TAYLOR MICROWAVE, INC.

Protecting RF Sources When Using Pulsed Bias Tees

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Pulsed bias tees allow a bias waveform and an RF signal to share the same connection to a device under test (DUT). They are useful for transistor characterization, pulsed amplifier measurements, and other applications requiring controlled bias timing.

A bias tee's DC-blocking capacitor does not guarantee protection against bias pulses. Pulse edges can couple backward through the RF path and expose a signal generator, network analyzer, or driver amplifier to damaging transients.

This article combines published manufacturer guidance with circuit analysis to explain the risk and establish a practical protection procedure.

How the pulse reaches the RF source

A basic bias tee connects the RF port to the combined RF+DC port through a series capacitor. An inductor connects the bias port to the combined port. Analog Devices describes this conventional capacitor-and-inductor arrangement in its wideband bias tee design guidance. [1]

Port	Function
J1	RF input connected toward the RF source
J2	Combined RF+DC connection to the DUT
J3	DC or pulsed-bias input

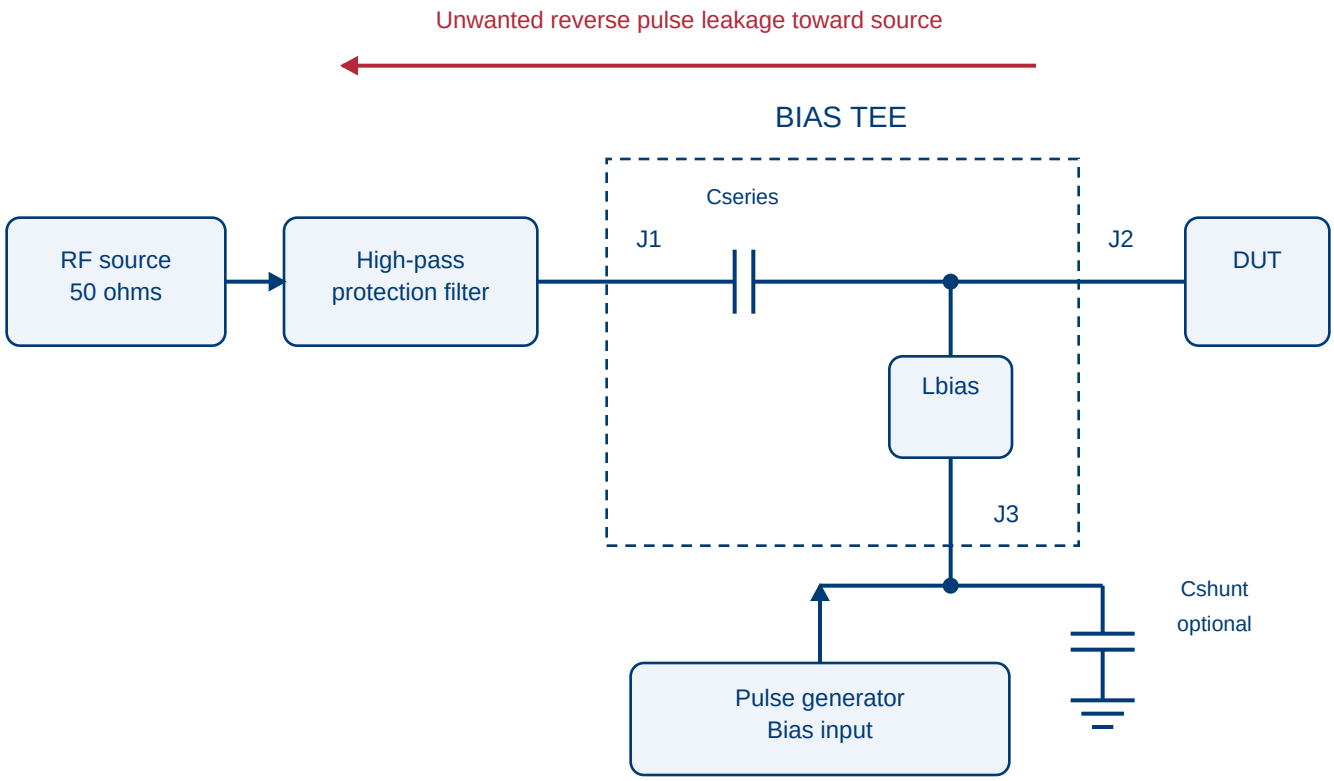
These labels are illustrative; verify the markings on the actual product. When a bias pulse reaches J2, its changing voltage drives current through the series RF capacitor:

$$i_C = C\,(dV/dt)$$

This circuit relationship explains why a capacitor can block steady DC while still passing a transient. Rising and falling pulse edges can produce opposite-polarity disturbances at J1. Their amplitude depends on the complete network, including the pulse generator, bias inductors, coupling capacitance, DUT impedance, cables, and RF source impedance.

A zero-volt DC reading at J1 does not establish that the port is safe during pulsing.

Pulsed bias tee and source-protection block diagram



Conceptual topology only; component values and protection require validation.

Figure 1. The series capacitor is in the J1-J2 RF path. The optional shunt capacitor is connected from the J3 pulse-input node to ground, before the bias inductor. Actual broadband bias tees may use multiple inductors and capacitors. Port labels must be verified on the actual unit.

How to use the diagram

RF path: the source drives the DUT through the protection filter and Cseries. The filter must pass the required RF band and withstand reverse transient exposure.

Pulse path: the pulse generator drives J3 through Lbias to J2. Minimize or omit Cshunt when compatible with RF isolation and stability to reduce generator loading and preserve pulse edges.

Source protection: choose the smallest Cseries that meets RF transmission requirements to reduce lower-frequency reverse coupling. Fast-edge energy can still pass; measure residual transients at the source connection before attaching the instrument.

Reduce series and shunt capacitance for different reasons

A pulsed bias tee requires coordinated selection of two different capacitors. The series coupling capacitor controls RF transmission and the coupling of pulse components toward J1. The shunt bypass capacitor at the bias input loads the pulse generator and affects how quickly the bias waveform reaches the DUT. Reducing one does not replace evaluating the other.

Capacitor	Location	Reason to reduce capacitance
Series coupling capacitor	In the RF path between J1 and J2	Attenuate lower-frequency pulse components returning toward J1 while preserving the required RF band.
Shunt bypass capacitor	From the J3 pulse-input node to ground, when fitted	Reduce pulse-generator loading and preserve pulse rise and fall times. Omit it when compatible with the complete design.

Series capacitor: reduce reverse pulse coupling

Choose the smallest series coupling capacitance that meets insertion-loss and return-loss requirements at the lowest RF operating frequency. Reducing capacitance increases capacitive reactance at a given frequency, improving rejection of lower-frequency pulse components. It also raises the RF low-frequency cutoff, so excessive reduction will degrade the desired RF signal.

In a simplified series RC circuit driven by an ideal voltage step, a smaller capacitance shortens the transient decay time. It does not necessarily reduce the instantaneous leading-edge peak, which depends on the source and load impedances and the edge speed. Real bias tees add inductance, parasitic coupling, and resonances. Verify peak voltage and pulse energy at J1 rather than assuming a smaller capacitor makes the source safe.

Shunt capacitor: minimize loading at J3

Use the smallest shunt capacitance compatible with the required RF isolation and stability, or omit it when appropriate, to preserve fast bias-pulse edges. A large bypass capacitor that is useful for steady DC bias can divert pulse current to ground, slow the waveform, and increase the pulse generator's current demand.

For a specified voltage slew rate, capacitor current is $i = C \times dV/dt$. Reducing this shunt capacitance reduces the charging current required for that same slew rate. The practical minimum includes connector, PCB, cable, device, and other stray capacitances; removing a discrete capacitor does not remove those contributions.

A simple resistance-capacitance model gives a 10-90% rise time of approximately $2.2 \times R \times C$. This is an initial estimate only: the bias inductors, DUT, source impedance, and wiring can produce a more complex response. Check the pulse at J2 under the intended load.

Reducing the J3 shunt capacitor is a pulse-fidelity measure, not a substitute for protection at J1. It may allow sharper edges to reach J2, which can increase high-frequency reverse leakage. Recheck RF leakage into the pulse generator, overshoot, ringing, and source protection after either capacitor is changed.

RF bandwidth and bias-pulse bandwidth are different

A bias tee's RF frequency range describes its RF signal path. It does not automatically describe how quickly a pulse can travel from J3 to J2. Marki Microwave's published DC-port step-response measurements illustrate that designs can have different rise times, settling behavior, and ringing. A faster response can also exhibit greater ringing. [2]

Pulse compatibility must therefore be specified using pulse amplitude, polarity, rise and fall times, pulse width, repetition rate, current, and load conditions.

A bypass capacitor on the bias terminal can load the pulse generator and slow the waveform. A pulse-compatible design may omit or reduce that capacitor, but this choice must be evaluated together with RF isolation, stability, and source loading.

Using a high-pass filter to reduce reverse pulse leakage

A useful protection arrangement places a high-pass filter between the RF source and J1. The filter passes the intended RF operating band while attenuating lower-frequency components of the returning bias waveform.

Select the filter using both the lowest RF frequency that must pass with acceptable insertion loss and return loss, and the frequency content of the unwanted transient that must be rejected.

Selecting a cutoff frequency from the pulse repetition rate alone is insufficient. Fast edges contain frequency components far above the repetition rate. For an approximately single-pole response, the familiar relationship below provides a rough indication of edge bandwidth:

$$\mathbf{BW \text{ approximately equals } 0.35 / t_r}$$

A 1 ns rise time corresponds to approximately 350 MHz; a 200 ps rise time corresponds to approximately 1.75 GHz. These are illustrative bandwidth estimates, not boundaries beyond which pulse energy disappears.

If the pulse spectrum overlaps the required RF passband, a high-pass filter cannot reject all of that pulse energy while passing the same frequencies. Additional protection or a change in pulse timing may be necessary.

Specify rejection where it matters

Specify attenuation across the relevant transient spectrum together with RF passband performance. For a single frequency component in an approximately matched system:

$$V_{out} = V_{in} \times 10^{(-A/20)}$$

Thus, 40 dB attenuation reduces a voltage component by a factor of 100, and 60 dB reduces it by 1,000. **Do not apply one stopband number directly to the entire pulse amplitude.** A real pulse contains many frequency components; filter phase response and reflections affect its waveform.

The filter must withstand the incident transient. Check voltage stress, pulse energy, RF power, insulation, connectors, and internal component ratings. Reflected stopband energy can alter ringing at the bias tee and DUT.

Choosing the right RF coupling capacitor

The coupling capacitor belongs in series between J1 and J2. Its job is to pass the required RF signal while blocking the steady bias voltage. It is different from a bias-port bypass capacitor, which connects the bias path to ground. Correct selection requires the lowest and highest RF frequencies, insertion-loss and return-loss targets, RF power, bias voltage, and pulse waveform. There is no universal capacitance or part number for all pulsed bias tees.

For a first estimate, make the capacitive reactance small compared with 50 ohms at the lowest RF frequency. A useful initial target is X_C no greater than 5 ohms:

$$X_C = 1 / (2 \pi f C) \mid C \text{ no less than } 1 / (2 \pi f_{min} \times 5 \text{ ohms})$$

Lowest RF frequency	Minimum C for Xc = 5 ohms
100 MHz	318 pF
500 MHz	63.7 pF
1 GHz	31.8 pF

These are ideal starting values, not qualified component recommendations. For a lossless series capacitor between matched 50-ohm ports:

$$IL = 10 \log_{10}[1 + (X_C/100 \text{ ohms})^2]$$

At 500 MHz, an ideal 100 pF capacitor has Xc = 3.18 ohms, insertion loss approximately 0.0044 dB, and return loss approximately 30 dB. This calculation excludes ESR, package inductance, PCB pads, and resonances. A 100 pF value alone does not establish operation through 18, 20, or 40 GHz.

Use a low-loss RF capacitor or a purpose-designed broadband DC-block component with measured S-parameters across the complete band. C0G/NP0 is a useful dielectric starting point, but package construction and mounting also matter. At microwave frequencies, assess the mounted impedance and resonances rather than relying on nominal capacitance. KYOCERA AVX discusses ESR, ESL, and parallel resonance in broadband coupling networks. [5]

Voltage: rate the capacitor for the maximum instantaneous differential voltage across its terminals, including bias, overshoot, polarity reversal, and RF voltage across the component, with appropriate derating. The line RF voltage is not automatically the RF voltage across the capacitor. A dielectric-withstand test rating is not a continuous working-voltage rating. Analog Devices specifically identifies coupling-capacitor voltage rating as a critical bias tee design parameter. [1]

Current and heating: in a matched 50-ohm line, I_{RMS} = sqrt(P_{RF}/50 ohms). At 50 W CW, this is 1 A RMS. Estimate capacitor dissipation as I_{RMS}^2 x ESR at the operating frequency, then verify the manufacturer's current and thermal limits, mounting, temperature, and mismatch conditions. Pulse-related charging current is an additional stress.

Protection tradeoff: a larger coupling capacitor extends low-frequency response and can increase the duration or energy of reverse-coupled transients. Selecting the smallest value that satisfies RF requirements may help, but does not eliminate fast-edge leakage. Do not enlarge the coupling capacitor as a source-protection measure. Validate the complete bias tee and protection network in the time domain.

Add protection appropriate to the remaining transient

Protection	Purpose	Important limitation
High-pass filter	Reduces pulse components below the RF band	Passes transient components within its passband
DC block	Prevents steady DC from reaching the source	Can transmit fast edges
Attenuator	Reduces reverse signal amplitude	Adds forward loss; requires adequate pulse ratings
Limiter	Restricts excessive signal amplitude	Leakage, response time, polarity, and energy ratings matter
Isolator or circulator	Redirects reverse RF within its rated band	Limited protection outside that band
Bias-path damping	Reduces selected overshoot or ringing	Can change pulse amplitude, speed, and DUT bias

Keysight identifies excessive CW and pulsed RF as potential damage mechanisms and discusses limiters as protective components. Select a limiter for the actual exposure and the protected instrument. [3]

Verify before connecting the RF source

The following procedure is an engineering recommendation based on the preceding analysis:

1. Identify the source limits. Obtain the manufacturer's allowed external DC, reverse power, and applicable transient limits for the exact instrument and configuration.

2. Disconnect the RF source. Replace it with a suitably rated measurement arrangement at the intended source connection plane.

3. Protect the measurement equipment. Use a termination, probe, attenuator, or sampling arrangement rated for the possible voltage, pulse energy, and bandwidth.

4. Begin at reduced pulse amplitude. Measure positive and negative peaks, ringing, and settling with the intended DUT or a representative load.

5. Increase toward the required operating conditions. Check the fastest edges, maximum amplitude, and relevant pulse widths and repetition rates.

6. Evaluate switching events. Include pulse enable, disable, startup, and shutdown. Assess credible load changes using appropriately rated test hardware.

7. Establish adequate margin before connecting the source. A measurement into 50 ohms may not reproduce the source's impedance outside its operating band; account for that uncertainty.

Connection and operating practices

Complete connections before applying bias, disable bias before disconnecting equipment, and use appropriate current compliance. Anritsu explicitly recommends these practices and notes that a series resistor in the bias supply path can reduce transients. For pulsed operation, check its effect on the desired waveform. [4]

Disabling the RF output should not be treated as proof that the source connector is electrically isolated.

Information for a pulsed-bias application review

Provide Taylor Microwave with the RF frequency range, RF power, pulse voltage and polarity, rise and fall times, pulse width, repetition rate, peak current, DUT impedance, and source model. These parameters allow the bias path and protection network to be evaluated together.

Protection is established by the residual transient at the source connection and the source's permitted exposure - not by the bias tee's DC rating or isolation specification alone.

Source references

[1] Analog Devices. AN-2061: Wideband Bias Tee Design Using 0402, SMD Components.

[2] Marki Microwave. Step Response of Marki Microwave Bias Tees.

[3] Keysight Technologies. Protecting Sensitive Components Using Power Limiters, 5989-4880.

[4] Anritsu. Notes on Handling Ultrafast Electronic Devices.

[5] KYOCERA AVX. Capacitors in Broadband Applications.

References support the manufacturer-specific observations identified in the text. Equations, filter-selection discussion, and the verification procedure are engineering analysis and guidance; they do not certify a particular setup.

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