

# Consider Source Harmonics When Characterizing Filters with VNAs

ShockLine™ MS4652xB Series Vector Network Analyzer

Filters are a key component in most RF and microwave systems. System designers select a filter for a given application based on several key specifications, including: operational bandwidth, passband insertion loss and ripple response, and cutoff band performance. Vector network analyzers (VNAs) are typically used to characterize these parameters and there are several instrument specifications to consider when selecting the right VNA for the job.

Depending on the type and performance of the filter to be tested, some VNA specifications will be more important than others in determining the right VNA for the application. For testing high rejection filters, the most important VNA specification is system dynamic range (SDR). If the instrument does not have enough dynamic range the measurement result will show the performance of the VNA rather than the filter.

The standard industry definition of VNA SDR is the difference between the maximum port output power and the noise floor of the receiver. This definition is used for SDR as it is relatively straightforward to test on a VNA, as output power can be directly measured and the noise floor is characterized by terminating the ports with 50 ohm loads so that there is no signal input to the ports. By not requiring any input signals, this definition eliminates any dependence on a specific test device to determine if the VNA meets SDR specifications.

A general assumption when selecting a VNA is that the system dynamic range specification represents the dynamic range the VNA can measure on all types of devices under test (DUTs). For many devices like cables, connectors, and other passive components that are not frequency selective, that assumption is true. However, for certain types of passive DUTs that are both highly reflective and frequency selective like some high rejection filters, there are measurement interactions with the DUT that can make the effective dynamic range of the VNA different from the specified SDR.

Ideally when measuring the transmission characteristic of a filter, the only signal measured at the receiver port is the fundamental signal from the VNA source port passed through the filter as the source is swept across frequency (Figure 1).

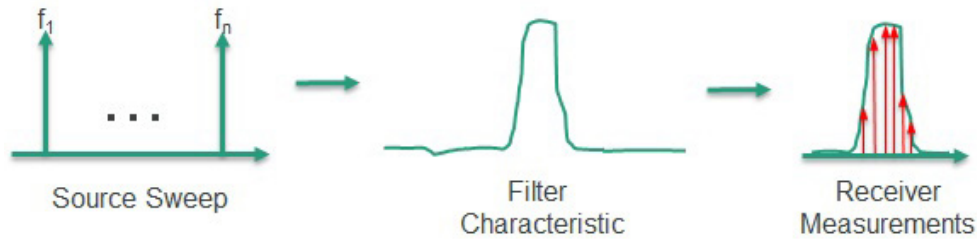


Figure 1. Ideal VNA filter sweep

This hypothetical ideal requires a source with no harmonics and a perfectly linear receiver, however, all real VNAs unfortunately have sources with some harmonic content and receivers with some level of non-linearity. Since VNAs are generally considered narrowband instruments, this harmonic source content is usually not an issue as those harmonics are usually well outside of the measurement band. However, some filters have high-pass characteristics outside the normal operational frequency band that create pathways for harmonic mixing products to appear at the receiver and affect the filter cutoff band measurements. This is especially true for filters that have a comeback or high-pass region that allow harmonics of the source signal to pass through to the receiver when the fundamental tone is in the cutoff band of the filter (Figure 2). These 2nd and 3rd harmonic components can then mix in the receiver (given some relatively minor level of nonlinearity) to produce the fundamental frequency.

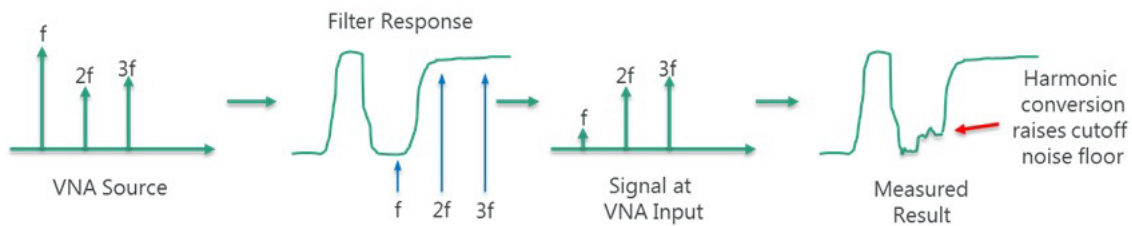


Figure 2. Filter with high-pass comeback measurement

Take the example of a bandpass filter (BPF) centered at 6.1 GHz measured on a ShockLine MS4652xB VNA. In this transmission plot we see the filter has a sharp rejection band approximately 95 dB below the pass band with a comeback or high-pass characteristic starting at approximately 9.46 GHz (Marker 3, Figure 3).

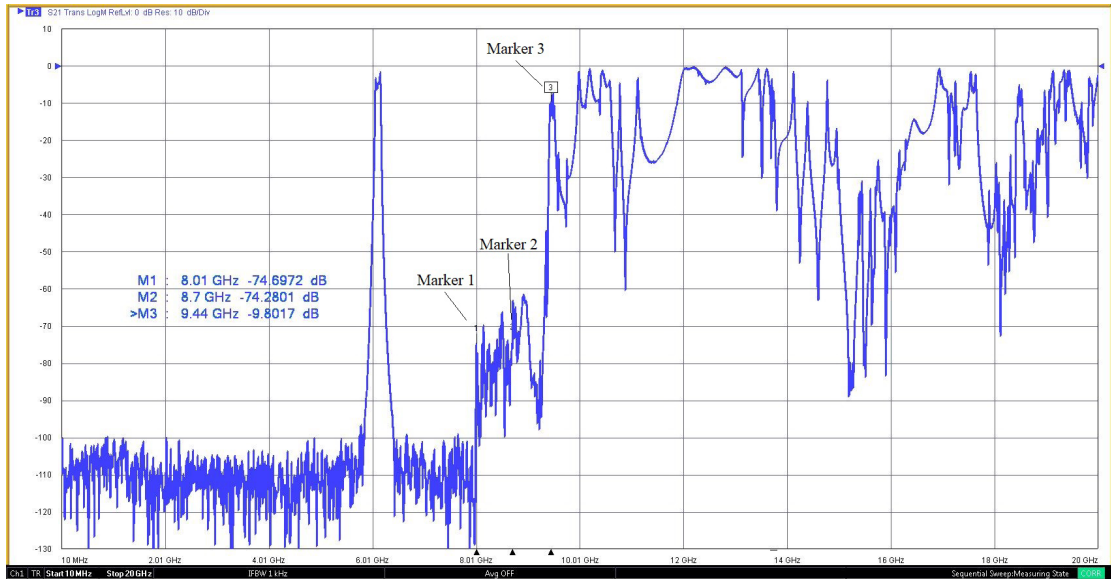


Figure 3. Bandpass filter characteristic on a ShockLine MS4652xB VNA

The filter high side rejection band is expected to be flat to about 8.7 GHz (Marker 2, Figure 3) before the filter stops operating, however this plot shows a step in the noise floor starting at 8 GHz (Marker 1, Figure 3) that is well above what the filter cutoff level should be. This step is mainly due to a couple traits of the ShockLine MS4652xB architecture – the baseband-to-microwave transition in the VNA and high harmonic content from the source.

The ShockLine MS4652xB architecture is made up of essentially two VNAs in one, very much like the VectorStar™ VNA. The ShockLine MS4652xB has a lower frequency baseband VNA that transitions to a higher frequency architecture for microwave measurements. The transition between the baseband and microwave sections of the VNA occurs at approximately 8 GHz, causing the step in the noise floor. Figure 4 shows the same measurement setup as in Figure 3 with the ports terminated. Note the step in the terminated measurement.

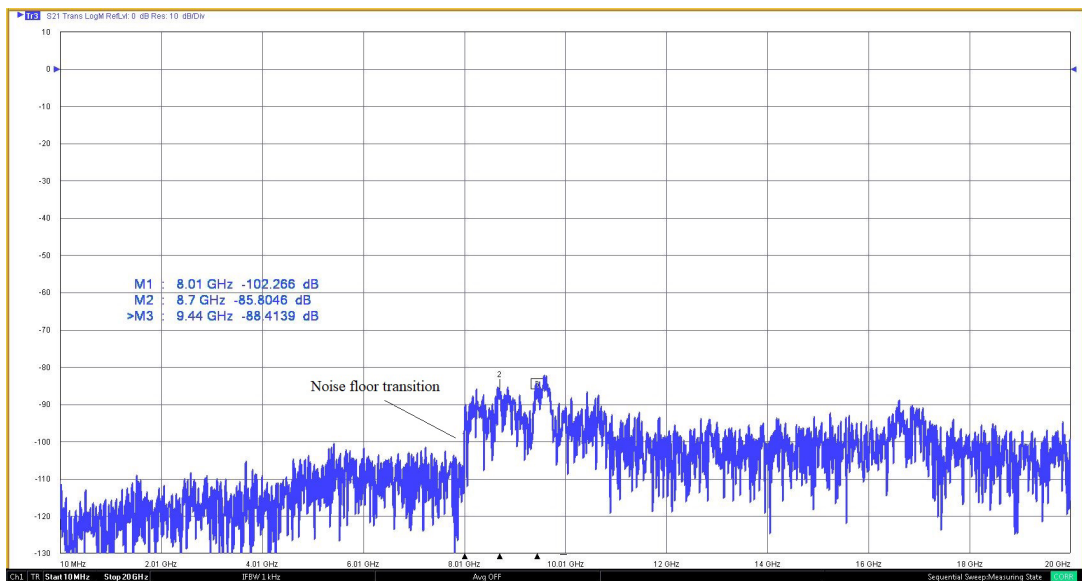


Figure 4. Noise floor with ports terminated

The ShockLine MS4652xB has a system dynamic range specification of at least 114 dB in the 8 GHz to 8.7 GHz range with an IF bandwidth of 10 Hz. At an IFBW of 1 KHz, like the plots shown here, the expected dynamic range should be ~20 dB worse or about 94 dB. If we look at the filter response (Figure 3) overlaid on the noise floor measurement (Figure 4), we see that the step is still above what we see with the ports terminated (Figure 5).

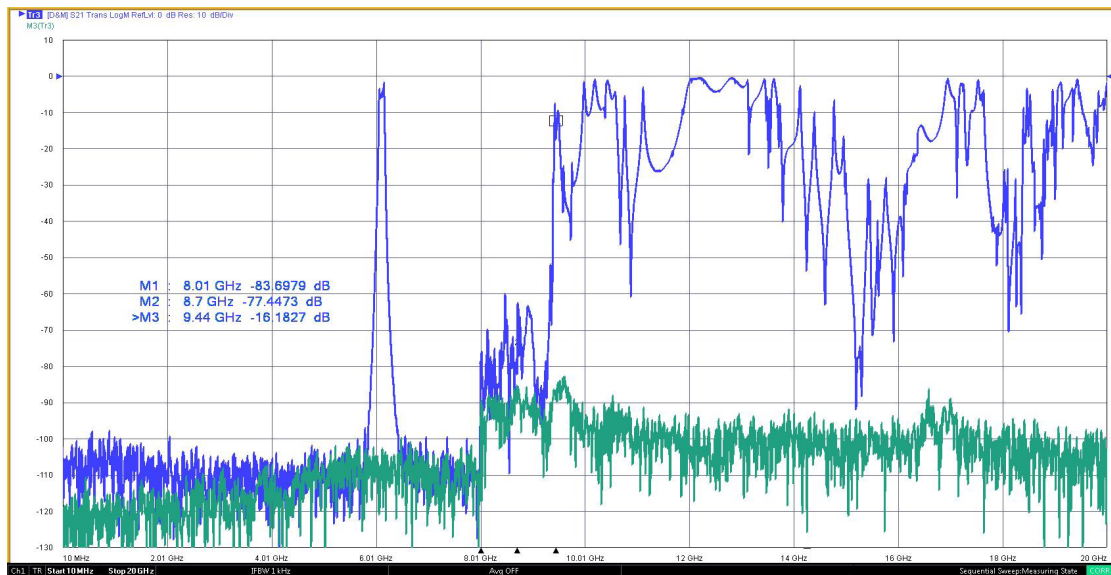


Figure 5. Filter and noise floor overlaid

As introduced earlier, harmonics on a VNA source can mix back into the receiver if the BPF has a high frequency comeback in the appropriate frequency range. For this particular BPF, the comeback region does happen to allow the source harmonics of the 8 – 8.7 GHz sweep to pass through to the receiver and mix down to the fundamental frequency, causing the receiver to measure a higher floor than expected. To confirm this explanation, a 10.4 GHz low-pass filter (LPF) is added in series with the 6.1 GHz BPF under test to attenuate the source harmonics of the ShockLine MS4652xB VNA as the fundamental sweep frequency goes from 8 to 8.7 GHz.

Figure 6 shows the results before and after adding the low-pass filter to the measurement on the same plot. The blue trace is the transmission measurement without the additional low-pass filter and the brown trace is the transmission characteristic with the LPF in series. The blue trace shows a significantly higher rejection band measurement in the 8 to 8.7 GHz region than the brown trace. This shows that reducing source harmonic content with a series LPF clearly improved the cutoff band measurement between 8 GHz and 8.7 GHz. Note that the LPF has minimal effect on the transmission measurement prior to the 10.4 GHz filter cutoff.

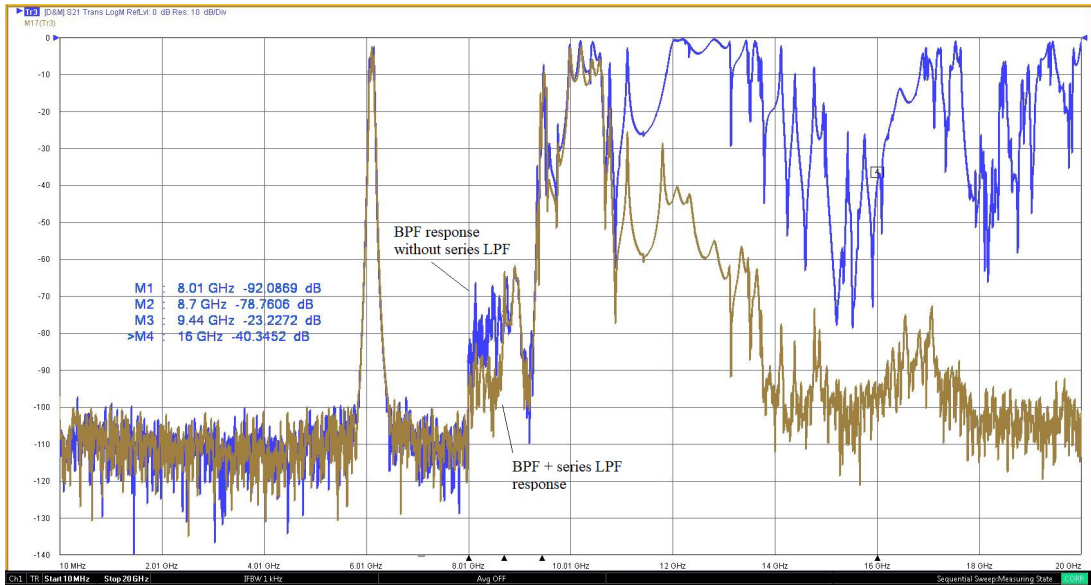


Figure 6. BPF transmission plot with and without series LPF

Figure 7 shows a plot with the measured BPF+LPF combination response overlaid with the noise floor and LPF responses. The BPF+LPF response matches the terminated noise floor characteristic much more closely in the cutoff region of interest than what was shown in Figure 5.

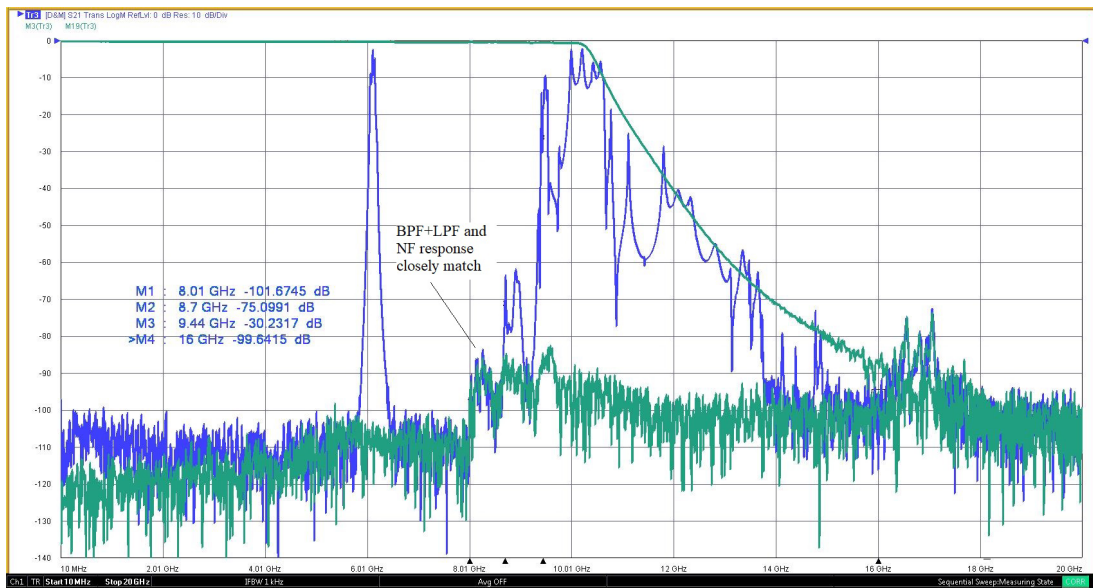


Figure 7. 6.1 GHz BPF with 10.4 GHz LPF in series; noise floor, LPF, and BPF+LPF responses overlaid



A new software mode was recently introduced in the ShockLine MS4652xB VNA to try and reduce the source harmonic content for applications like the one described here. The mode is called High Fidelity mode, and can be turned on and off by the user from the power menu (see Figure 8).

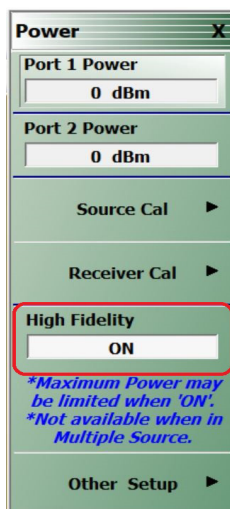


Figure 8. Power menu with high fidelity mode

A factory calibration must be done on the ShockLine MS4652xB VNA in order to have access to this mode. Units without this factory calibration will not have access. Maximum port power may be limited below nominal levels in order to achieve the desired lower source harmonic levels.

Using the new High Fidelity mode, the ShockLine MS4652xB VNA source harmonics are reduced, resulting in a measurement that is similar to what was achieved using the series LPF. Figure 9 shows the BPF measurement with the LPF in series with the normal ShockLine MS4652xB source harmonics overlaid on the BPF measured with no LPF and the MS46524B setup in low harmonic mode. The trace measurements are closely overlapping until the 10.4 GHz 3dB cutoff of the LPF.

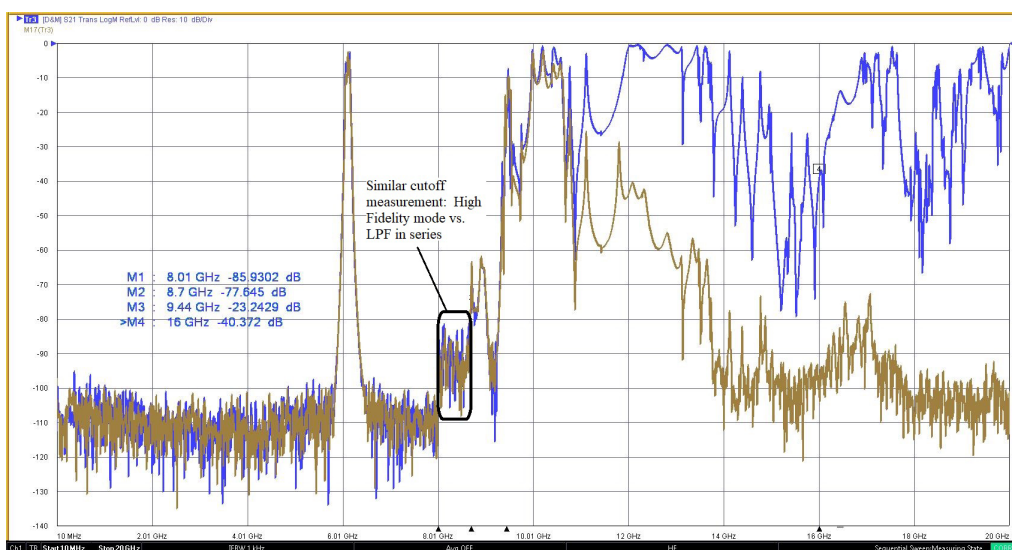


Figure 9. Effect on BPF cutoff measurement: high fidelity mode vs. filtered source harmonics

## Conclusion

There are several variables involved in selecting the appropriate VNA for characterizing transmission characteristics of deep cutoff filters. In particular, having enough system dynamic range in the VNA is key to being able to properly characterize the filter cutoff performance. However, as this application note illustrates, the published SDR specification is not the only aspect of a VNA like the ShockLine MS4652xB solution to consider when deciding if a VNA can measure the cutoff performance of a target filter.

This application note discussed how high source harmonics may interact with the out-of-band comeback characteristics of a filter under test to affect the filter transmission measurement. A low-pass filter was used to reduce the source harmonics injected into the filter to show the effect that lowering the harmonic content would have the cutoff band measurements. The ShockLine MS4652xB VNAs now have a new High Fidelity mode that reduces source harmonics in a key frequency band to help improve filter dynamic range tests like the one described here.

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