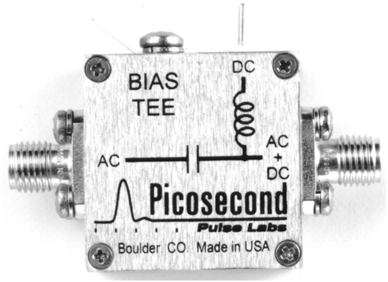
Picosecond Pulse Labs

Application Note AN-1e

Broadband Coaxial Bias Tees

James R. Andrews, Ph.D., IEEE Fellow



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 these 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 10 GigaBit fiber optic digital and > 1 GHz analog systems. These higher bandwidth systems are using laser diodes and photodiodes with risetimes of 20 ps or less. To support these fast 20 ps risetimes requires system components with -3 dB bandwidths in excess of 20 GHz. An approximate equation relating risetime and bandwidth is: Tr (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 topline 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.

Figure 1 shows the basic schematic diagrams of the two most common bias tee designs. Capacitor C is a DC block installed in the center conductor of the 50 Ohm coaxial line. It prevents the DC power from flowing out the AC port. For low-current applications, such as biasing photodiodes, a resistor R is used 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 instead use an inductor.

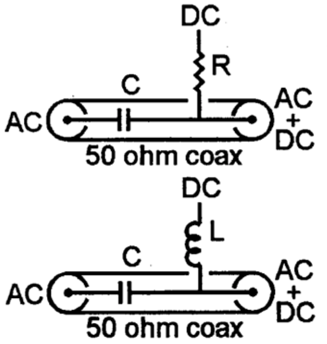


Figure 1: Bias Tee Schematic Diagrams

The low-frequency performance of a bias tee can be very easily calculated from elementary circuit theory. For the R-C bias tee, the DC blocking capacitor determines the -3 dB low-frequency cutoff (f_o).

$$f_o = \frac{1}{[2 * \Pi * (Rg + R_L) * C]}$$

Where Rg is the signal generator source impedance and R_L is the load impedance. For example, with 50 Ohm source and load impedances and a 0.22 μF blocking capacitor, the -3 dB cutoff is 7.23 kHz. For the L-C bias tee, the -3 dB low frequency cutoff is determined by the rising series impedance of the DC-blocking capacitor C and also the decreasing shunting impedance of the DC feed inductor L.

The microwave performance, high-frequency roll-off and risetime of a bias tee are limited by the parasitic reactances and losses associated with the components R, L and C and the care in which they are mounted within the coaxial environment. Any impedance discontinuities from 50 Ohms created by their mounting or the bias tee package 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 L. 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. Any physically realizable inductor always is plagued with parasitic capacitances, losses, etc. that cause multiple resonances and prevent it from behaving as the ideal textbook inductor. 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 L shown in Figure 1 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 Ohm 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.

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 most of the major telecom companies. PSPL now offers a wide selection of bias tees for various bandwidth, voltage and current requirements. PSPL is continuing its development of additional models for higher bandwidths and higher currents. PSPL also offers to design and build custom bias tees.

Table 1 on page 3 lists the broadband bias tees currently offered by PSPL. These are all 50 Ohm units. The fastest risetime is 7 ps. Bandwidths up to 50 GHz are available. Max. current ratings range from 10 mA to 1 Amp. Max. voltage ratings range from 16 V to 200 V. Low frequency cutoffs range from 5 kHz to 100 kHz. For two models, 5550B and 5575A, the low frequency cutoff is a function of the DC current. For these two models, the magnetic core of the largest mH inductor saturates at high currents, thus lowering the effective value of L and raising the low-frequency cutoff. Detailed specification sheets are available from PSPL’s web site for all of these models. The specification sheets include plots of frequency domain S parameters and time domain pulse responses.

PSPL’s highest performance bias tee is the new Model 5542. It features a bandwidth extending from 10 kHz to 50 GHz. It is rated at 16 V and 100 mA and is available with either 2.9 mm or 2.4 mm connectors. A dual inductor version of the 5542 is also available.

PSPL also offers a family of four high current (8 Amps), high voltage (100 V) bias tees. They are narrowband components covering decade bands from 200 MHz to 20 GHz.

Figures 2 - 7 on page 3 show the typical performance of the PSPL Model 5541A bias tee. The 5541A has a risetime of only 8 ps. Figure 2 shows the pulse response when driven by a 10 ps risetime input step. For this measurement an HP-54124A, 50 GHz oscilloscope and a PSPL 4015C, 15 ps pulse generator were used. For 10 ps measurement details see PSPL AN-5c. Figure 3 shows the TDR impedance profile of the AC input port. Figures 4 - 7 show the frequency responses for insertion loss, group delay and return loss. These were measured using a Wiltron 37369A, 40 GHz vector network analyzer.

The measured 8 ps risetime of the 5541A would imply a 44 GHz bandwidth (BW = 0.35 / Tr). However, close examination of Figure 5 shows that there are multiple resonance spikes occurring in the 5541A’s insertion loss for frequencies above 26 GHz. These are due to the 5541A’s SMA connectors, which support higher order waveguide modes above 26 GHz. The minimums of S21 show only 1 dB of loss up to 40 GHz which correlates well with the measured 8 ps risetime. Due to the SMA resonances, use of the 5541A for frequency domain applications above 26 GHz is not recommended.

Table 1: PSPL Broadband Bias Tees (detailed specification sheets available on request or at www.picosecond.com)

Model	Type	Tr (ps)	BW (GHz)	fo (kHz)	S21 (dB)	S11 (dB)	Volts max	I Max (amps)	R (ohms)	L (mH)	C (µF)
5530A	RC	28	12	20	0.2	>25	200	10m	1k	---	0.082
5535	RC	28	12	7	0.2	>25	50	10m	1k	---	0.22
5541A	LC	8	>26	80	0.4	20	50	100m	3.7	1.0	0.02
5542	LC	7	50	10	0.2	>25	16	100m	5.6	1.5	0.22
5545	LC	12	>20	65	0.7	23	50	500m	1.1	0.34	0.03
5547	LC	23	15	5	0.5	23	50	500m	1.5	1.34	0.44
5550B	LC	20	18	100	0.9	>15	50	500m*	0.4	1.0	0.02
5555	LC	20	18	100	0.9	>15	50	500m	0.6	0.11	0.02
5575A	LC	30	12	10	0.6	>18	50	500m*	0.6	8	0.22
5580	LC	28	15	10	1.0	>15	50	1.0	0.8	1.1	0.22

Time Domain and Frequency Domain Responses of PSPL Model 5541A Bias Tee

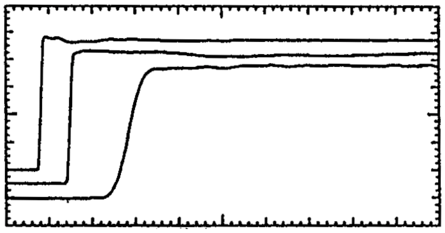


Figure 2: Response to 10 ps Risetime Input Step. 20%/div. Top to Bottom: 1 ns/div, 200 ps/div and 20 ps/div.

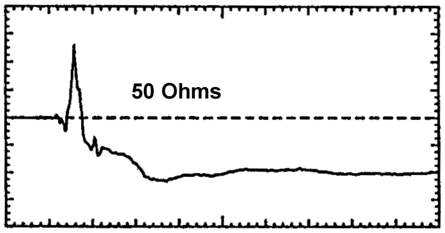


Figure 3: 35 ps TDR of AC Input Port. 2.5% ρ/div and 500 ps/div.

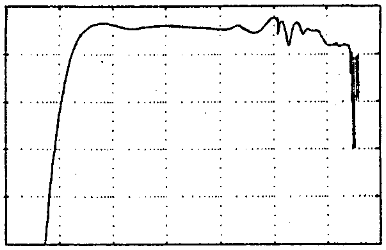


Figure 4: Insertion Loss, S21. Log Plot from 10 kHz to 100 GHz. Vertical Scale is 1 dB/div.

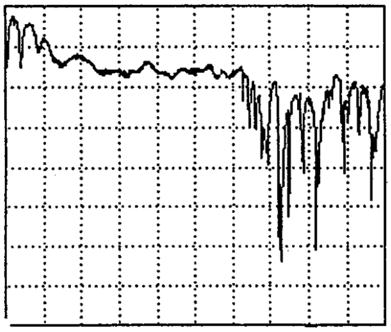


Figure 5: Insertion Loss, S21. Linear Plot from 40 MHz to 40 GHz. 0.5 dB/div and 4 GHz/div.

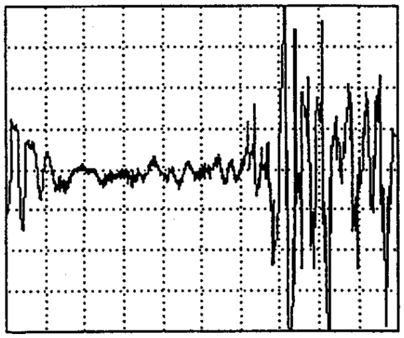


Figure 6: Group Delay, S21. Linear Plot from 40 MHz to 40 GHz. 10 ps/div and 4 GHz/div.

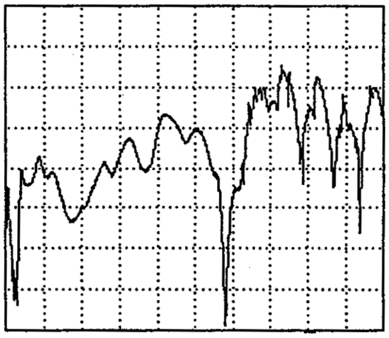


Figure 7: Return Loss, S11. Linear Plot from 40 MHz to 40 GHz. 5 dB/div and 4 GHz/div.