great analysis!

10/10

ECEN 5224 **HIGH SPEED DIGITAL DESIGN** **NAGARAJ SIDDESHWAR**

DATE – 16th APR 2018 **HW8** **SOUMOJIT BOSE**

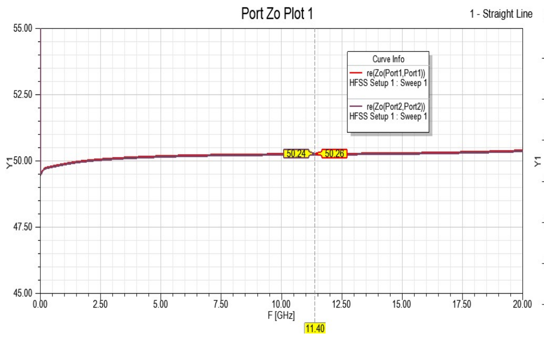
1. **Review each of the 4 HFSS models for the interconnects. Apply rule #9. What do you expect to see in the S-parameters of these four structures?**
2. **Run each simulation to at least 20 GHz and look at the S-parameters.**

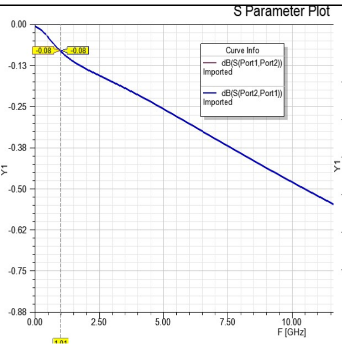
a) **What can you conclude when you analyze these S-parameters? How reasonable are they?**

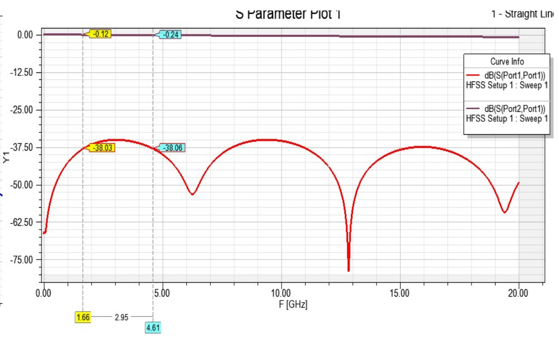
b) **At what frequency is the return loss > -15 dB? For each structure? At what bandwidth should you be concerned about these signal path discontinuities?**

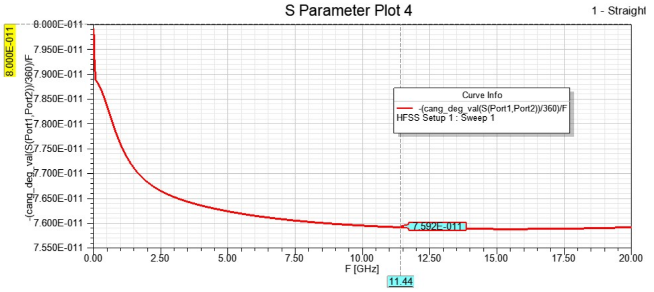
Note: Answers for Q1 and Q2 are combined.

Model	Comments
Straight Line	The Characteristic Impedance of the Microstrip is 52.58 ohm as per IPC formulae (w=14 mil, h=8 mil, FR4, t=0.7 mil) and Port Impedances at Tx and Rx to be 50 ohm as per Port Z0 graph. Hence, the maximum amplitude of S11 is expected to be a minimum (in order of -30 dB or -35 dB) as the network is almost matched. Also, S21 starts with 0 dB at lower freq and should be ripple free since S11 never reaches -12 dB and above. At freq of 1 GHz, for a Df of 0.02, Dk of 4.4, len of 0.5 in, w of 14 mil, S21 = -(sqrt(f)/w+2.3*freq*sqrt(Dk)*Df*len). S21 = -0.07 dB. The simulated value is -0.08 dB. The first parallel resonant frequency dip happens at f = c/(sqrt(Dk)*2*len). So f= 5.72 GHz. The simulated value is 6.29 GHz as shown. The simulated value of S21 @ 1GHz is -0.08 dB. Since the network with port termination is symmetrical, S12 = S21. All these are verified from the HFSS results shown below. The time delay is Td = l/ 6in/ns = 0.5/6 =83 ps whereas the simulated value is 74 ps. As this is a perfectly matched network, S11 never reaches above -15 dB. The bandwidth is found to be around 2.95 GHz. The below snapshots support all the above explained points.

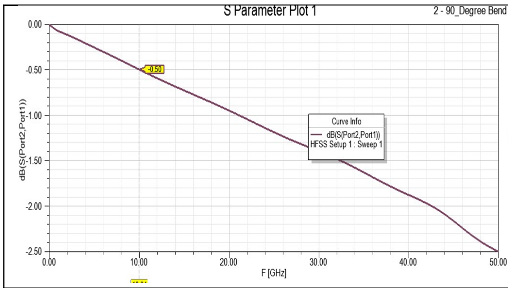


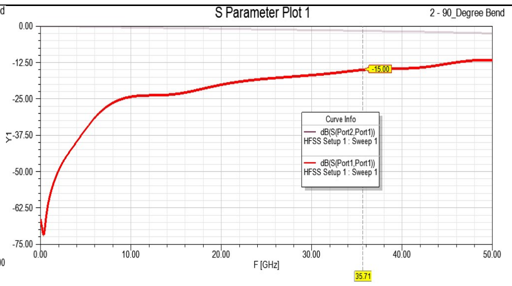


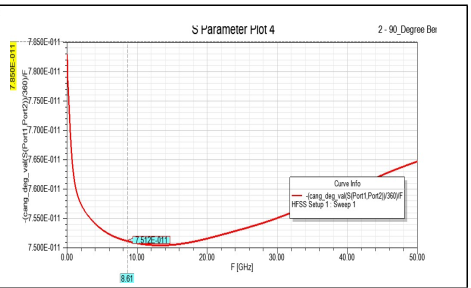




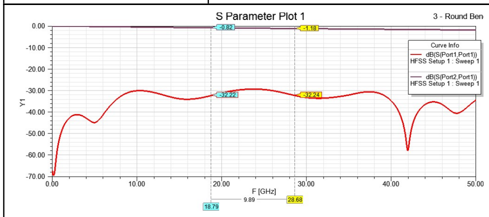
Model	Comments
90 Degree Bend	The maximum amplitude of S11 is expected to be a minimum (in order of -30 dB or -35 dB) at lower freq as the network is not completely unmatched. Also, S21 starts with 0 dB at lower freq and should be ripple free till S11 reaches -12 dB and above. At freq of 10 GHz, for a Df of 0.02, Dk of 4.4, len of 0.5 in, w of 14 mil, S21 = -(sqrt(f)/w+2.3*freq*sqrt(Dk)*Df*len). S21 = -0.48 dB. The simulated value is -0.5 dB. Since the network with port termination is symmetrical, S12 = S21. All these are verified from the HFSS results shown below. Due to increase in width at the 90 Degree bend, effective Capacitance at the bend increases and hence Z0 decreases in an inversely proportional manner. The width at the edge is 14 mil. As a thumb rule, capacitance increase at 90 degree bend is 2fF/mil. So, total increase is 28 fF. Hence, TD increases when compared to the straight line. This should be observed in Phase response of S21 of both the interconnects. Also, this has a unique effect as this capacitance is equivalent to a shunt capacitor with Impedance (Xc) inversely proportional to freq. At lower freq, Xc is high; so S11 is highly negative. As freq increases, Xc decreases, so Reflection co efficient becomes negative. So, S11 starts increasing due to increasing Impedance mismatch. All the above discussed points are observed in the snapshot below. At f= 35.71 GHz, S11 reaches above -15 dB. Impedance is inversely proportional to Bandwidth. So, as the decreasing lobe of S11 is more than 50 GHz, the Bandwidth is considerably higher than 50 GHz; the same being observed in simulation. The time delay is Td = l/ 6in/ns = 0.5/6 =83 ps whereas the simulated value is 75ps. The below snapshots support all the above explained points.

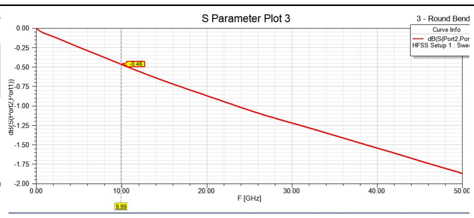


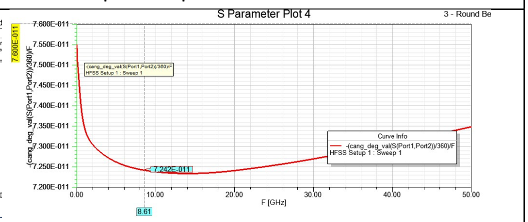




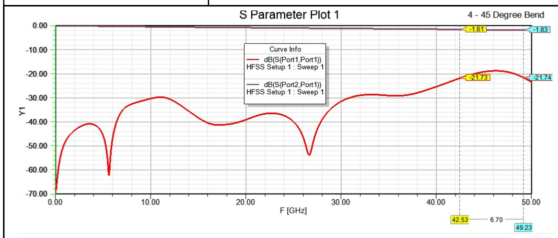
Round Bend	Due to the round bend, the change in width at bend is almost negligible compared to that of a 90 Degree bend. Hence, the Impedance is uniform throughout. The maximum amplitude of S11 is expected to be a minimum (in order of -30 dB or -35 dB) as the network is almost matched. Also, S21 starts with 0 dB and should be ripple free at lower freq as S11 never reaches -12 dB and above. At freq of 10 GHz, for a Df of 0.02, Dk of 4.4, len of 0.5 in, w of 14 mil, S21 = -(sqrt(f)/w+2.3*freq*sqrt(Dk)*Df*len). S21 = -0.48 dB. Since the network with port termination is symmetrical, S12 = S21. All these are verified from the HFSS results shown below. Hence, TD is almost same when compared to the straight line. This should be observed in Phase response of S21 of both the interconnects. As this is almost a perfectly matched network, S11 never reaches above -15 dB. Bandwidth is found to be 9.89 GHz. The time delay is Td = l/ 6in/ns = 0.5/6 =83 ps whereas the simulated value is 72 ps; comparable to a Straight line as a round bend is almost uniform. The below snapshots support all the above explained points.

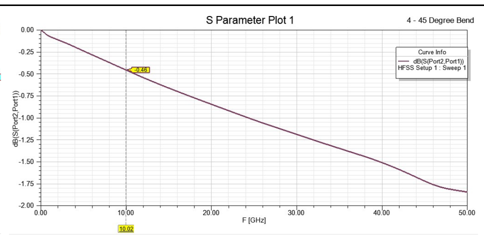


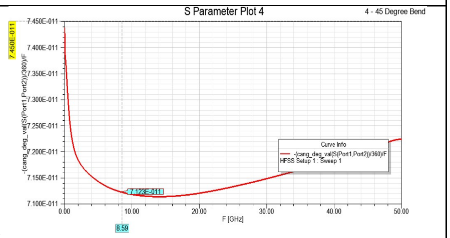




45 Degree Bend	The maximum amplitude of S11 is expected to be a minimum (in order of -30 dB or -35 dB) at lower freq as the network is not completely unmatched at lower freq. Also, S21 starts with 0 dB at lower freq and should be ripple free till S11 reaches -12 dB and above. At freq of 10 GHz, for a Df of 0.02, Dk of 4.4, len of 0.5 in, w of 14 mil, S21 = -(sqrt(f)/w+2.3*freq*sqrt(Dk)*Df*len). S21 = -0.48 dB. The simulated value is -0.46 dB. Since the network with port termination is symmetrical, S12 = S21. Referring to http://www.ultracad.com/articles/90deg.pdf, its concluded that a 90-degree bend increases the corner width by 41%, whereas a 45 Degree bend increases by 8%; 2 would induce a max of 16% variation. So, although the change in Impedance would be not much comparable to a Straight line, two 45 Degree bend would give an Impedance mismatch quite lesser than a 90 Degree bend. The time delay is Td = l/ 6in/ns = 0.5/6 =83 ps whereas the simulated value is 75 ps. The Bandwidth is found to be 6.7 GHz. As the impedance mismatch is not comparable when compared to a 90 Degree bend, S11 is not expected to reach -13 dB. The below snapshots support all the above explained points.

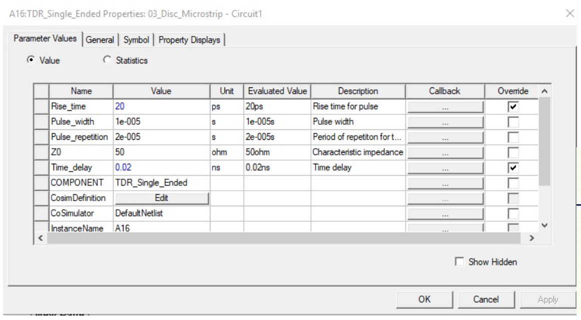


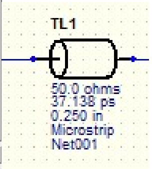




3. Look at the TDR response of each discontinuity using HFSS or HyperLynx. Is it inductive or capacitive?

Note: TDR Settings used:

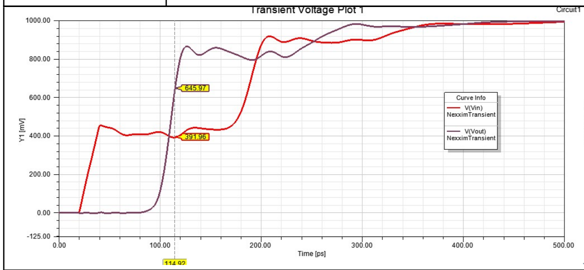


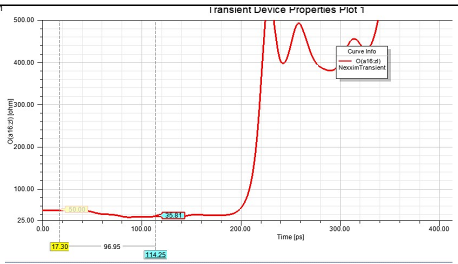


A Zline of 50 ohm on FR4, leads to a TD of 37.138 ps.

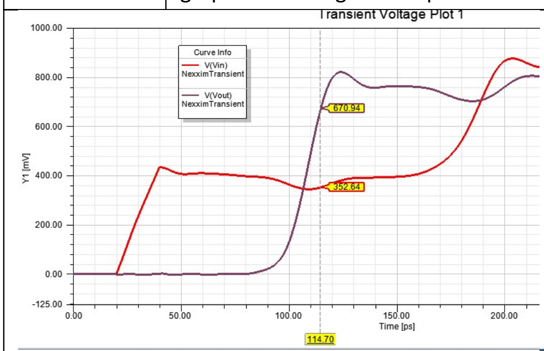
Model	Comments
90 Degree Bend	As we know, an increase in width leads to decrease in Capacitance per unit length at that point and hence decrease in Z0 at that point. Hence, a capacitive discontinuity is expected. The TDR source gives a total delay of 40 ps (Rise time+delay). Also, the Microstrip length being 37.13 ps, the impedance mismatch would be visible at a time t = 2* Microstrip length+40 ps = 114.5 ps. As per the

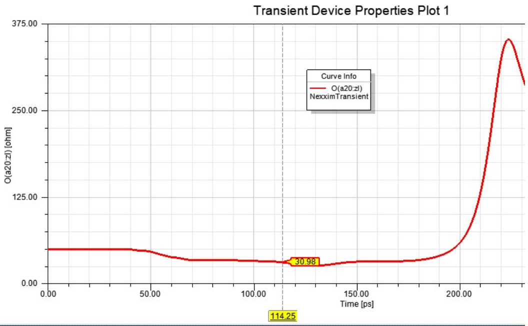
	Transient analysis on input Voltage and Impedance, it can be seen that Z decreases at that time instant to 35 ohm from 50 ohm in Z graph and Voltage also dips in the Voltage transient response. Hence, its clearly seen that it's a capacitive discontinuity.



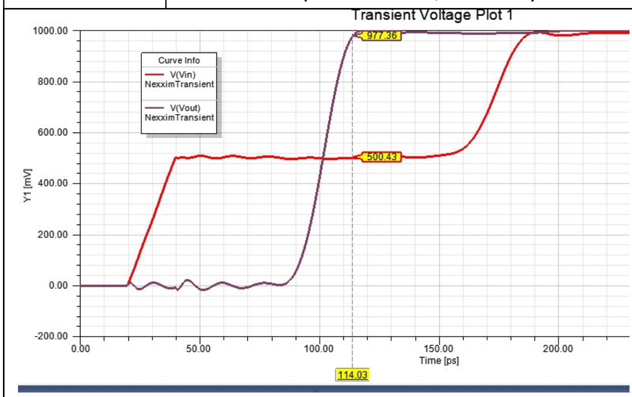


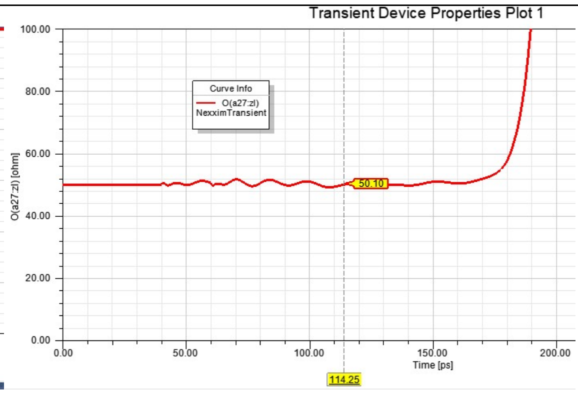
Round Bend	As we know, an increase in width leads to decrease in Capacitance per unit length at that point and hence decrease in Z0 at that point. Hence, a capacitive discontinuity is expected. The TDR source gives a total delay of 40 ps (Rise time+delay). Also, the Microstrip length being 37.13 ps, the impedance mismatch would be visible at a time t = 2* Microstrip length+40 ps = 114.5 ps. As per the Transient analysis on input Voltage and Impedance, it can be seen that Z decreases at that time instant to 30 ohm from 50 ohm in Z graph and Voltage also dips in the Voltage transient response. Hence, its clearly seen that it's a capacitive discontinuity.





45 Degree Bend	As we know, a 45 Degree bend is a more accurate uniform line compared to a round bend. Hence, a negligible capacitive discontinuity is expected. The TDR source gives a total delay of 40 ps (Rise time+delay). Also, the Microstrip length being 37.13 ps, the impedance mismatch would be visible at a time t = 2* Microstrip length+40 ps = 114.5 ps. As per the Transient analysis on input Voltage and Impedance, it can be seen that Z is constant at that time instant to 50 ohm in Z graph and Voltage is also constant in the Voltage transient response. Hence, its clearly seen that it's a negligible capacitive discontinuity. The below graphs explains the same.





4. Build a simple model in hyperlynx of the uniform line and the discontinuity. Match the line impedance to the HFSS simulated result. How well can you model the discontinuity as a single C or L? up to what frequency will this be an accurate model?

Model	Comments
90 Degree Bend	The width at the edge is 14 mil. As a thumb rule, capacitance increase at 90-degree bend is 2fF/mil. So, total increase is 28 fF. The HFSS data is obtained till 20 GHz. As seen from the image below, till a freq of 20 GHz, the capacitor model in Hyperlynx is a pretty good approximation to the HFSS data in terms of S11 of both. Also, the S21 plots obtained are also quite comparable.

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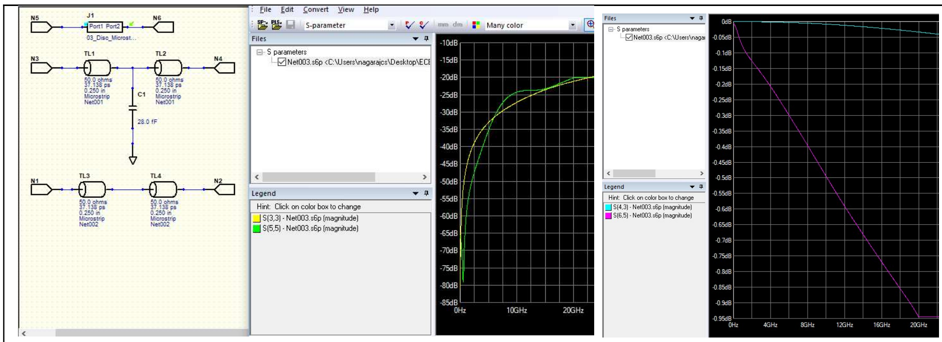
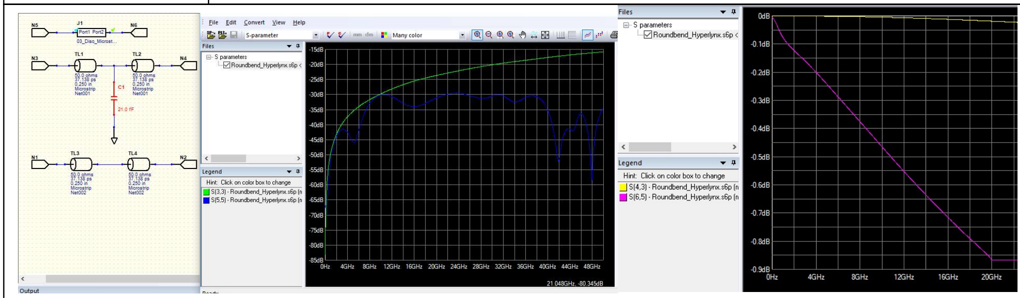
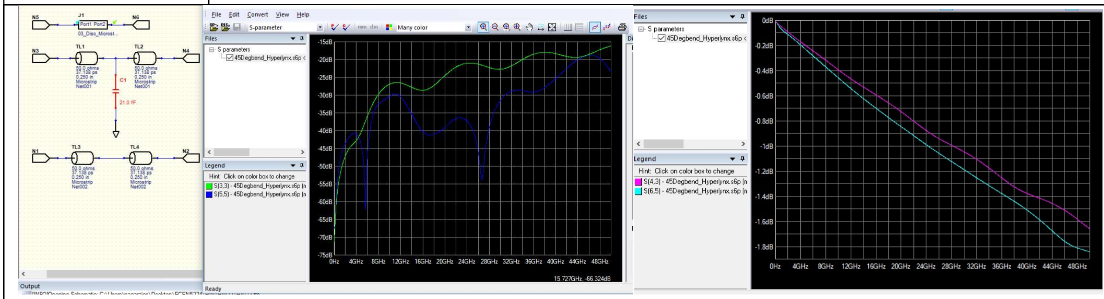


Round Bend	The width at the edge is 14 mil. As a thumb rule, capacitance increase at round bend is 1.5fF/mil. So, total increase is 21 fF. The HFSS data is obtained till 14 GHz. As seen from the image below, till a freq of 14 GHz, the capacitor model in Hyperlynx is a pretty good approximation to the HFSS data in terms of S11 of both. Also, the S21 plots obtained are also quite comparable.



45 Deg Bend	The width at the edge is 14 mil. As a thumb rule, capacitance increase at round bend is 1.5fF/mil. So, total increase is 21 fF. The HFSS data is obtained till 14 GHz. As seen from the image below, till a freq of 14 GHz, the capacitor model in Hyperlynx is a pretty good approximation to the HFSS data in terms of S11 of both. Also, the S21 plots obtained are also quite comparable.



Conclusions:

what about round bend?

1. **Practically speaking, a 45 Degree bend is a Uniform line with almost negligible Impedance mismatch when compared to a 90 Degree bend.**
2. **The time delay faced while travelling through a 90 Degree bend, 45 Degree bend, Round bend and Straight line is almost the same; change in 10s of ps.**
3. **The bend discontinuity can be effectively replaced by a Capacitor to get a quick solution in a 2D Field solver when compared to the field solution in a 3D solver.** ok
4. **Among the turns discussed, 90 Degree bend should be avoided.**

   but 90 degree is one of easiest to build. Based on trade-offs, we need to decide which one to choose. We cant elimiate 90 degree. Yes, it has the worst S11.
5. **For a 45 Degree bend and Round bend, the Bandwidth is almost the same as the Straight line.**