Mobile antennas reaching the 600 MHz band, comparison of different band proposals

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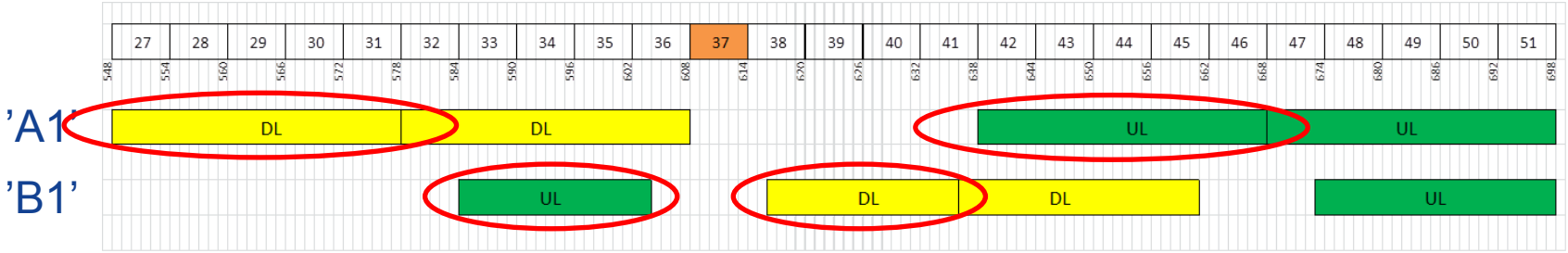
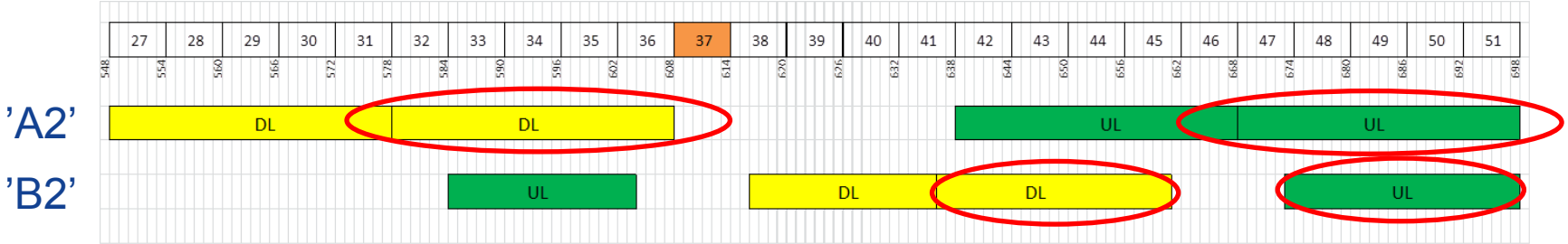
600 MHz band plan proposals: six cases (1/2)

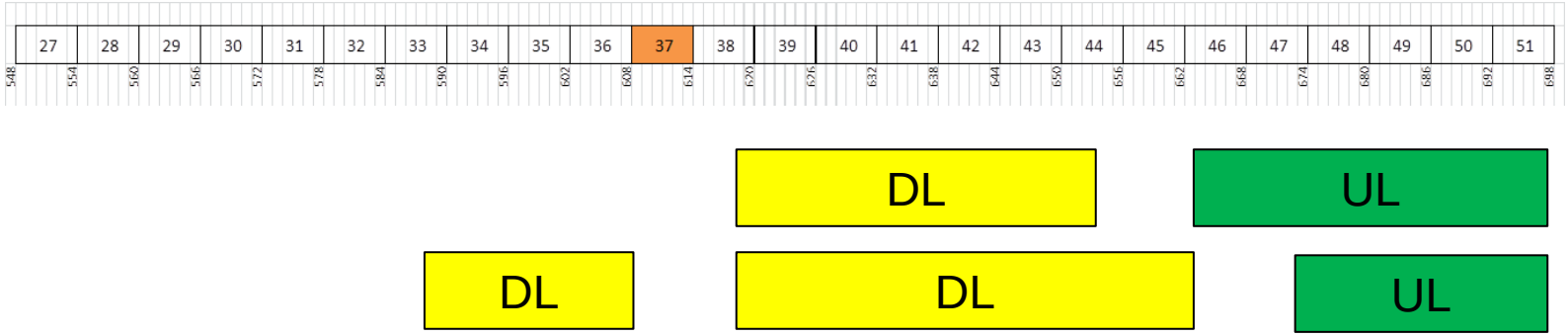




An unfortunate choice of naming, not to be mixed up with the 3GPP band numbers!

Band	UL [MHz]	DL [MHz]	BW [MHz]	BW [%]
A1	638-668	548-578	30	19.7
A2	668-698	578-608	30	18.8
B1	584-604	616-636	20	8.5
B2	673-698	636-661	25	9.3
B3	663-698	618-653	35	12.2
B4	673-698	588-608, 618-663	25/75	17.1

600 MHz band plan proposals: six cases (2/2)



We focus on ’A2’, ’B2’, ’B3’, and ’B4’ in these slides!

Band	UL [MHz]	DL [MHz]	BW [MHz]	BW [%]
A1	638-668	548-578	30	19.7
A2	**668-698**	**578-608**	**30**	**18.8**
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B4	**673-698**	**588-608, 618-663**	**25/75**	**17.1**

Antenna simulations

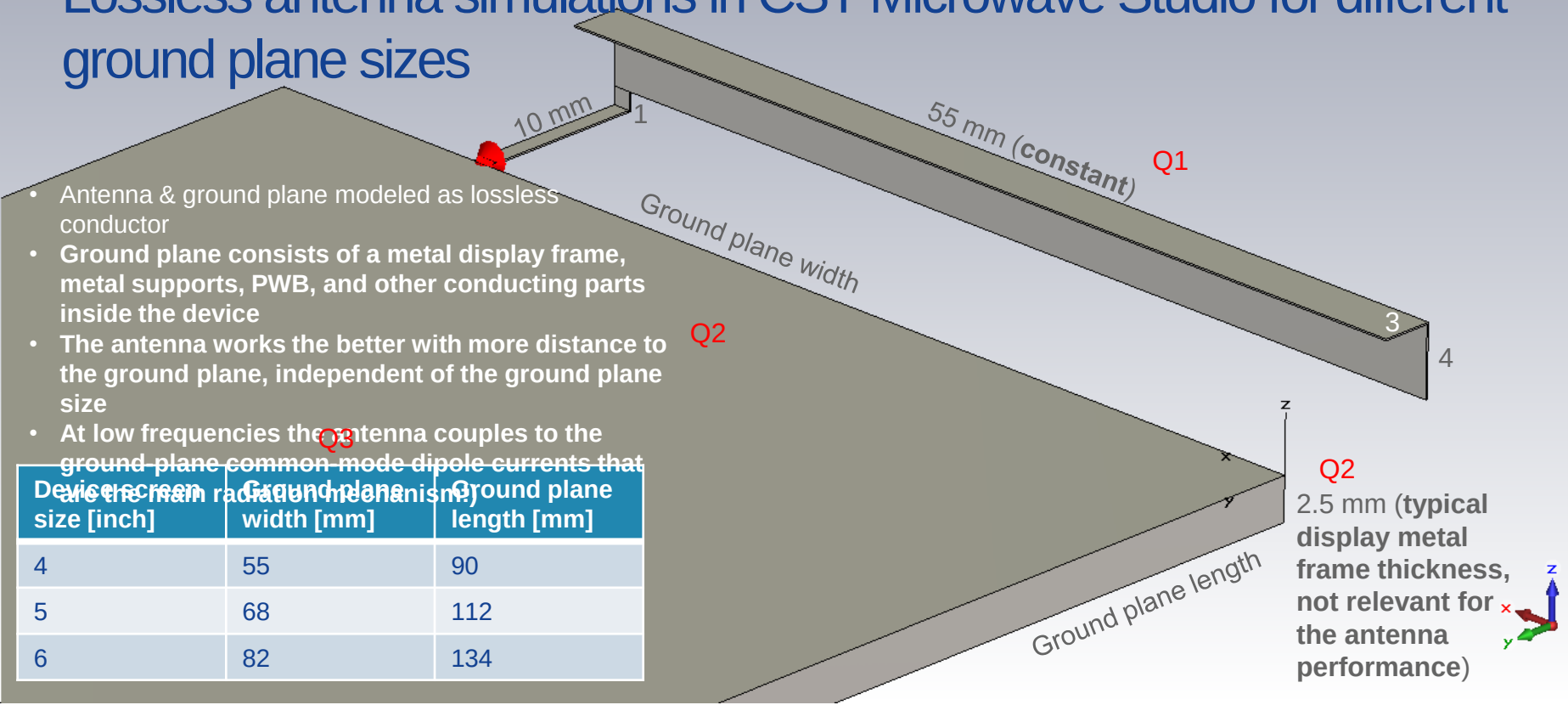
No MIMO antenna considered (Alternatively, perfect isolation between the antennas). Also, the envelope correlation between the antennas not considered.

Lossless antenna simulations in CST Microwave Studio for different ground plane sizes

- Antenna & ground plane modeled as lossless conductor
- **Ground plane consists of a metal display frame, metal supports, PWB, and other conducting parts inside the device**
- **The antenna works the better with more distance to the ground plane, independent of the ground plane size**
- **At low frequencies the antenna couples to the ground-plane common-mode dipole currents that are the main radiation mechanism)**

Q3

Device screen size [inch]	Ground plane width [mm]	Ground plane length [mm]
4	55	90
5	68	112
6	82	134



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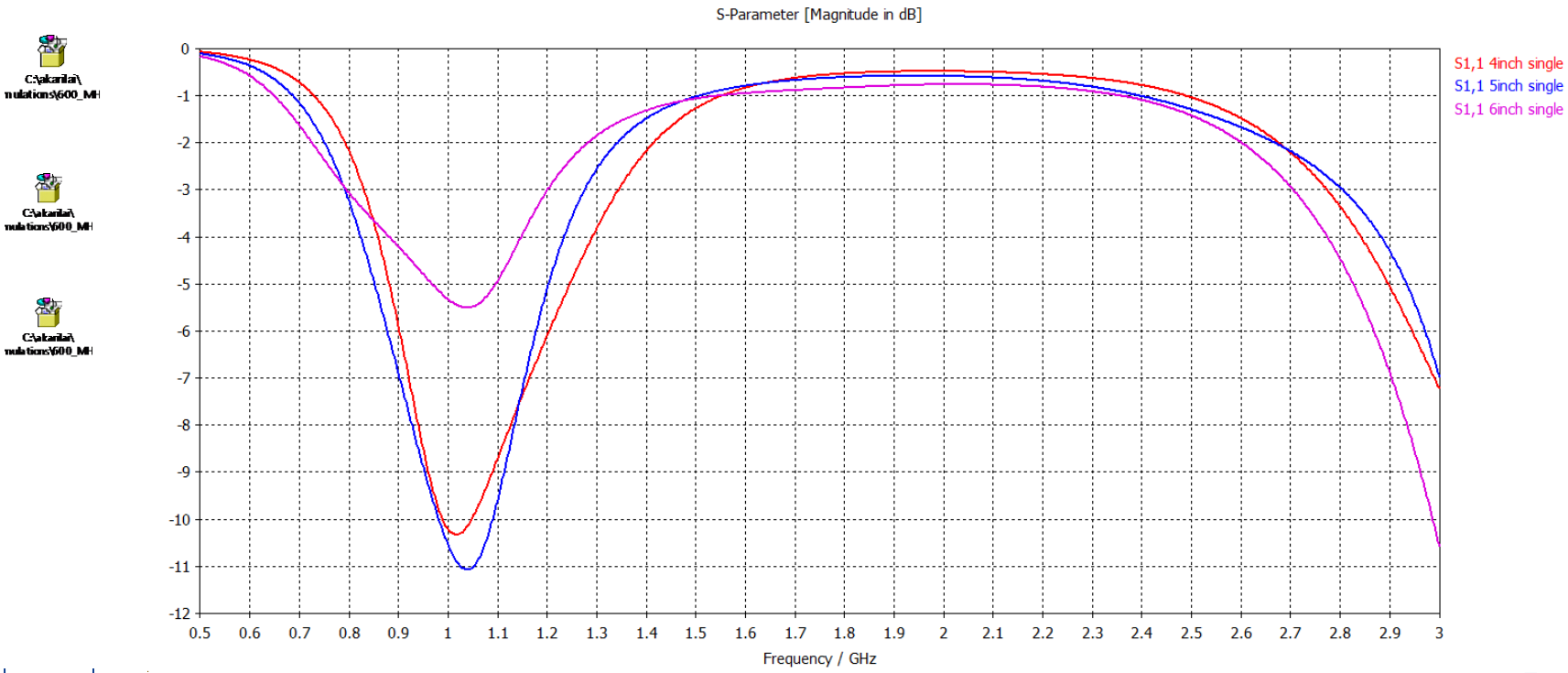
S parameters from the simulations



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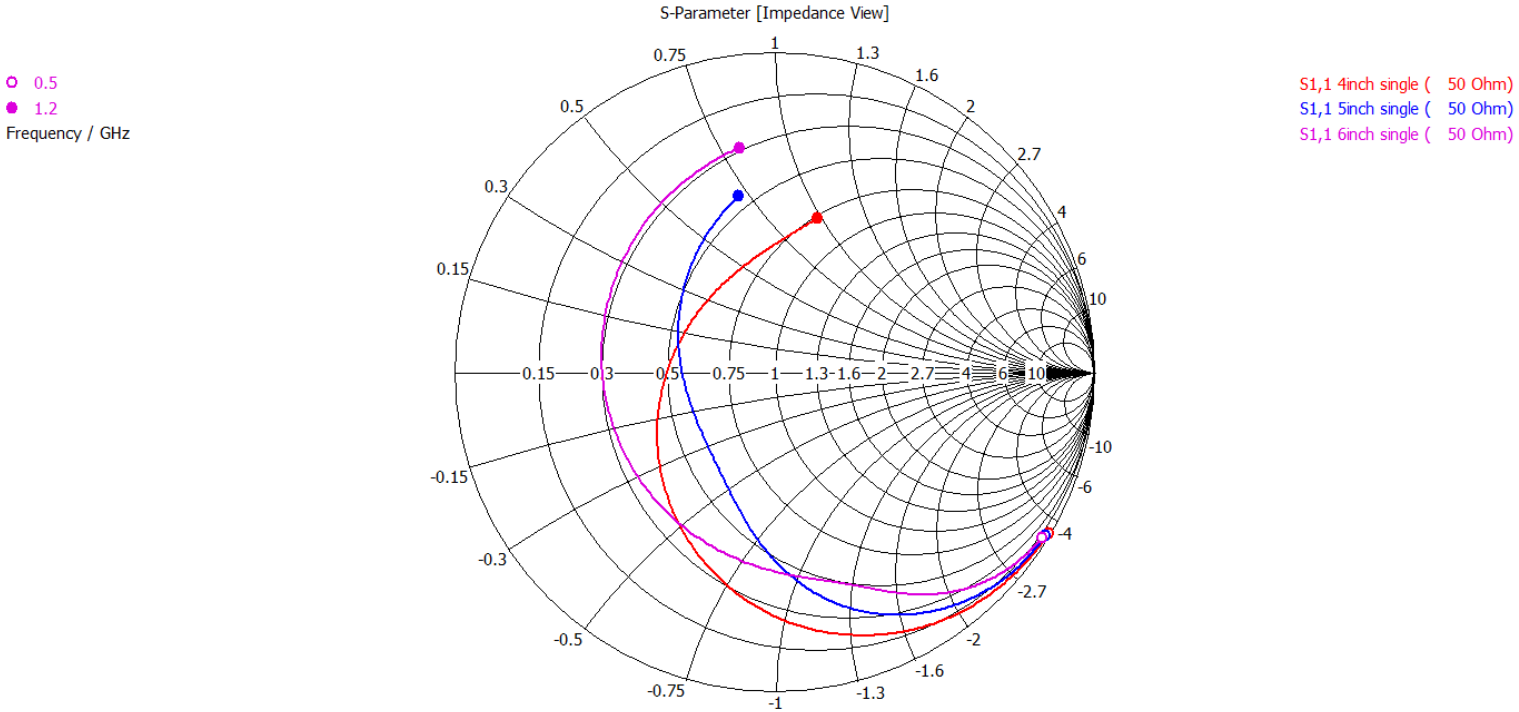
Impedances from the simulations



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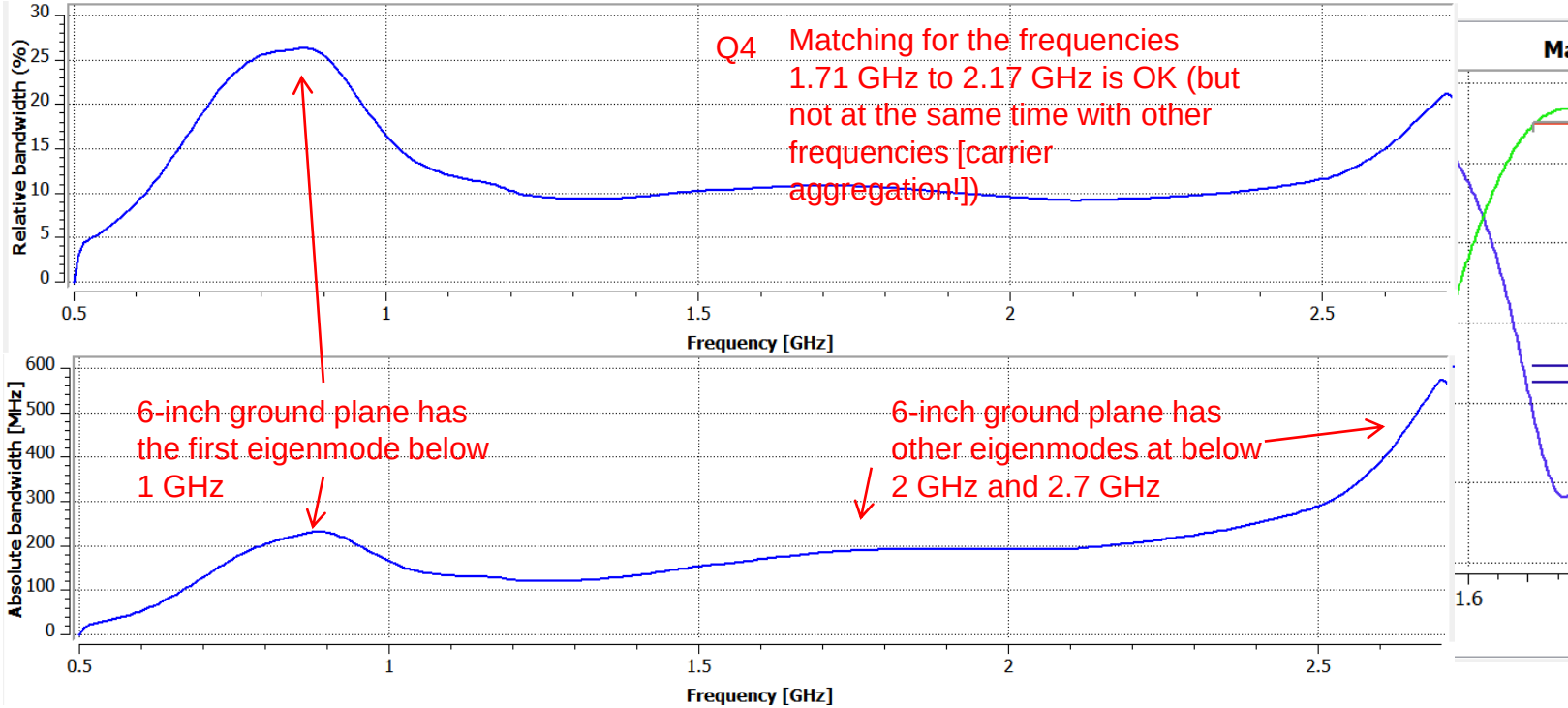
Bandwidth potential for the 6-inch case (Optenni Lab)



Bandwidth potential

Bandwidth potential refers to the obtainable symmetric bandwidth of an antenna through a lossless two-component matching circuit. For each frequency, a matching circuit is constructed such that it is conjugately matched to the termination impedance at this frequency. The symmetric bandwidth at a desired matching level is recorded. The analysis is repeated for each frequency of the original load impedance file.

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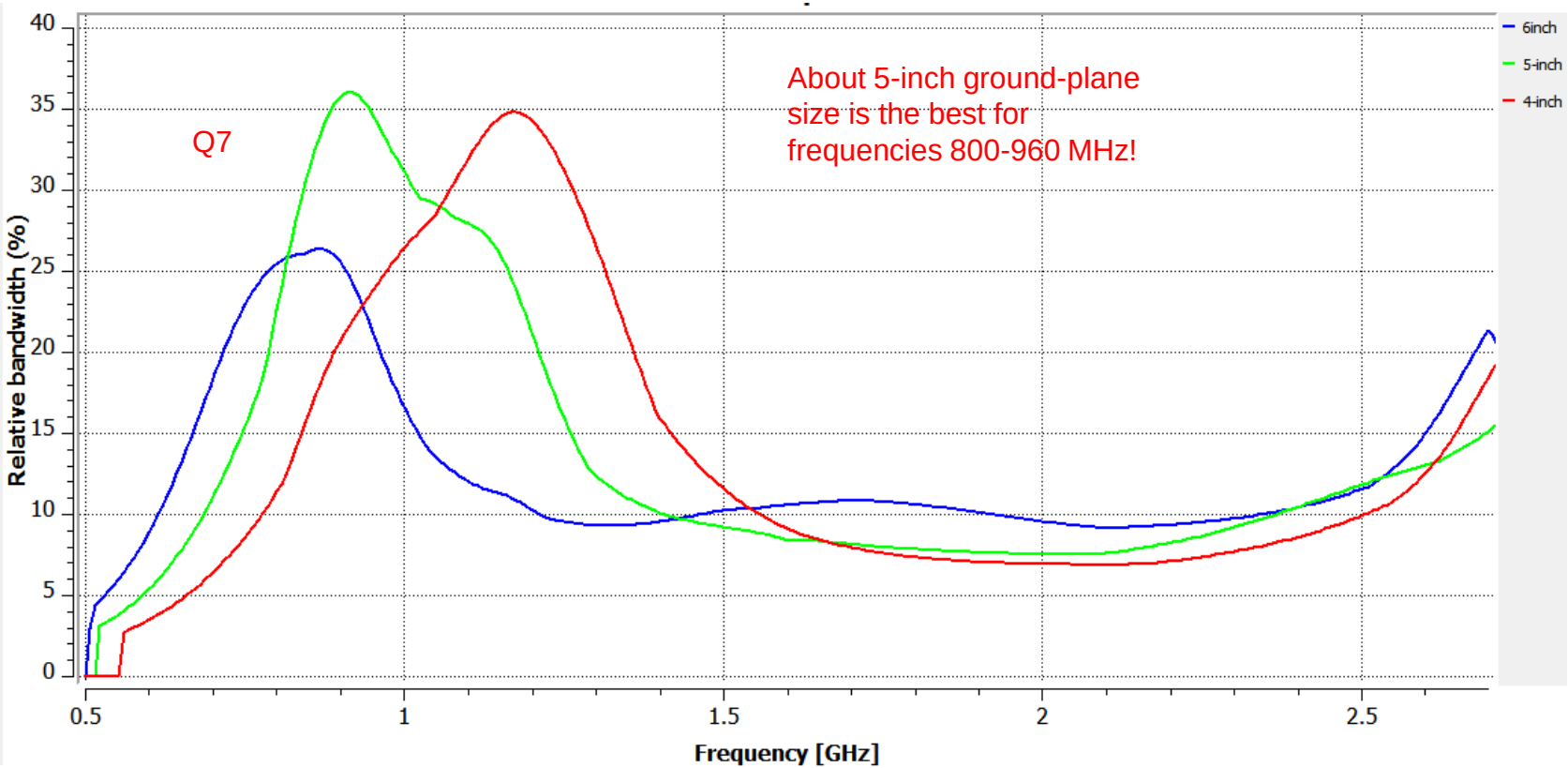
Bandwidth potential for all cases (Optenni Lab)



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Q5 & Q6: Single or multiple antennas?

5) Related to this, some people tell us that a single antenna is typically used for all the 3GPP bands in the phone, so for a North American provider one antenna might be TX and RX for quad band GSM plus a few other bands, like AWS-1 (Band 4), 700 MHz (Band 12, 13, or 17), and Band 1; and then a second RX only antenna for the bands supporting LTE, and then one or more antennas for WiFi, Bluetooth, and GPS. Other people tell us separate antennas are used for bands above and below 1 GHz, at least for TX, so there are even more antennas in the phone. Which one is correct? Do companies in fact make handsets both ways? If so, what are the tradeoffs?

6) What is the typical design for the device antenna system used for carrier aggregation where the instantaneous bandwidth is large? Are multiple antennas or tuning circuits required?

- In principle, one single main antenna can cover all the needed 3GPP bands (including all possible carrier aggragation cases), and a second antenna all the diversity/MIMO bands
- Separate antenna(s) usually for WiFi, BT, and GPS (isolation and complexity issues)
- Single and separate antenna solutions used in the industry
- If two antennas are used for cellular bands (for example, below 1 GHz and above 1 GHz):
    - Design is maybe easier
    - Isolation must be taken care of
    - More antenna volume needed?
    - Antennas can be tunable separately, also in the carrier aggragation case (if low-band + high-band CA)
- No carrier aggregation devices in the market yet...?

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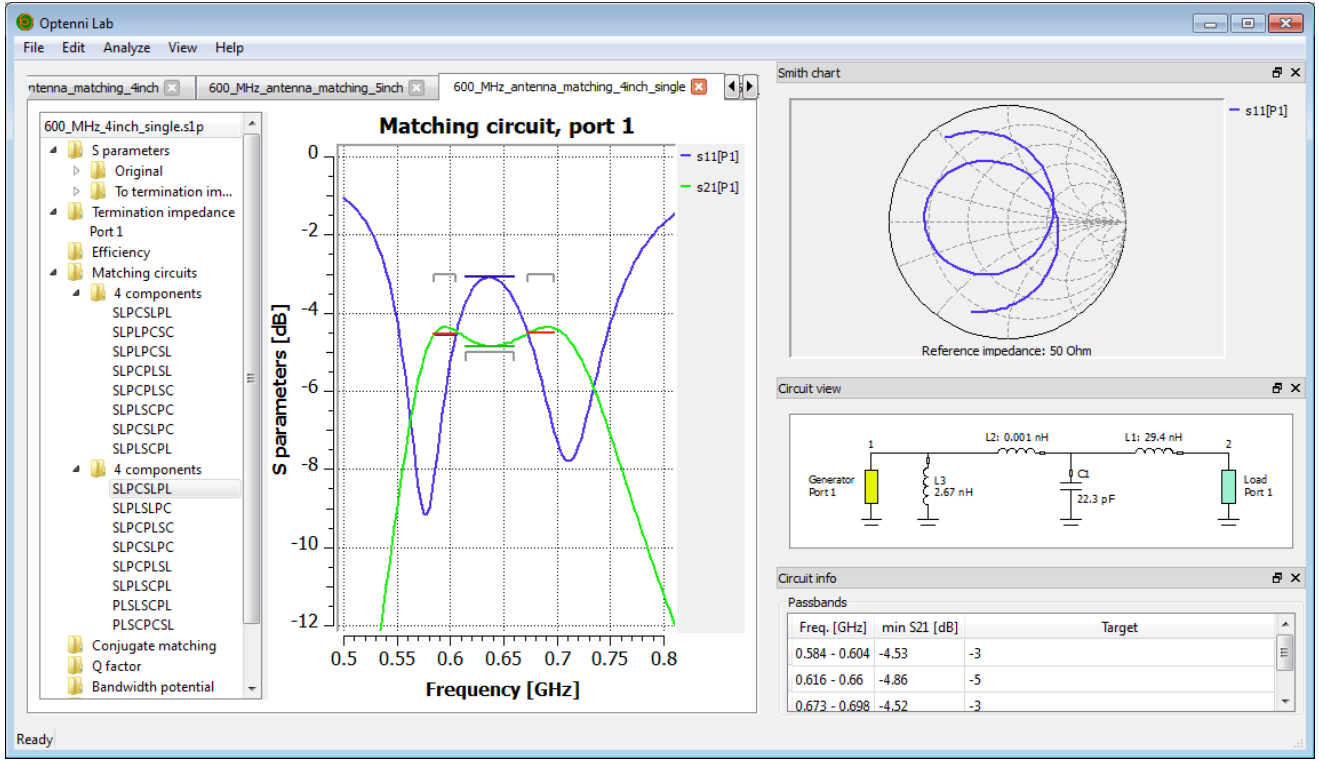
Optenni Lab software used for matching-circuit generation

Q13: Dissipative losses: $\frac{1}{G_P} = L_P = -S_{21,\mathrm{dB}} + 10\log(1 - |S_{11}|^2)$

- Four L/C lossy matching components allowed
- Optimize for the maximum power accapted by the antenna
- Best topology chosen for total effieciency comparison in each matching scenario
- When creating a B17-optimized antenna, use the L1 series inductor from the B17 matching circuit in the 600-MHz-band optimized matching circuit



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Q8-Q11: Matching components

8) How does the limit of four components for the tuning circuit compare to real world phones; is it aggressive or conservative? (We have seen five in another document.)
9) Is it the case that the capacitors are variable and the inductors are fixed? (We can't tell from this slide; we saw that in another source.)
10) Is there one tuning circuit for each antenna in the device (presumably on the antenna side of the switch), or separate tuning circuits for each band supported by each antenna (presumably on the duplexer side of the switch), or some other topology?
11) Why is it that it makes sense that if the antenna was optimized for Band 17, one of the inductor values would be reused for 600 MHz, but not the other inductor or the capacitors?
12) We don't understand the targets on the S parameter chart in the middle of the slide very well, can you explain further?

8) Normal/aggressive for regular antennas resonating by themselves, conservative for a tunable antennas (that includes for example a couple of tunable capacitors and a few SMD coils)
9) Here, for the sake of simplicity, brevity, and speed, the matching networks were generated for each case separately ('B17 antenna' slightly different case) using the Optenni Lab software.
10) Antenna tuning circuits are always as close to the antenna as possible (for the best bandwidth) in general.
11) First, we wanted to artificially create a B17 antenna, for example, from the 6-inch impedance. For that we used 4 reactive components (with losses). All the components were hence specificially chosen for the B17 (imagine an antenna somewhat optimized for B17 + 3 reactive components / tunable circuit). Next, in order to tune the 'antenna somewhat optimized for B17' to 600 MHz we can change only the 3 reactive components, thus not being able to optimize the antenna anymore totally for the 600-MHz band.

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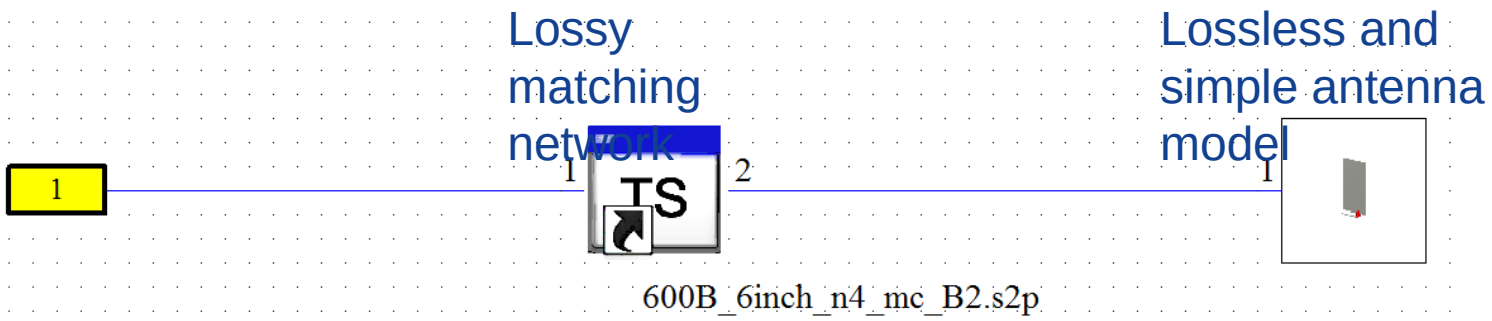
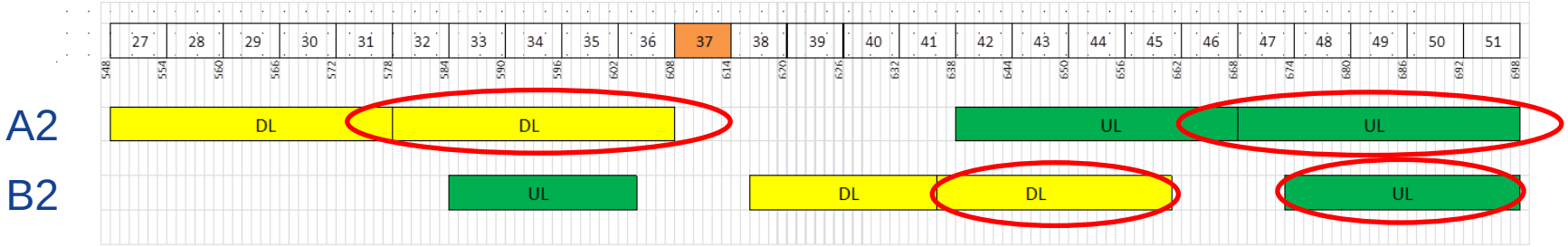
Emphasis on Tx frequencies and only the 600-MHz band considered: ’A2’ and ’B2’

Optimize for 2 dB worse efficiency for Rx frequencies in Optenni Lab

Total efficiency calculations for 600 MHz band optimized antannas





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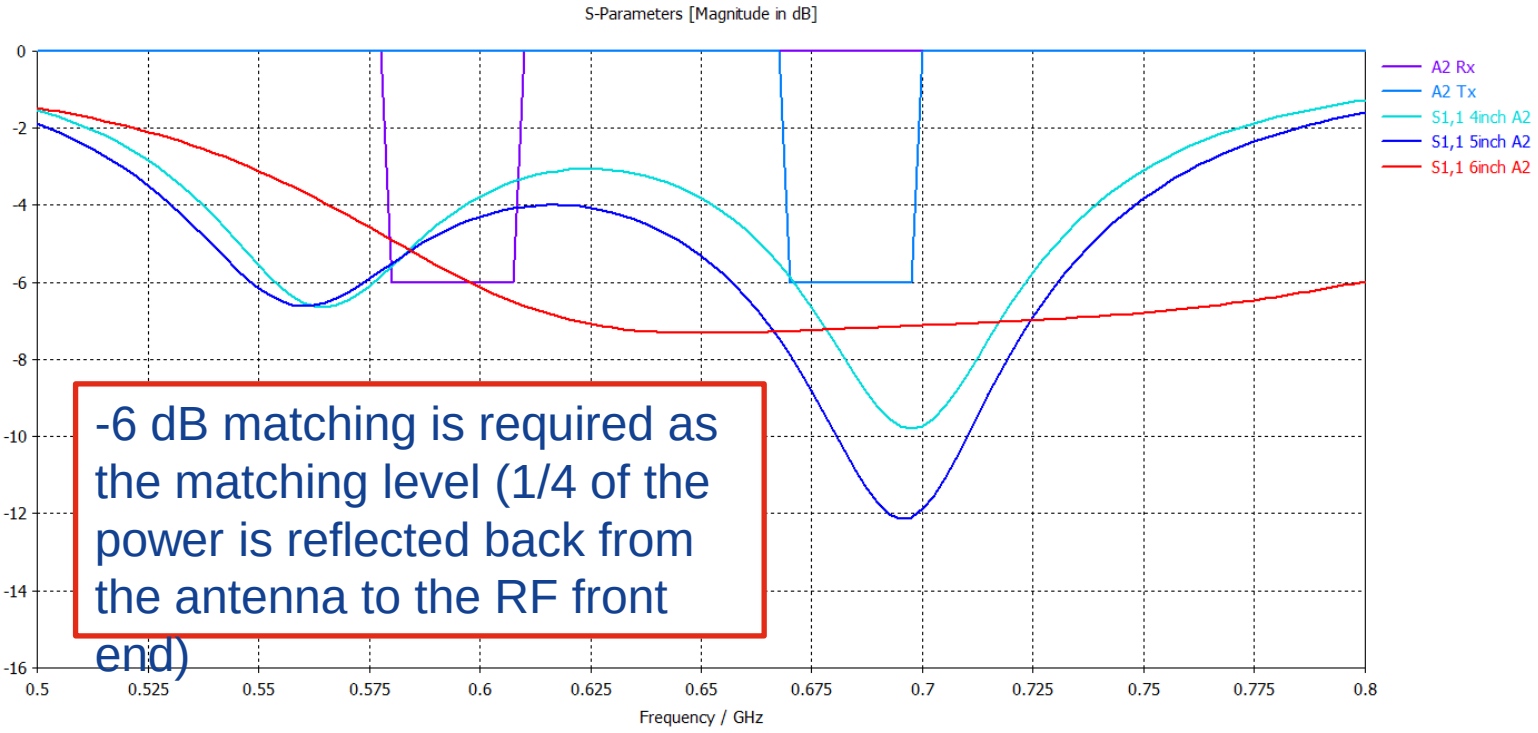
Matching levels for band combination A2



-6 dB matching is required as the matching level (1/4 of the power is reflected back from the antenna to the RF front end)

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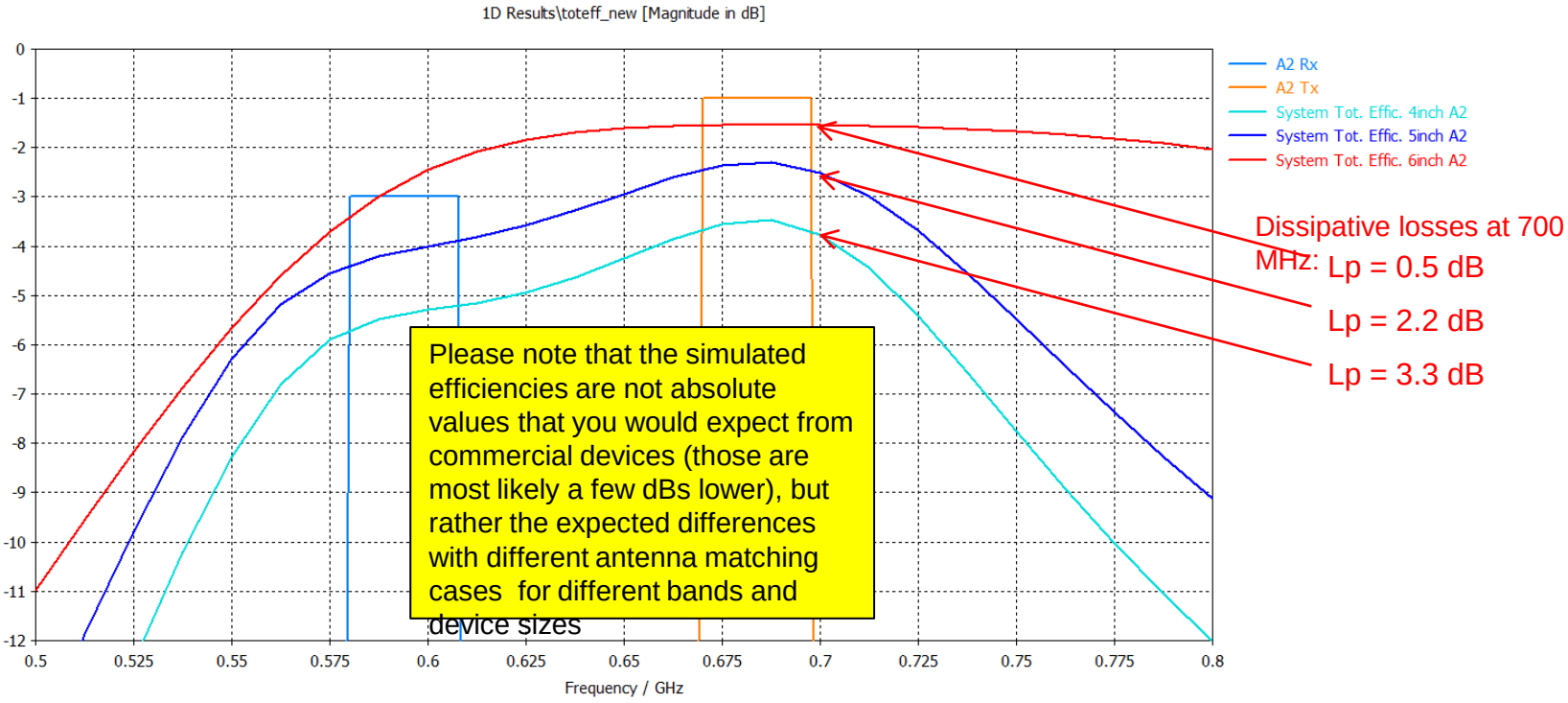
Total efficiencies for band combination A2



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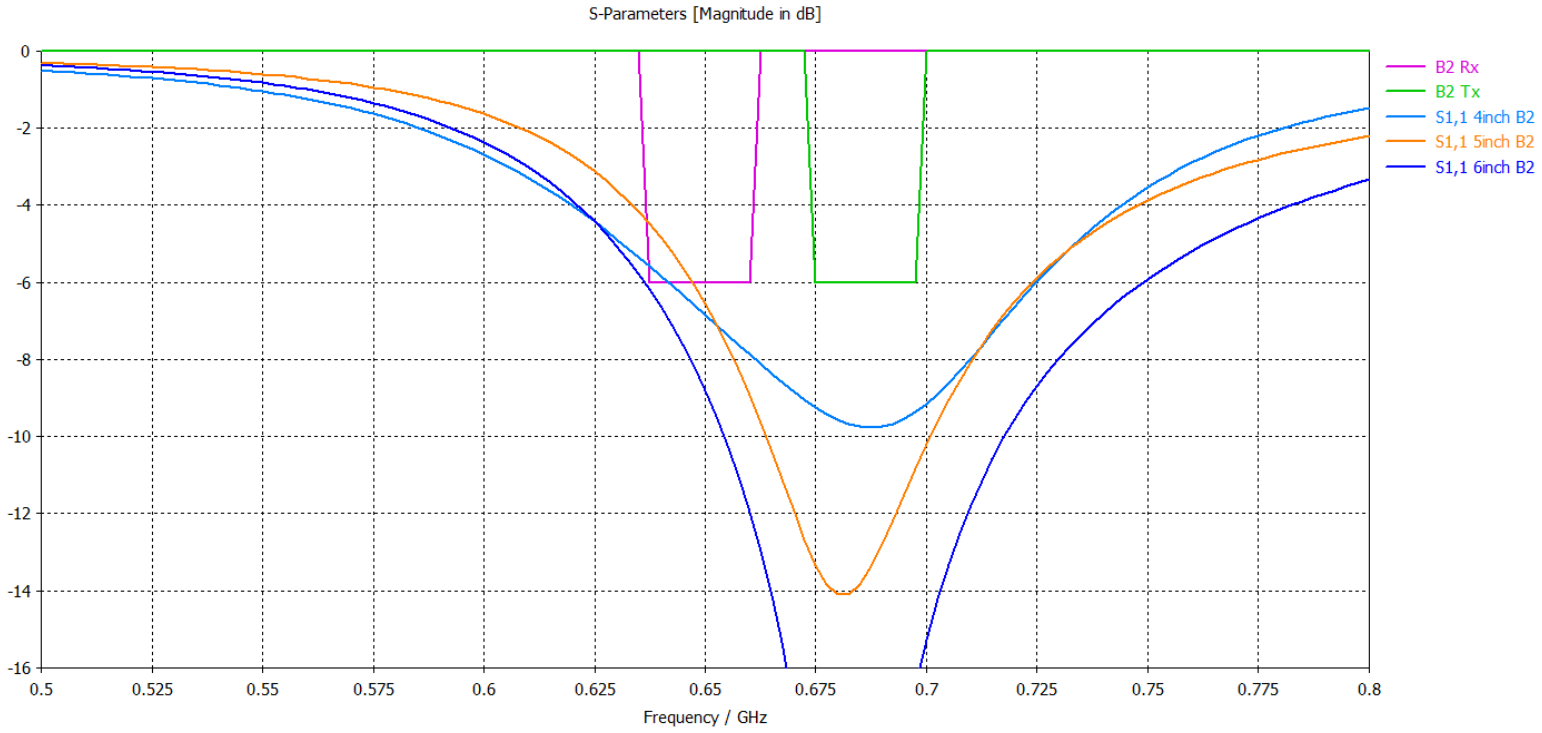
Matching levels for band combination B2



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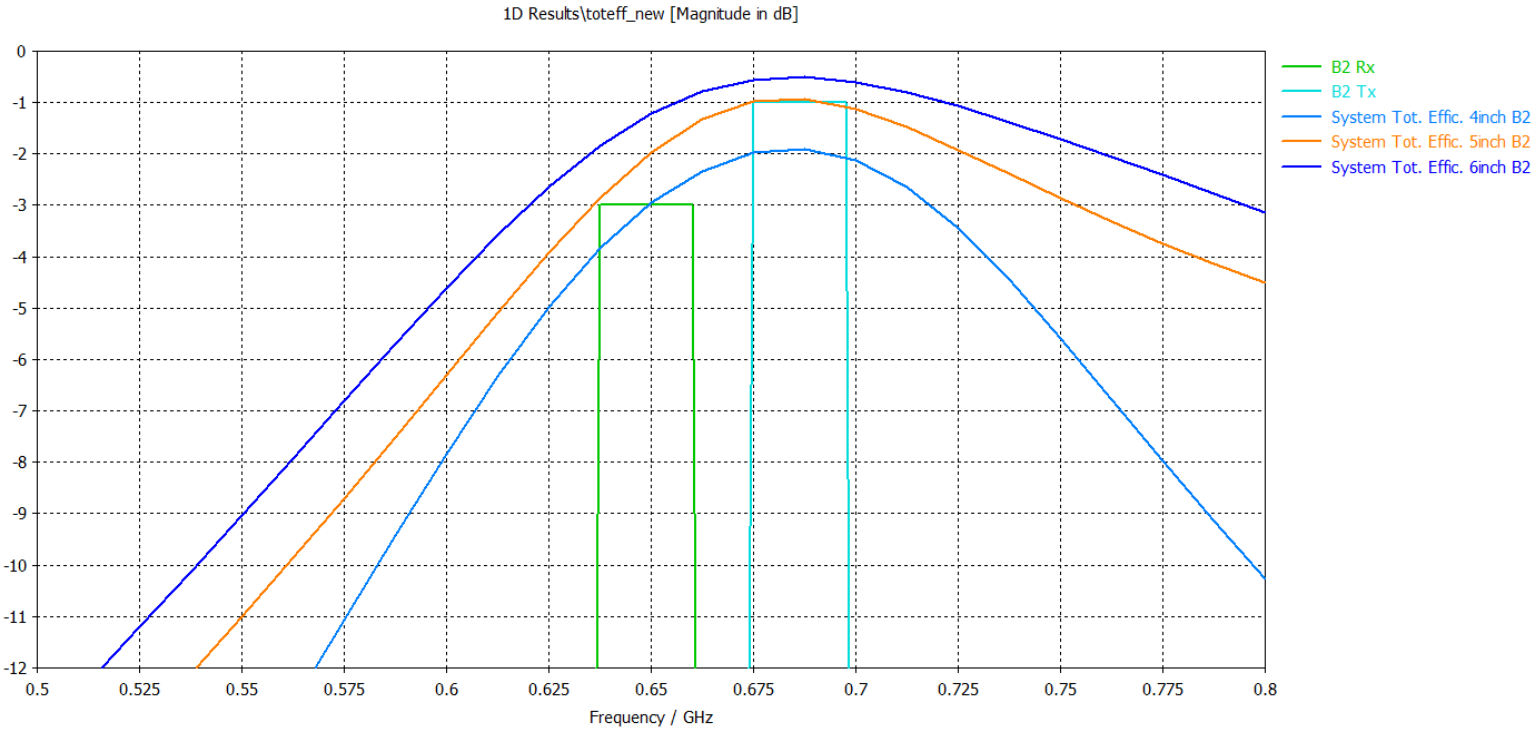
Total efficiencies for band combination B2



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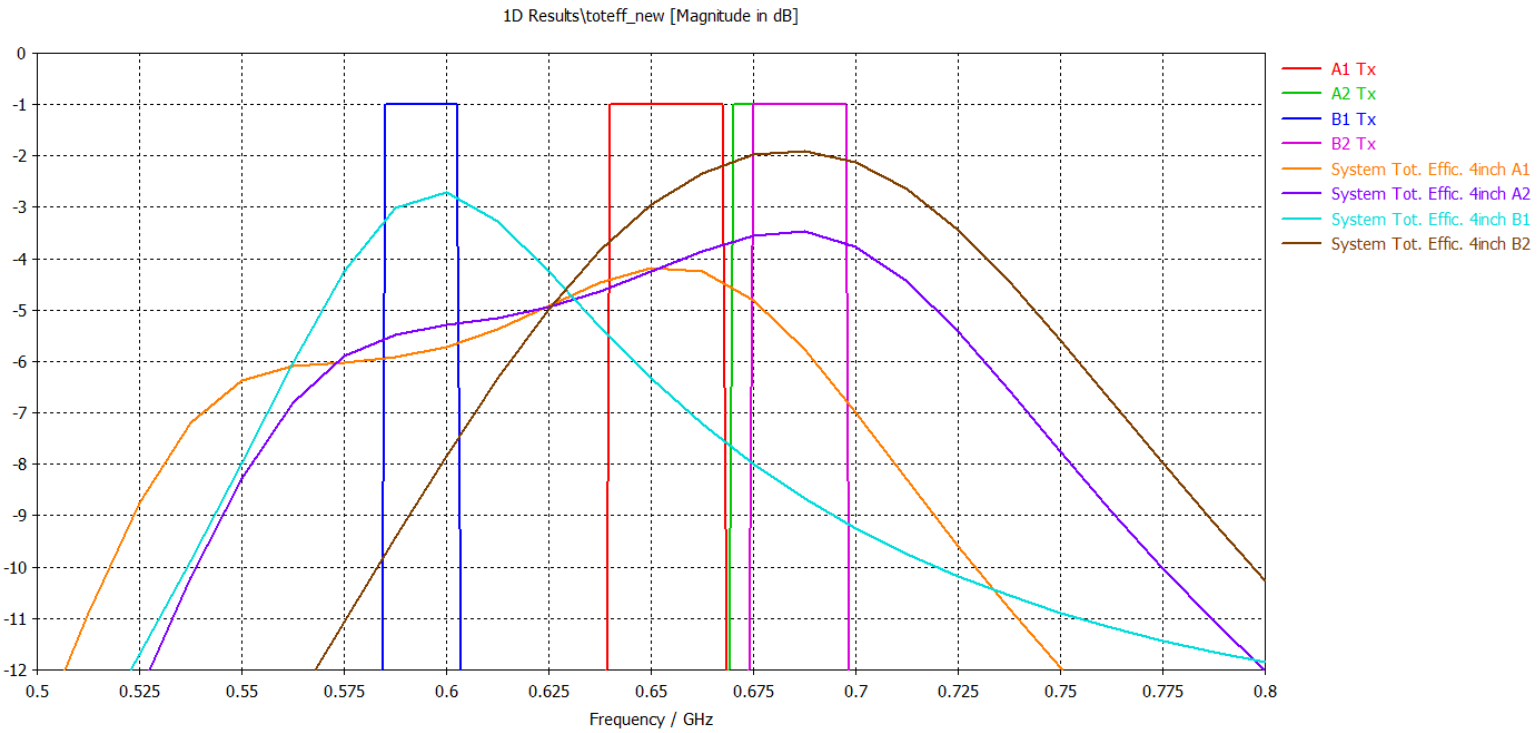
Total efficiencies for 4-inch devices



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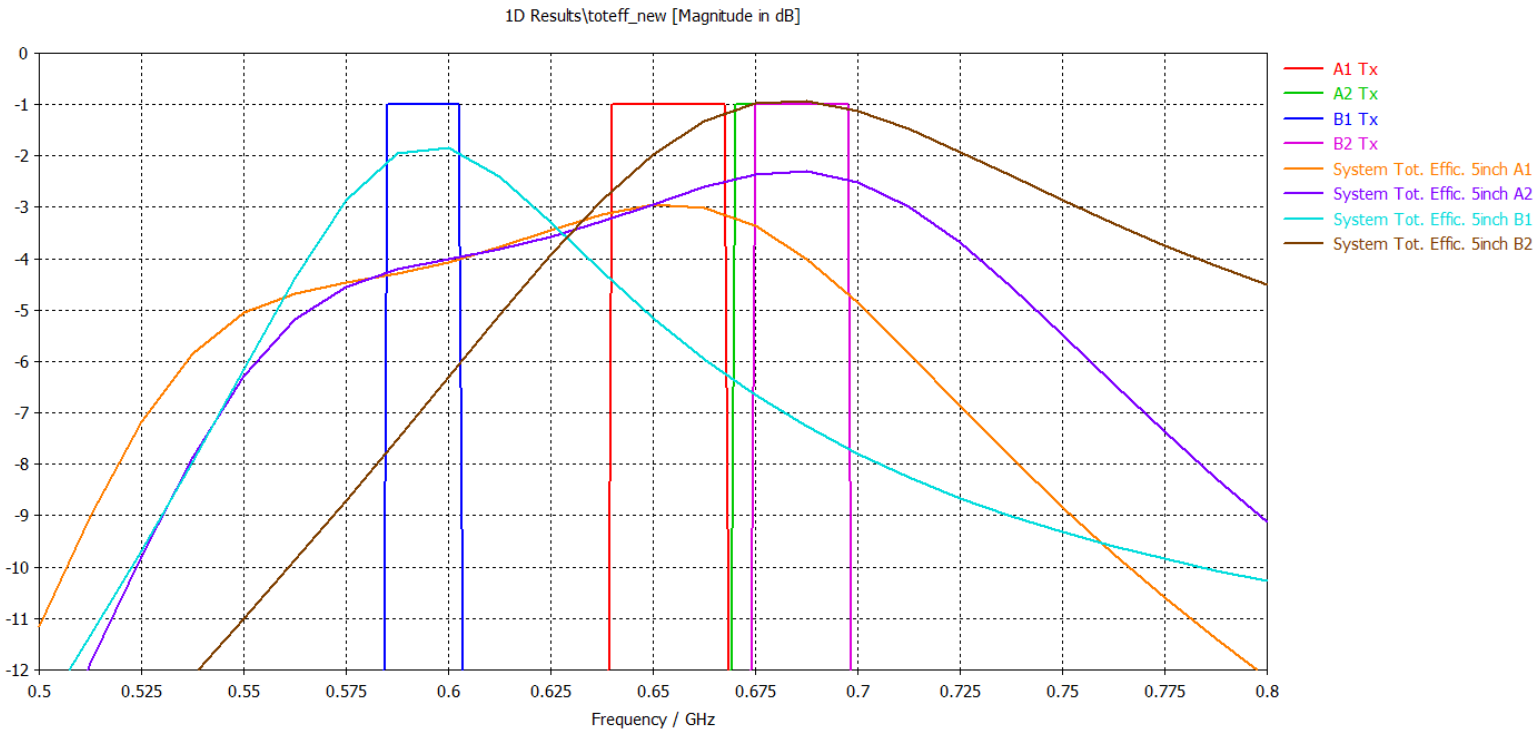
Total efficiencies for 5-inch devices



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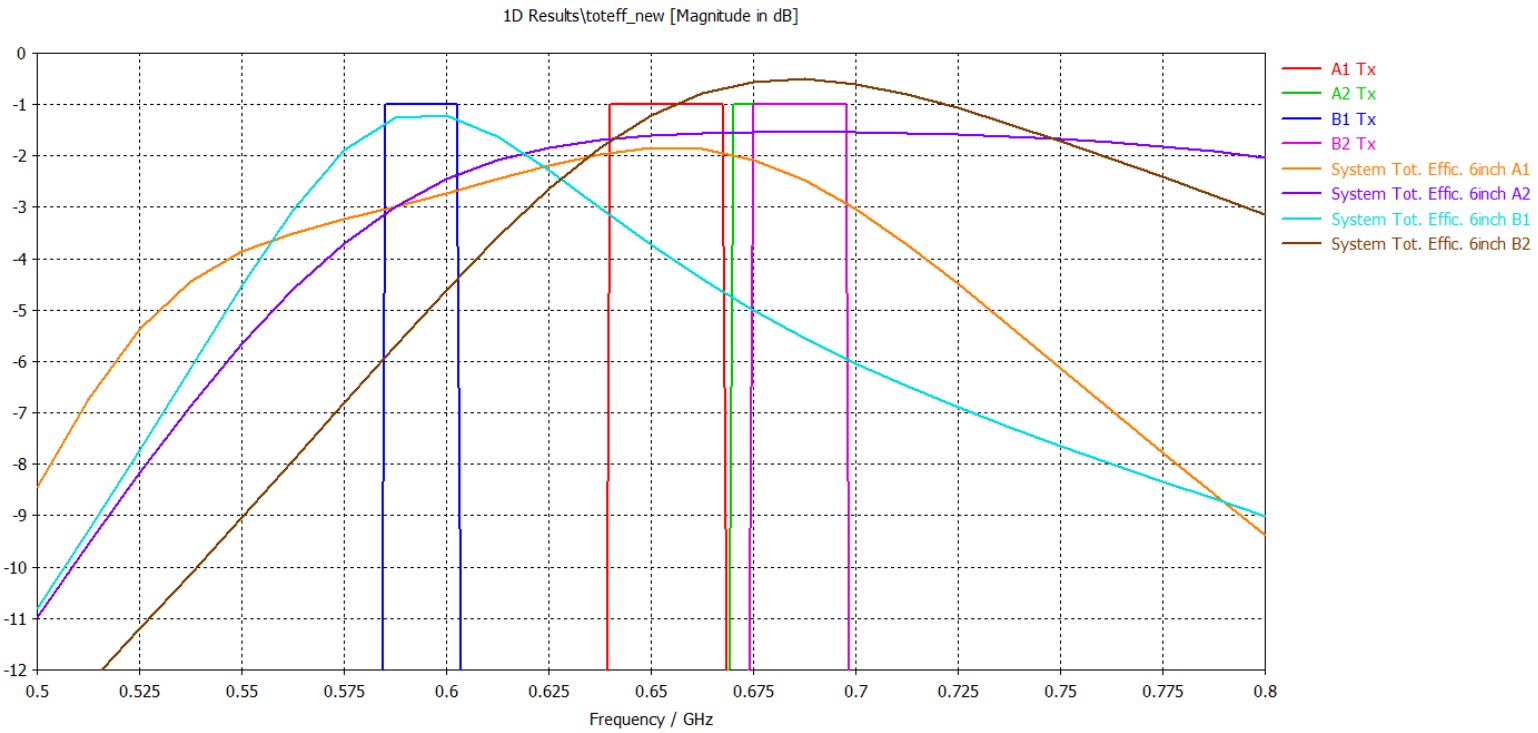
Total efficiencies for 6-inch devices



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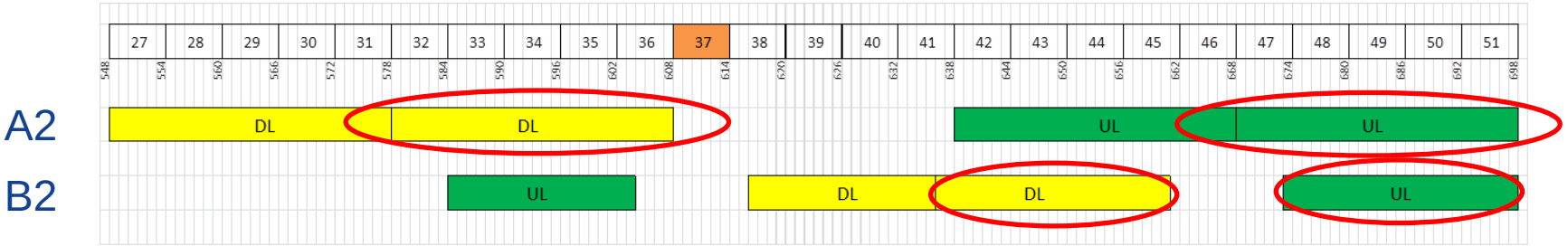
Summary for band combinations ’A2’ and ’B2’ using an antenna designed for the 600 MHz band

- 1.0 to 1.5 dB better efficiency with ’B2’ when compared to ’A2’ at Tx frequencies
- Matching not good enough with ’A2’ at Rx frequencies



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B17 antenna tuned to 600 MHz: ’A2’ and ’B2’

Optimize for 2 dB worse efficiency for Rx frequencies in Optenni Lab

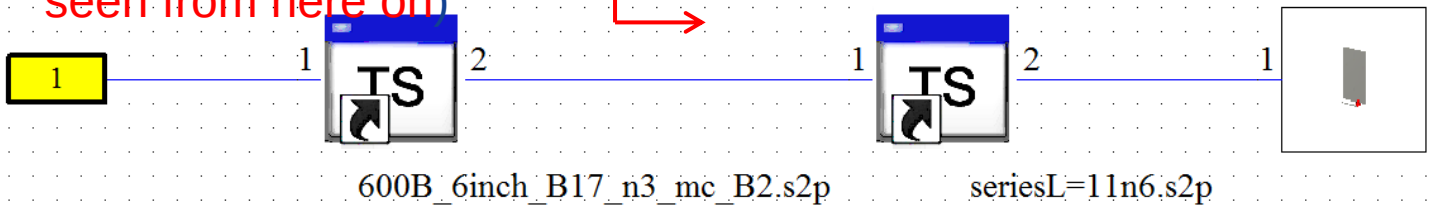
Total efficiency calculations for B17 antenna optimized at 600 MHz

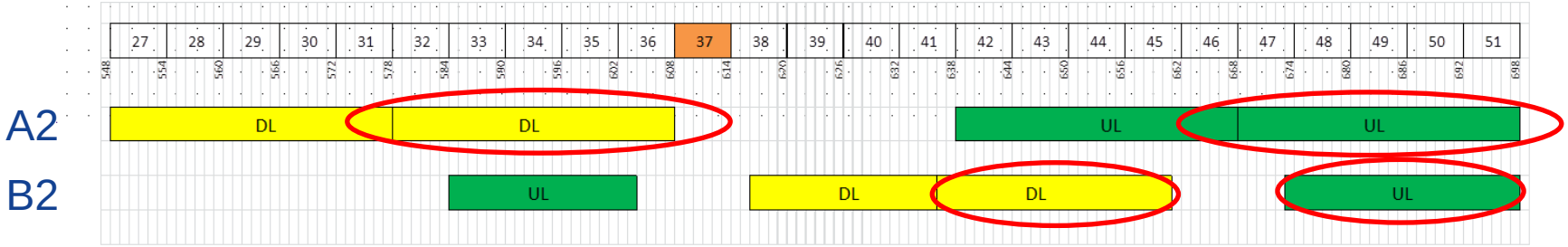
Z

Lossy matching network optimized for the 600 MHz band (Q14: impedance Z seen from here on)

Lossy inductor from the B17 matching circuit

Lossless and simple antenna model





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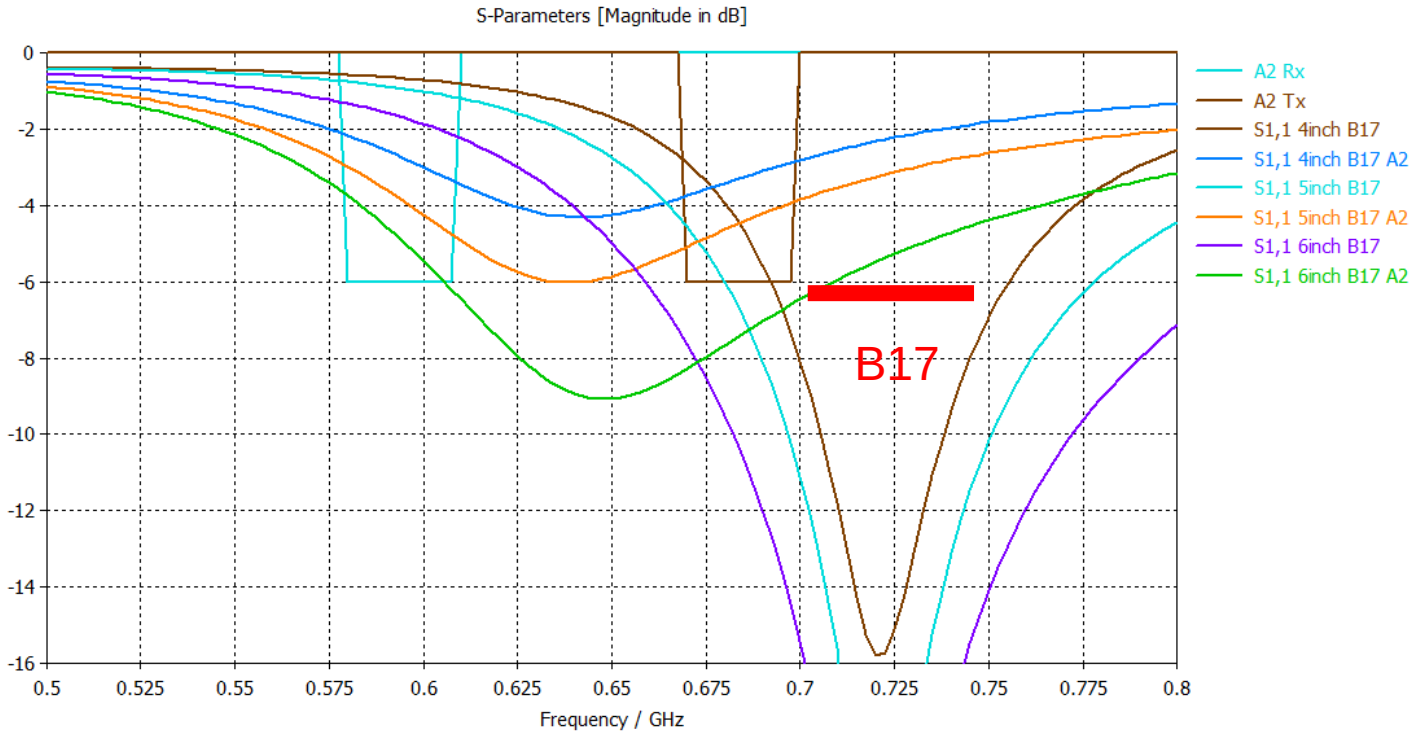
Matching levels for band combination A2 (B17 antenna)



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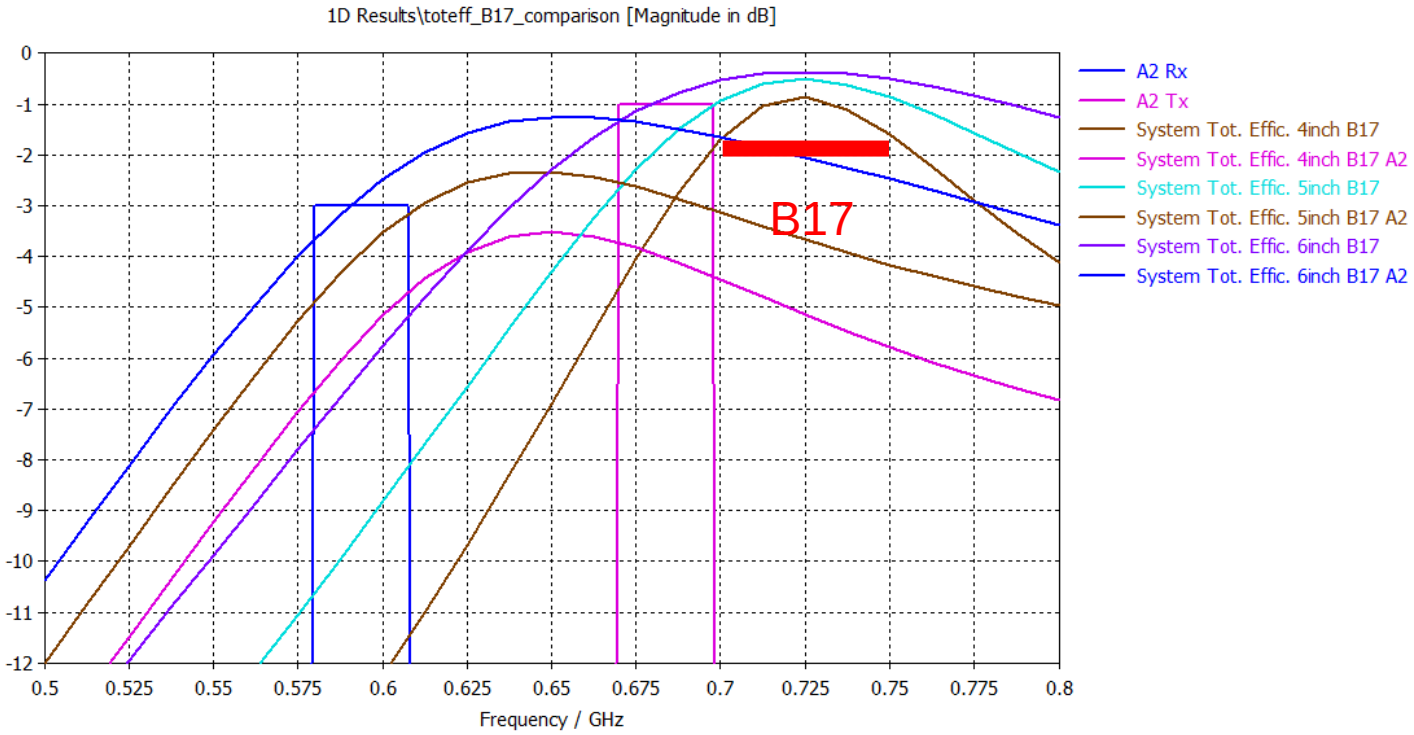
Total efficiencies for band combination A2 (B17 antenna)



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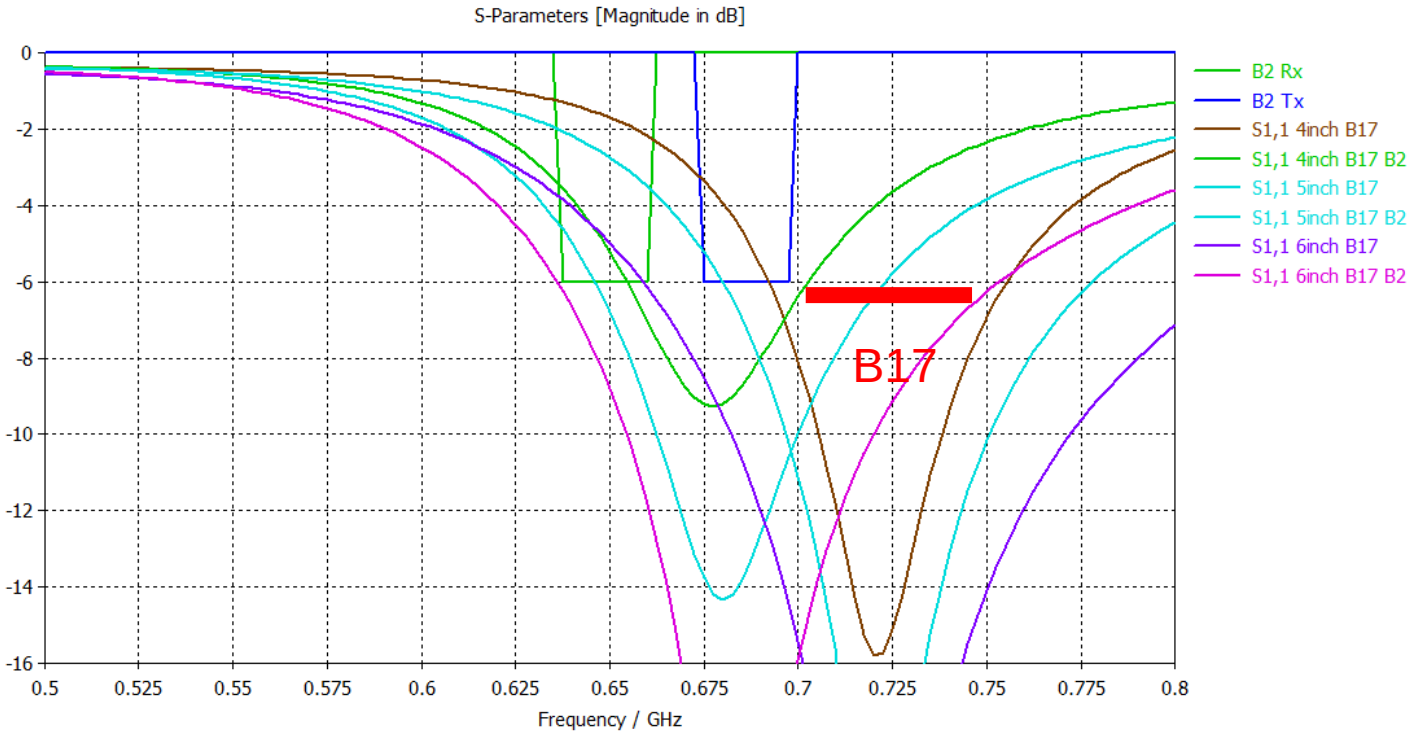
Matching levels for band combination B2 (B17 antenna)



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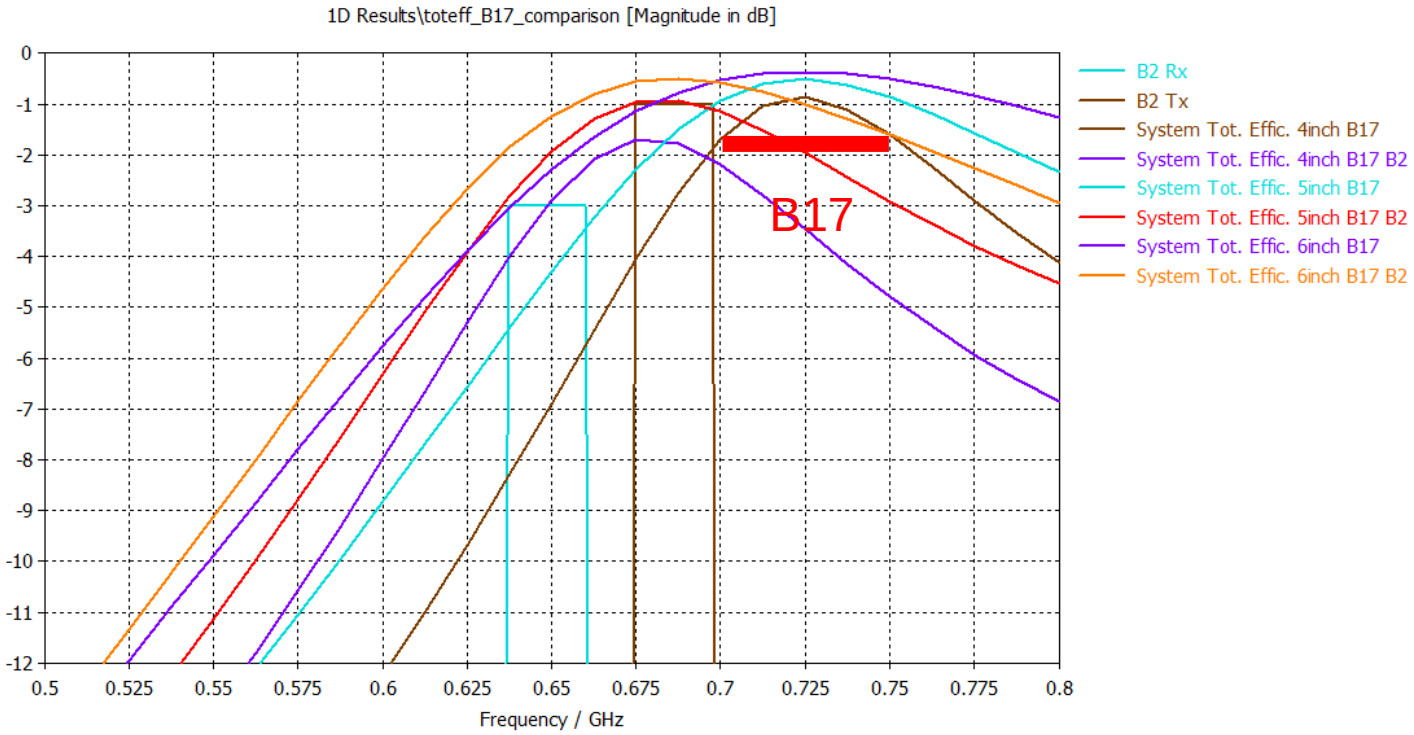
Total efficiencies for band combination B2 (B17 antenna)



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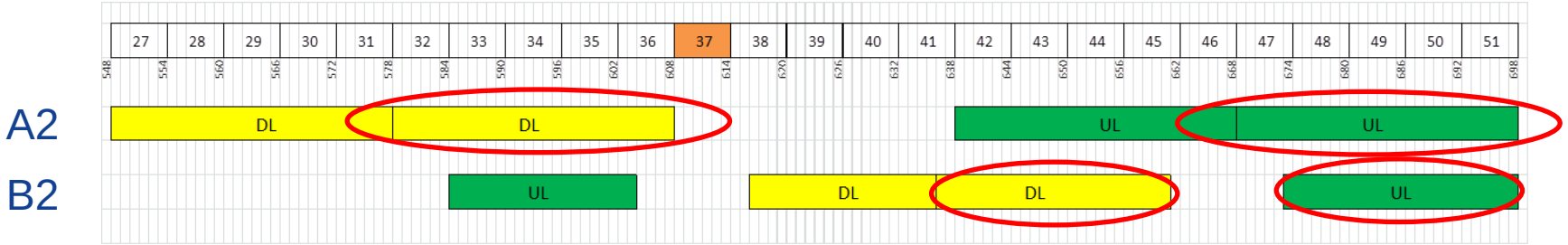
Summary for band combinations ’A2’ and ’B2’ using a B17 antenna

- B17 antenna can be tuned down in frequency in the ’A2’ case only with 6 inch devices. In that case the efficiency penalty is about 1 dB and the matching at Rx frequencies is not good enough.
- In ’B2’ case smaller devices can be tuned down with less than 1 dB efficiency penalty. 5 and 6 inch devices have good matching at Rx frequncies as well.



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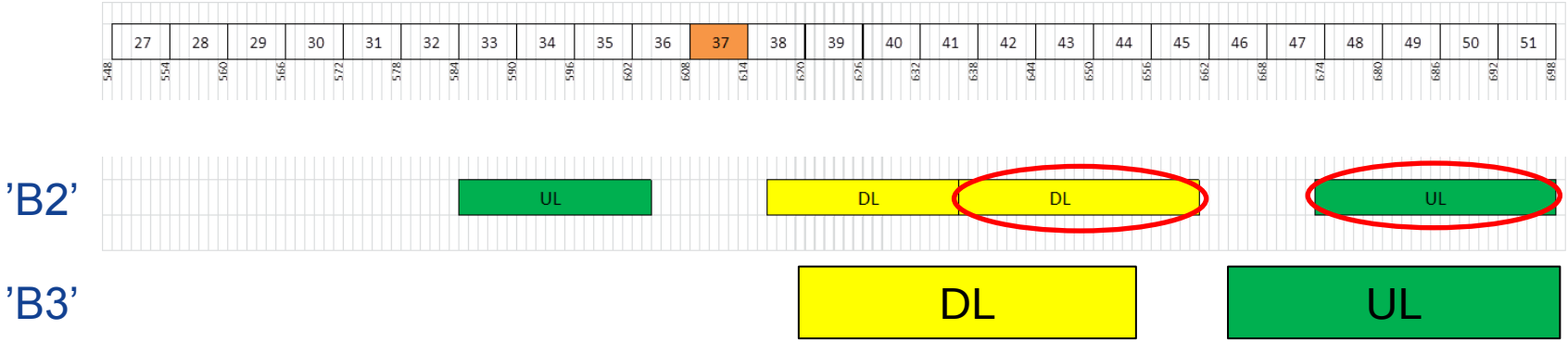
Emphasis on Tx frequencies and only the 600-MHz band considered

B2: 2x25MHz UL/DL
B3: 2x35MHz UL/DL

600 MHz band plan proposals ’B2’ and ’B3’



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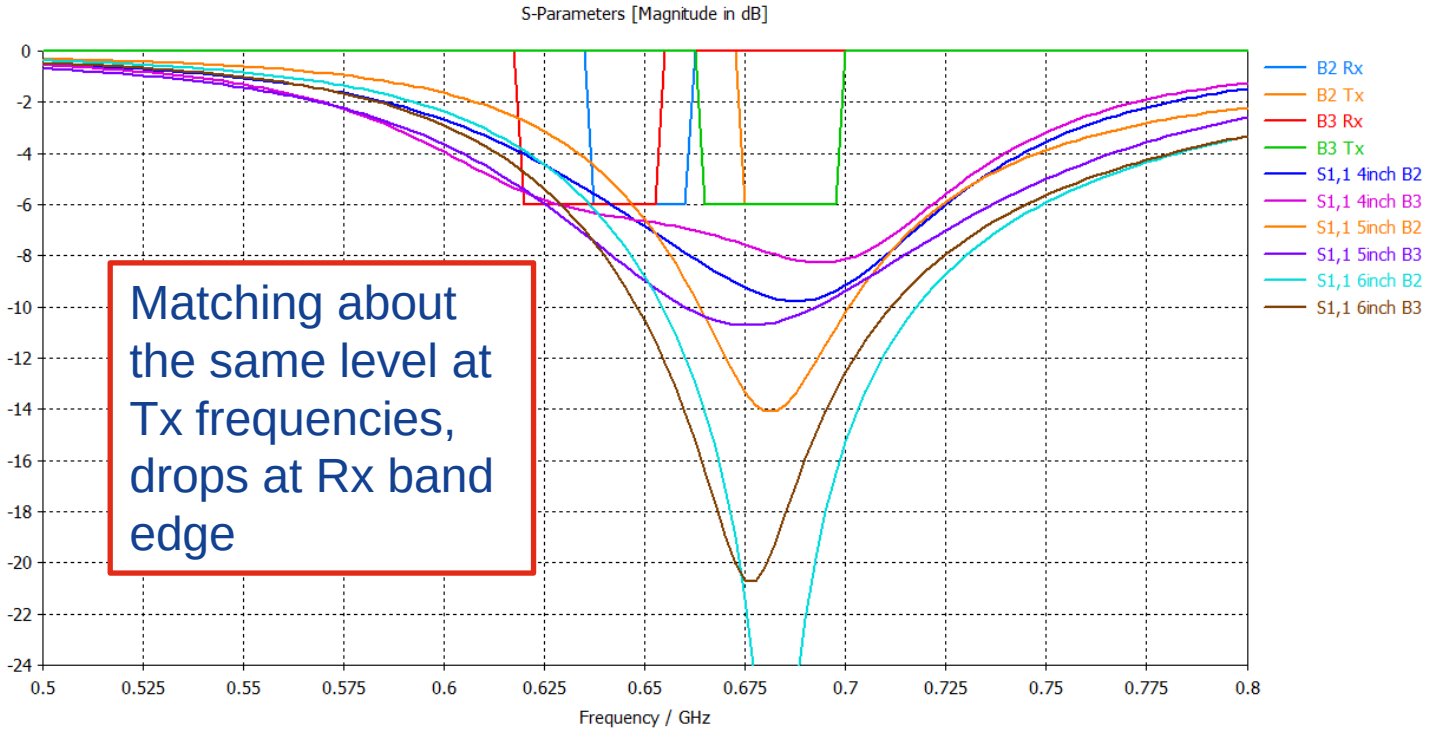
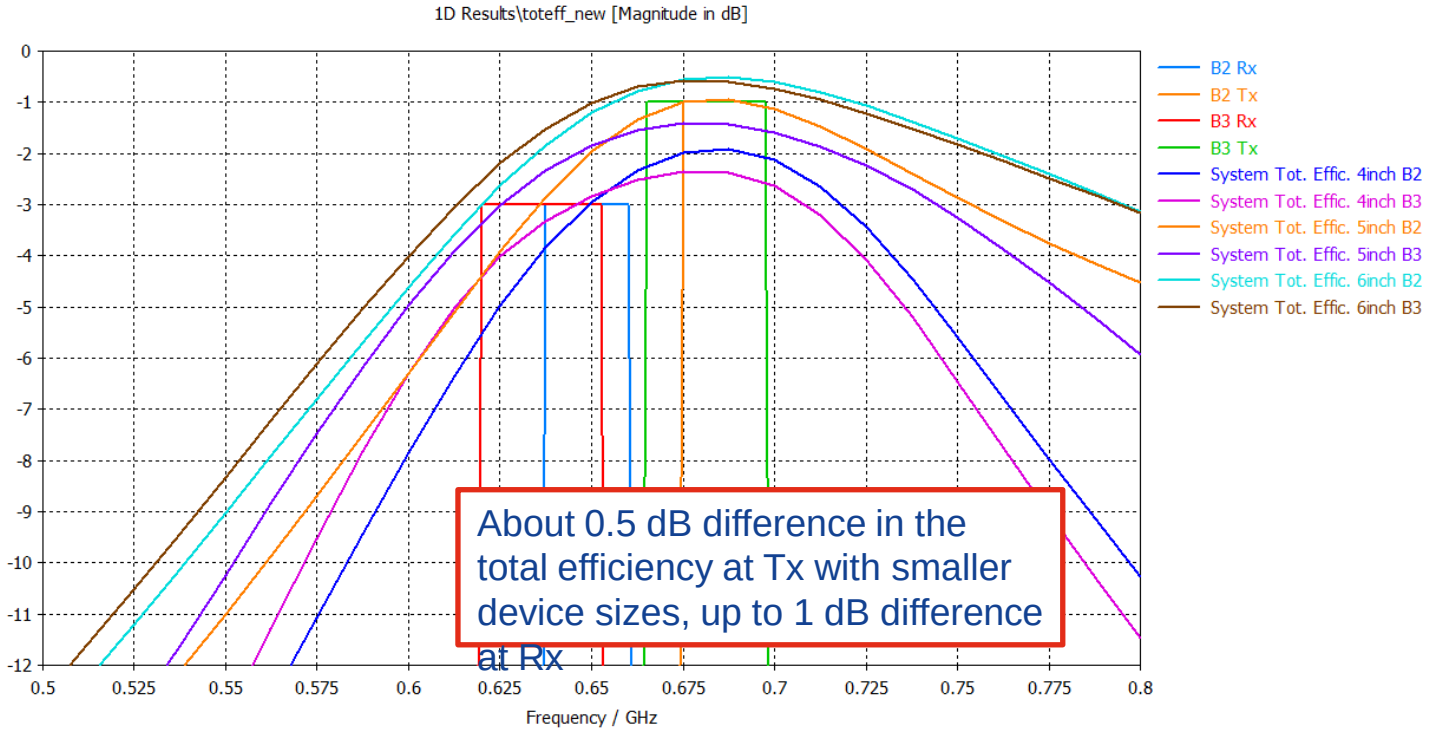
Matching levels for band combinations ’B2’ and ’B3’



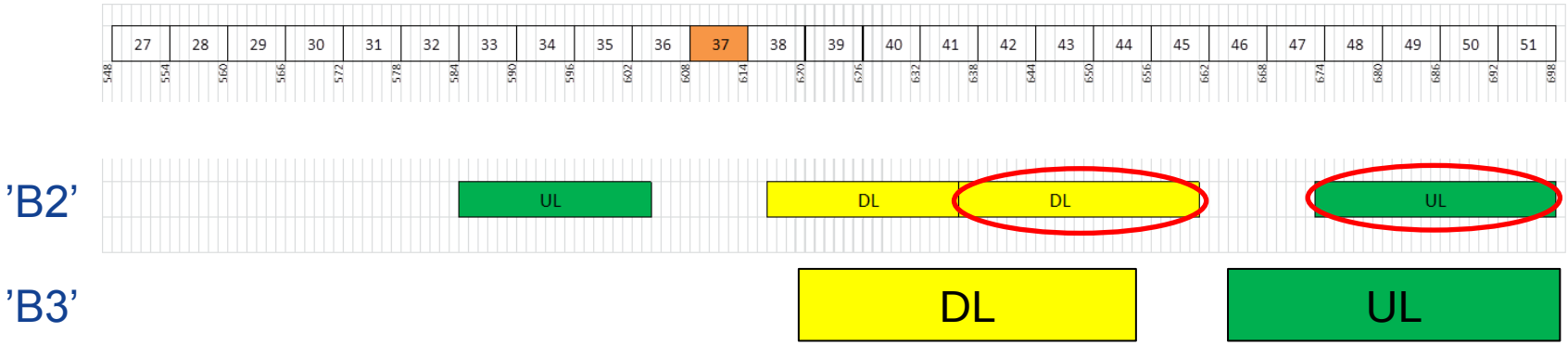
Total efficiencies for band combinations ’B2’ and ’B3’



About 0.5 dB difference in the total efficiency at Tx with smaller device sizes, up to 1 dB difference at Rx

Summary for band combinations ’B2’ and ’B3’

- With similar antenna and device size, ’B3’ has about 0.5 dB worse efficiency at Tx frequencies
- At the lower Rx band edge, ’B3’ has about 1 dB worse efficiency



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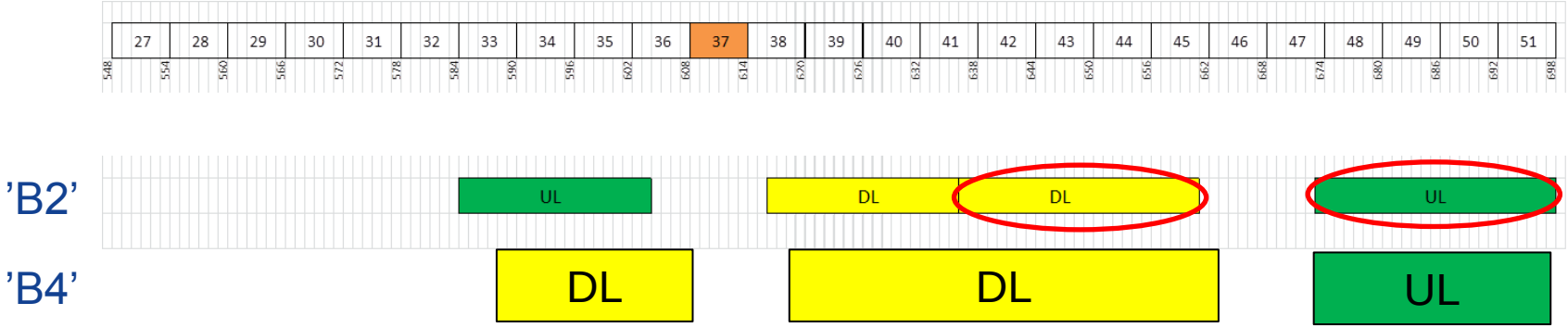
Emphasis on Tx frequencies and only the 600-MHz band considered

B2: 2x25MHz UL/DL
B4: 2x25MHz UL/DL + 2x20MHz DL/DL

600 MHz band plan proposals ’B2’ and ’B4’



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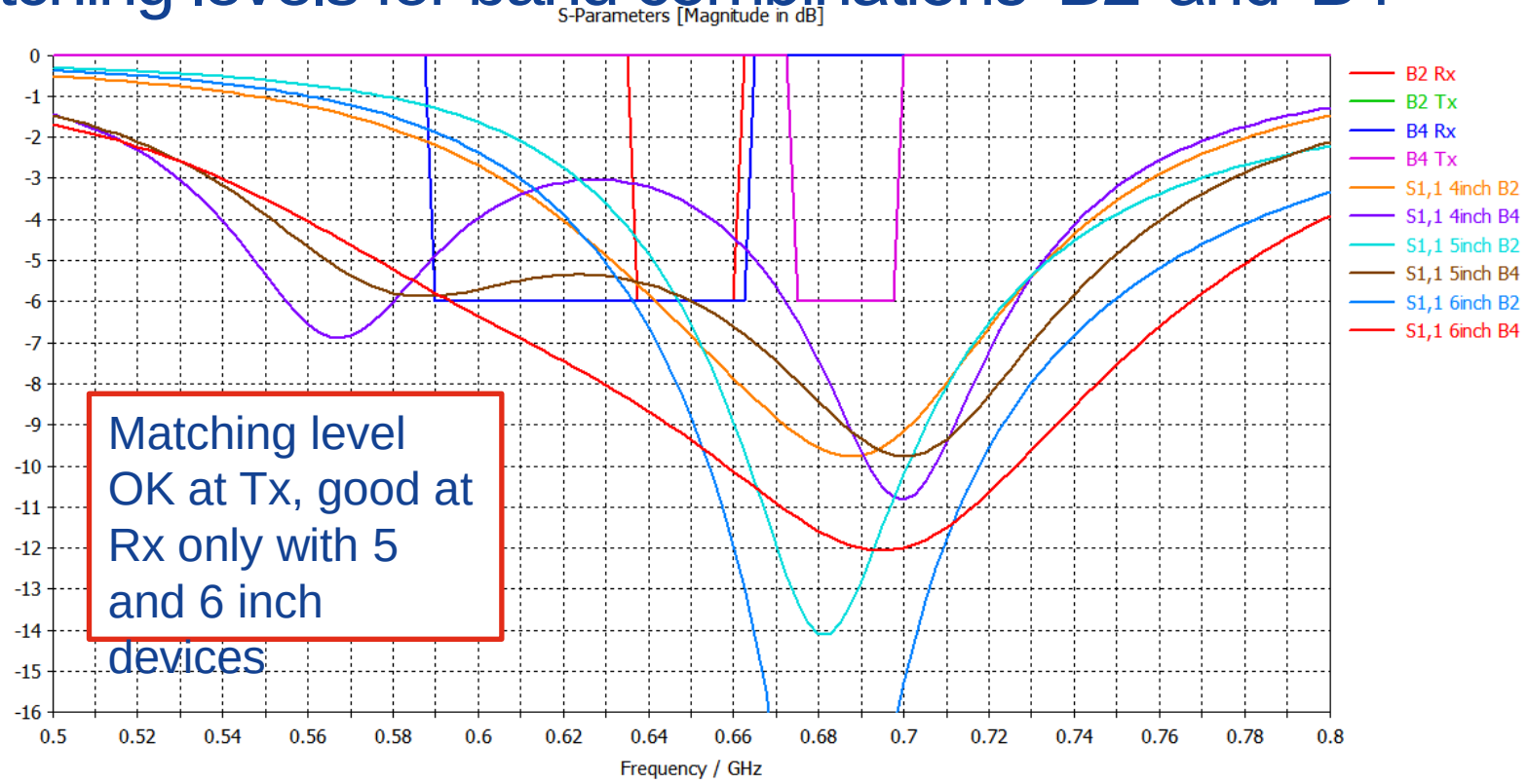
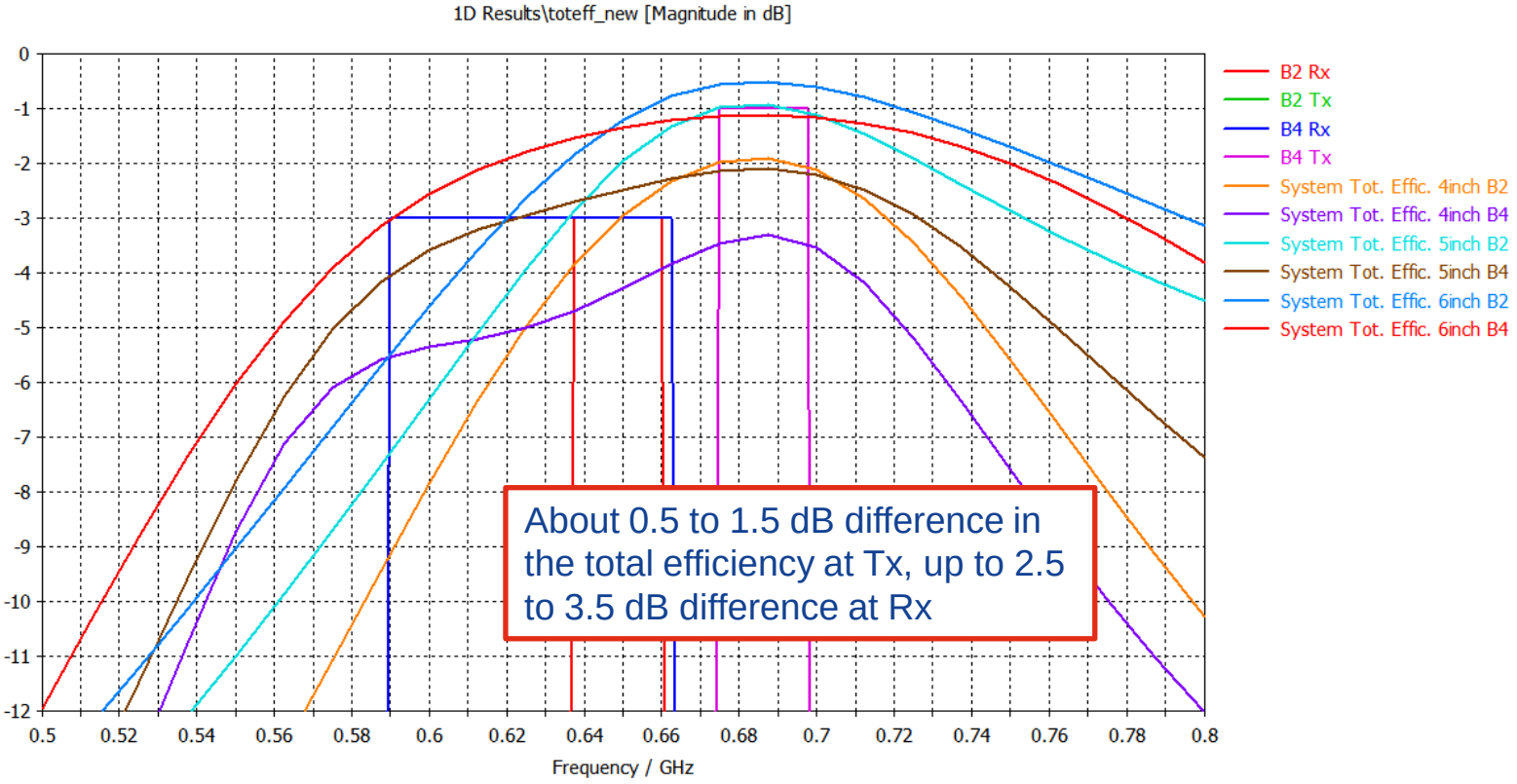
Matching levels for band combinations ’B2’ and ’B4’



Matching level OK at Tx, good at Rx only with 5 and 6 inch devices

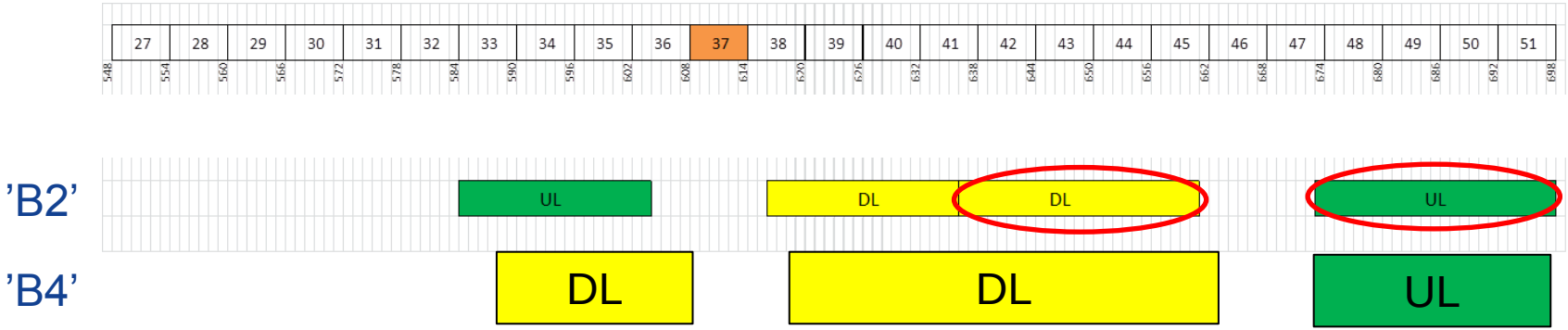
Total efficiencies for band combinations ’B2’ and ’B4’



About 0.5 to 1.5 dB difference in the total efficiency at Tx, up to 2.5 to 3.5 dB difference at Rx

Summary for band combinations ’B2’ and ’B4’

- With similar antenna and device size, ’B2’ has about 0.5 to 1.0 dB better efficiency at Tx frequencies
- At the lower Rx band edge, ’B4’ has about 2.5 to 3.5 dB better efficiency



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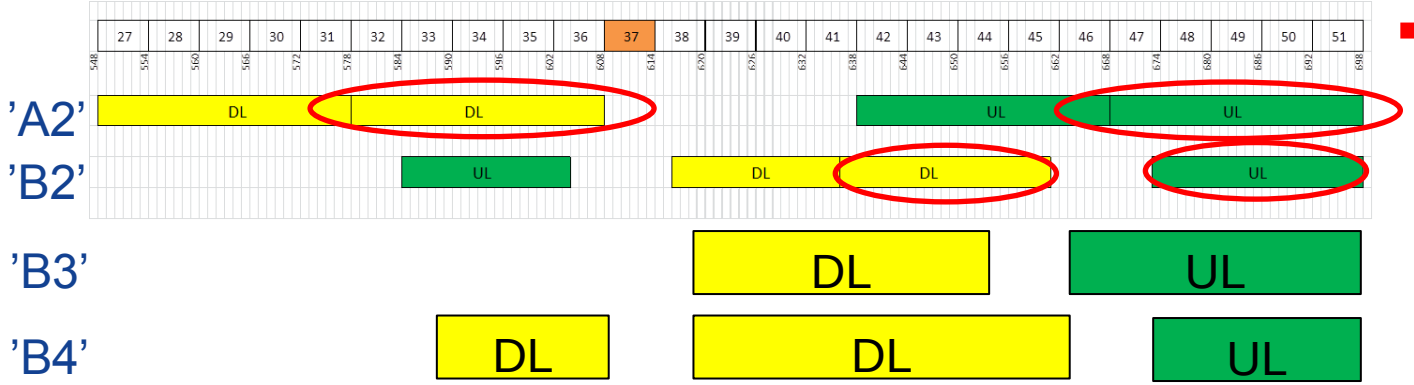
Conclusion

1. The closer the Tx and Rx bands are the better, the efficiency and matching are
2. The higher the absolute band is in frequency, the better the performance
3. If a B17 antenna should be used at 600 MHz, the 600-MHz band should be right next to it
4. As a separate antenna, ’B2’ is the easiest case, ’B3’ is most likely the second easiest, and ’A2’ and ’B4’ are the hardest



B17

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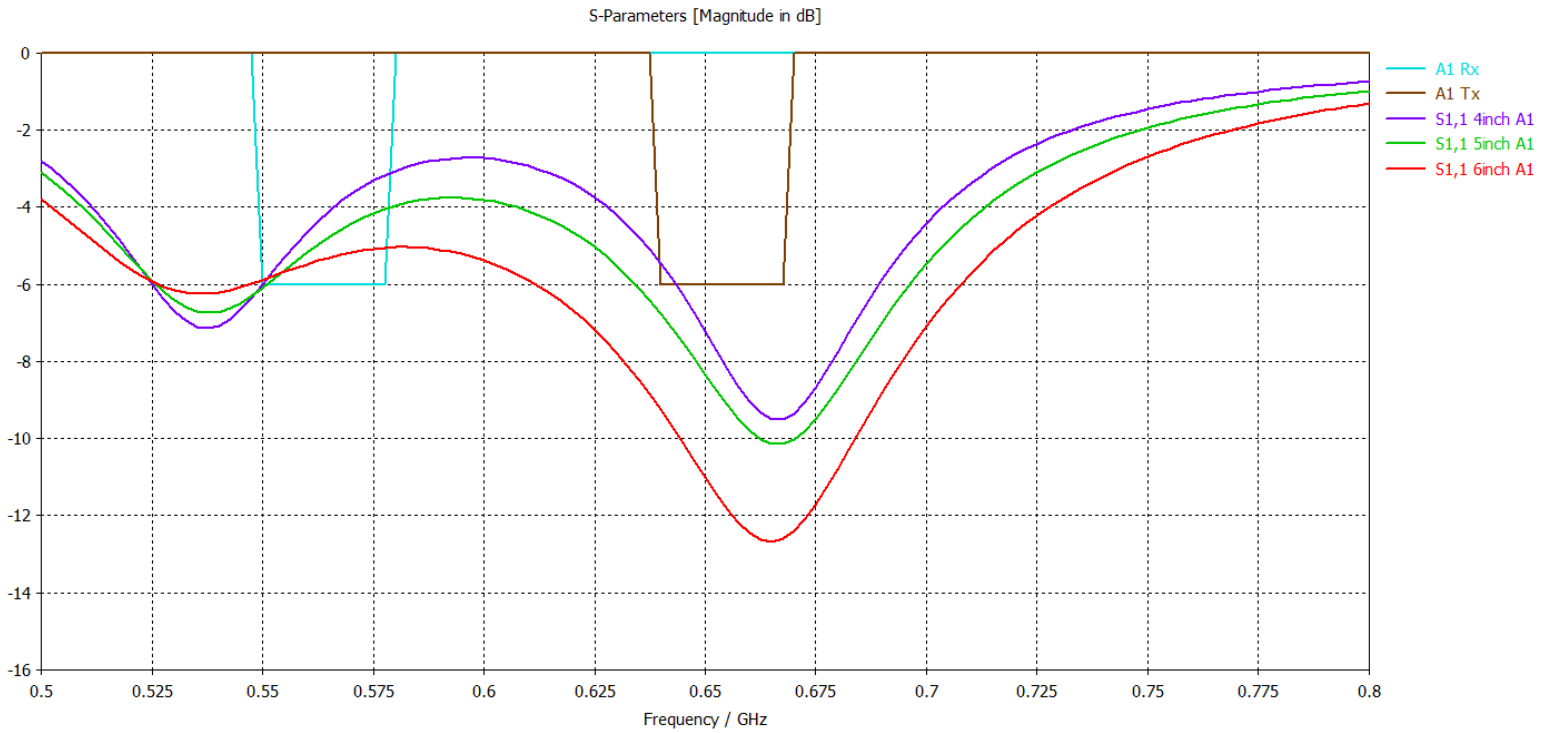
Back-up slides

Matching levels for band combination A1



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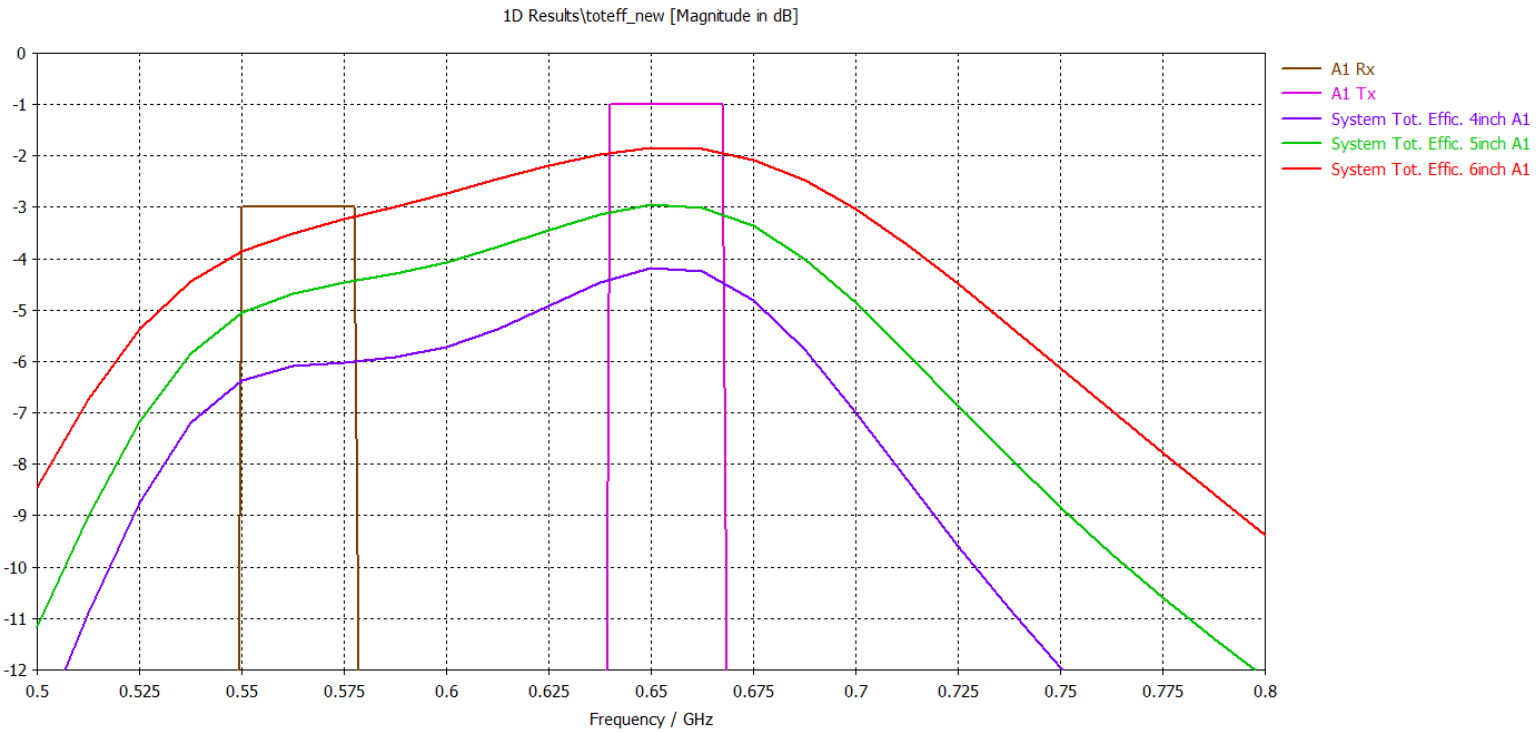
Total efficiencies for band combination A1



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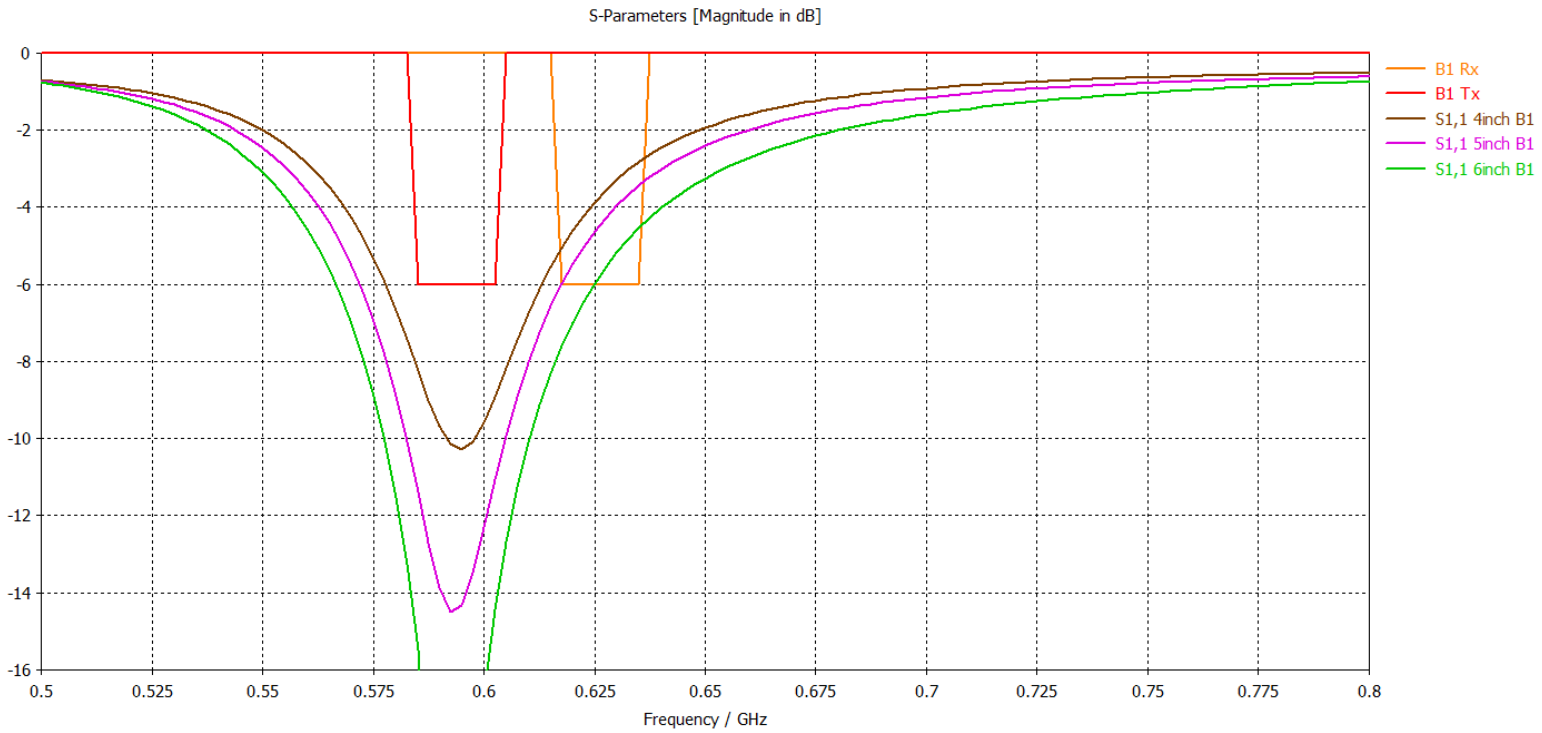
Matching levels for band combination B1



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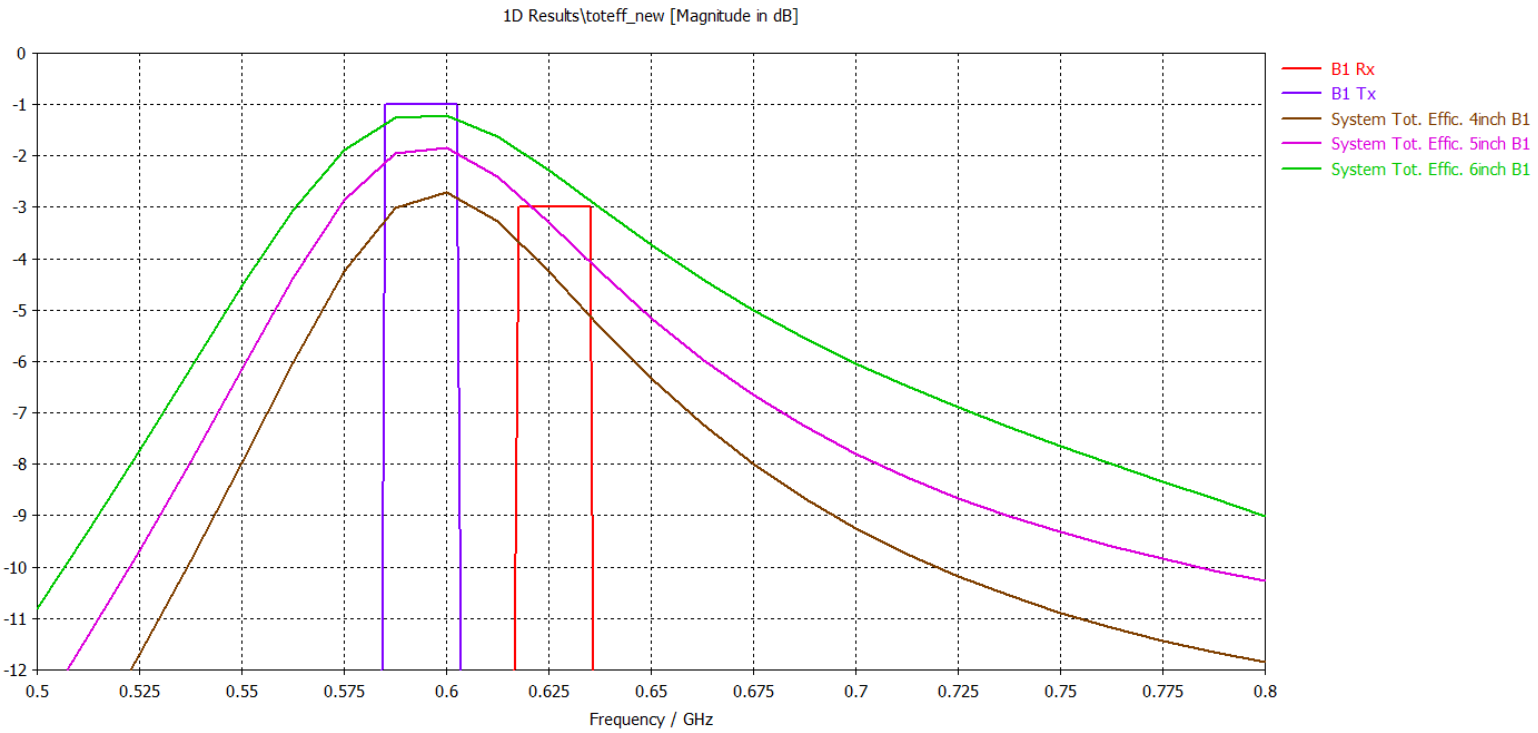
Total efficiencies for band combination B1



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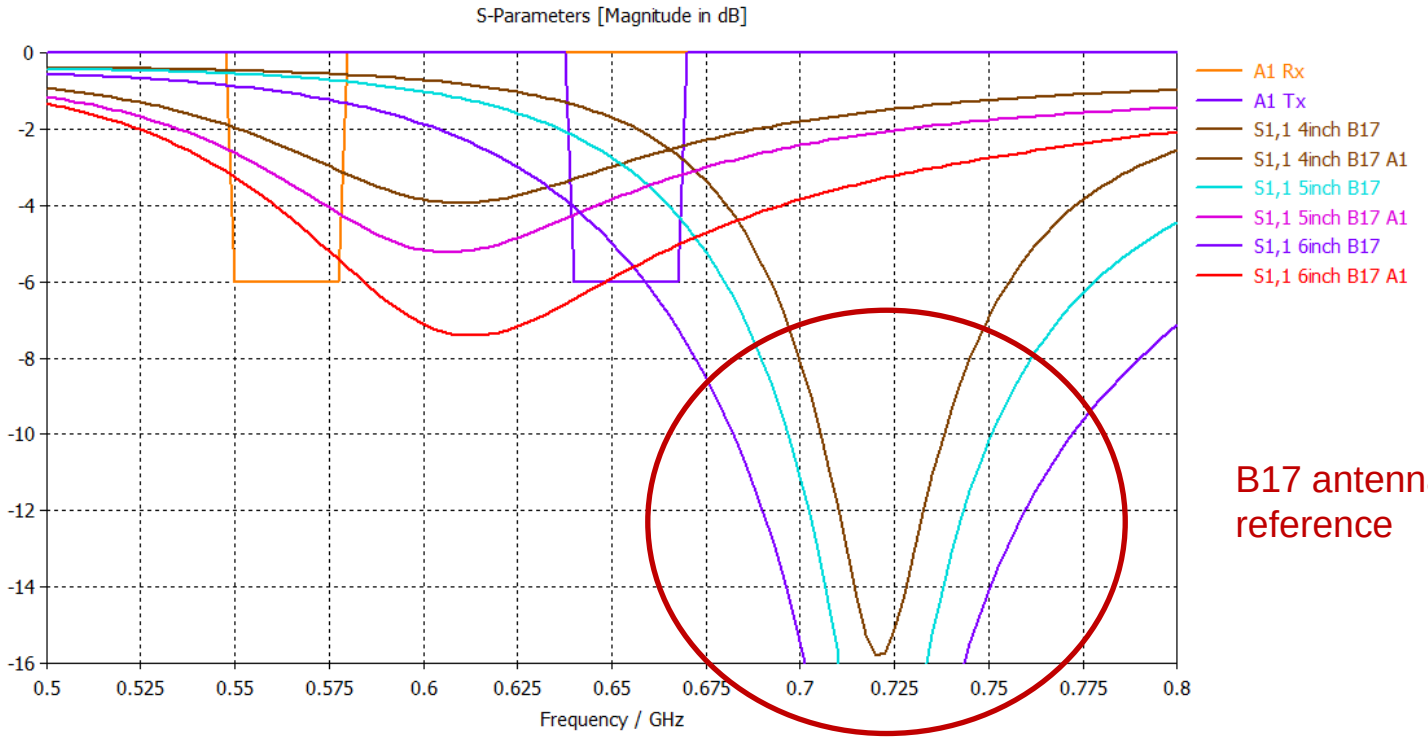
Matching levels for band combination A1 (B17 antenna)



B17 antenna as a reference

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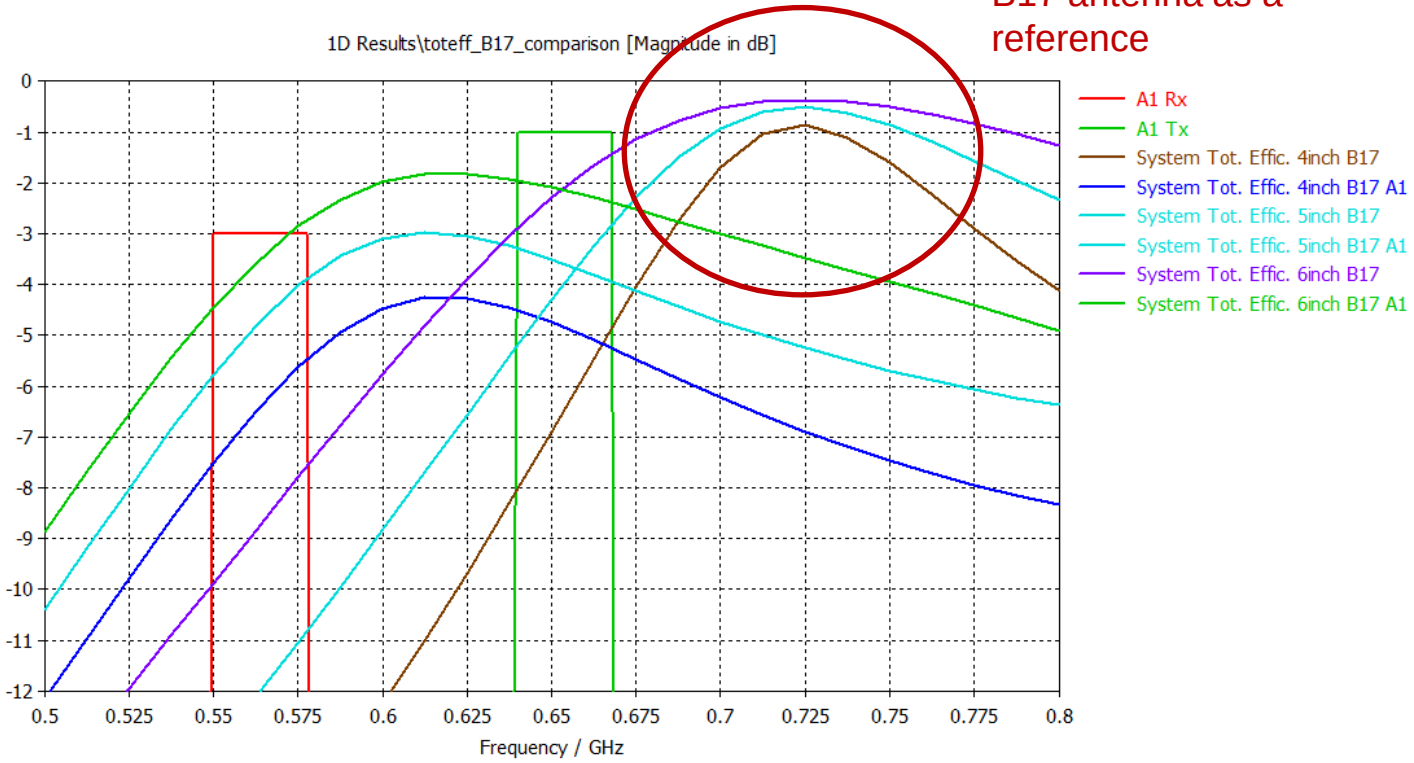
Total efficiencies for band combination A1 (B17 antenna)

B17 antenna as a reference



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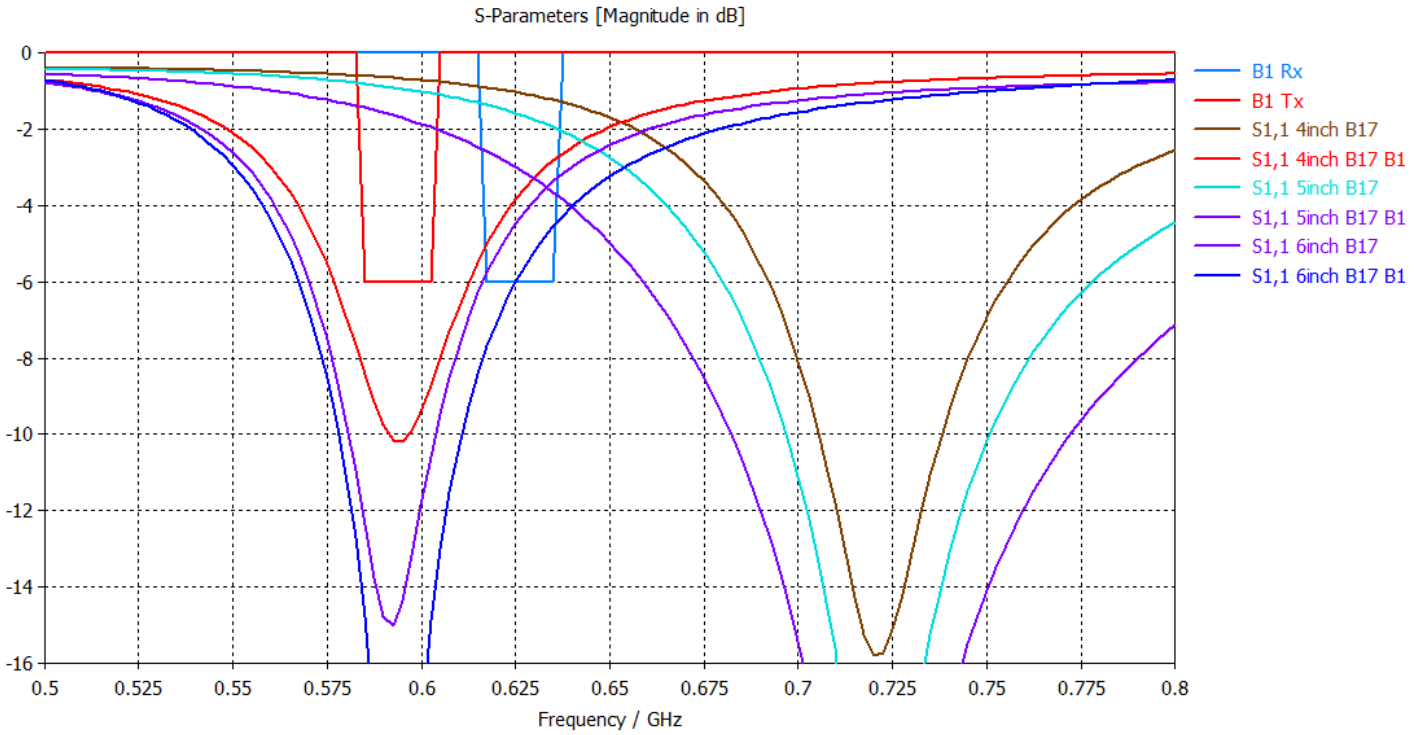
Matching levels for band combination B1 (B17 antenna)



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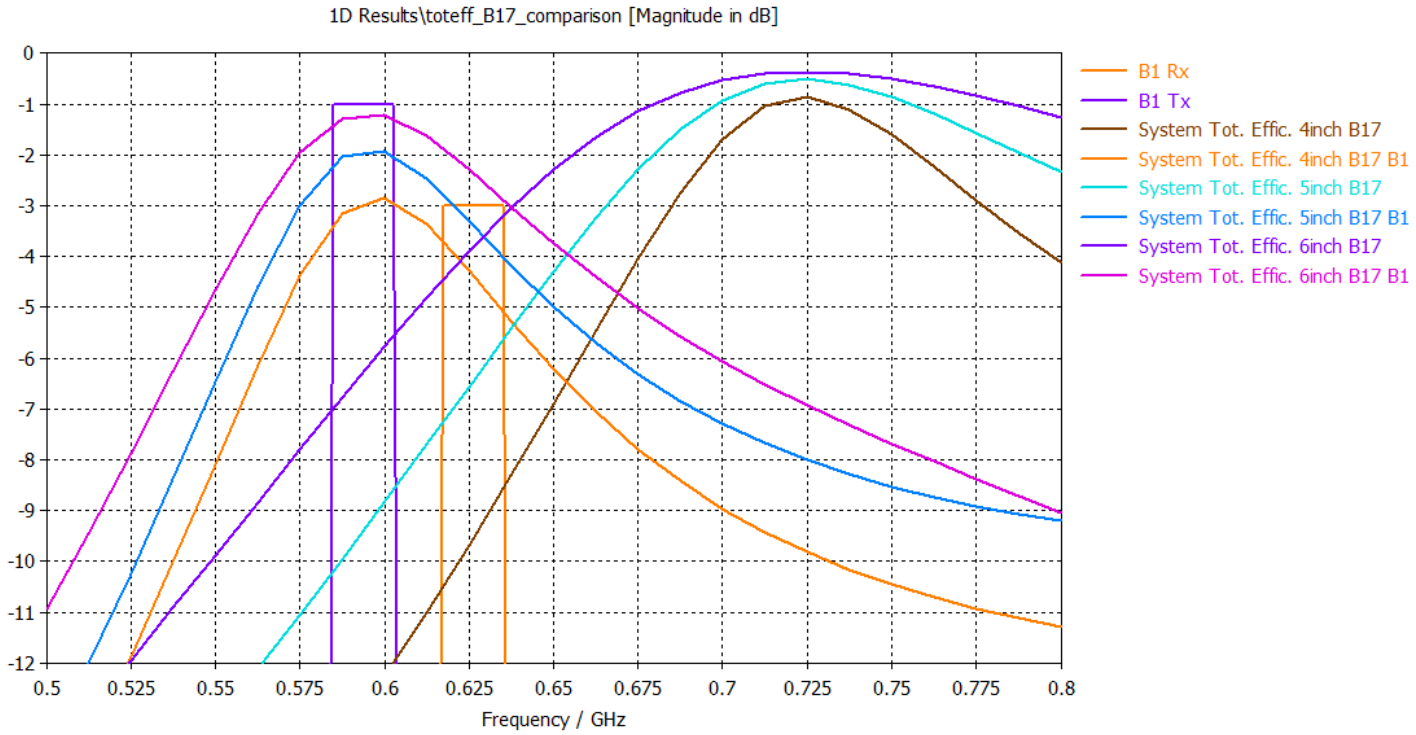
Total efficiencies for band combination B1 (B17 antenna)



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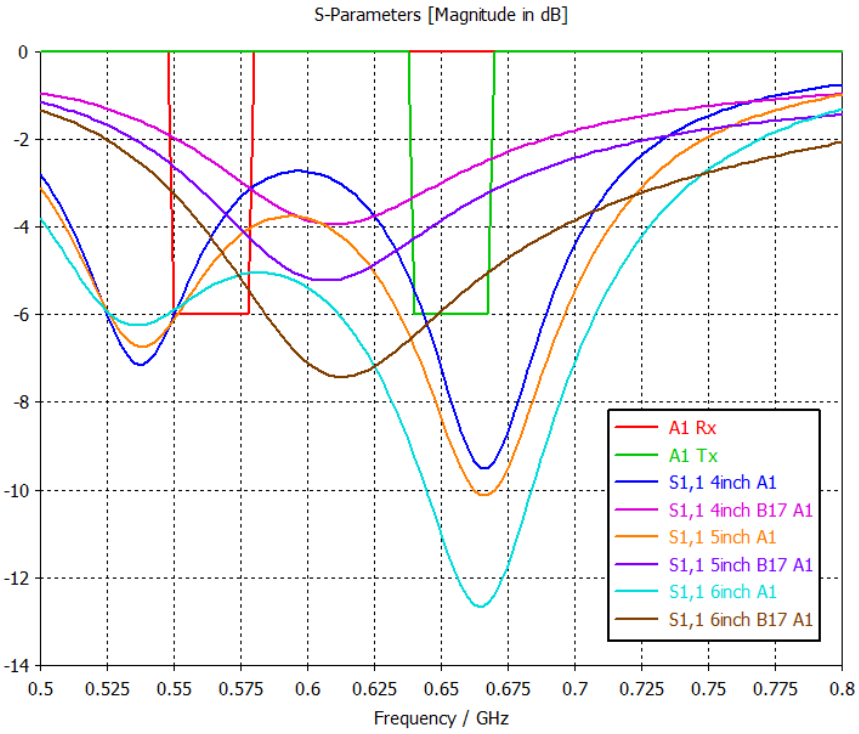
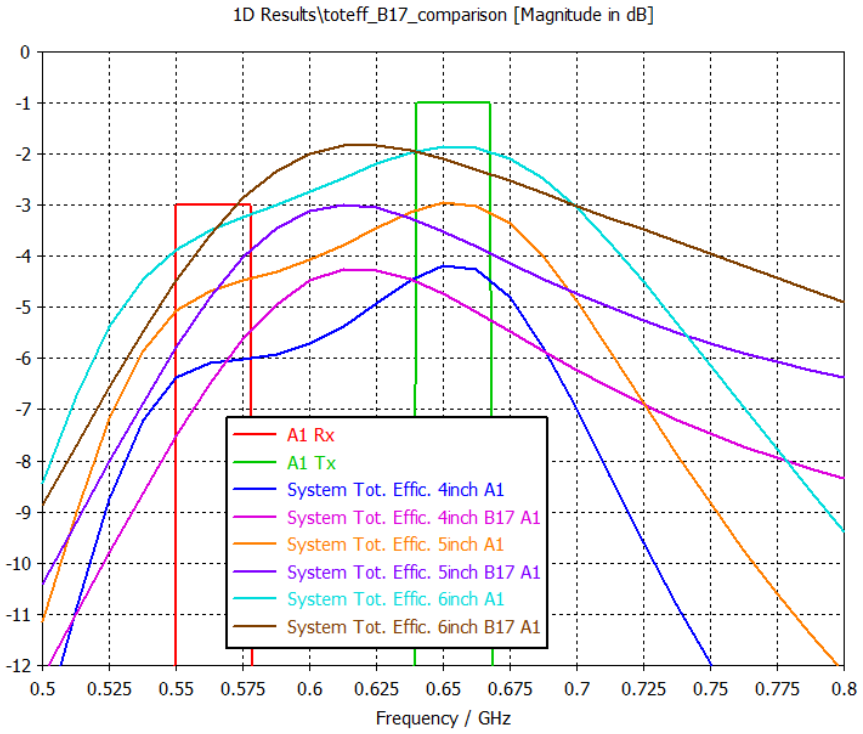
B17-to-600-MHz-optimized and 600-MHz-optimized antenna comparison: A1 (example)





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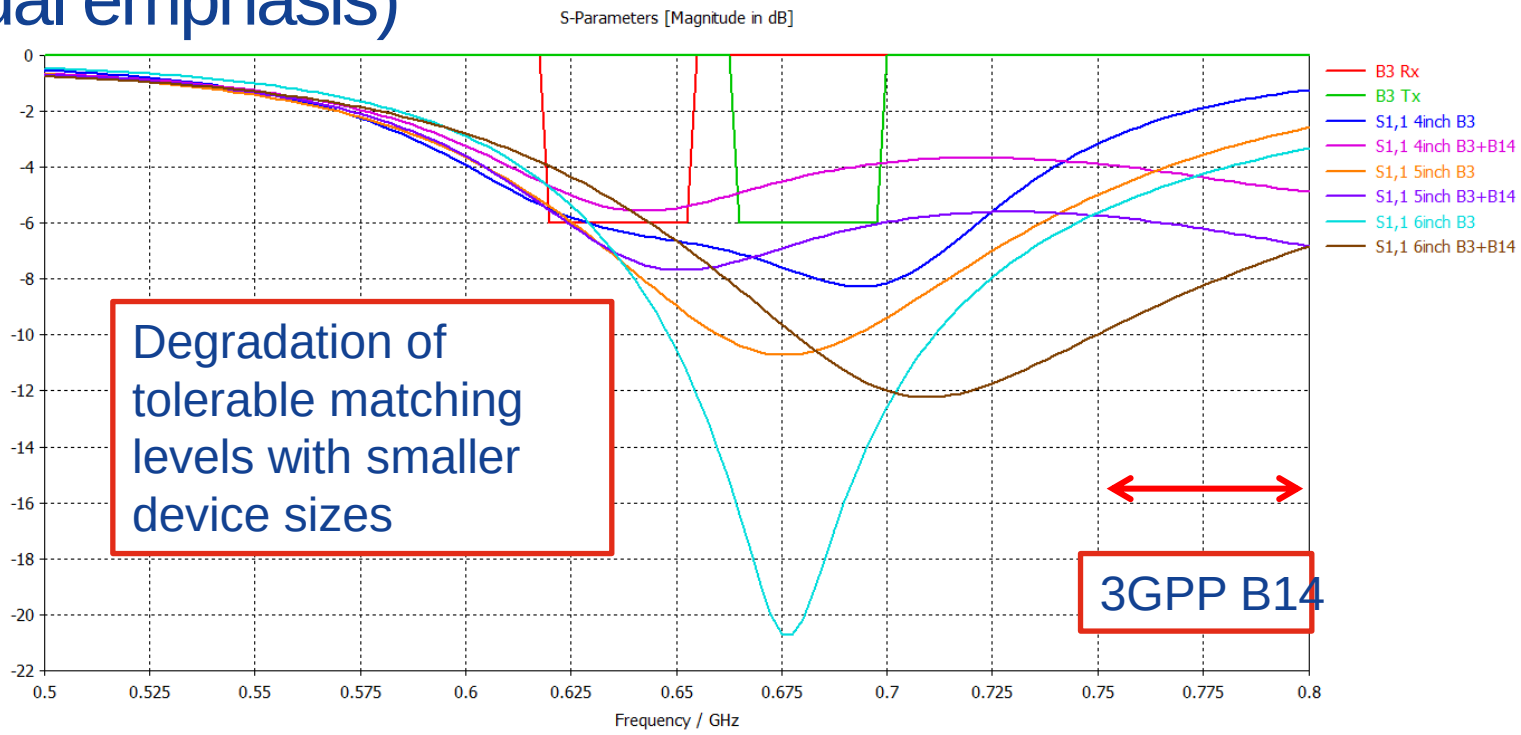
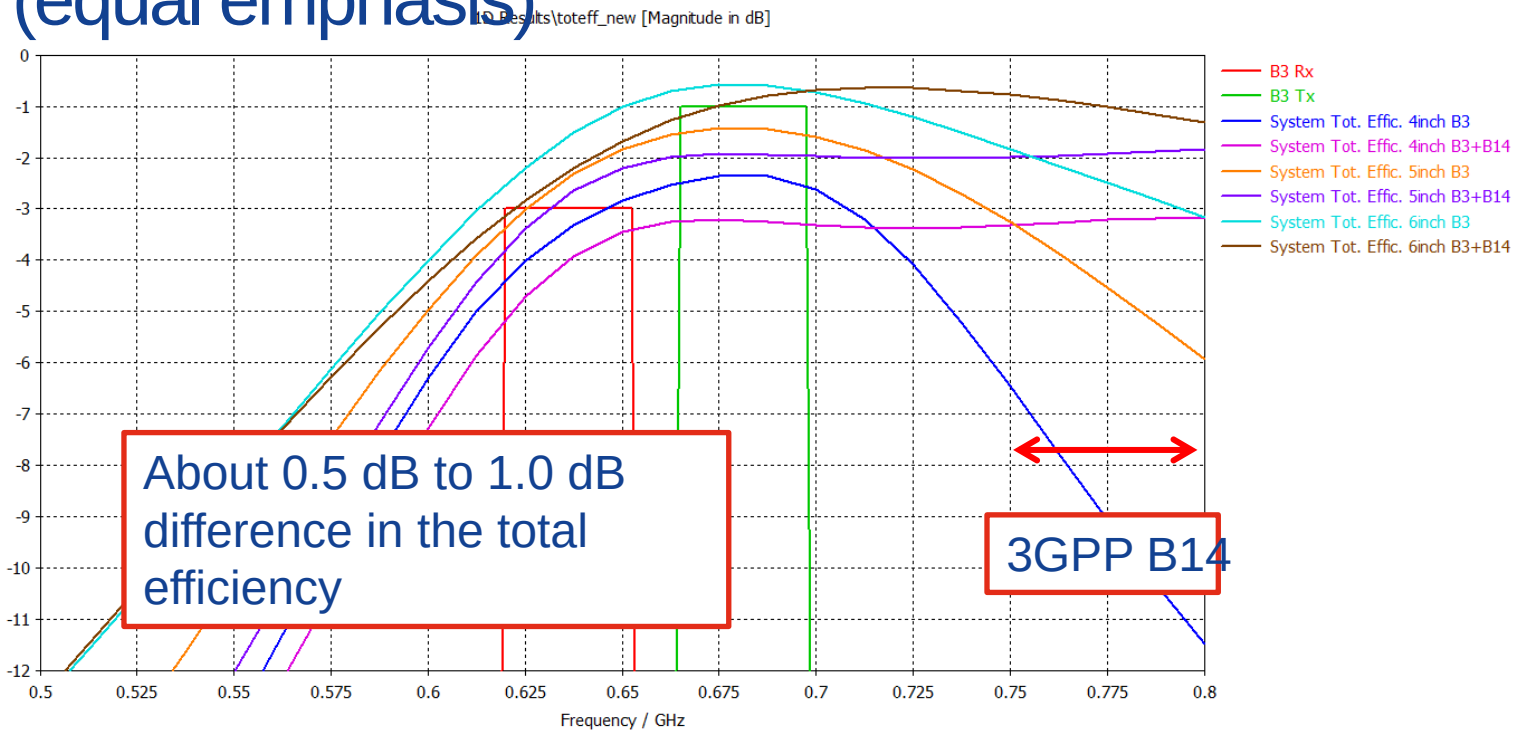
Matching levels for band combinations ’B3’ and 3GPP B14 (equal emphasis)



Total efficiencies for band combinations ’B3’ and 3GPP B14 (equal emphasis)



Comments: 600 MHz only, A1, A2, B1, and B2

- Good matching levels (-6 dB) obtainable for all Tx frequencies, for Rx only with the ’B2’ proposal.
- One inch increase in device size increases the total efficiency about 1 dB. The increase saturates with relatively large antennas with good matching levels
- 1 to 2 dB total-efficiency difference between the band proposals at Tx frequencies

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Comments: 600 MHz with B17 antenna, A1, A2, B1, and B2

- Good matching levels (-6 dB) obtainable for all device sizes at Tx frequencies only in B1 and B2 cases and in the A2 case with 6-inch device
- One inch increase in device size increases the total efficiency about 1 dB. The increase saturates with relatively large antennas with good matching levels
- 1 to 2 dB total-efficiency difference between the band proposals at Tx frequencies
- 1 to 4 dB total-efficiency difference between B17 antenna and B17 antenna tuned at 600-MHz bands, also the matching difference can be large
- Not much difference in total efficiencies between B17-to-600-MHz and 600-MHz optimized antennas, large difference in matching

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Conclusion (A1, A2, B1, and B2)

- As a general result, one inch increase in device size increases the total efficiency about 1 dB. This is due to the lower eigenfrequency of the ground plane currents in larger devices (the impedance is easier to match). The increase saturates with relatively large antennas with good matching levels
- 1 to 2 dB total-efficiency difference between the 600-MHz band proposals at Tx frequencies
- 1 to 4 dB total-efficiency difference at Tx frequencies between B17 antenna and B17 antenna tuned to 600-MHz bands
- Not much difference in total efficiencies between B17-to-600-MHz and 600-MHz-band-optimized antennas, but large differences in matching because the matching cannot be properly optimized. Bad matching leads to load-pull problems with the power amplifier.

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