Student Design Competition
IEEE IMS 2024 Washington, DC

Reflectionless High-pass Filter Design for Load-Pull Measurement Setups

TC-3 Microwave Measurements Committee, TC5-Filters Committee

Introduction

Filters are frequently used and are essential products in communication systems. They are passive components that process a signal to select (such as a bandpass filter) or eliminate a specific frequency (such as a notch filter). Traditional filter topologies demonstrate large reflections out of the pass band due to their structures. This may cause stability problems in wideband systems.

Re-designing filters with reduced reflections (or matched) in the stopband is possible, and it supports the systems' reliability since it helps to eliminate unexpected resonances and oscillations [1,2].

Large signal measurement setups are quite complicated systems often requiring many different components used to control power and impedances. They are mostly used for source-pull and load-pull measurements. Although it is expected that a DUT should remain stable enough to perform source-pull and load-pull measurements, band-limited components, such as circulators and diplexers, can cause unwanted resonances on load-pull setups, leading to oscillations during the measurements.

The stability of RF transistors and circuits is a vast topic but, we know that some basic methods can prevent oscillations. Providing a wideband 50 Ω termination at the input of the network is quite handy to improve the stability [3]. Figure 1 depicts an active load-pull setup's input stage. In this configuration, the bias-tee and coupler often provide wide operation bandwidth with small insertion loss. However, the circulator below 10 GHz typically has less than 20% bandwidth. This means that it will have a large reflection outside of the operation band which might cause undesired resonances.

In this design competition, the students will design a reflectionless filter to use in a load-pull setup to improve the stability of the DUT.

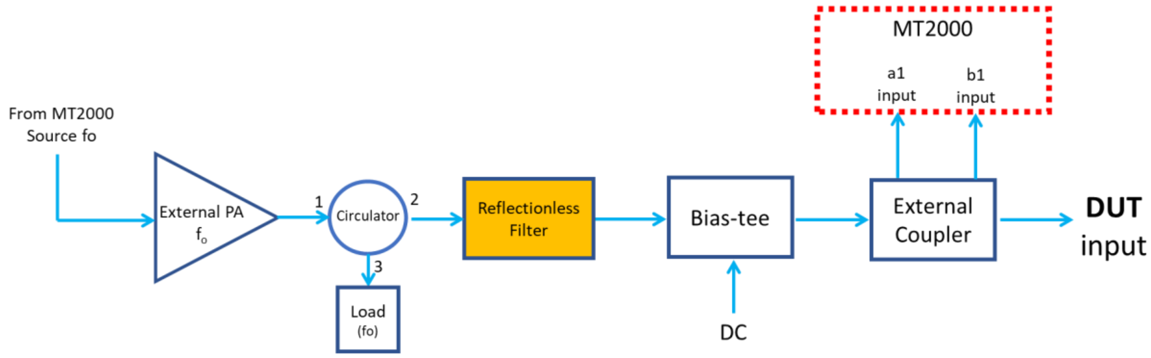

Figure 1. Input stage configuration of an active load-pull setup.

Design specifications and rules

In this competition, the students will design a reflectionless bandpass filter. Here are the design specs and rules:

- Passband: max 1.5 dB insertion loss between 2.3 GHz and 6 GHz (There is no limit for max frequency, check the "Scoring" for details)
- Stopband: min 10 dB insertion loss at 1.7 GHz (There is no limit for min frequency, check the "Scoring" for details)
- S11 and S22 should be lower than -13 dB between 1.7 GHz and 6 GHz
- Any substrate materials and passive components (ceramic, multi-layer, etc.) are allowed to design the circuits.
- The connectors should be Female type and suitable for 3.5 mm Male cable connections (such as 2.92 mm, 3.5 mm, or SMA)
- The total area of the designs should not exceed 300 cm^2 (15 cm x 20 cm, 30 cm x 10 cm, etc.).
- No active components, such as transistors or ICs are allowed. There should not be any biasing requirement or battery (or supercapacitor) connected.

Students can contact the organizing committee for their questions and technical guidance anytime. We are more than happy to answer their questions and share our design and fabrication experience.

The Design Competition is open to teams of undergraduate and/or graduate students that are registered at a university or other educational institution. Students must show a valid student ID during the competition.

Students may enter as individuals or as a team. There may be no more than three students on a team. Each student may be a member of only one team. Each team may submit up to two entries but can only receive an award for one entry. There is no age restriction.

The students are advised to use e-mail addresses issued by their respective institutions for all communication regarding the competitions instead of personal e-mails (e.g., Gmail, Hotmail).

Evaluation process

A wideband VNA will be used to measure the S-parameters of the designed filters. The VNA will be calibrated at 0 dBm power using a Maury Characterized Calibration Kit, using SOL-R (unknown thru) and Insight Software. All measurements are referenced to 50 Ω impedance.

Before measurements, the organization committee will visually inspect the submitted circuit to ensure that there are no active components or biasing present. Sealed casings are not allowed. If the circuit is placed in a package or enclosure, it should be suitable for visual inspection (removable cover, transparent box, etc.).

The students will connect their circuit(s) to the coaxial RF cables having 3.5mm male connectors for the measurements. The implemented circuits should be structurally reliable enough to handle mechanical forces such as torquing and cable tension. The competition committee does not accept any responsibility in case of physical damages during the competition. The designs meeting the technical design rules will be evaluated during the competition.

No tuning is allowed during the S-parameter measurement while the circuit is connected to the VNA.

The connectors of the measurement ports will be 3.5mm Male type phase-stable coaxial cables. Therefore, the designs should have suitable Female connectors at their input and output ports. Max of 10 minutes will be given to each circuit to complete cable connections and prepare the circuit for the measurement. If there is enough time after measuring all of the participants' circuits, it may be possible to re-measure some circuits if time permits.

Remote participation is allowed if there is a last-minute travel issue, such as visa problems, COVID, etc. In that case, the circuits should arrive at the Maury Microwave US location at least 5 days before the competition. The organizers will do their best to protect the circuits and measure safely. Organizers do not accept any responsibility in the case of an damage or loss during the shipment.

Scoring

The winner will be determined by the circuit that achieves the widest bandwidth in compliance with the design rules. The below scoring will be used to evaluate the designs based on their 2-port S-parameter measurement results:

- Passband (>6 GHz) Score = ([Max Frequency (S11 & S22 < -13 dB & S21 > -1.5 dB)] – 6) x 2 {max score is 10}
- Stopband (<1.7 GHz) Score = (1.7 – [Min Frequency (S11 & S22 < -13 dB & S21 < -10 dB)]) x 5
- Insertion Loss Score = 1.5 - |Max insertion loss in dB| x 10
- Short circuit termination bandwidth score (S11<-10 dB)= Max Frequency – Min Frequency (in GHz)
- Total Score = Passband Score + Stopband Score + Insertion Band Score + Short circuit termination bandwidth score

For the short circuit termination bandwidth, second port of the designed filter will be terminated with the short (M) standard of the calibration kit. And then S11 parameter of the filter will be measured. The frequency range with smaller than -10 dB S11 will be considered as the short circuit termination bandwidth.

Figure 2 depicts the limitations based on simulation data. If there is a tie, the design having the min insertion loss will be the winner.

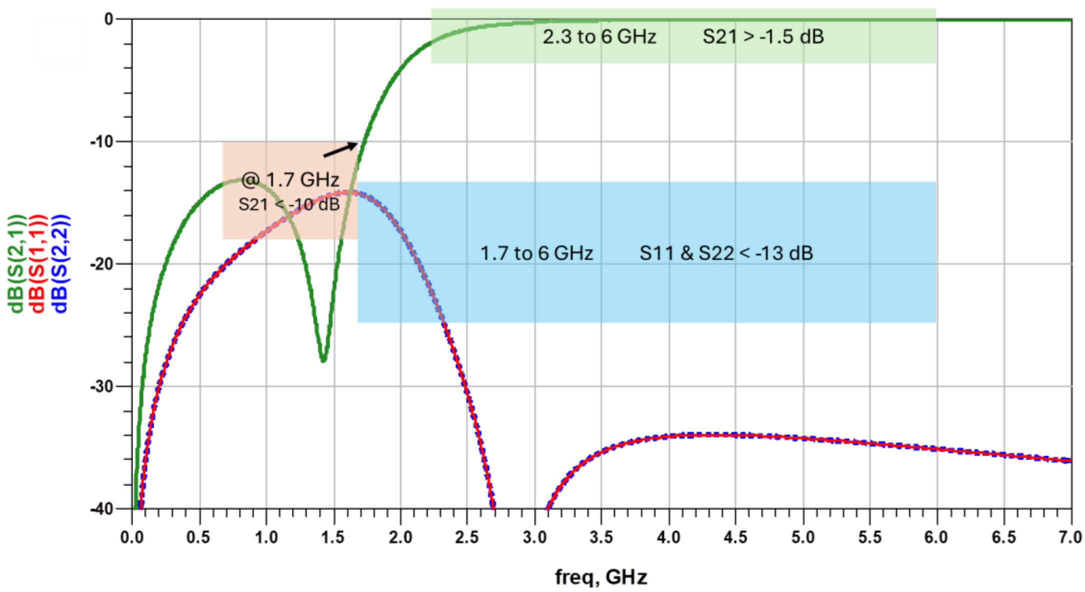

Figure 2. Design rules of S21 and S11 in the stopband and passband

The jury might disqualify the designs not revealing a proper reflectionless filter characteristic to eliminate traditional reflective high-pass designs.

Example Evaluation:

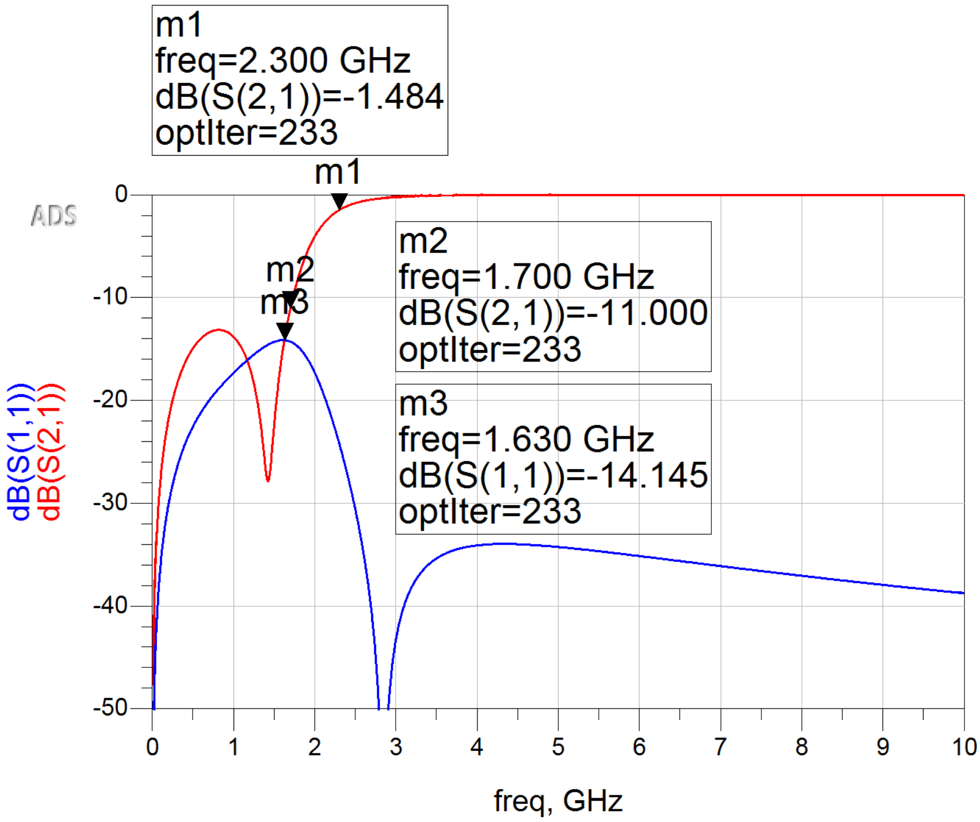

Figure 3. Evaluation example (simulated data).

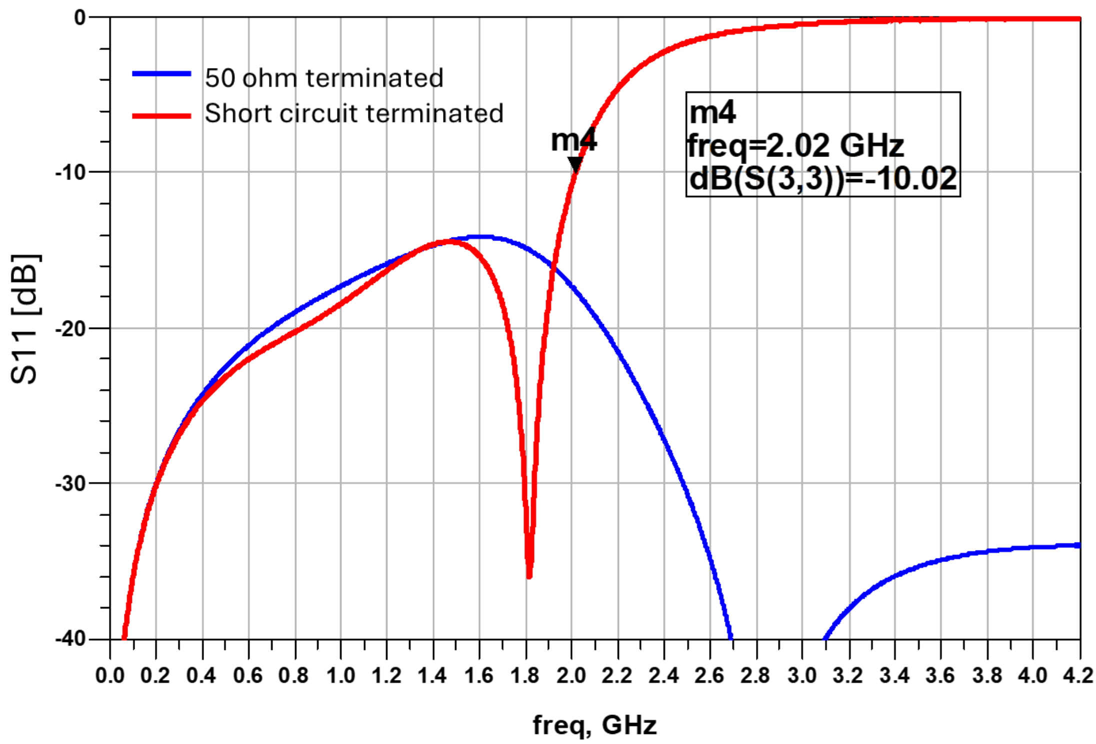

Figure 4. Evaluation example for short circuit termination (Simulated data: Blue curve is 50 Ω terminated, red curve is short terminated.).

The design meets:

1) S21 > -1.5 dB in the required (operation) band 2.3-6 GHz [Pass]
2) S11 & S22 < -13 dB in the required (operation) band 2.3-6 GHz [Pass]
3) Frequency limitations:
    a. Passband max frequency is **16 GHz** since S11<-13 dB and S21>-1.5dB above 6 GHz (16 GHz was not showed on Figure 2)
    b. Stopband min frequency is 0 Hz since S11<-13dB and S21<-10dB below 1.7 GHz
    c. Max insertion loss is **-1.48 dB** in the passband (2.3-6 GHz).
    d. Short circuit terminated bandwidth is 2.02 GHz (2.02-0 GHz).

Passband (>6 GHz) Score = 10, because (**16** – 6) x 2 = 20, however the max score is limited to 10.

Stopband (<1.7 GHz) Score = (1.7 – **0**) x 5 = 8.5

Insertion Loss Score = 1.5 - |**-1.48**| x 10 = 0.2

Short circuit terminated total bandwidth score = 2.02 – 0 = 2.02

Total Score = Passband Score + Stopband Score + Insertion Band Score = 8 + 8.5 + 0.2 + 2.02 = 18.72

Hints: In IMS-2023, many teams got full score on Passband and Stopband. Please pay extra attention to the Inserton Loss Score. The Short Cirtuit Termination Score is added this year. The passband was 4 GHz at the IMS-2023 competition.

How to Participate:

Competing teams will be required to register to the IMS Student Design Competition according to the rules posted on the IMS-2024 homepage.

Students may enter as individuals or as a team. There may be no more than four students on a team with a maximum of one entry per competing team.

Contact information

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Resources

[1] Matthew A. Morgan, Reflectionless Filters, Artech House Publishers, 2017

[2] Mini-Circuits, “Reflectionless filters improve linearity and dynamic range,” Microw. J., vol. 58, no. 8, pp. 42–50, Aug. 2015.

[3] O. Ceylan, L. Marco-Platon, S. Pires, “Refine Biasing Networks for High PA Low- Frequency Stability”, 2018, Microwaves & RF, 57(4), 52–56.

Document revised on 27th of March, 2024. Revision notes:

The rules and scoring are the same. We revised the document to clarify the scoring and measurement method.

[Rev 1]

11 and S22 should be lower than -13 dB. It was stated in the rules, but “S22” was mising in the scoing section. It was added.

Before revision: Passband (>6 GHz) Score = ([Max Frequency (S11 < -13 dB & S21 > -1.5 dB)] – 6) x 2 {max score is 10}

Revised version: Passband (>6 GHz) Score = ([Max Frequency (S11 **& S22** < -13 dB & S21 > -1.5 dB)] – 6) x 2 {max score is 10}

[Rev 2]

Before revision: Stopband (<1.7 GHz) Score = (1.7 – [Min Frequency (S11 < -13 dB & S21 < -10 dB)]) x 5

Revised version: Stopband (<1.7 GHz) Score = (1.7 – [Min Frequency (S11 **& S22** < -13 dB & S21 < -10 dB)]) x 5

[Rev 3]

Figure 2: Colored areas are revised based on design rules, max -10 dB S22 at 1.7 GHz, max 1.5 dB insertion loss in passband (2.3-6 GHz), max -13 dB S11 & S22 between 1.7-6 GHz.

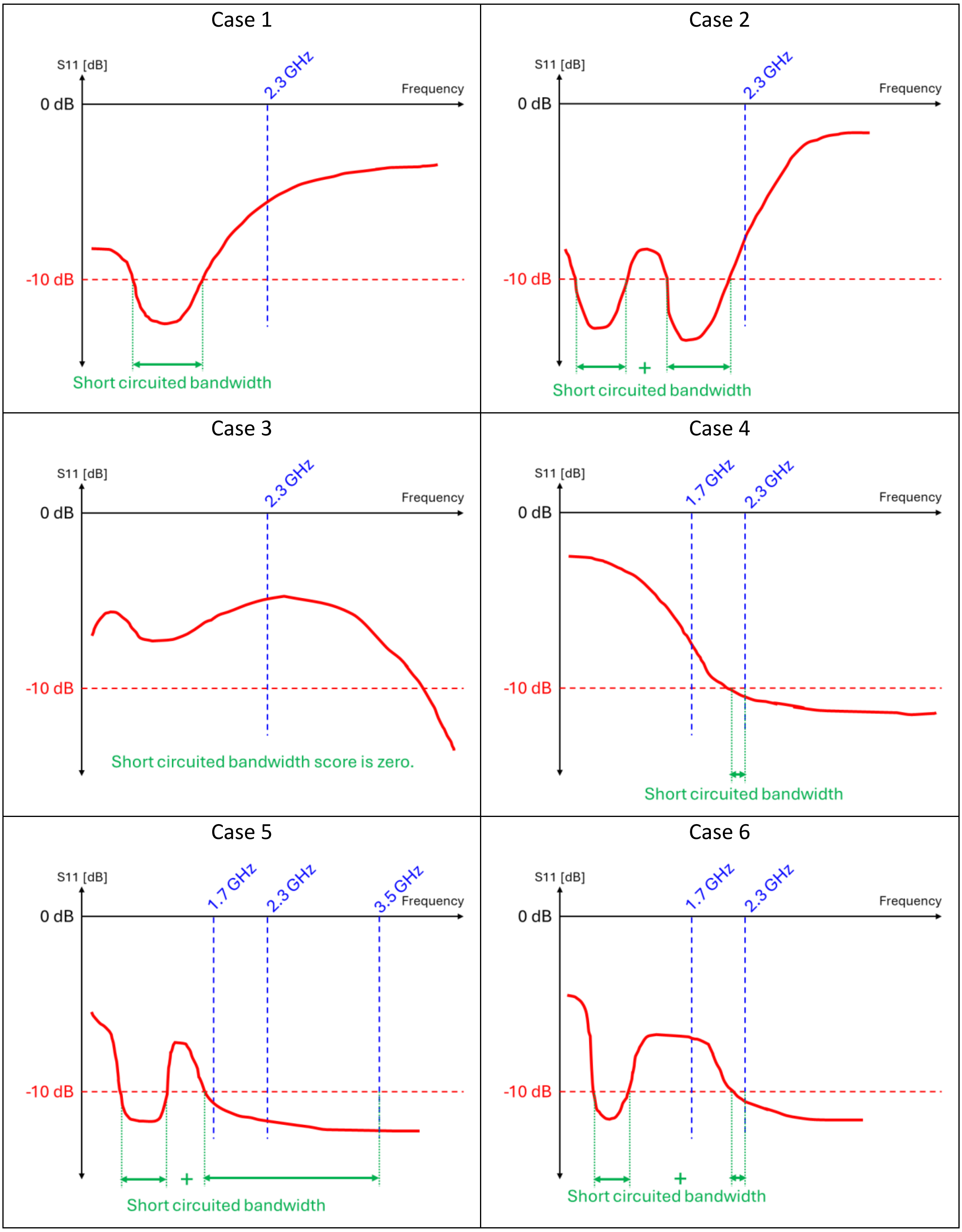
[Rev 4]

Short circuited bandwidth: Since the design is for a load-pull system to improve the low frequency stability of the DUT, performance in the low frequency region will be used for scoring. All frequency range providing smaller than -10 dB (S11) will be added to the final score. Above 3.5 GHz will not be added to the total score.

If the design does not provide an S11 of smaller than -10 dB in the range of 1.7 - 2.3 GHz, the upper region (>2.3 GHz) will not used for scoring (Case 4 and 6).

Before revision: Short circuit terminated bandwidth score

Revised version: Short circuit terminated **total** bandwidth score


Case 1
S11 [dB]
0 dB
-10 dB
2.3 GHz
Frequency
Short circuited bandwidth
Case 2
S11 [dB]
0 dB
-10 dB
2.3 GHz
Frequency
+
Short circuited bandwidth
Case 3
S11 [dB]
0 dB
-10 dB
2.3 GHz
Frequency
Short circuited bandwidth score is zero.
Case 4
S11 [dB]
0 dB
-10 dB
1.7 GHz
2.3 GHz
Frequency
Short circuited bandwidth
Case 5
S11 [dB]
0 dB
-10 dB
1.7 GHz
2.3 GHz
3.5 GHz
Frequency
+
Short circuited bandwidth
Case 6
S11 [dB]
0 dB
-10 dB
1.7 GHz
2.3 GHz
Frequency
+
Short circuited bandwidth