



## [What is the frequency of the S21 dip in microstrip?: Rule of Thumb #22](#)

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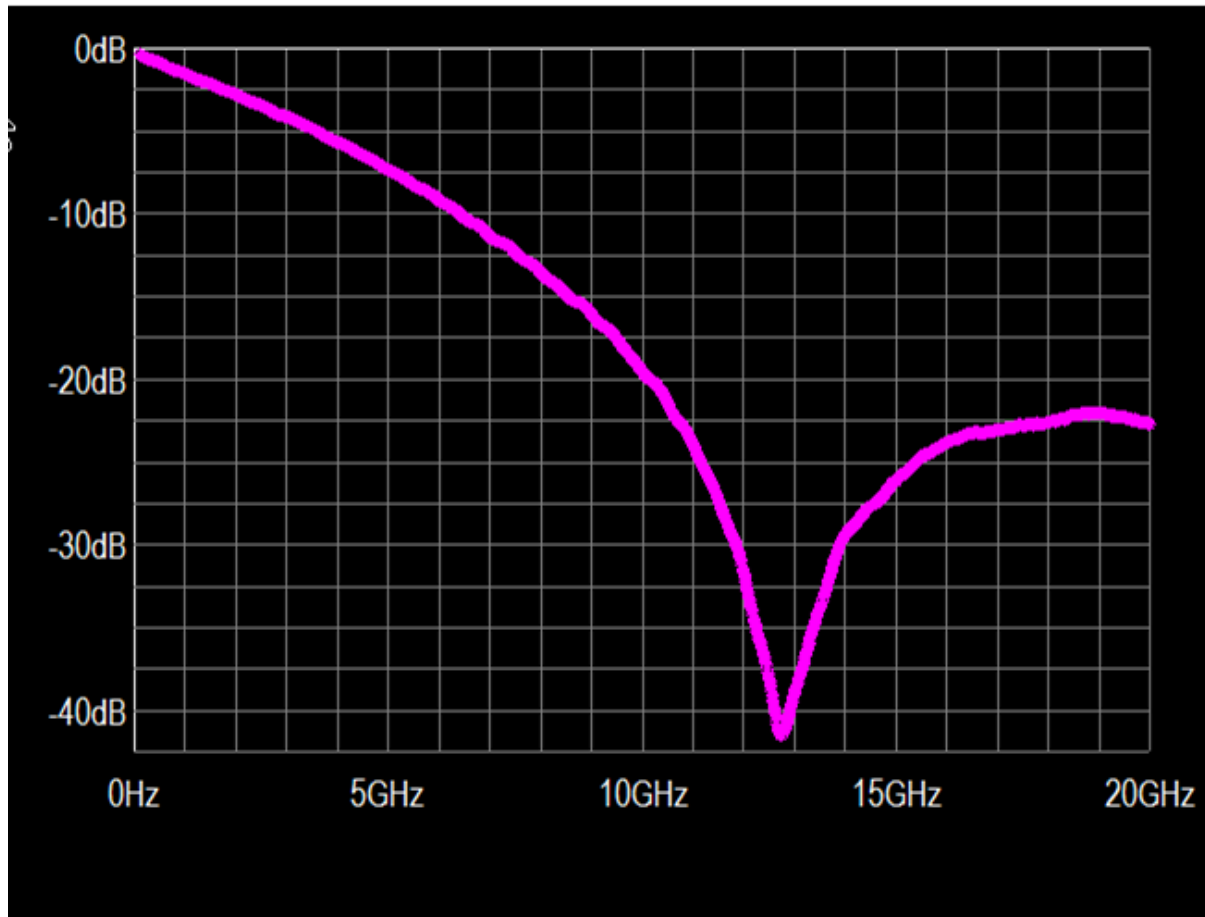
In every measurement of the single ended insertion loss of a microstrip differential pair, there is a sharp dip. This is a natural feature of all microstrips. It is not a resonance, but related to far end cross talk. Here's how you can estimate at what frequency you expect to see it.

**Spoiler summary:** When you measure the single-ended insertion loss of a tightly coupled microstrip differential pair, the frequency of the dip is roughly:  $f = 50 \text{ GHz/Len[in]}$ .

**Remember:** before you start using rules of thumb, be sure to read the [Rule of Thumb #0](#): Using rules of thumb wisely.

**Previous:** [Rule of Thumb #21: How to engineer acceptable far end cross talk](#).

When you measure the 4-port S-parameters of a tightly coupled microstrip differential pair, you *always* see a sharp dip in S21. An example is shown in **Figure 1**.



**Figure 1**

What could possibly be causing this dip? Your first thought is that it is due to some sort of resonance, or maybe there is a stub in the circuit you hadn't noticed. Both of these explanations are wrong.

When we drive one line in the differential pair with a single-ended signal, we can describe the signal as a combination of a differential and common signal component, each exactly in phase at the source. The differential and common components on line 1 add at the source, while the differential and common components of the signal on line 2 subtract and cancel out to zero. The resulting signal looks like a single-ended signal on line 1.

If the differential and common signals propagate down the line at the same speed, the single-ended signal will always look like a single ended signal. But, if the differential signal travels a little faster than the common signal, after some distance traveling down the line, the differential and common signals will be shifted exactly 180° out of phase.

When they are out of phase, they will now subtract and cancel out on line 1, and add on line 2. This looks like all the energy on line 1 has now coupled to line 2. The S21 insertion loss will be a tiny signal, or a large, negative value in decibels.

If we can estimate the frequency of the dip, based on this root cause, we can use it in debugging a problem. If our estimate of the dip frequency matches the measured dip, this is strong evidence we have the root cause. Using this rule of thumb, we can anticipate where the dip frequency might be, and it will not be a mystery.

At the end of the line, the difference in time delay between the arrival of the differential and common signal is:

$$\Delta T = TD_{\text{comm}} - TD_{\text{diff}} = \frac{\text{Len}}{v_{\text{comm}}} - \frac{\text{Len}}{v_{\text{diff}}} = \text{Len} \times (WD_{\text{comm}} - WD_{\text{diff}})$$

In this case, WD is the wiring delay, which is 1/speed for each of the signals. It is in ns/inch. The only way to know this is by calculating with a 2D field solver that takes into account the relative electric field distribution for the odd and even modes.

The frequency at which the dip will occur is when this time delay difference is half a cycle. This means that the time delay of a complete cycle would be  $2 \times \Delta T$ . This allows us to estimate the frequency of the dip:

$$f_{\text{dip}} [\text{GHz}] = \frac{1}{2\Delta T} = \frac{1}{\text{Len}[\text{inches}]} \times \frac{1}{2 \times 0.01 \text{ ns/inch}} = \frac{50 \text{ GHz}}{\text{Len}[\text{inches}]}$$

The measured example above was for a tightly coupled microstrip differential pair in FR4 of 50Ω. It was 4 inches long. We would expect the dip frequency to be  $50 \text{ GHz}/4 = 12.5 \text{ GHz}$ . We measured it as about 12.8 GHz.

We also see that as the coupled length increases, the frequency of the dip decreases. However, it is not a physical resonance. The frequency of the dip also depends on the coupling. The smaller the coupling, the smaller the difference in the wiring delays between the differential and common signals. The smaller the difference, the higher the dip frequency.

Now you try it:

1. A tightly coupled microstrip differential pair is 10 inches long. At what frequency would you expect to see a sharp dip in the insertion loss?
2. Suppose the lines were loosely coupled: would you expect the dip frequency to be higher or lower than the estimate above?

Next rule of thumb #23: How much capacitance in a corner?

**Also see:**

- [Bogatin's Rules of Thumb](#)
- [Not all common currents are bad](#)
- [Strange microstrip modes](#)

Additional information on this and other signal integrity topics can be found at the Signal Integrity Academy, [www.beTheSignal.com](http://www.beTheSignal.com).



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