RF and Phase Noise in IFO Subsystems

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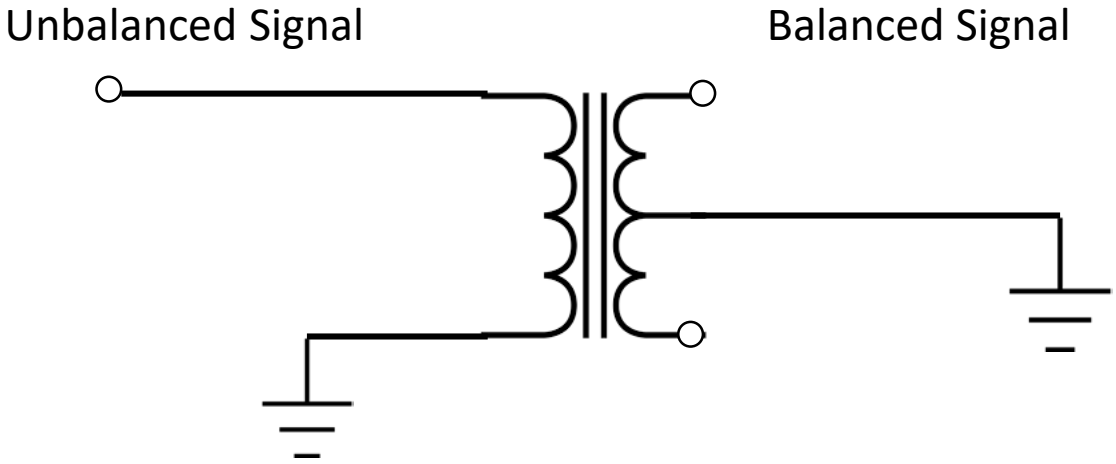
RF Noise in ISC Racks

- Radio Frequency Oscillators are used throughout the IFO (ex. RF sidebands for length sensing in resonant cavities via Pound-Drever-Hall technique).
- RF Noise can be caused by cross-talk (coupling between nearby elements), or by radiation.
- Noise in ISC (Interferometer Sensing and Control) rack RF lines can cause transients in the control signals, resulting in loss of lock or directly cause noise in the interferometer output.

Baluns

- ISC Rack patch panels are equipped with ”Baluns” to serve as ground isolation transformers between racks.
- The name Balun is short for ”Balanced to Unbalanced”
- A class of devices that use a transformer to convert a signal from a balanced representation (i.e. differential signal as on a twisted pair) to an unbalanced signal (i.e. signal measured relative to ground as on coax) or vice-versa.

General Baluns

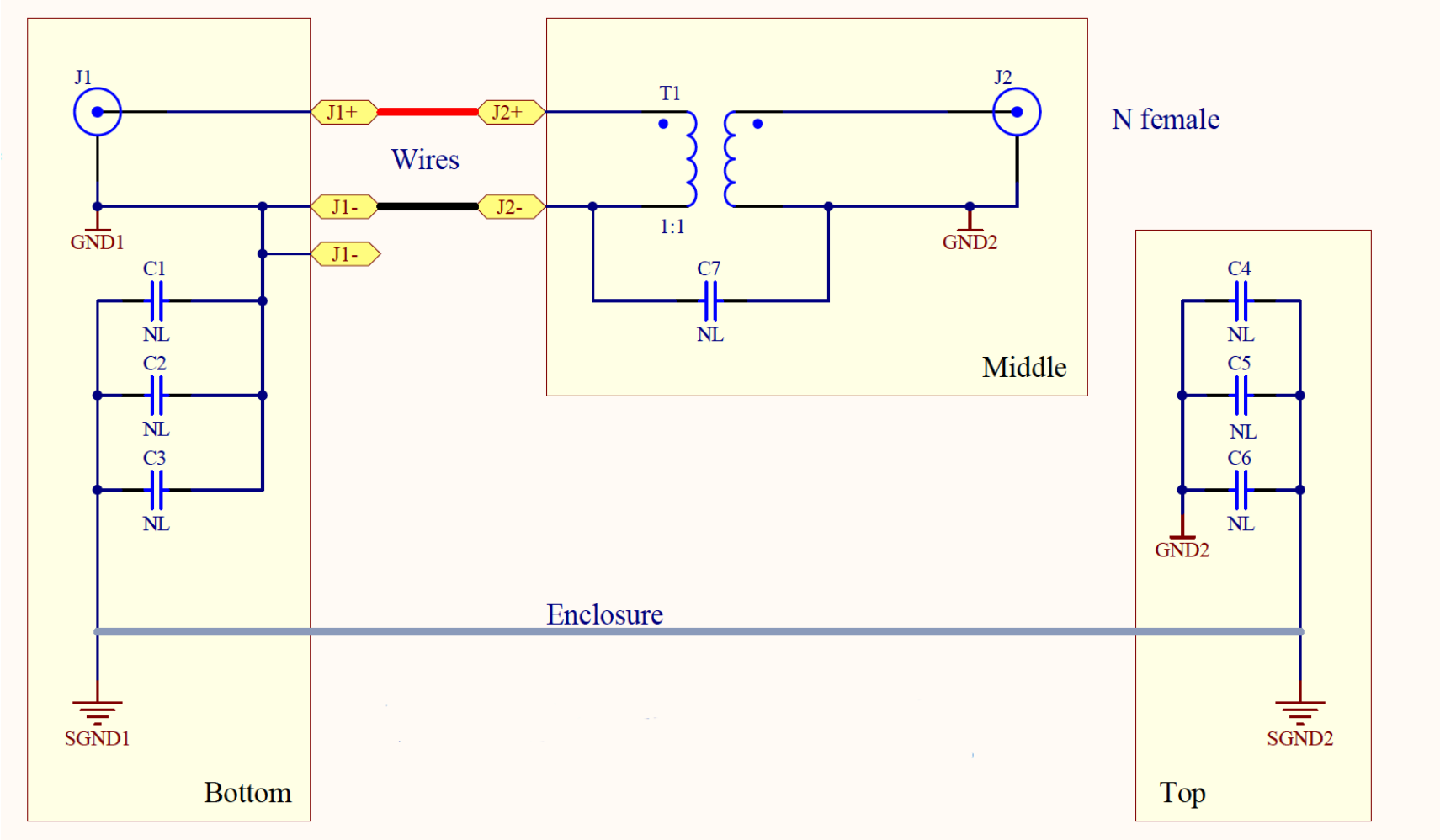


- In a transformer balun a center tap transformer is used to convert between representations
- The ends of the balanced signal are 180° out of phase

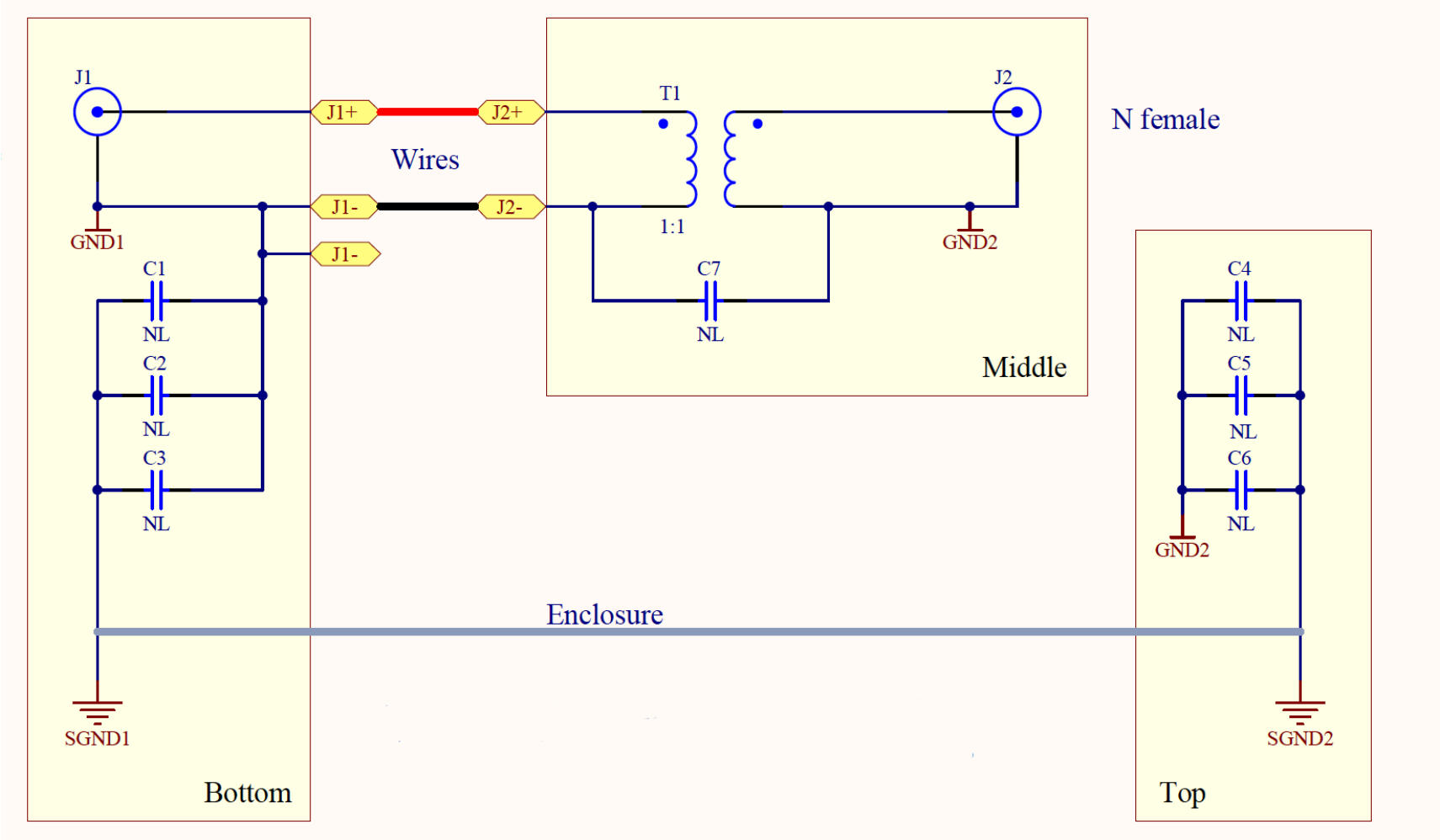
Our Baluns

- We utilize a balun to convert an unbalanced RF signal that is measured relative to ground in the originating rack, to an unbalanced signal relative to ground in the receiving rack.
- This prevents differences in rack grounds from effecting the relative amplitude of the RF signal.
- This type of device is also known as a Ground Isolation Transformer

Original Design



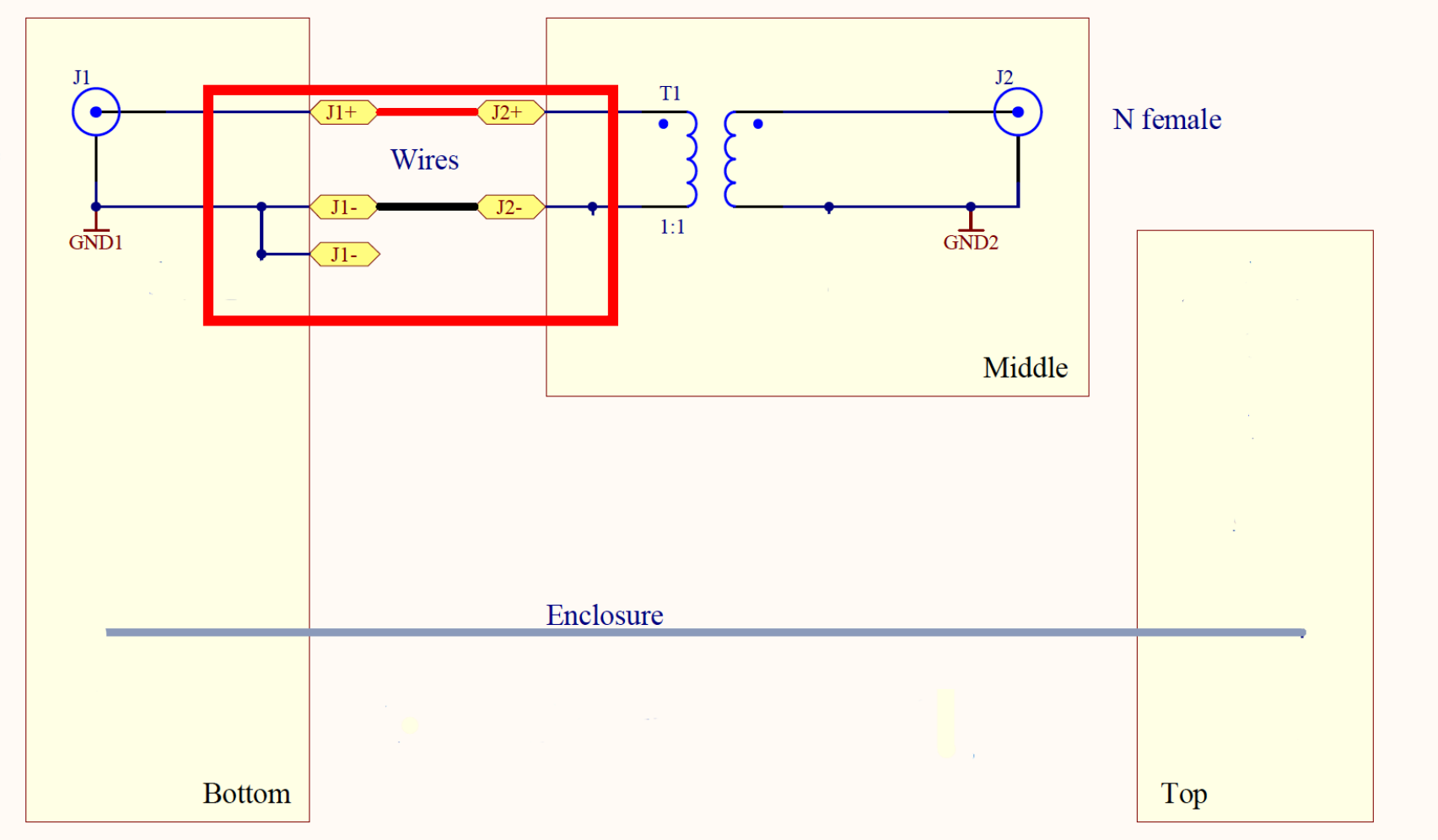
The problem?


J1
J1+
J2+
Wires
J1-
J2-
J1-
GND1
C1
NL
C2
NL
C3
NL
SGND1
Bottom
T1
1:1
J2
N female
GND2
C7
NL
Middle
C4
NL
C5
NL
C6
NL
GND2
SGND2
Top
Enclosure

The problem?

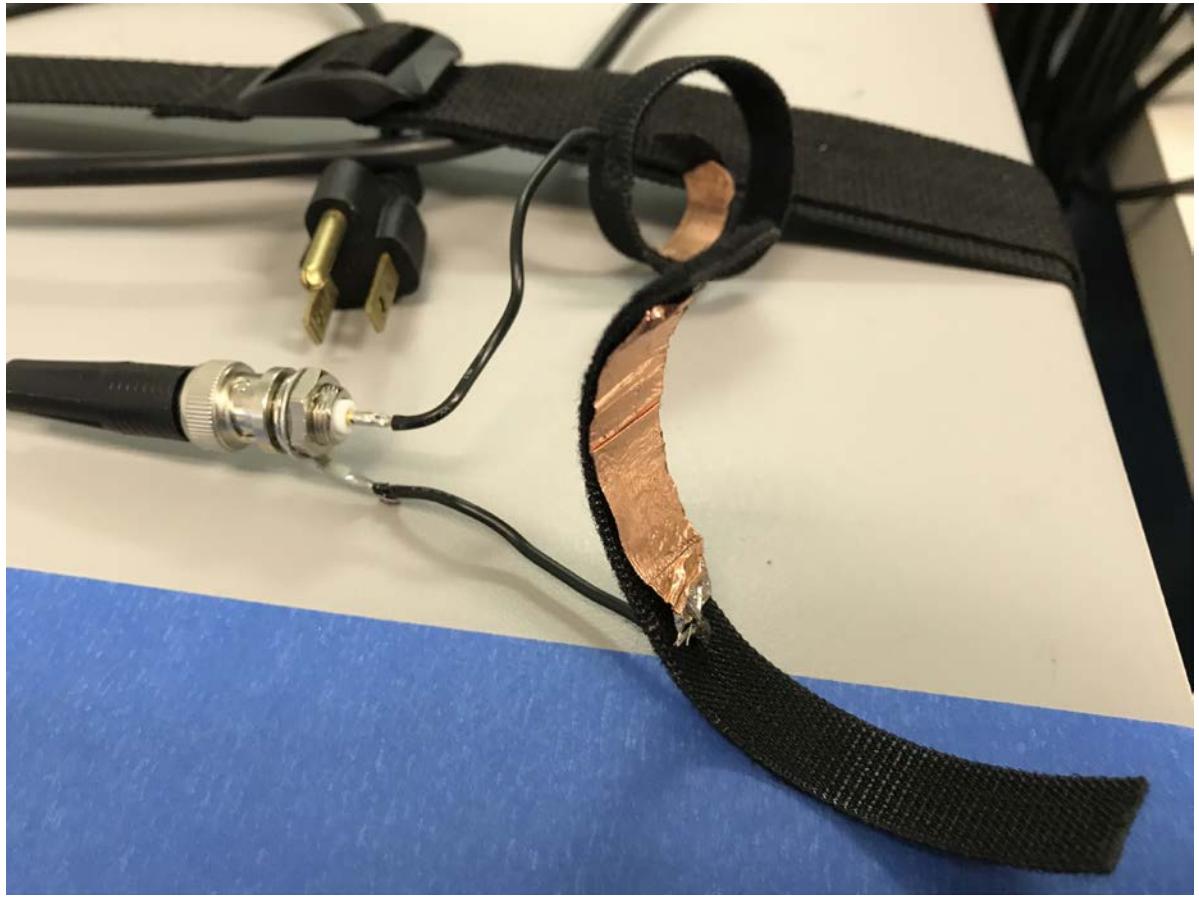
- Capacitors were not installed
- Internal wiring is not optimal for RF
  - Inconsistent impedance (not 50 Ω) - can cause reflections
  - Unshielded wires radiate like antennas
  - Both end pieces are PCB material and easily pass radiated RF

The problem?


J1
J1+
J2+
Wires
J1-
J2-
J1-
GND1
T1
1:1
J2
GND2
N female
Middle
Enclosure
Bottom
Top

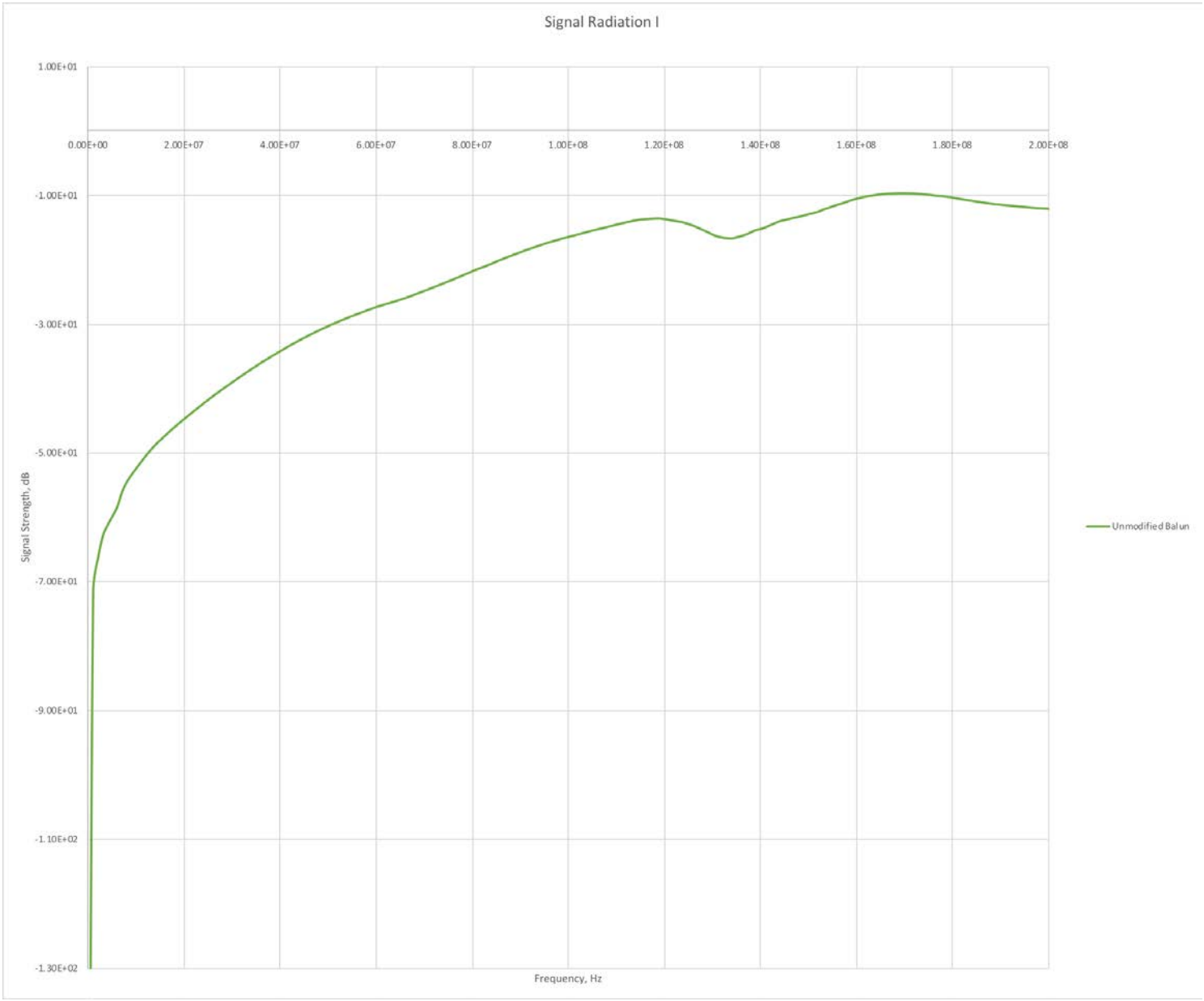
Measuring Noise

- A custom test lead was fabricated to measure the potential difference between the two ground ends of the balun.
- Since one ground of the balun is connected to chassis ground of the test instrument, a voltage across the lead is a measure of the coupling between the balun and a radiated signal.



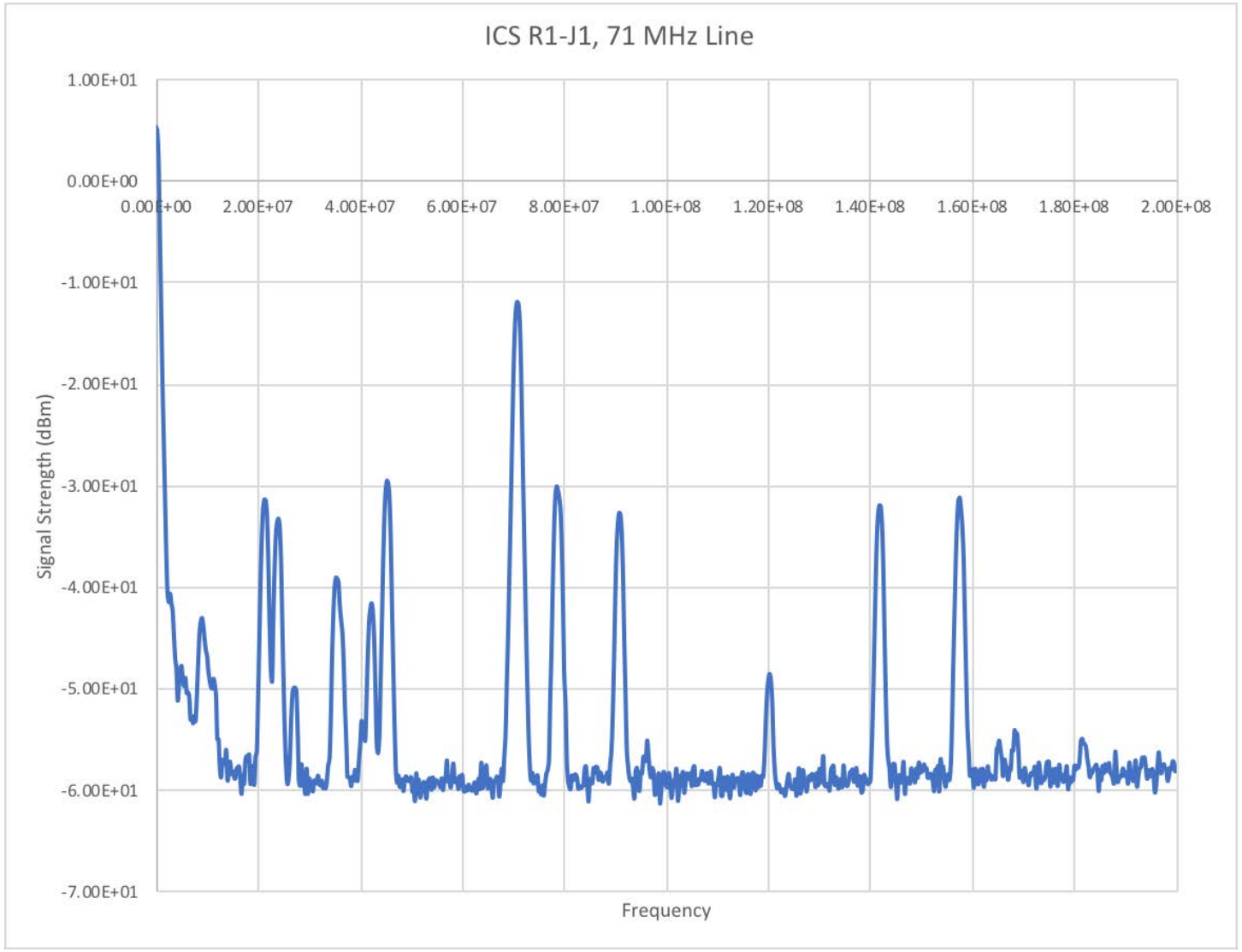
Measuring Noise

- Using a Network Analyzer we measured signal leakage as a function of frequency.
- The open end of the balun was terminated (50 Ω).
- Balun connected to RF out of analyzer, test lead to analyzer input.



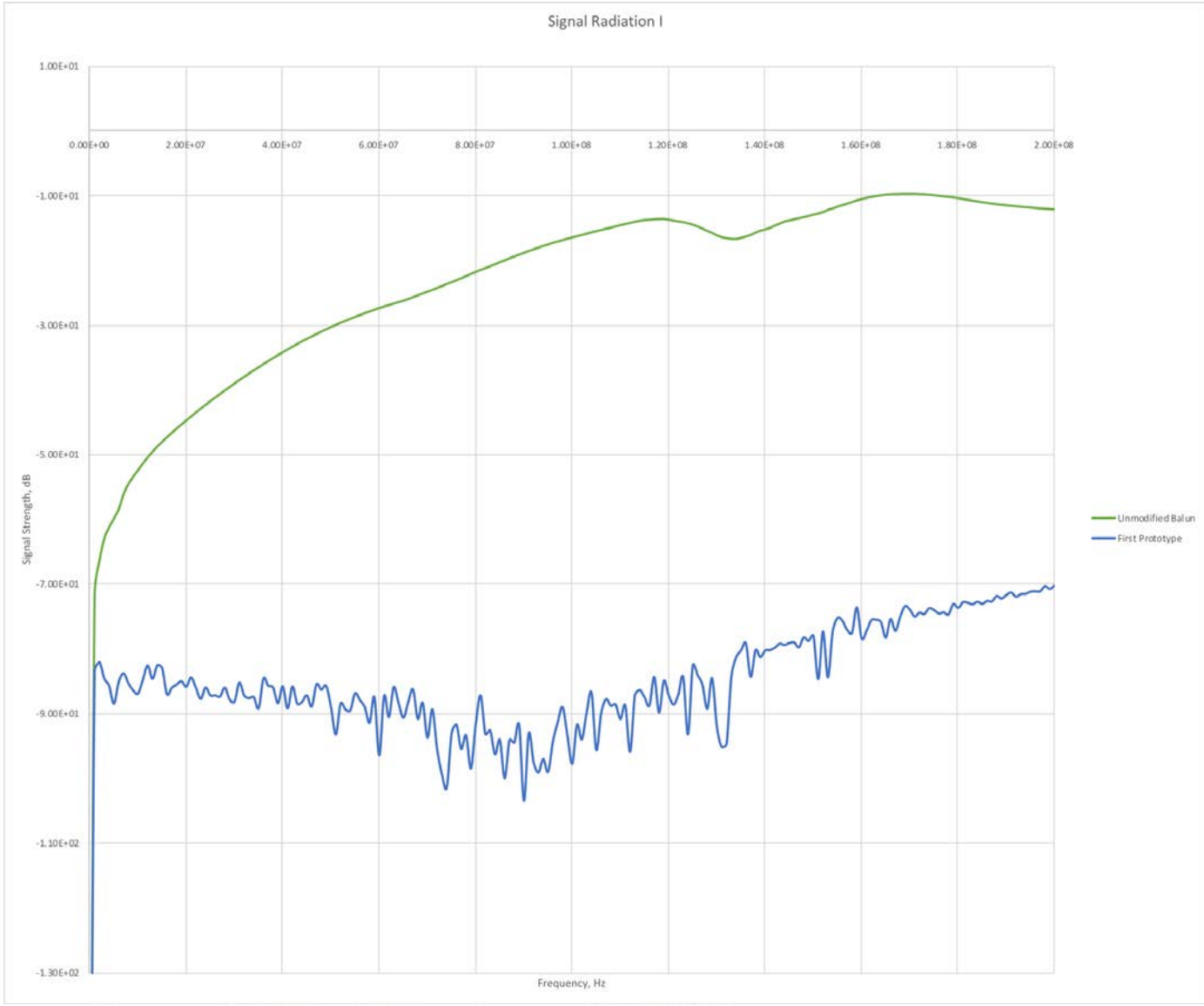
Measuring Noise

- Inside the LVEA we used a spectrum analyzer to do the same measurement, but with live RF instead of the RF out of the NA.
- We observed peaks due to neighboring signal lines on all baluns.



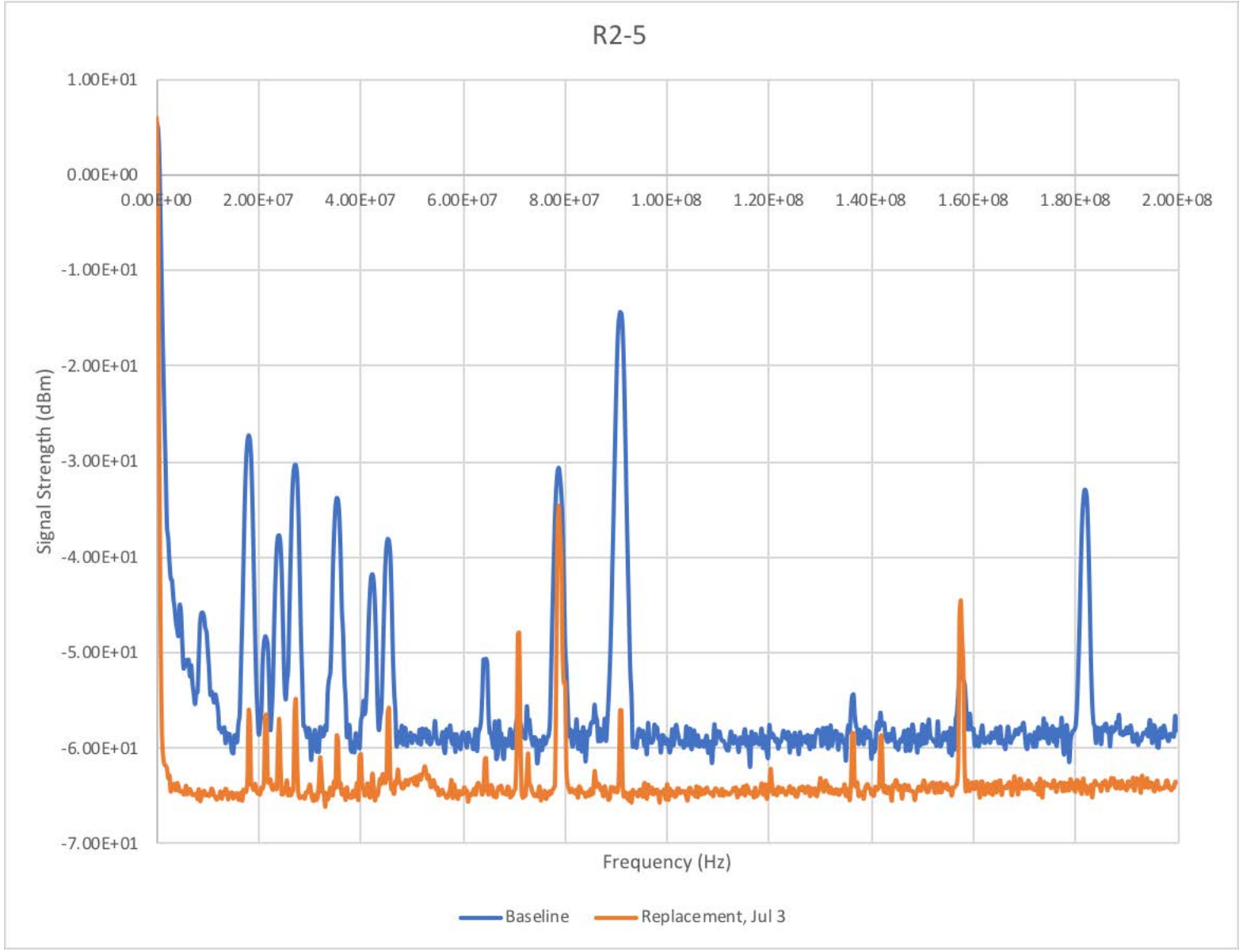
The Solution

- Prototyped new design in three stages
- The first prototype (P1)
  - Installed capacitors on one end
  - Replaced opposite end with copper plate
  - Replaced internal ground (black) wire with copper braiding
- Significantly attenuated leakage, but difficult to repeat results.



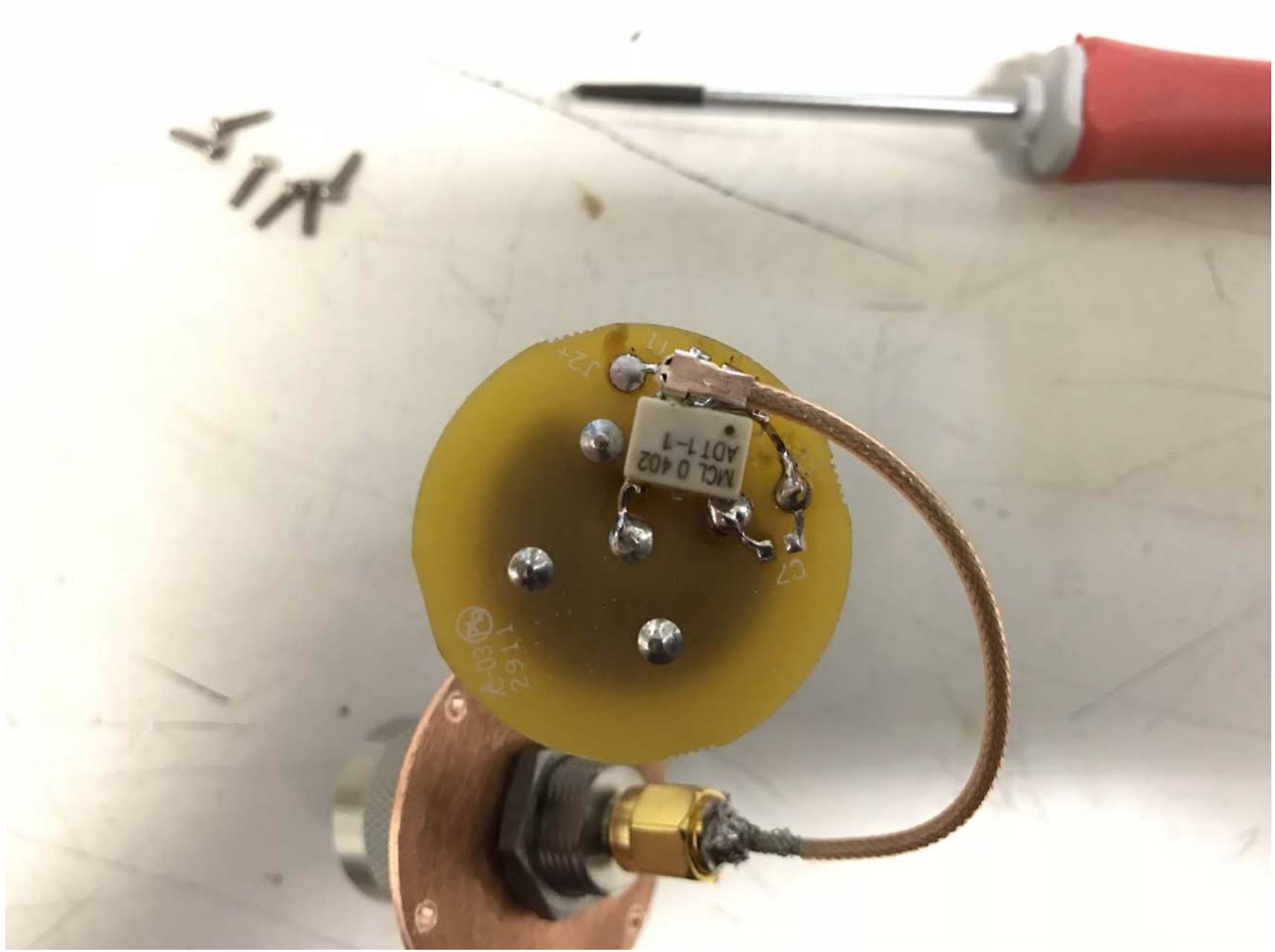
The Solution

- P1 balun was placed on the 118 MHz line in ISC Rack R2, and leakage was measured before and after replacement.
- 35 - 40 dB attenuation of radiated signal.



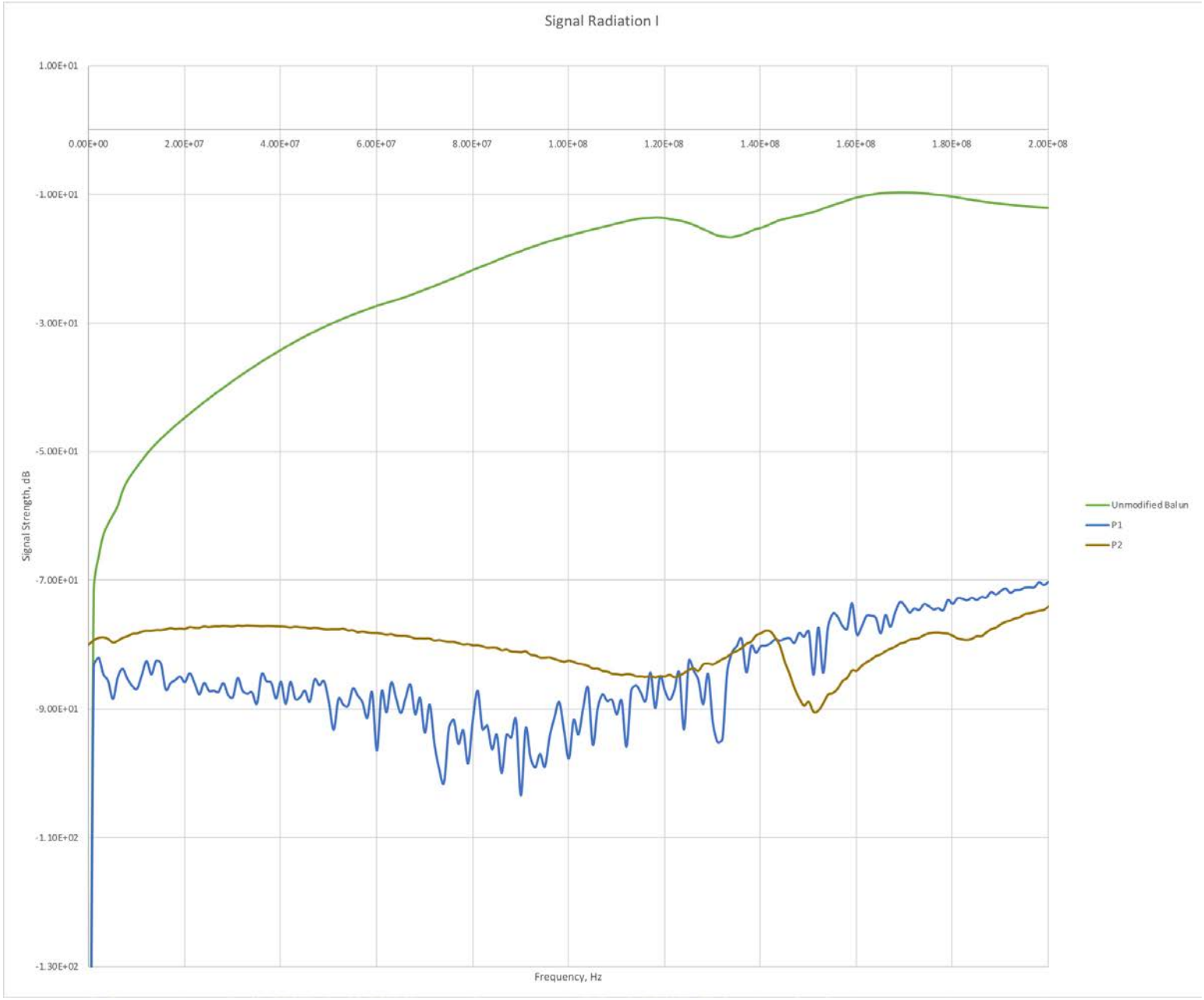
The Solution

- The second prototype (P2)
  - Installed capacitors and copper end piece as in (P1)
  - Moved transformer on interior PCB and placed UMCC (Ultra Miniature Coaxial Connector) jack on board.
  - Replaced Male N-type solder cup connector with Male N – Female SMA adapter.
  - Replaced wires with RG-178 coax


MCL 0 402
AD T-1

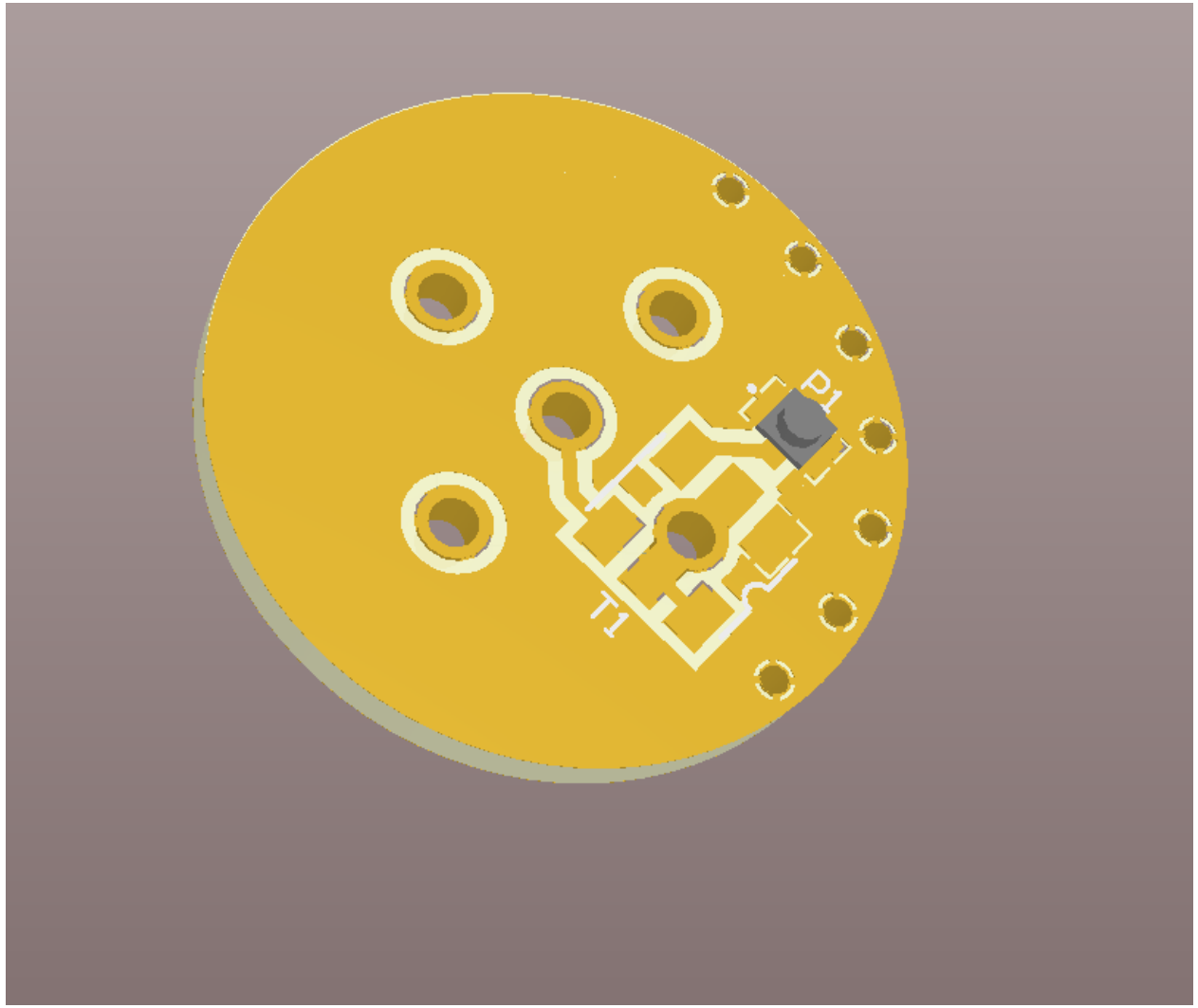
The Solution

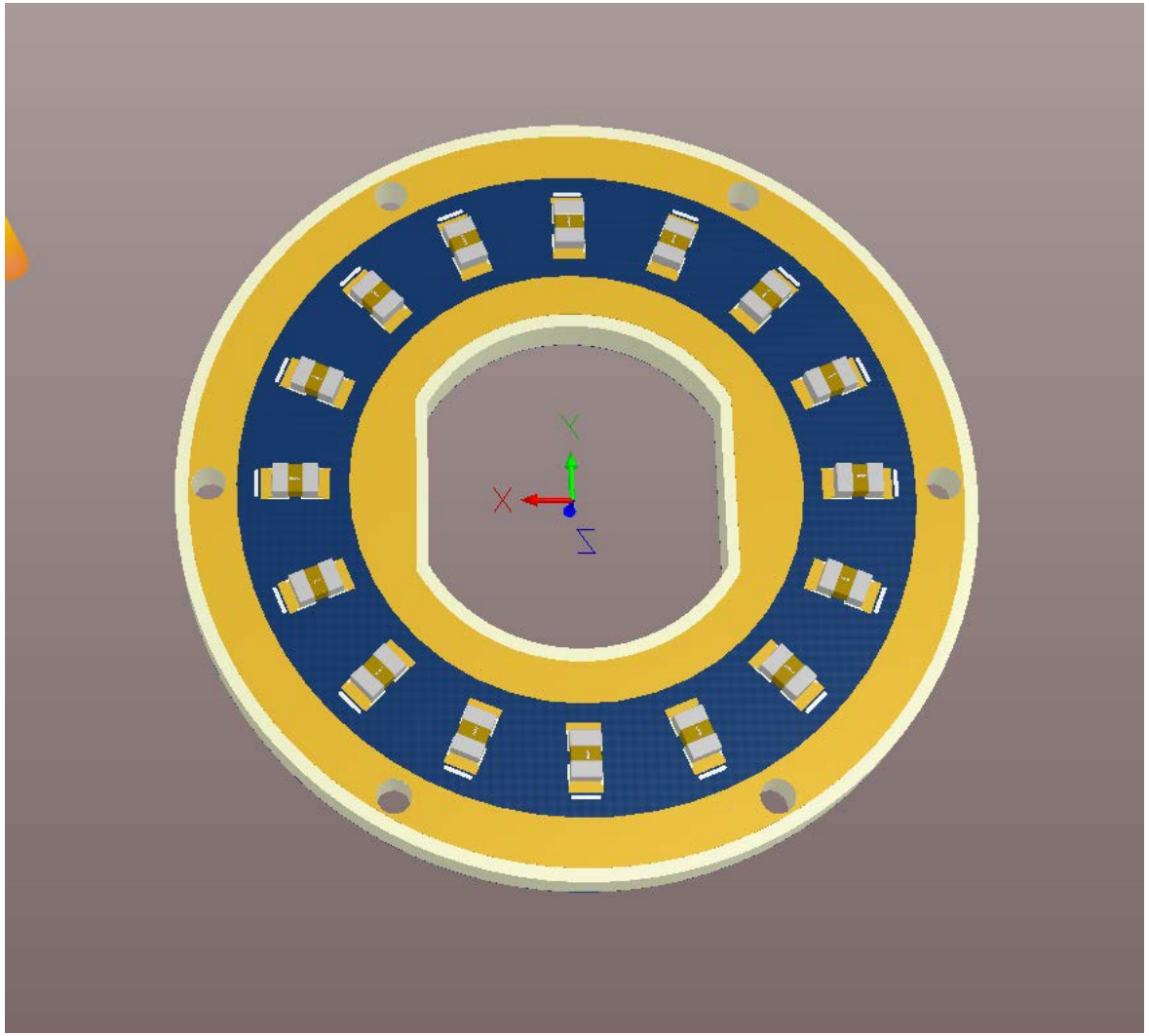
- P2 was a test of a possible board redesign for the internal board.
- Similar attenuation as P1 but more repeatable



The Solution – Final Design

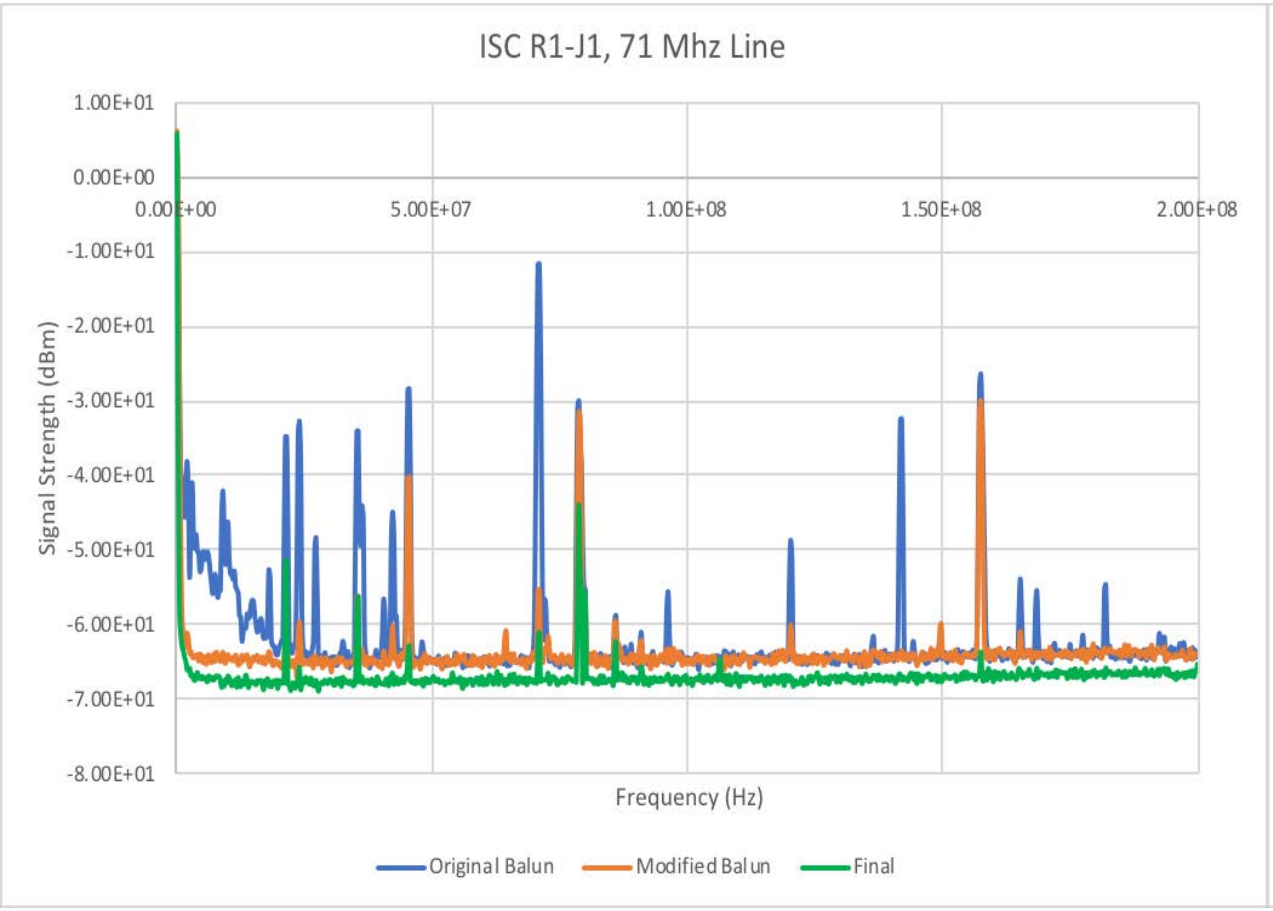
- The P2 modifications (transformer moved, UMCC added) were added to the board drawing in Altium and 3 were ordered.
- Additional board modifications: added ground plane to interior board, added more pads to end board for capacitors

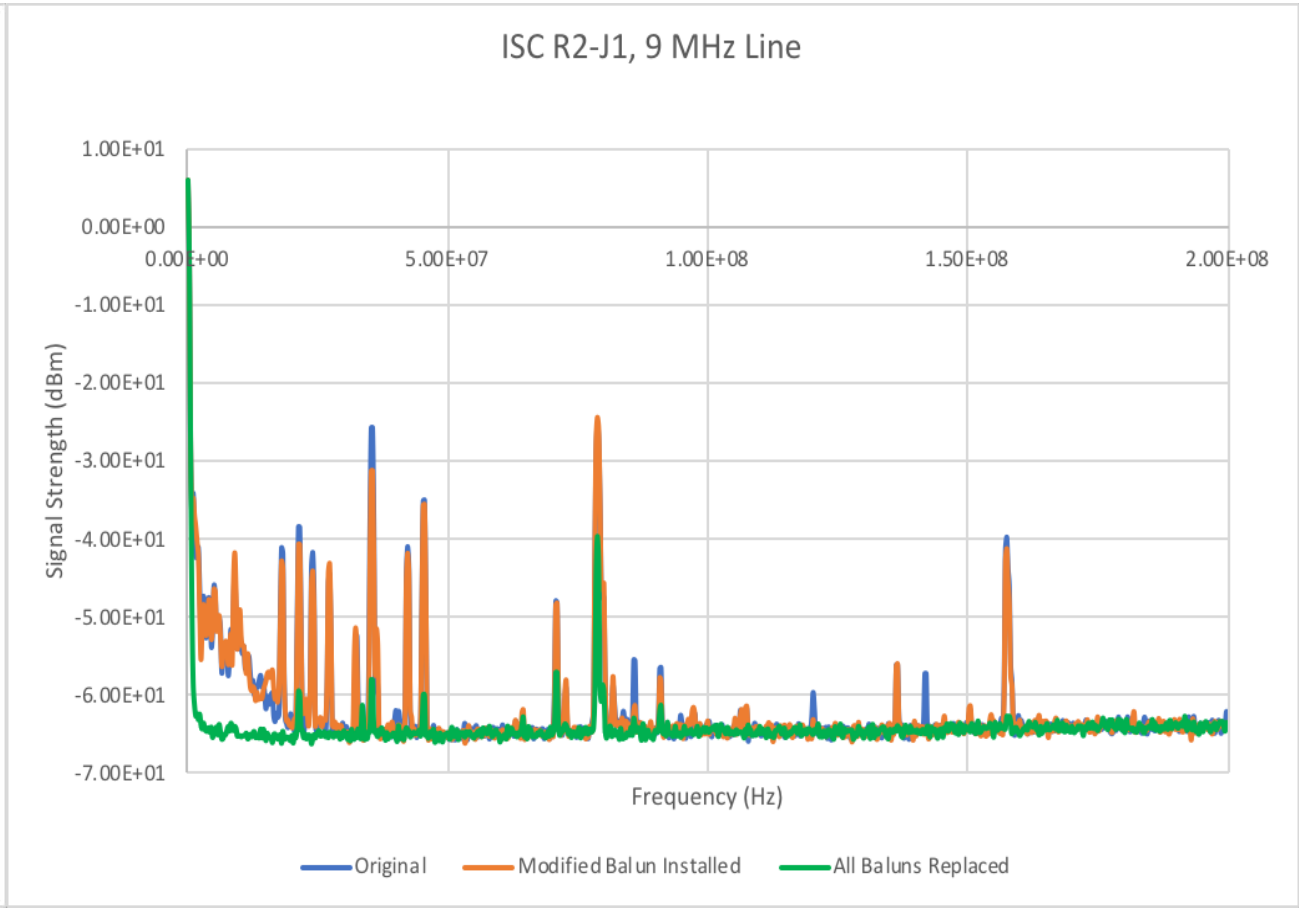




Results

- Three P1 and three P2 modified baluns were installed in the ISC Racks so that no original baluns remained.
- Bode plots were generated for each new balun, and phase shift through the original baluns were measured after removal. The phase difference for each line due to replacement of the balun was annotated in the alog so it was accessible to commissioners.
- After replacement peaks corresponding to other baluns were attenuated 30-40 dB.
- The largest peak remaining is the AOM 79 MHz.


ISC R1-J1, 71 Mhz Line
1.00E+01
0.00E+00
-1.00E+01
-2.00E+01
-3.00E+01
-4.00E+01
-5.00E+01
-6.00E+01
-7.00E+01
-8.00E+01
0.00E+00
5.00E+07
1.00E+08
1.50E+08
2.00E+08
Signal Strength (dBm)
Frequency (Hz)
Original Balun
Modified Balun
Final


ISC R2-J1, 9 MHz Line
1.00E+01
0.00E+00
-1.00E+01
-2.00E+01
-3.00E+01
-4.00E+01
-5.00E+01
-6.00E+01
-7.00E+01
0.00E+00
5.00E+07
1.00E+08
1.50E+08
2.00E+08
Signal Strength (dBm)
Frequency (Hz)
Original
Modified Balun Installed
All Baluns Replaced

Phase Noise

- A 1 Hz Comb was present in the IFO output data
- Possible candidate: phase adjustments of the GPS 1 pps Disciplined Oscillators
- We mixed 10 MHz atomic clock with the 10 MHz GPS disciplined oscillator.
- No comb was found and very little phase noise was observed.