Student Design Competition

APMC 2025 Jeju Island, Korea

Bias-Tee Design for Active Baseband Controlled Load-pull Applications

Supported by MTT-S TC-3 Microwave Measurements Committee

Introduction

Circuits and transistors without a biasing network require bias-tees for RF measurements, such as S-parameters. The purpose of a bias tee is to isolate the RF path for high-frequency measurements from the DC path for biasing. Figure 1 illustrates the use of a bias tee in an S-parameter measurement setup.

A general-purpose bias-tee typically covers a wideband range. They often consist of a large inductor to isolate the DC path from the RF path. However, this structure limits their current handling capability, as the wideband and large value inductors result in a small DC current rating. Additionally, the impedance of the DC path to the RF path in these bias tees is usually high, which is not ideal for measurements involving modulated signals.

Load-pull measurements use large signals. In these measurements, the device is driven until a few dB of power gain compression is achieved to obtain large signal parameters for the optimum output power and efficiency. In the saturation region, higher current values are needed from the supply to achieve increased output power. Consequently, this type of measurement requires bias tees that can handle these large currents.

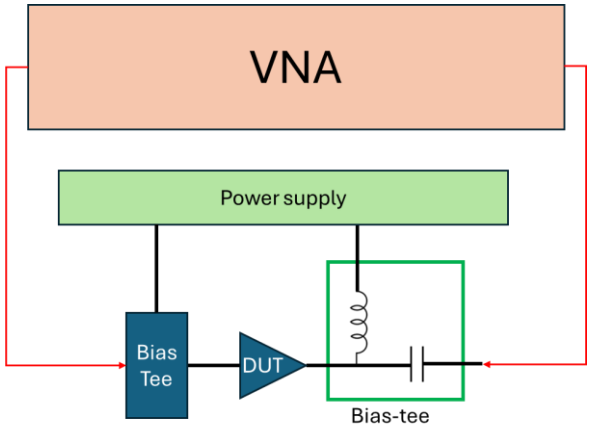

Figure 1. An S-parameter measurement setup with bias-tees.

Advanced load-pull setups can use modulated signals for large signal analysis. All active RF devices generate intermodulation distortion (IMD) products under modulated signal excitation. For instance, when a two-tone signal is applied to a device, it generates IMD products around the center (carrier) frequently depending on the spacing of the tones, such as at $2f_2$-f_1, $2f_1$-f_2, $3f_1$-$2f_2$, and $3f_2$-$2f_1$ frequencies. The amplitude values of these signals indicate the nonlinearity of the DUT.

Additionally, it is important to consider IMD products, such as at the f_2-f_1 and $2f_2$-$2f_1$ frequencies, for evaluating the nonlinearity of the DUT. They appear on the supply line and cause supply voltage

modulation, which negatively affects the linearity of the DUT. Figure 2 presents the spectrum of the two-tone products and supply voltage modulation. Low frequency IMD products can not be removed due to structure of bias-tees. However, they can be manipulated by an active baseband control system. It needs a suitable bias-tee to inject the control signal. Figure 3 shows an active baseband control system.

In this design competition, students will design a bias tee for load-pull applications with active baseband control. The design should be able to handle large current and have wide baseband to improve modulated signal measurement performance.

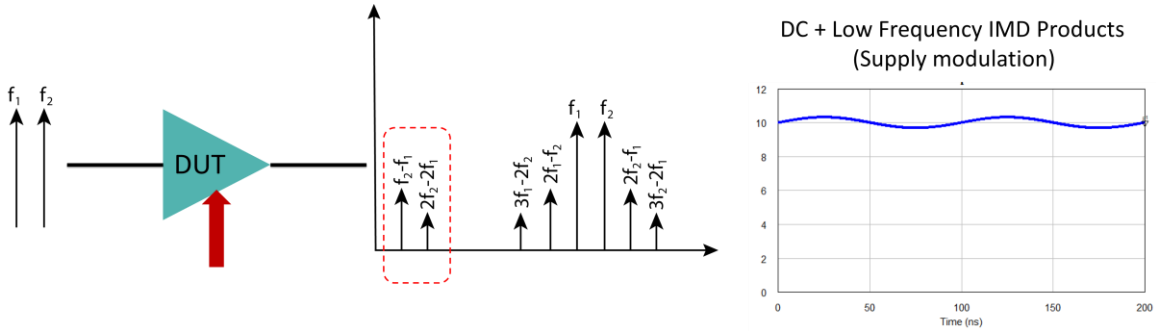

Figure 2. Two-tone output spectrum of a large signal measurement and supply voltage modulation.

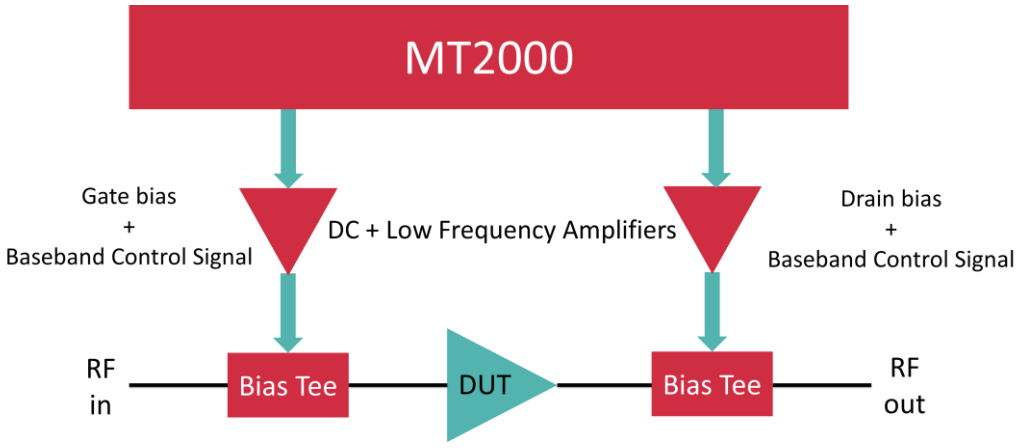

Figure 3. Active baseband control system.

Design specifications and rules

In this competition, students will design a bias tee for the 2.7-9.5 GHz frequency range. Figure 4 depicts the ports. Here are the design specs and rules:

- Should block the DC on the RF port (Port-2)
- RF-path Insertion loss (S21) between 2.7-9.5 GHz: < -1 dB (While Port-3 is 50 ohm)
- Reflection: <-15 dB (S11) between 2.7-9.5 GHz (While Ports 2 and 3 are 50 ohm)
- DC rating: min 30V, 1A (at 30V)
- Any substrate materials and passive components (such as ceramic and multi-layer) are allowed for circuit design.
- The connectors should be Female type and suitable for 3.5 mm Male cable connections (2.92 mm, 3.5 mm, and SMA connectors are compatible.)
- The total area of the designs should not exceed 100 cm^2 (10 cm x 10 cm, 20cm x 5 cm, etc.). Extension of connectors will not be considered (only PCB dimension).

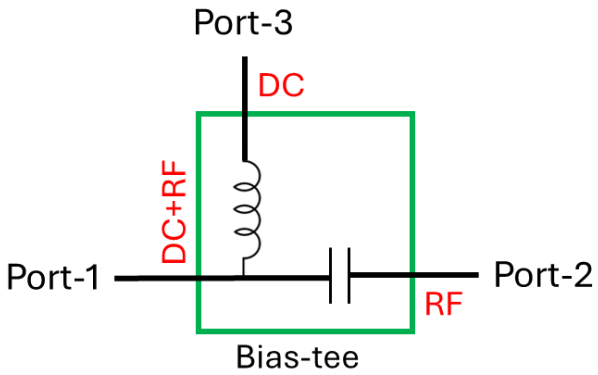

Figure 4. Port definitions for measurements.

Off-the-shelf commercial bias network components are not permitted. The students should design and implement the bias-tees themself.

Students can contact the organizing committee with their questions and for technical guidance at any time. 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 individually or form a team of up to 3 students. A student is allowed to join only one team. Multiple entry is not allowed. 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 vector network analyzer will be used to measure the S-parameters of the designed bias-tees. 3.5 mm coaxial cables will be used for RF measurements. A power supply and resistor load will be used to test the DC ratings.

Before measurements, the organization committee will visually inspect the submitted circuit to ensure no commercial bias-tee component is installed. 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, which have 3.5 mm 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 damage during the competition. The designs meeting the technical design rules will be evaluated during the competition.

Each circuit will be given a maximum of 5 minutes to complete cable connections and prepare the circuit for the measurement (including tuning if necessary). The measurements will be done in a conference room open to all participants. A constant temperature condition is not guaranteed.

No tuning is allowed during the measurements while the circuit is connected to the phase noise analyzer.

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 for damage or loss during shipment.

Scoring

The bias-tee providing the widest baseband will be the winner.

The students will bring their circuits to the competition. They should have a short report, including PCB and component information (model, maker, etc.), simulation results (if available), and measurement results (if available). The designed bias-tees must meet these requirements before scoring:

1. Visual inspection (no commercial bias-tee component)
2. DC blocking structure (such as a capacitor)
3. Dimensions of the circuit (<100cm^2)
4. RF bandwidth providing less than an S21 of -1 dB and S11 of -15 dB (between 2.7-9.5 GHz)
5. Resistance between Port-1 and Port-3 smaller than 0.5 ohm (A multimeter will be used)
6. DC power handling for 15 seconds at 30V with 30 ohm (±1%) load

The winner will be determined by the circuit that achieves the maximum score based on the evaluation of the widest baseband range:

- S31 is smaller than -3 dB
- S33 is smaller than -10 dB

The designed bias-tee should meet the specs starting from DC. Example scoring:

CASE 1:

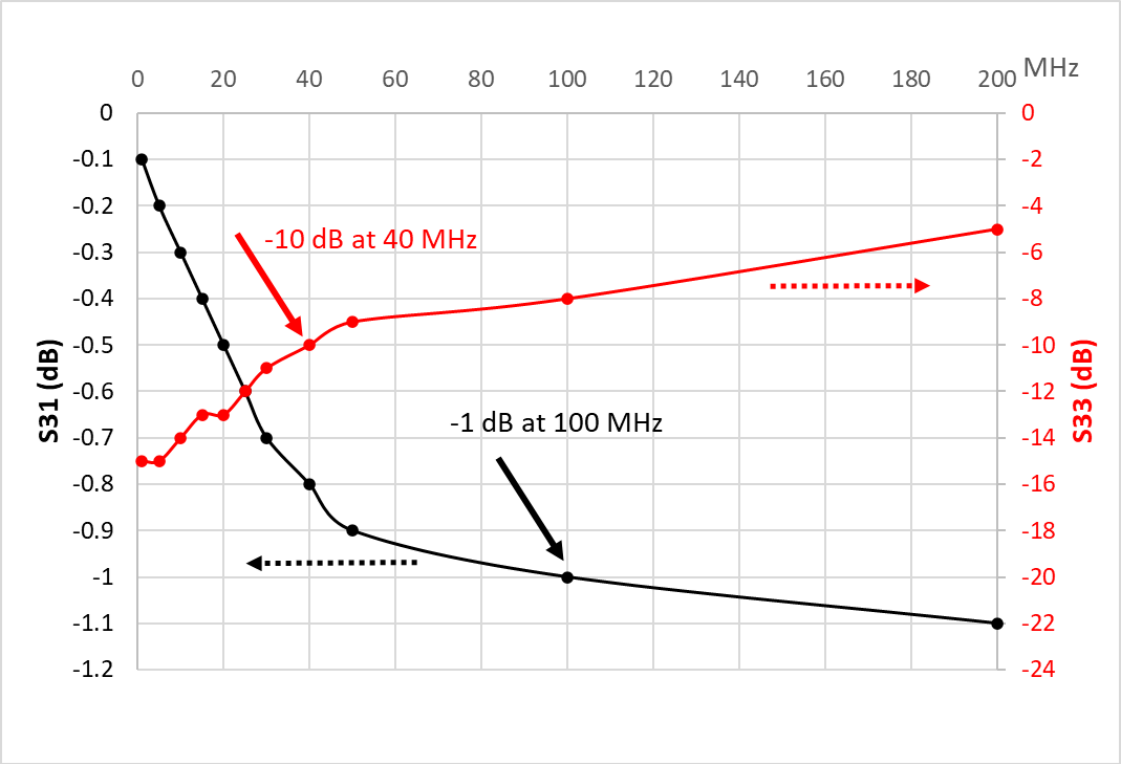

Figure 5. Measurement and scoring, Case 1

S33 = -10 dB at 40 MHz, S31 = -1 dB at 100 MHz

This circuit's score is **40 MHz**.

CASE 2:

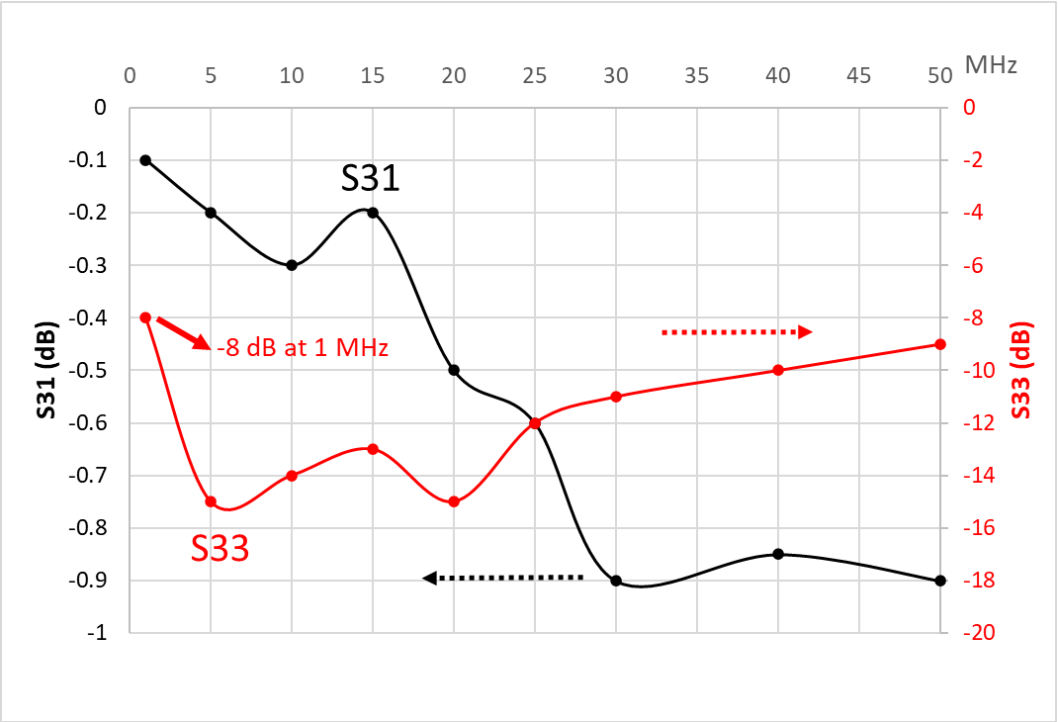

Figure 6. Measurement and scoring, Case 2

Since it does not meet one of the requirements (S33 < -10 dB at low frequency region), this design is disqualified.

(All numbers are random. Do not use them as a reference!)

How to Participate:

Competing teams will be required to register for the APMC-2025 Student Design Competition according to the rules posted on the conference 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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