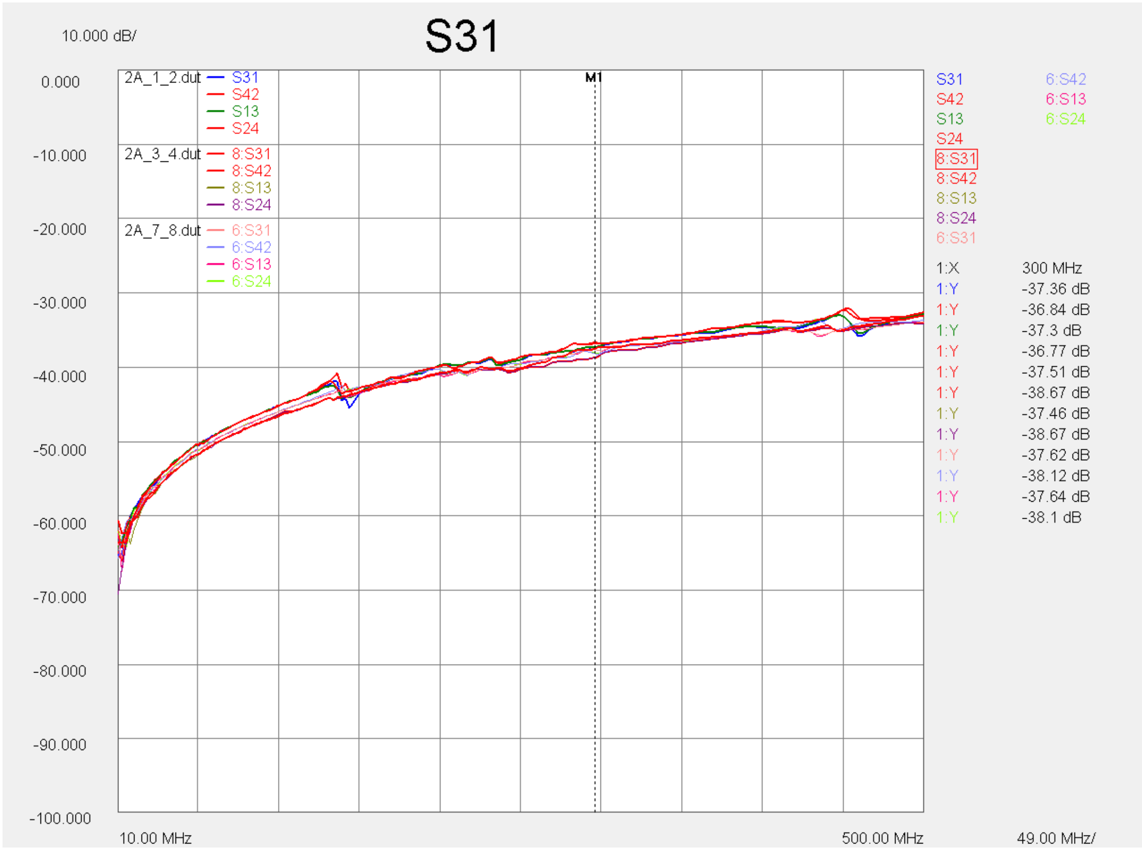


Figure 23: Near Ended Cross Talk VS Frequency Overlays for Measurements of 2A Configurations with Entire Test Setup

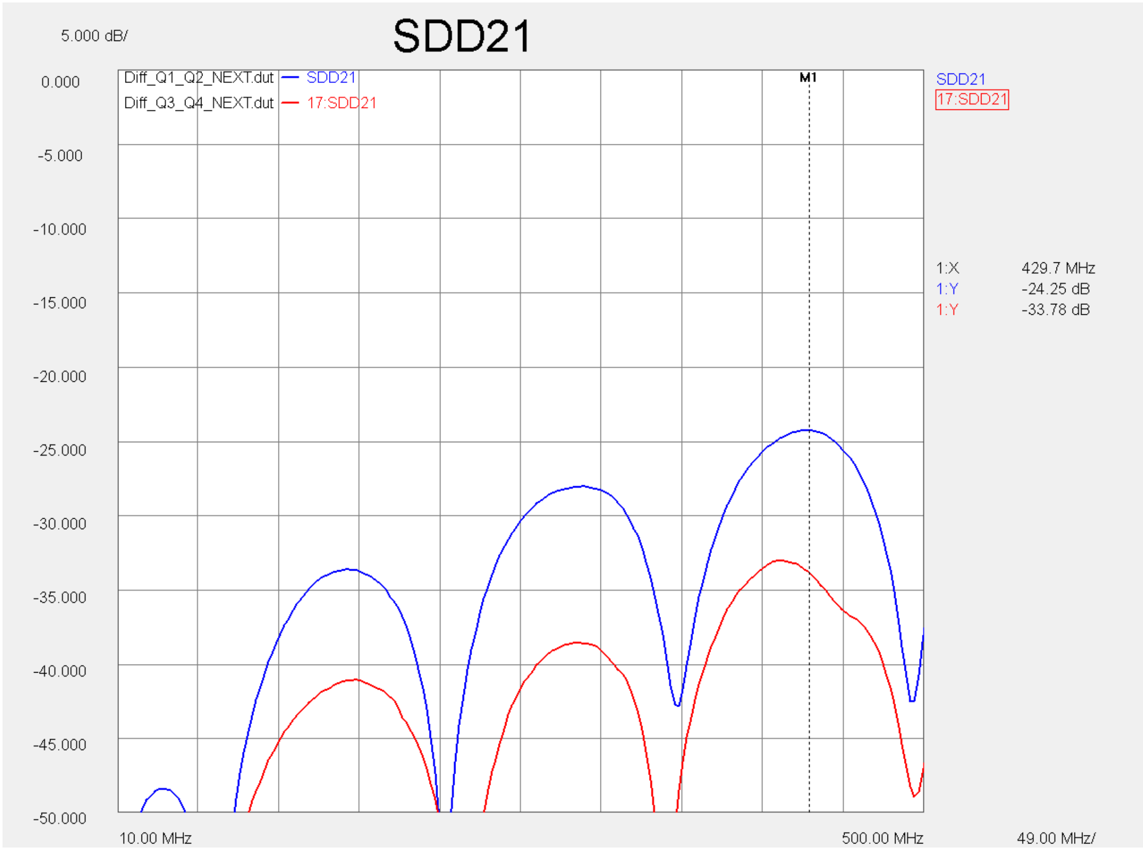


Figure 24: Near Ended Cross Talk VS Frequency Overlays for Measurements of Ethernet Configurations with Entire Test Setup

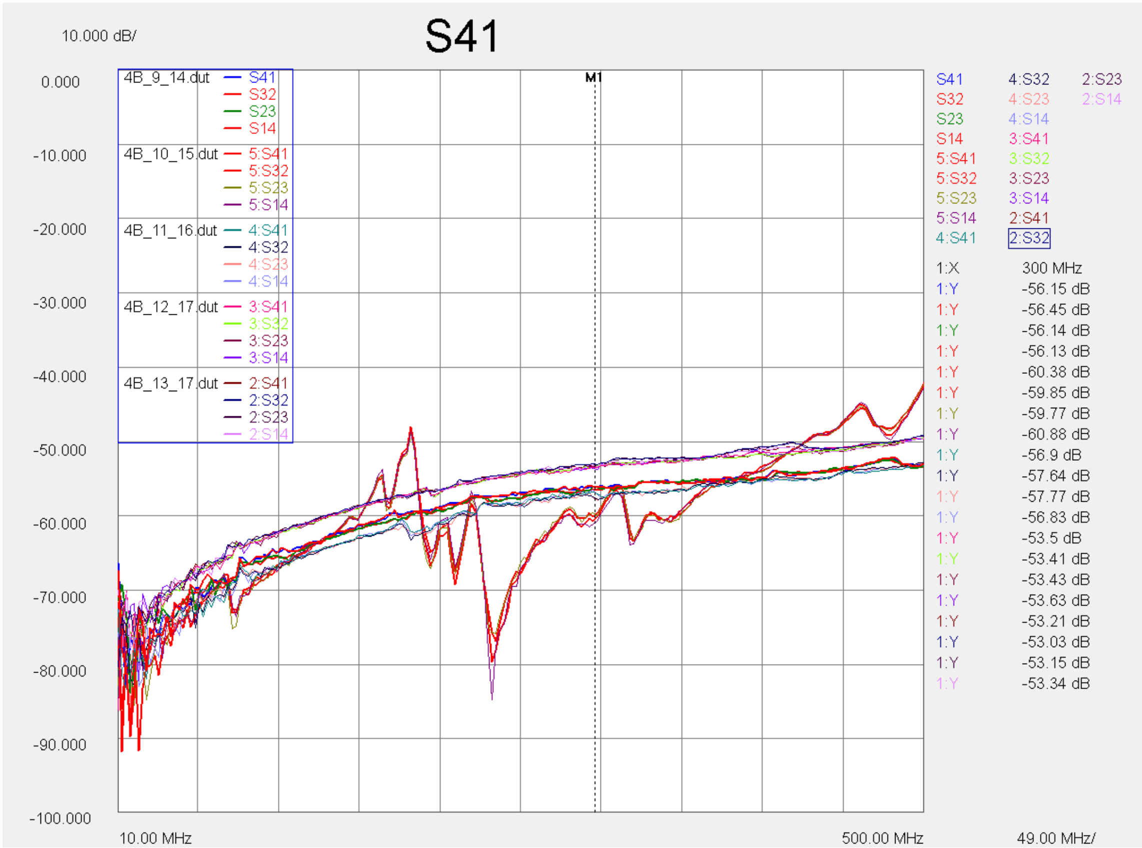


Figure 25: Far Ended Cross Talk VS Frequency Overlays for Measurements of 4B Configurations with Entire Test Setup

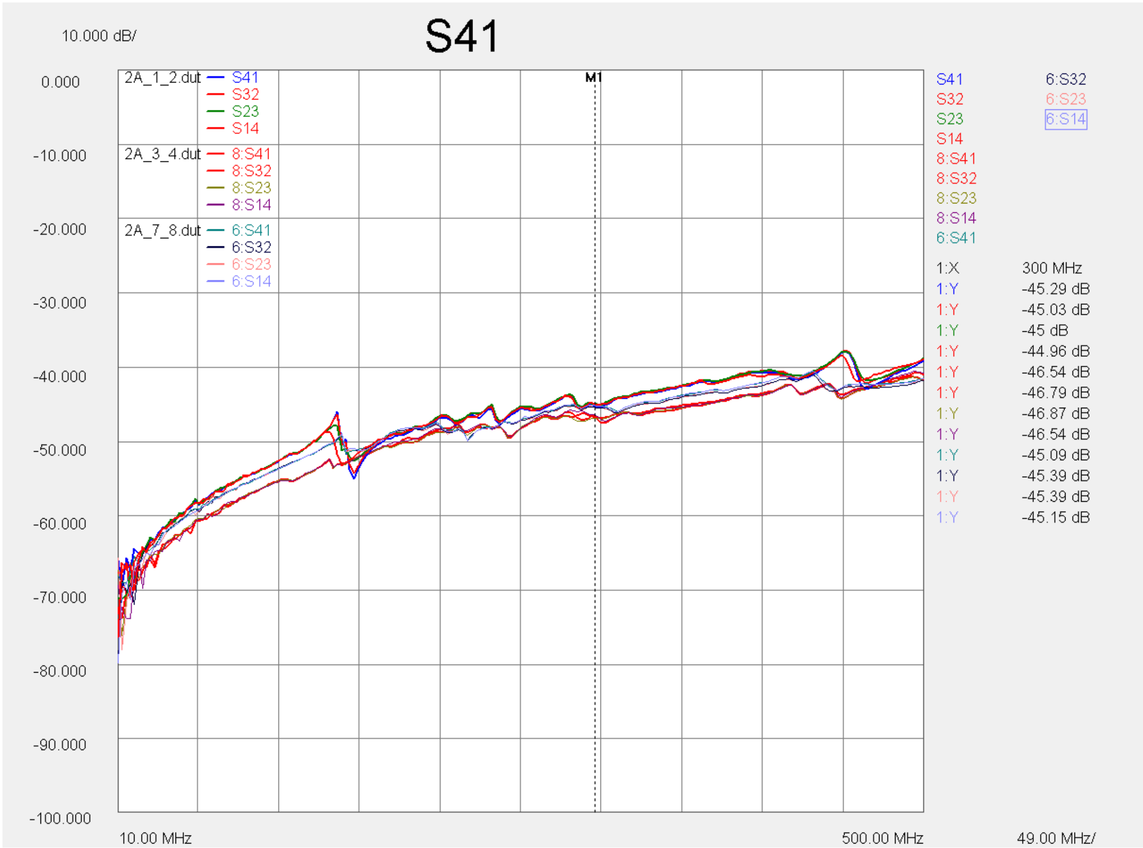


Figure 26: Far Ended Cross Talk VS Frequency Overlays for Measurements of 2A Configurations with Entire Test Setup

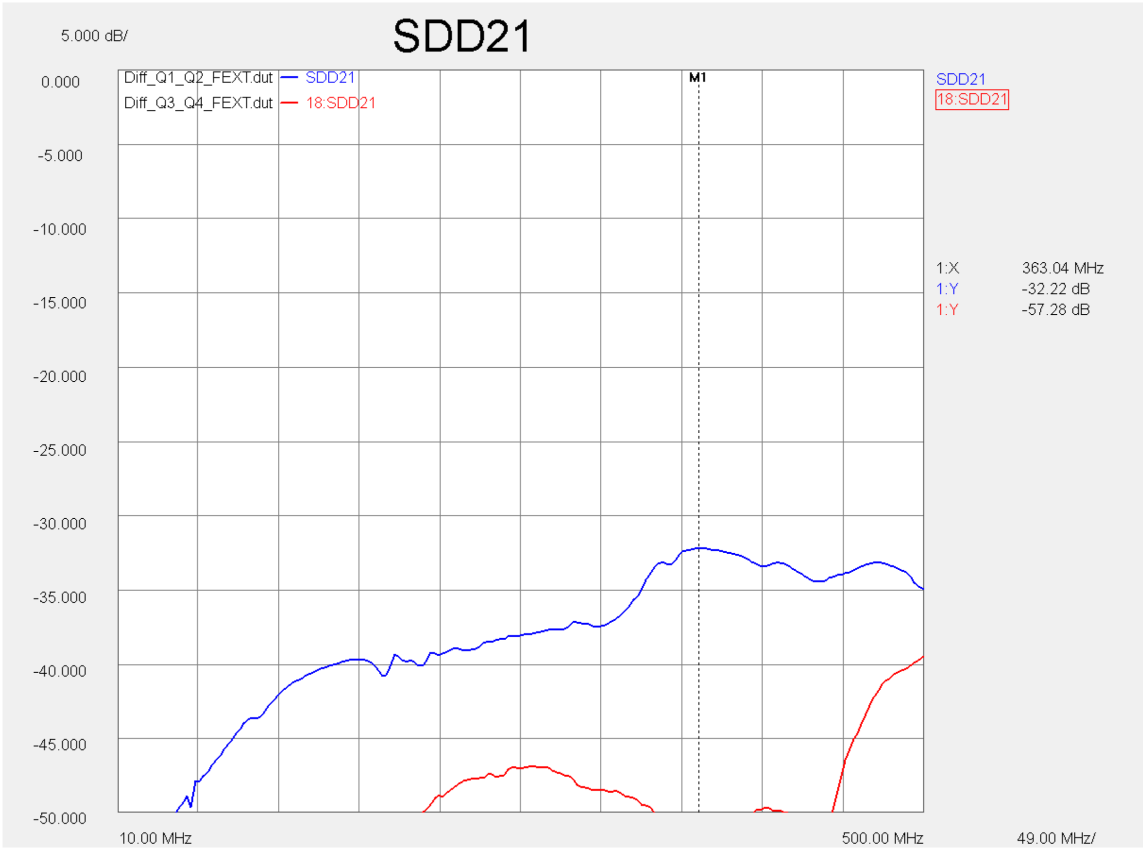


Figure 27: Far Ended Cross Talk VS Frequency Overlays for Measurements of Ethernet Configurations with Entire Test Setup

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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