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RF Testing

Z-Wrap-110 Loss 31 July 01
Z-Axis J. Sortor

TEST METHOD:

To accurately measure complex impedance, it is required that the network analyzer be calibrated up to the phase plane of the unit under test (UUT). A full 2-port calibration includes a short circuit, open circuit, and 50 Ohm termination calibration for each half board as well as a 2-port through loss calibration.

1) The transmission line on a full board is cut at the center and a slot is cut into the board to connect one of the lines to the ground plane underneath. This board is used to calibrate each of the 2 ports for the open and short.

2) Next, solder a 50 Ohm chip resistor across the open and shorted end. This will be the termination standard.

3) Remove the resistor and the short from the board connect the 2 transmission lines together. This will be used as the through calibration.

TEST PROBLEMS:

I originally started out by interconnecting 2 full size boards together using the Z-Wrap-110. I found that the high frequency response was much more capacitive than I thought it should be. To verify this, I sheared the boards in half and repeated the test. As it turned out, the increased capacitance of the opposing board had very little effect on the impedance and through loss. ie: The half board had about the same response as the full size boards.

I found that it was necessary to interconnect the top ground plane to the bottom using small pieces of copper tape to get a stable reading of return loss and through loss. I guess the ground connection of the Z-Wrap connector did not provide an adequate path from ground plane to ground plane. Adding more via holes or using a longer piece of Z-Wrap should resolve this problem.

CALCULATIONS:

I originally thought that it would be possible to use my parallel wirebond program to calculate the series inductance of the Z-Wrap but this gave extremely small inductance values. The problem is that wirebonds are over a ground plane. The Z-Wrap circuit is an inductor that is perpendicular to the ground plane. The wirebonds also have length and height compared to the Z-Wrap which is just a straight inductor.
I tried to modify my wirebond program but did not want to spend a lot of time on this project. I instead modeled the Z-Wrap as a thin strap inductor with a specified width and length. This approximation seemed to match the measured results realizing that the actual series of the parallel Z-Wrap wires would be slightly greater than the strap. I'll send you a copy of this basic program in a separate email so you can play with the values.

OBSERVATIONS:

1) The return loss plot (S11) on all 3 types of material is about the same. This makes sense since we are calibrating the losses and effects of the fixture out of the measurement.

2) The calculated value of (S11) on 0.060 FR-4 @ 1 GHz is slightly better than the calculated value on 0.031 FR-4. The inverse is true with the measured values. The inductance of the Z-Wrap on the 0.060 board is less since the trace width is wider. This makes the series inductance less which should improve the performance, but the distance from ground planes on the top and bottom boards is greater which also adds to the series inductance.

3) The sharp increase in through loss on the 0.060 FR-4 is probably due to a resonance caused by an interaction of the Z-Wrap inductance and the capacitance of the board traces, or the fiberglass itself is resonating at 2 GHz. Using 0.060 FR-4 above 1 GHz is not recommended for a high quality RF design.

4) The increase in through loss on the 0.031 FR-4 is not as pronounced since I did not have equipment available to record data above 3 GHz. This type of Z-Wrap product should work well in low power 2 GHz applications.

5) The calculated vs. measured return loss data on the 0.031 Duroid is very close at all frequencies. Rogers RT/5500 Duroid is a high quality, low loss microwave material. The loss tangent is 20 times better than FR-4 but the price is comparatively higher.

6) The through loss of the 0.031 Duroid shows the same type of peak at 2.5 GHz that was seen on the 0.031 FR-4. The loss should always increase with frequency as the calculated performance has shown. This makes me suspicious that there is a problem with the board layout. Perhaps increasing the number of via holes and shifting via holes closer to the Z-Wrap connector would improve the high frequency response. 0.031 Duroid is usable up to 6 GHz.

7) Duroid material is difficult to work with since the substrate is soft. I had to use two small clamps to press the boards to compress the Z-Wrap connector. In production, Duroid is always attached to a backing plate or sweat soldered to a heat spreader. The backing plate could be a piece of FR-4.

IMPROVEMENTS:

The pure loss element in this circuit is the series inductance introduced by the Z-Wrap connector. Using a thinner connector would reduce the inductance but it is possible to cancel the inductance using a small printed tab, or open circuit stub, on the PC board. The open stub makes the Z-Wrap connector look like part of the 50 Ohm transmission line.

Let's take the worse case situation where the Z-Wrap connector adds 1.0 nH of inductance to the circuit.

type num #1 #2 #3

TRL 1 50 90 INS 2 1.00 TRL 1 50 90 50 Ohm, 90deg, 1GHz series L (nH) 50 Ohm, 90deg, 1GHz
freq S11 S21

30 -54.5 -0.00 100 -44.0 -0.00 500 -30.0
-0.00 1000 -24.0 -0.01 1500 -24.0 -0.02
2000 -18.1 -0.03 2500 -16.2 -0.04 3000 -
14.6 -0.15

Now add a short section of 50 Ohm line that extends slightly beyond the Z-Wrap connector.

type num #1 #2 #3

TRL 1 50 90 OST 1 50 2.5 INS 2 1.00 OST 1 50 2.5 TRL 1 50 90 50 Ohm, 90deg, 1GHz 50 Ohm, 2.5deg, 1GHz series L (nH) 50 Ohm, 90deg, 1GHz 50 Ohm, 2.5deg, 1GHz
freq S11 S21

30 -86.7 -0.00 100 -76.3 -0.00 500 -62.4
-0.00 1000 -56.6 -0.00 1500 -53.4 -0.00
2000 -51.5 -0.00 2500 -50.4 -0.00 3000 -
50.0 -0.00 4000 -51.4 -0.00 5000 -61.3 -
0.00 6000 -51.1 -0.00 7000 -41.2 -0.00
8000 -35.2 -0.00 9000 -30.6 -0.01 10000
-26.7 -0.01

On 0.031 FR-4, the open stub would have to extend 0.045 beyond the Z-Wrap connector. Ideally, this small addition to the artwork will push the performance beyond 10 GHz. Of course the ideal calculation differs greatly from a practical implementation.

0.060 FR-4 CALCULATED PERFORMANCE:

Physical length (each half board) = 1.009 Electrical length (each half board) @ 1 GHz = 56.9 deg Z0 = 50 Ohms Line width = 0.108 Z-Wrap length = 0.110 Wire diameter = 0.002 Wires = 18

Inductance (Ltot) = 6.667E-10 Henries XL= 4.191 Ohms @ 1.0 GHz

Calculated 0.060 FR-4 Performance:

type num #1 #2 #3

TRL 1 50 56.9 INS 2 0.67 TRL 1 50 56.9
50 Ohm, 56.9deg, 1GHz series L (nH) 50 Ohm, 56.9deg, 1GHz

Calculated performance:

freq S11 S21

30 -58.0 -0.00 100 -47.5 -0.00 500 -33.5 -0.00 1000 -27.5 -0.01 1500 -24.0 -0.02 2000 -21.5 -0.03 2500 -19.6 -0.04

0.031 FR-4 CALCULATED PERFORMANCE:

Physical length (each half board) = 1.009 Electrical length (each half board) @ 1 GHz = 56.9 deg Z0 = 50 Ohms Line width = 0.055 Z-Wrap length = 0.110 Wire diameter = 0.002 # Wires = 9 Inductance (Ltot) = 1.034E-9 Henries XL= 6.497 Ohms @ 1.0 GHz

Calculated 0.031 FR-4 Performance:

type num #1 #2 #3 0.031 Duroid CALCULATED PERFORMANCE:

TRL	1	50	56.9		50 Ohm, 56.9deg, 1GHz
INS	2	1.04			series L (nH)
TRL	1	50	56.9	1	50 Ohm, 56.9deg, 1GHz

Calculated performance:

freq	S11	S21
30	-54.2	-0.00
100	-43.8	-0.00
500	-29.8	-0.00
1000	-23.8	-0.02
1500	-20.3	-0.04
2000	-17.8	-0.07
2500	-15.9	-0.11
3000	-14.4	-0.16

Physical length (each half board) = 1.009 Electrical length (each half board) @ 1 GHz = 44.3 deg Z0 = 50 Ohms Line width = 0.086 Z-Wrap length = 0.110 Wire diameter = 0.002 # Wires = 21 Inductance (Ltot) = 7.914E-10 Henries XL= 4.970 Ohms @ 1.0 GHz

0.031 Duroid circuit file:

type num #1 #2 #3

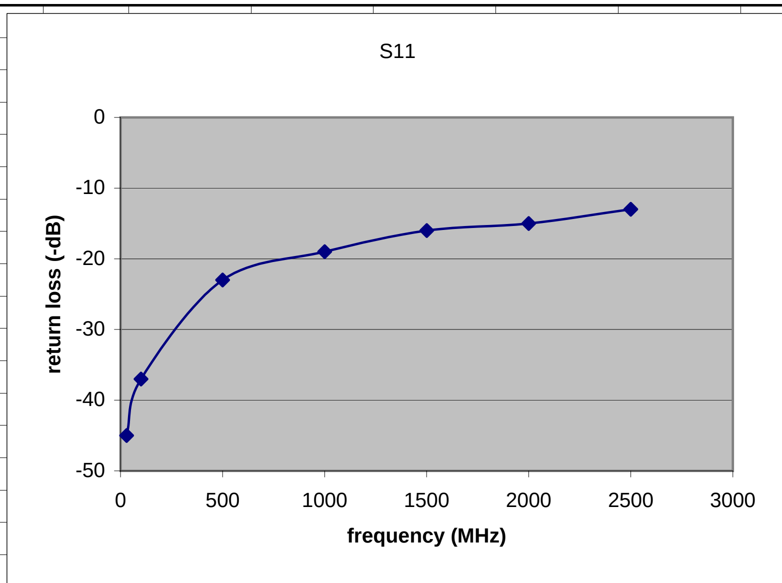
TRL	1	50	44.3		50 Ohm, 44.3deg, 1GHz
INS	2	0.79			series L (nH)
TRL	1	50	44.3	1	50 Ohm, 44.3deg, 1GHz

Calculated performance:

freq	S11	S21
30	-56.5	-0.00
100	-46.1	-0.00
500	-32.1	-0.00
1000	-26.1	-0.01
1500	-22.6	-0.02
2000	-20.1	-0.04
2500	-18.2	-0.07
3000	-16.6	-0.10

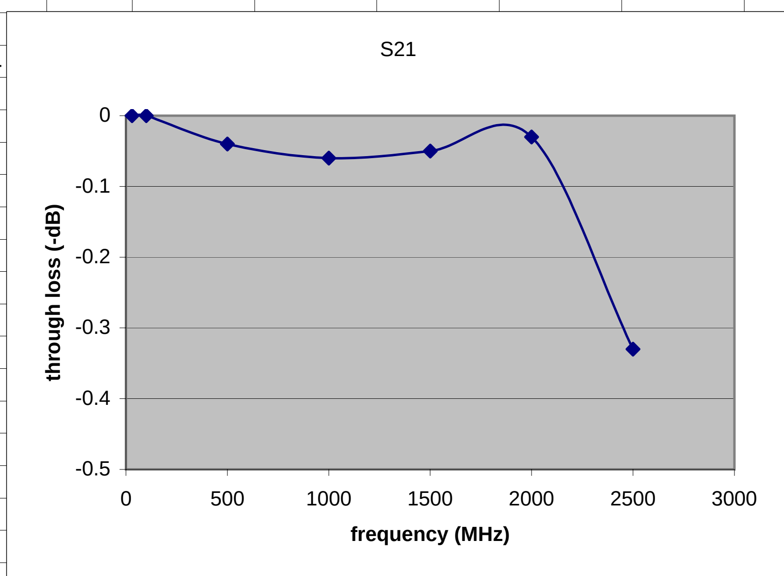
Z-Wrap-110
PCB = 0.060" FR-4

freq	S11
30	-45
100	-37
500	-23
1000	-19
1500	-16
2000	-15
2500	-13



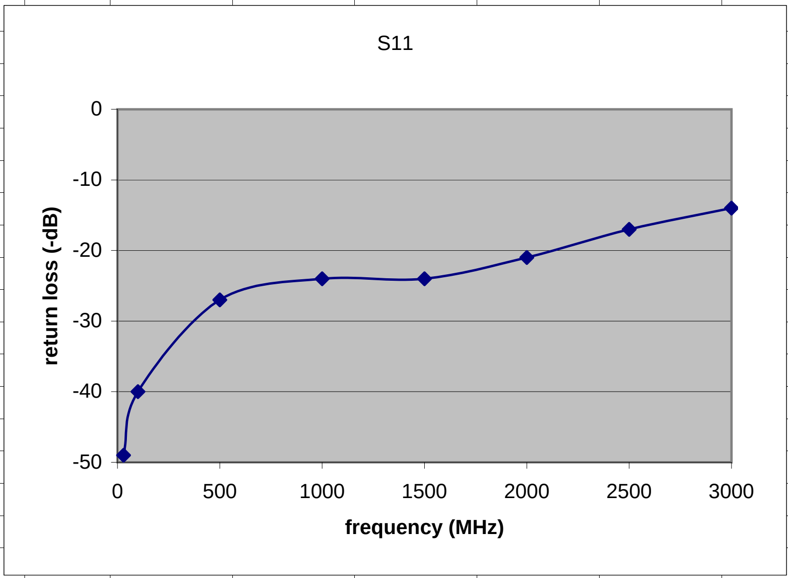
Z-Wrap-110
PCB = 0.060" FR-4

freq	S21
30	0
100	0
500	-0.04
1000	-0.06
1500	-0.05
2000	-0.03
2500	-0.33



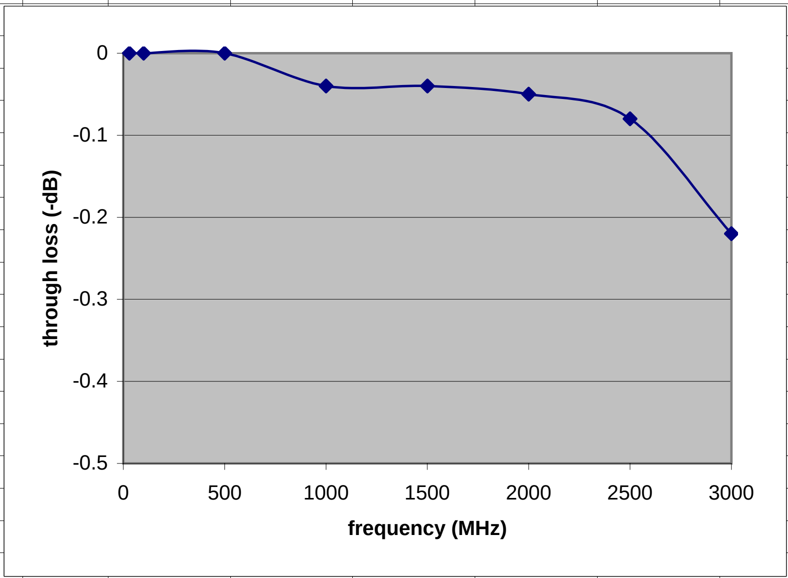
Z-Wrap-110
PCB = 0.031" FR-4

freq	S11
30	-49
100	-40
500	-27
1000	-24
1500	-24
2000	-21
2500	-17
3000	-14



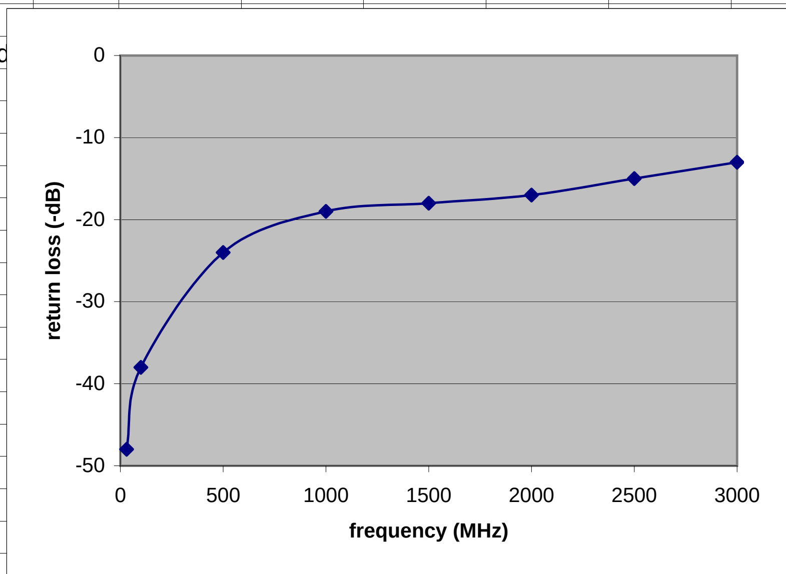
Z-Wrap-110
PCB = 0.031" FR-4

freq	S21
30	0
100	0
500	0
1000	-0.04
1500	-0.04
2000	-0.05
2500	-0.08
3000	-0.22



Z-Wrap-110
PCB = 0.031" Duroid

freq	S11
30	-48
100	-38
500	-24
1000	-19
1500	-18
2000	-17
2500	-15
3000	-13



Z-Wrap-110
PCB = 0.031" Duroid

freq	S21
30	0
100	0
500	-0.01
1000	-0.07
1500	-0.08
2000	-0.06
2500	-0.05
3000	-0.11