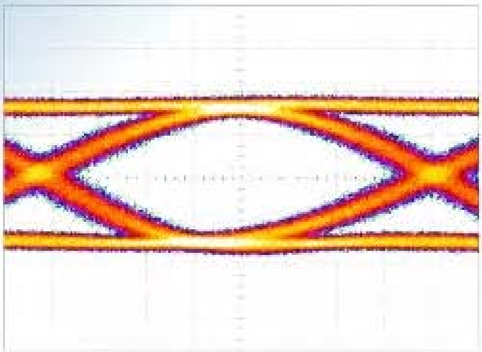
SHF Communication Technologies AG

Wilhelm-von-Siemens-Str. 23 • Aufgang D • 12277 Berlin – Marienfelde • Germany

Phone ++49 30 / 772 05 10 • Fax ++49 30 / 753 10 78

E-Mail: sales@shf.biz • Web: http://www.shf.biz



Application Note

AN-BT65-1

Impact of Bias Tees on Communication Signals

Resonance free transmission performance from 20 kHz to over 65 GHz
Innovative construction – Patent pending

Selecting a bias tee for your application looks pretty straightforward, but watch out - sometimes important data are not given to enable an appropriate decision.

Here is a summary of the specifications you should consider:

Bandwidth and frequency response

It is obvious that a low insertion loss, the amount of bandwidth and the frequency response of S_{21} are important. If you want to transmit 44 Gbps signals, a flat frequency response and a bandwidth of 65 GHz are required to transmit all relevant spectral components of the signal. The limiting factor in the bandwidth of the SHF BT65 is the performance of the V connectors. Figure 1 shows a sharp spike at ~71GHz, which corresponds to the moding frequency of the V connectors. Aside from this, the performance is very good to over 100GHz.

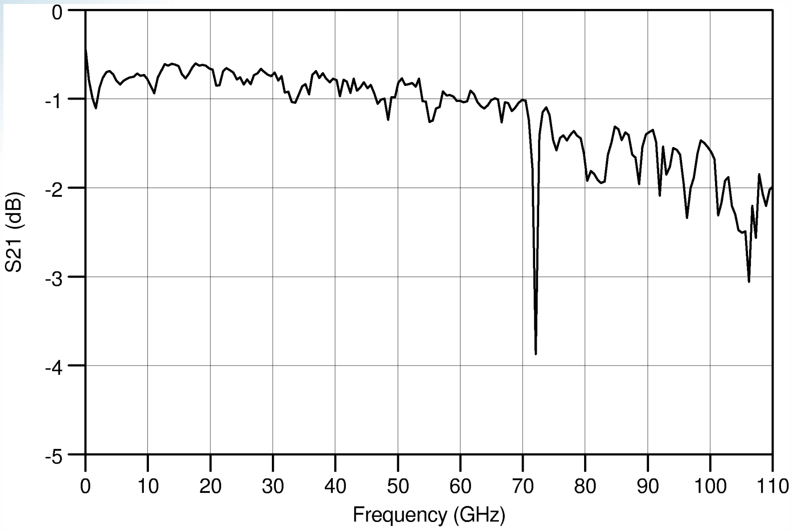


Fig.1:
Frequency Response of an SHF BT65 Bias Tee

Measured with:
Agilent 8510XF Network Analyzer

Fig. 1 shows a typical frequency response of a 65 GHz SHF bias tee. Note that the data also includes additional attenuation due to 1mm to 1.85mm adaptors between the bias tee and VNA.

As pseudo random bit streams show a spectrum with a $[\sin(x)/x]^2$ envelope which tolerates the omission of spectral lines close to DC only to a limited extent. It is therefore important to have a low frequency cut off and a linear transmission of the low frequency spectral components as well (Fig. 2).

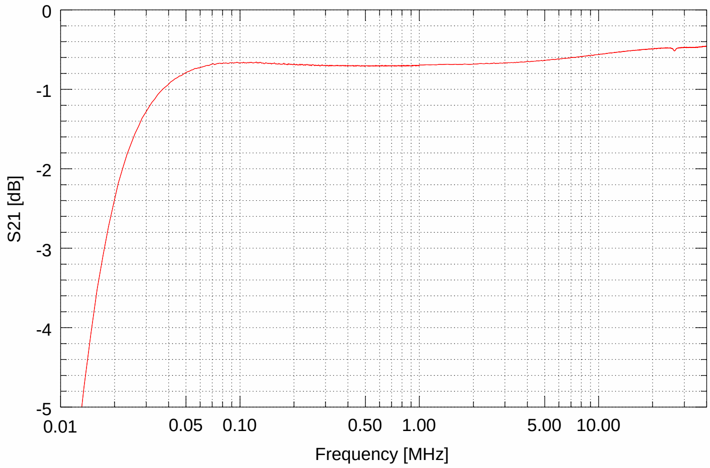


Fig. 2:
Frequency Response of an SHF Bias Tee at low Frequencies

Measured with:
Agilent 4395A Network Analyzer

Linear phase and group delay

When pulses or communication signals are to be transmitted, not only the amplitude of the transfer function but also its phase is quite important. If the phase of the bias tee is not linear, distortions will occur.

Fig. 3 explains this effect: A square wave (simulated up to its 5th harmonic) is shown after the transmission through a network with a linear and a network with a non-linear phase response.

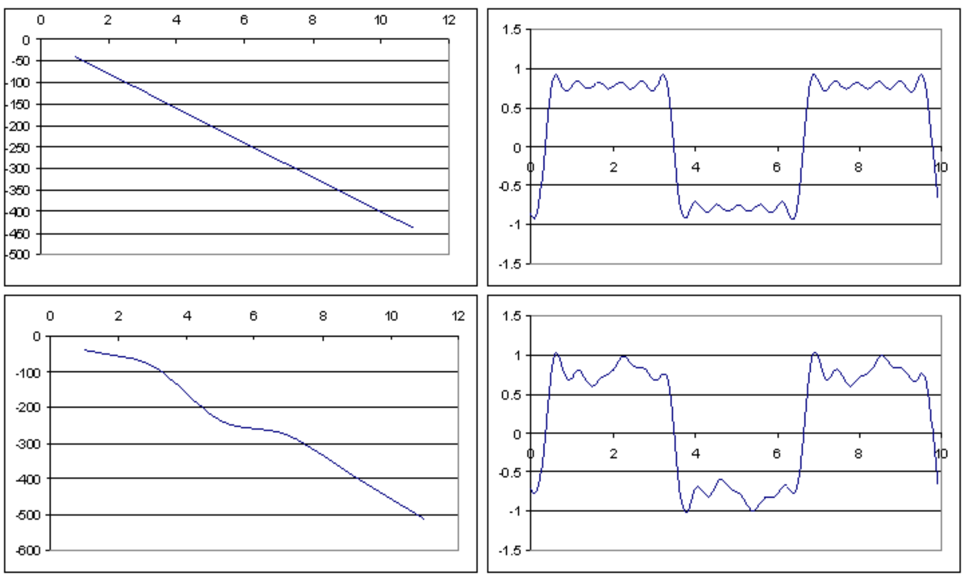


Fig. 3: Influence of a Non-Linear Phase Response

At higher frequencies, the amplitude slope of even small components might be very steep and thus a non-linearity would be difficult to see. Because of this, another specification is more commonly used: group delay.

The group delay is the derivative of the phase versus frequency. More mathematically,

$$t_g = -\frac{d\varphi}{d\omega} \approx -\frac{\Delta\varphi}{2\pi\Delta f} \quad .$$

Modern network analyzers determine the group delay by measuring the phase at discrete frequencies and calculating the phase difference at two different frequencies in their CPU.

The step value Δf is called the aperture and can be selected by the operator of the network analyzer – creating a new problem: Without specifying the aperture, the group delay specification is meaningless. If two group delay measurements are to be compared they have to be made with the **same** aperture because larger aperture values tend to “average” the ripple, making it appear as though the group delay is smaller than it really is.

Fig. 4 shows a group delay measurement from one of our bias tees compared with the bias tee of another vendor:

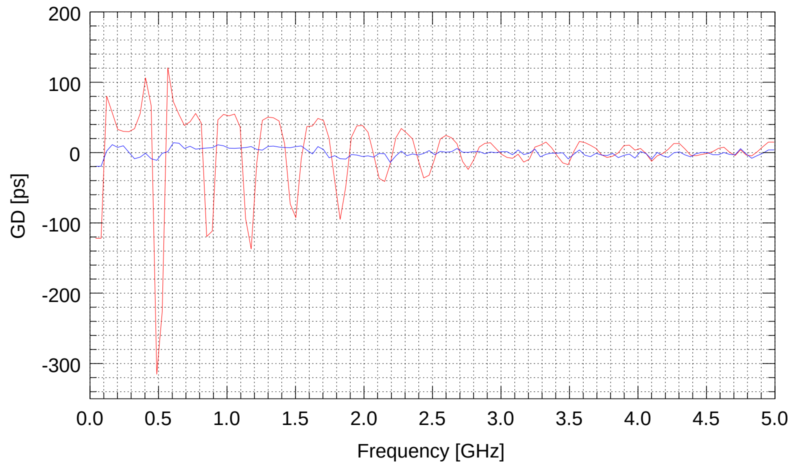


Fig.4:
Group Delay

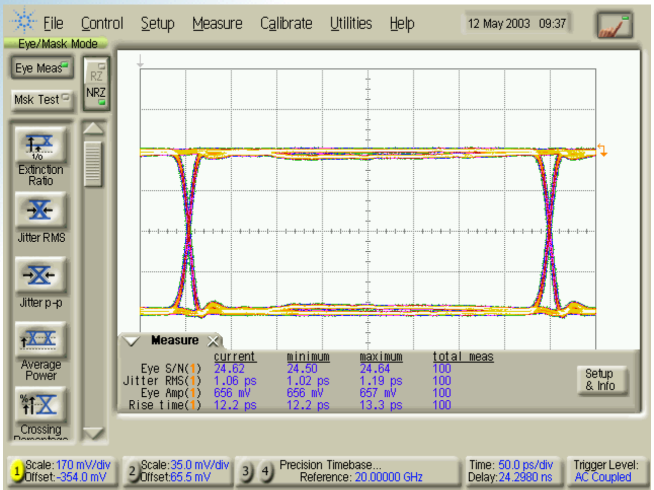
SHFBT65
Other Vendor

Measured with:
Anritsu 37397C Network Analyzer

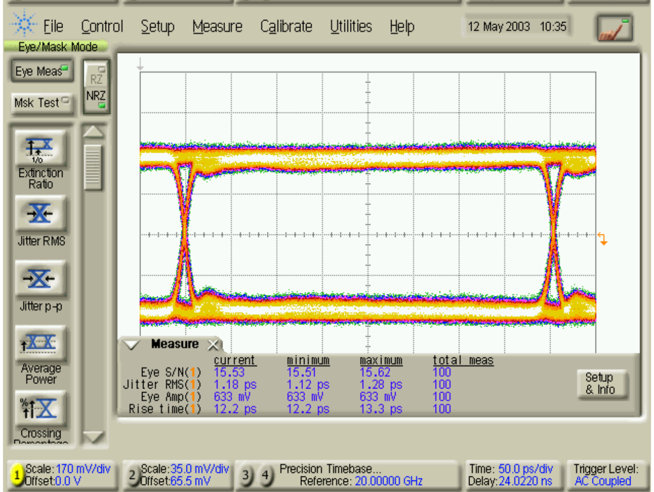
Aperture: 40MHz

Clearly, the group delay of the SHF bias tee is flatter at low frequencies. The important point to note here is that the data sheet of the other vendor displays a group delay measurement with a variation of only ± 2ps. This measurement is not wrong but an aperture of around 500 MHz was used. Our measurement shown above was taken with an aperture of 40 MHz. If a bigger aperture is chosen the ripple will be smoothed out and cannot be detected any more.

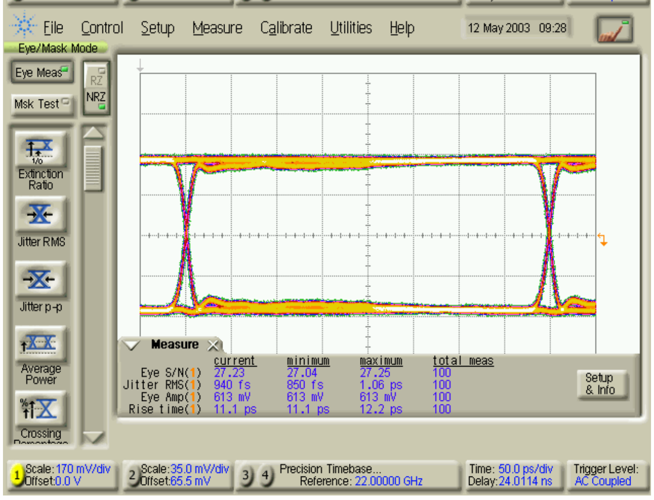
To determine whether a given group delay ripple will have any impact on your signal, you have to look at the eye diagram. Fig 5 shows the results. As you can see, a group delay ripple causes a broadening of top and base line.



Electrical input signal at 2.5 Gbps
Generated by SHF BPG 44 Opt. LJ
NRZ, PRBS 2^{23} –1,
measured with
Digital Communications Analyzer
Agilent 86100B / 83484A
50 cm Sucoflex 102EA + 3 dB V-Gold attenuator between the generator and the sampling head input

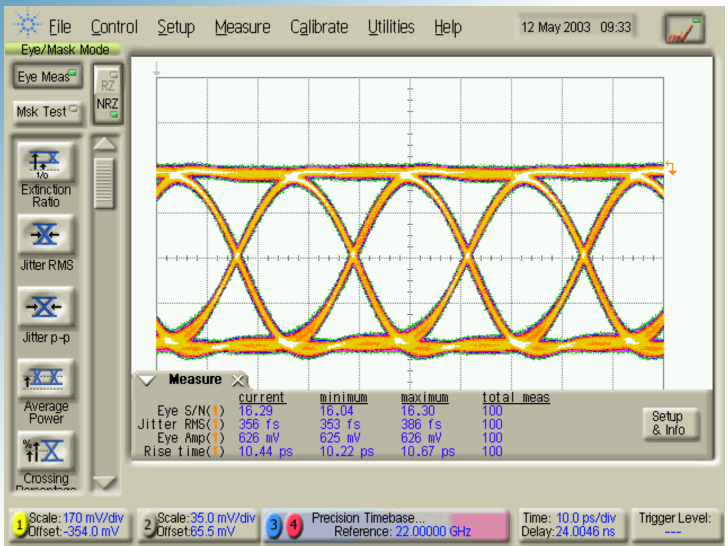


Other Vendor
Electrical output signal at 2.5 Gbps
measured with:
Digital Communications Analyzer
Agilent 86100B / 83484A
50 cm Sucoflex 102EA between the generator and the bias tee
3 dB V-Gold attenuator before the sampling head input
Note: The low frequency group delay ripple introduces line broadening.



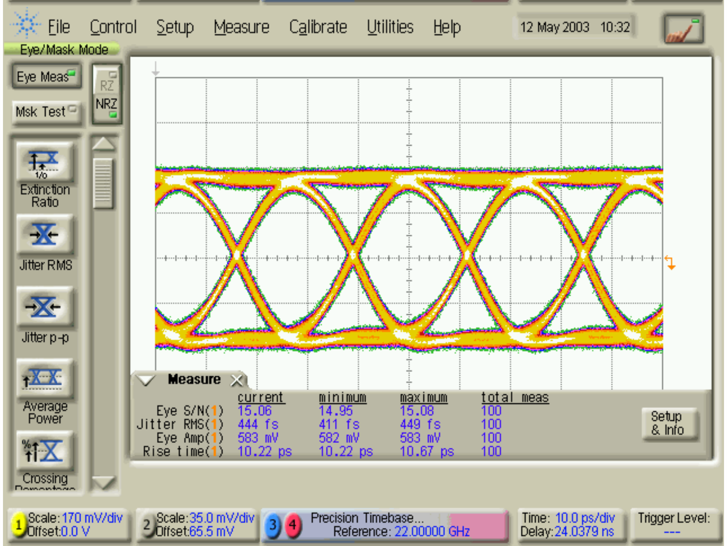
SHF BT65
Electrical output signal at 2.5 Gbps
measured with:
Digital Communications Analyzer
Agilent 86100B / 83484A
50 cm Sucoflex 102EA between the generator and the bias tee
3 dB V-Gold attenuator before the sampling head input
Note: No additional broadening of top and base line.

Fig. 5: Eye diagrams at 2.5Gbps



Electrical input signal
at 44 Gbps
Generated by SHF BPG 44 Opt LJ
NRZ, PRBS 2^{23} –1,
measured with
Digital Communications Analyzer
Agilent 86100B / 83484A
50 cm Sucoflex 102EA + 3 dB V-Gold attenuator between the generator and the sampling head input

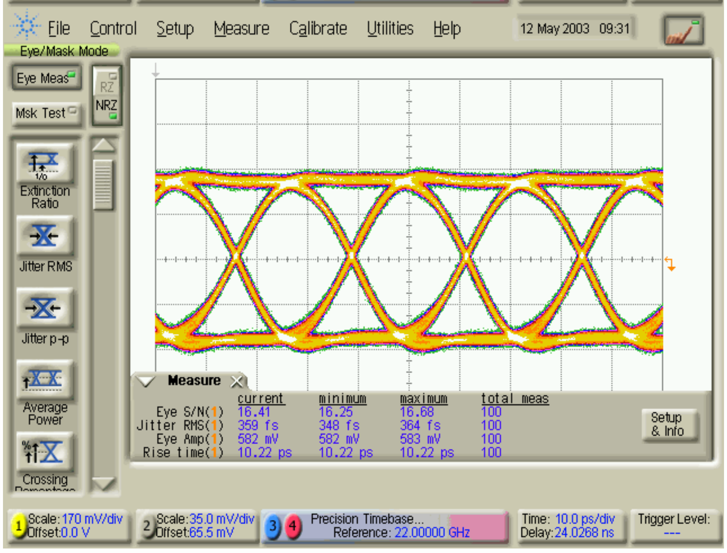
Q-Factor: 16.29
Jitter: 356 fs
Eye amplitude: 626 mV



Other Vendor
Electrical output signal
at 44 Gbps

measured with
Digital Communications Analyzer
Agilent 86100B / 83484A
50 cm Sucoflex 102EA between the generator and the bias tee
3 dB V-Gold attenuator before the sampling head input

Q-factor: 15.06
Jitter: 444 fs
Eye amplitude: 583 mV



SHF BT65 Electrical output signal
at 44 Gbps

measured with
Digital Communications Analyzer
Agilent 86100B / 83484A
50 cm Sucoflex 102EA between the generator and the bias tee
3 dB V-Gold attenuator before the sampling head input

Q-factor: 16.41
Jitter: 359 fs
Eye amplitude: 582 mV

Fig 6: Eye diagrams at 44 Gbps

A high quality bias tee shows negligible performance degradation with 44 Gbps data signals.

Influence of DC voltage and current on the low frequency cut off

It is obvious that DC parameters like maximum voltage and current are also important specifications. Rather less known is the effect that capacitors change their value depending on the DC voltage applied and that inductors might go into saturation according to the amount of DC current flowing through. This of course will change the low frequency cut-off point.

We evaluated this influence with a setup according to Fig. 7. If you also want to characterize a bias tee versus DC voltage or current make sure that the attenuator can handle the currents involved.

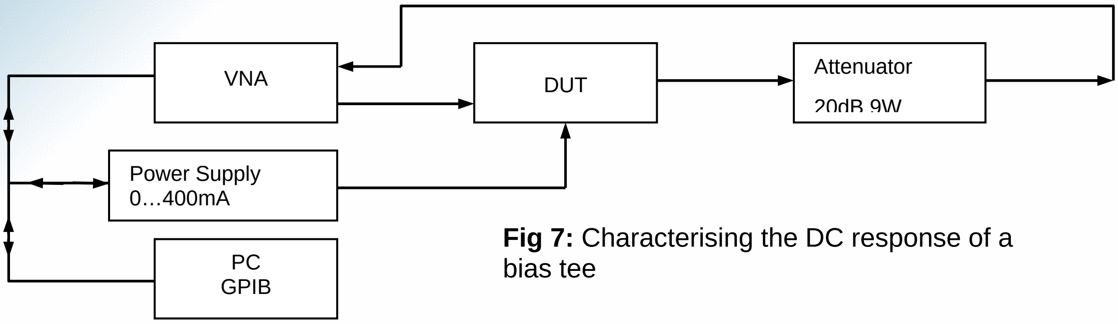
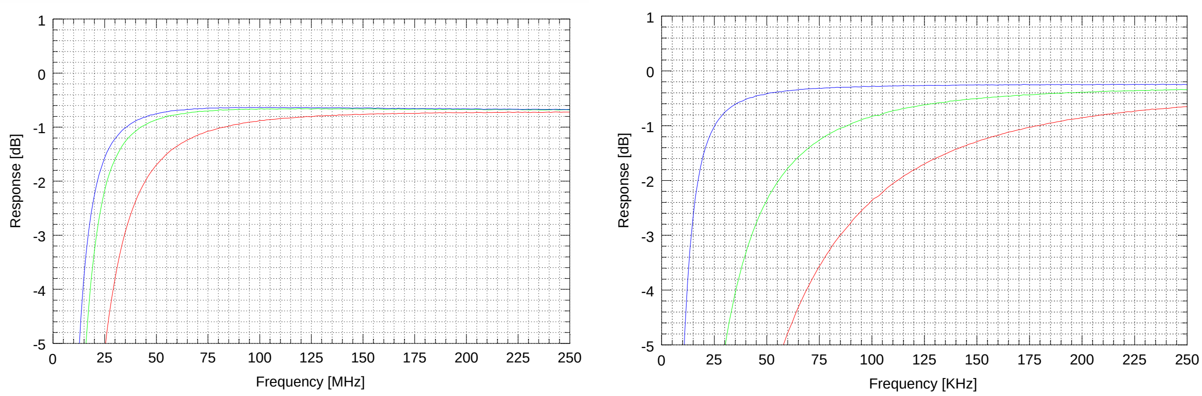


Fig 7: Characterising the DC response of a bias tee

The measurement reveals the behavior that the low frequency cut off increases with increasing bias voltage and current. This surprising result shows that a bias tee that seems to be superior at 0 V bias (normally shown in data sheets) is worse under more realistic operating conditions. Figure 8 shows the low frequency response of bias tees with no bias applied and the performance with applied voltage.



SHF BT65
Low Frequency Cut Off versus Bias
@ 0mA -3dB @ 18 kHz
@ 200mA -3dB @ 27 kHz
@ 400mA -3dB @ 45 kHz

Measured with:
HP4395A Network Analyzer,
Agilent E3646A Power Supply,
20dB/9W Power Attenuator (SHF)

Other Vendor
Low Frequency Cut Off versus Bias
@ 0mA -3dB @ 15 kHz
@ 200mA -3dB @ 48 kHz
@ 400mA -3dB @ 85 kHz

Measured with:
HP4395A Network Analyzer,
Agilent E3646A Power Supply,
20dB/9W Power Attenuator (SHF)

Fig 8: Comparison of low frequency cut-off frequency with different bias voltages for the SHF BT65 and a bias tee from another manufacturer

Isolation

For some measurements (e.g. if you want to measure very small DC currents) it is important that there is no RF signal present at the DC port. The isolation of the bias tee characterizes this. SHF bias tees have a specified minimum isolation of 40 dB, so the maximum RF signal at the DC port would be only one ten-thousandth of the original signal.

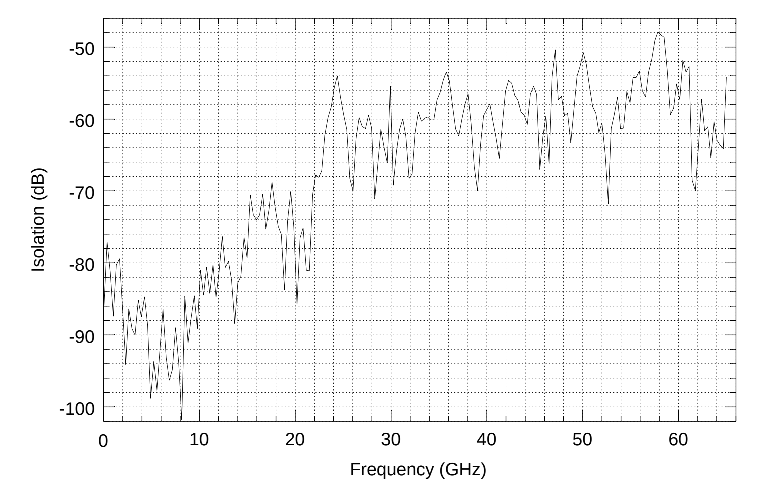


Fig 9 Isolation measured between the bias port and HF-in port.

And finally…

The inductance of our bias tee at the rated current is > 0.4 mH. This is important information if you connect a capacitive load to the DC port of the bias tee and it has no internal bypass capacitor to ground. The external capacitor will create a series resonating circuit in connection with the inductance of the bias tee. The resonant frequency is given by the formula

$$f_{\mathrm{Res}} = \frac{1}{2\pi\sqrt{LC}}.$$

If the resonant frequency of this circuit lies above the lower cut off frequency of the bias tee, this will generate a narrow band notch in the transmission characteristic.

Knowing the inductance of the bias tee helps you to determine whether the series resonance might affect your measurement and also shows you how much AC signal current will be bypassed to ground in the audio frequency range.

Conclusions

To determine which bias tee is best for your application requires consideration of a whole set of parameters. Low frequency cut off, group delay **and** aperture and eye diagrams have to be compared as well as the influence of DC voltage and current on the low frequency transmission characteristic.
For some applications, the isolation of the bias tee and the value of the internal inductor are also important.