Broadband Coaxial Bias Tees

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Bias Tees are coaxial components that are used whenever a source of DC power must be connected to a coaxial cable. When properly designed, the bias tee does not affect the AC or RF transmission through the coaxial cable. The usual application is to provide a means of powering an active device such as a transistor, laser diode or photodiode. Other uses would be to provide power to operate remotely located coaxial relays or amplifiers, or to transmit low frequency analog or digital signals on the same coax cable along with RF signals.

Bias tees have been around and used for a long time. There are several microwave and RF manufacturers that have built bias tees for many years. Most of their tees were designed only for specific octave frequency bands. However, in today's modern digital and analog world, very wideband systems are now being used. For these systems, octave bandwidth components are grossly inadequate and cause extremely severe pulse distortion. Telecom and CATV companies are now fielding extremely wideband 12 GigaBit fiber optic digital and > 1 GHz analog systems. These higher bandwidth systems are using optical modulators, laser diodes and photodiodes with risetimes of 15 ps or less. To support these fast 15 ps risetimes requires system components with -3 dB bandwidths in excess of 25 GHz. An approximate equation relating risetime and bandwidth is: T_r (10%-90%) * BW (-3 dB) = 0.35

Digital telecom systems also require very low frequency responses to reduce bit error rates due to sagging pulses. If a very long duration square wave pulse is passed through an AC-coupled circuit (such as a bias tee), the toplines and baselines of the pulse will eventually decay exponentially back down to zero. This can happen in a digital system with an NRZ digital code whenever a long string of either "0"s or "1"s occurs. In order to maintain acceptable bit error rates for GigaBit data systems, the low frequency cutoffs of various system components must extend well out into the microsecond domain. Thus system components must have -3 dB low frequency cutoffs down to ultrasonic frequencies of tens of kHz or lower.

Picosecond Pulse Labs (PSPL) was originally founded in 1980 to produce extremely fast picosecond risetime pulse generators. In the design of these generators we needed bias tees to power various semiconductors. We found that the narrow-band bias tees then available commercially were totally unacceptable for pulse applications. Thus, we were forced to design our own bias tees. Our bias tee designs were so successful that we decided to offer them for sale. Today, PSPL is a major supplier of bias tees to many companies.

PSPL now offers a wide selection of bias tees for various bandwidth, voltage and current requirements (see Table 1). Bandwidths up to 50 GHz are available. Max. current ratings range from 10 mA to 8 Amp. Max. voltage ratings range from 16 V to 1.5 kV. Low frequency cutoffs for broadband bias tees range from 3.5 kHz to 750 kHz. PSPL also offers a family of four, high current (8 Amps), high voltage (100 V) bias tees. They are modest bandwidth components covering decade bands from 200 MHz to 20 GHz. Most bias tees are 50 Ω coaxial modules. There are also surface mount modules available. Detailed specification sheets are available from PSPL's web site for all models. (*www.picosecond.com*). The detailed specification sheets include plots of frequency response S parameters and time domain pulse responses.

Table 1. PSPL Bias Tees

(detailed spec. sheets available at www.picosecond.com)

Model Number	High Freq (-3dB)	Low Freq (-3dB)	Insertion Loss S21	Risetime (10-90%)	Bias Mod. Bandwidth*	Max Voltage	Max Current	Max RF CW Power
5530B	12 GHz	20 kHz	0.2 dB	28	30 kHz	200	10 mA	2 W
5531	10 GHz	750 kHz	0.3 dB	35 ps	1 MHz	1.5 kV	20 mA	20 W
5541A	>26 GHz	80 kHz	0.4 dB	8 ps	16 kHz	50 V	100 mA	2 W
5542	50 GHz	10 kHz	0.3 dB	7 ps	8 kHz	16 V	100 mA	5 W
5545	20 GHz	65 kHz	0.7 dB	12 ps	37 kHz	50 V	500 mA	2 W
5546	7 GHz	3.5 kHz	0.5 dB	45 ps	4.5 kHz	50 V	500 mA	2 W
5547	15 GHz	5 kHz	0.5 dB	23 ps	6 kHz	50 V	500 mA	2 W
5550B	18 GHz	100 kHz[1]	0.9 dB	20 ps	16 kHz	50 V	500 mA[1]	2.5 W
5575A	12 GHz	10 kHz[1]	0.6 dB	30 ps	10 kHz	50 V	500 mA[1]	3.5 W
5580	15 GHz	10 kHz	1.0 dB	28 ps	9 kHz	50 V	1 Amp	2.5 W
5585	16 GHz	2 GHz	0.4 dB	NA	2 MHz	100 V	6 Amps	20 W[3]
5586	4 GHz	1 GHz	0.2 dB	NA	275 kHz	100 V	8 Amps	100 W[3]
5587	1.8 GHz	200 MHz	0.05 dB	NA	275 kHz	100 V	6 Amps	100 W[3]
5589	2.8 GHz	300 MHz	0.05 dB	NA	275 kHz	100 V	7 Amps	100 W[3]
SM100[2]	13 GHz	14 kHz	0.2 dB	21 ps	15 kHz	16 V	500 mA	2 W
SM101[2]	15 GHz	7 kHz[1]	0.2 dB	21 ps	29 kHz	16 V	500 mA	1 W

[1] Modulation bandwidth is with 50 Ω source impedance.
[2] Surface mount packaged parts. Other parts are coaxially packaged.
[3] Contact PSPL Sales for test information.

The bias tee coaxial package in the photo on page 1 shows the basic schematic diagram of a bias tee. DC power is brought in from the port labeled "DC" through an inductor to the center conductor of the 50 Ω coaxial line. This power is available on the port labeled "AC+DC". The capacitor is a DC block installed in the center conductor of the 50 Ω coaxial line. It prevents dc power from flowing out the "AC" port. AC or RF power may be applied to either the "AC" or the "AC+DC" port. For low-current applications, such as biasing photodiodes, a resistor is often used instead of an inductor to provide the connection between the DC input and the coaxial center conductor. To avoid loading the coax line, the resistor value is chosen to be much greater than the coax impedance. For higher-current applications in which the potential drop across R or the power dissipated in R would be too great, it is necessary to use an inductor.

The low-frequency performance of a bias tee can be very easily calculated from elementary circuit theory knowing the inductance and capacitance values. These values are given on the PSPL bias tee specification sheets. The bias tee is a high pass filter for transmission through the 50 Ohm coax line between ports "AC" to "AC+DC". The bias tee is a low pass filter for transmission from the "DC" port to the "AC+DC" port.

The microwave performance, high-frequency roll-off and risetime of a bias tee cannot be determined simply from the inductance and capacitance values. The high frequency performance is limited primarily by the parasitic reactances and losses associated with the DC feed inductor and secondarily by the DC blocking capacitor. It is also dependent upon the care in which they are mounted within the coaxial environment. Any impedance discontinuities from 50 Ω created by their mounting, the bias tee package design or the coaxial connectors will also limit the high-frequency performance and bandwidth.

The mid-band frequency response and also the time domain step response, pulse fidelity and flatness are primarily determined by the behavior of the DC-feed inductor. In reality, it is impossible to use a single inductor to cover all frequencies from audio to microwaves. Real inductors are probably the worst components in that they never perform according to textbook theory.

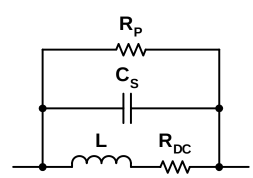


Figure 2. Typical circuit model for a real inductor

Any physically realizable inductor is always plagued with parasitic capacitances, losses, etc. that cause multiple resonances and prevent it from behaving as the ideal textbook inductor. Figure 2 is a circuit diagram showing the dominant parasitic elements associated with an inductor. R_{dc} is the DC resistance of the inductor wire. C_s is the equivalent stray capacitance between the windings of the inductor coil. R_p is the equivalent AC loss of the inductor that determines the Q of the coil.

Manufacturers making narrow, octave-band bias tees can get away with using only a single inductor optimized for that band. One cannot use a single inductor for broadband bias tees. Thus for broadband bias tees, the single inductor shown in the simple schematic diagram is, in reality, several inductors connected in series. Each inductor is optimized to cover various frequency bands from microwave, UHF, VHF, HF and MF down to audio frequencies. The smallest nanohenry, microwave inductor is connected directly to the 50 Ω coax line center conductor. Progressively larger inductors in μH to mH values are then connected in series out to the DC port. Additional R, L and C components are also needed to ensure controlled "Q"s and smooth frequency crossovers from one inductor to the next. Thus, a good broadband bias tee is a very complex R-L-C network.

PSPL bias tees were designed with extensive use of SPICE modeling. Very complex SPICE models were created for all of the critical components used including the DC blocking capacitors and the various DC feed inductors. With these models in hand, additional compensating networks were designed to carefully control the frequency cross-overs between each successive inductor (microwave, to VHF, to audio). PSPL Application Note, AN-11 "SPICE Models for PSPL Coaxial & SMD Components" (*available from* www.picosecond.com) discusses these further. SPICE models for PSPL's bias tees are available and can be downloaded from the PSPL web site. With a SPICE model, the user can calculate the anticipated performance in their particular system. One application might be the modulation bandwidth and pulse response for putting DC plus a modulating signal onto the "DC" port of a bias tee. (see Table 1)

All bias tees have various maximum limitations. (see Table 1) The max. voltage rating is typically determined by the dc blocking capaitor. The max. dc current rating is set by the series feed inductors. PSPL bias tees also have a max. RF power rating. This is usually set by the dissipation in resistive elements used in the complex R-L-C crossover networks used between the various dc feed inductors. SPICE modeling was used to determine the power dissipation vs. frequency for every resistor. The max. power rating on the spec. sheet is the worst case scenario for the weakest resistor at its frequency of max. dissipation. These ratings are for CW operation. Higher peak powers can usually be handled as long as the duty cycle is low and the average RF power is below the CW rating. At present, PSPL does not have a means of precisely determining the peak power rating for our bias tees.

PSPL's highest performance bias tee is the Model 5542. It features a bandwidth extending from 10 kHz to 50 GHz. It has excellent performance both in the frequency domain and the time domain as shown by the following figures.

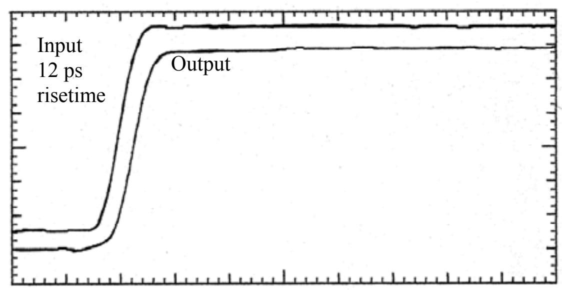
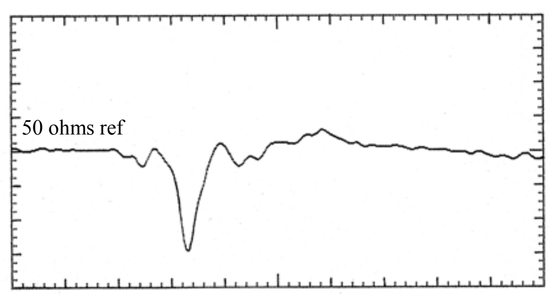


Figure 3. 5542 Pulse Step Response at 20 ps/div.
Top trace is 12 ps risetime input pulse, bottom trace is 5542's output.

Figure 4. 25 ps TDR of 5542
2% rho/div & 100 ps/div.



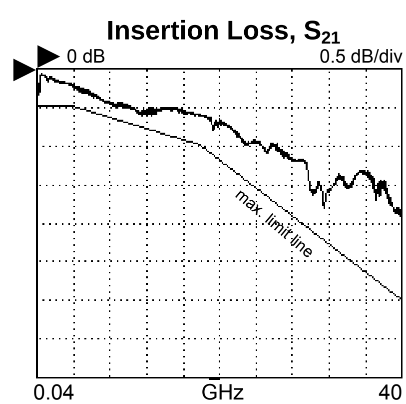


Figure 5. PSPL 5542 bias tee
insertion loss from 40 MHz to 40 GHz

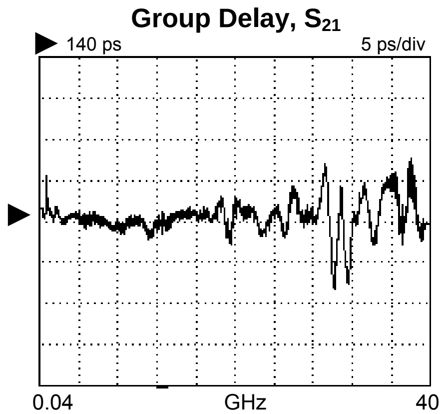


Figure 6. PSPL 5542 bias tee group delay from 40 MHz to 40 GHz

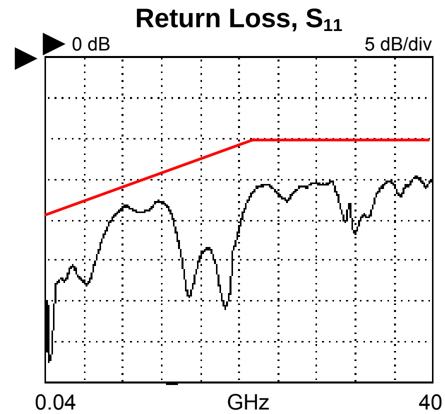


Figure 7. PSPL 5542 bias tee return loss from 40 MHz to 40 GHz

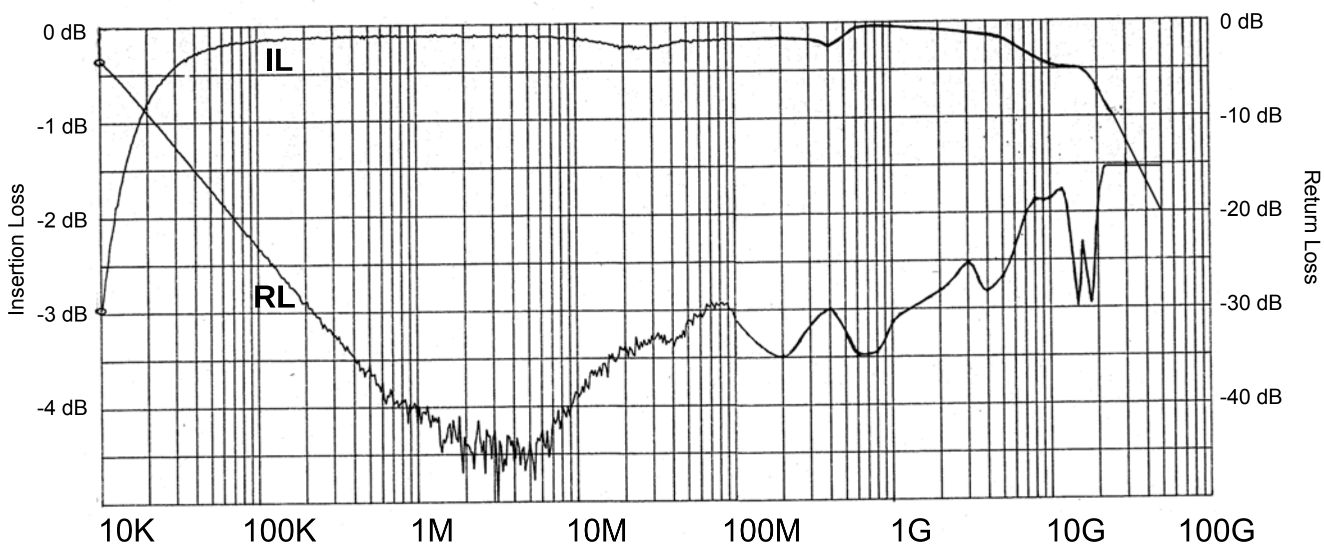


Figure 8. PSPL 5542 bias tee log frequency response from 10 kHz to 50 GHz. Top trace is insertion loss, S_{21} at 0.5 dB/div. Lower trace is return loss, S_{11} at 5 dB/div.