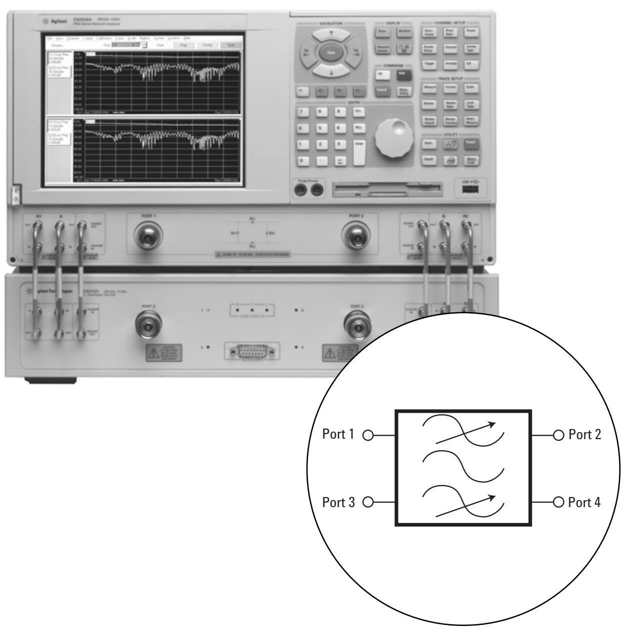
Agilent
Balanced Measurement Example: SAW Filters

Application Note 1373-5



Introduction

SAW filters are commonly used in wireless communication products because of their very sharp response characteristics, relatively low insertion loss, and low cost. In addition, their physical structure is such that they can be designed with single-ended RF ports, differential RF ports, or a combination of the two. This allows circuit designers to take full advantage of the benefits of either unbalanced or differential circuit topologies.

Typically, a SAW filter is most conveniently designed with relatively high port impedances. This high impedance works to the benefit of designers of handheld wireless subscriber products who are also concerned about minimizing power consumption.

The combination of balanced RF ports and non-50Ω reference impedances tend to make characterizing SAW filters, and designing them into products, a challenging undertaking. Agilent's balanced-measurement solutions address this challenge, and make testing and designing with SAW filters as straightforward as using any 50Ω single-ended component.

Agilent Technologies

Mixed-mode S-parameters

Single-ended S-parameters do not adequately describe the performance of balanced devices because the circuit is electrically different depending on whether it has a single-ended stimulus or a differential stimulus. Therefore, using conventional single-ended S-parameters to design differential circuits can lead to misleading and erroneous conclusions.

In addition to multiport single-ended S-parameters, Agilent balanced-measurement systems give the user the ability to examine the mixed-mode S-parameters. The mixed-mode S-parameters allow the two modes of propagation of a balanced device (differential and common) to be examined independently in both stimulus and response. This is best illustrated by examining measured data on actual devices.

Single-ended SAW filter S-parameters

Consider a single-ended SAW filter with port definitions as shown in Figure 1.

One such device, by Sawtek, has port impedances of 700Ω differential on both balanced ports. The 50Ω single-ended S-parameters of this device are shown in Figure 2.

The reflection parameters show that the input impedances on each port are considerably higher than 50Ω, and slightly capacitive. The transmission parameters show the bandwidth of the filter and the shape of the skirts.

The first problem in examining this data is that the filter, designed for 350Ω terminations, is measured in a 50Ω system. Therefore, the transmission parameters include a considerable amount of mismatch loss in addition to ohmic loss.

Figure 3 shows data on the same device measured in a 350Ω system.

The 350Ω data now shows the reflections closer to the center of the Smith chart. The significant capacitive component to the impedance is clearly visible.

The transmission parameters now give the user a better idea of the filter characteristics since much of the return loss has been removed.

The change in terminating impedance has also affected the passband ripple and the rejection characteristics, as shown in Figure 4.

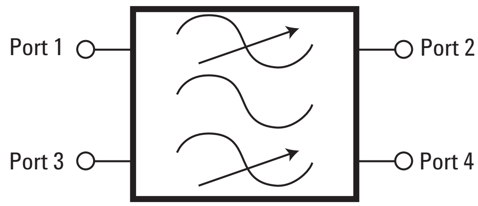


Figure 1. Single-ended SAW filter

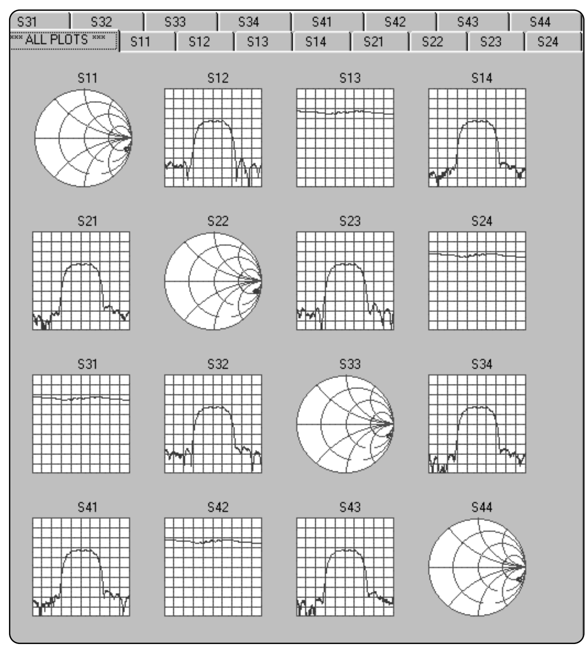


Figure 2. 50Ω Single-ended S-parameters of a 700Ω device

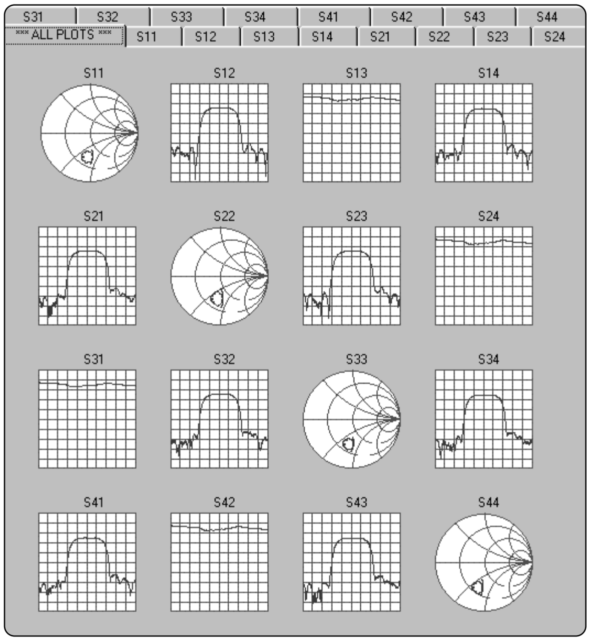


Figure 3. 350Ω Single-ended S-parameters of a 700Ω device

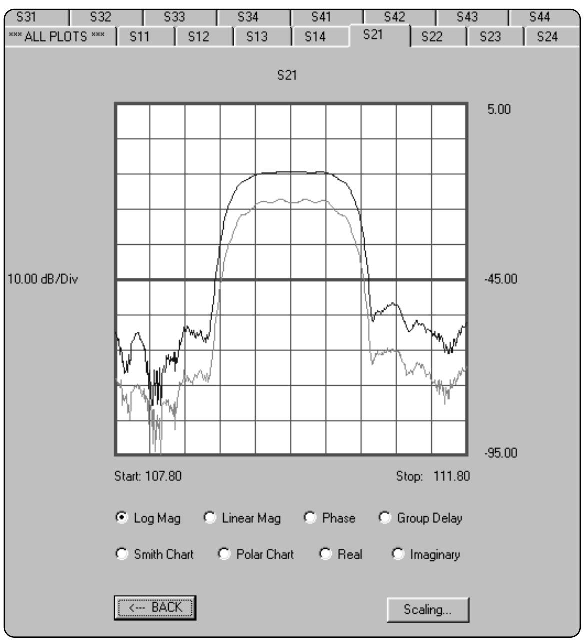


Figure 4. Effect of terminating impedance change on passband ripple and rejection

Mixed-mode SAW filter S-parameters

Since the SAW filter described earlier is driven with differential signals, the single-ended S-parameters are misleading. Therefore, we should consider the mixed-mode S-parameters of this device.

Figure 5 shows the mixed-mode S-parameter data on the same SAW filter examined in the single-ended S-parameter example in figure 3. This data has a 350Ω reference impedance on each terminal. Therefore, the differential-mode reference impedance is 700Ω, and the common-mode reference impedance is 175Ω.

The quadrant in the upper left corner shows the two-port differential stimulus/differential response characteristics. The input impedance at the center frequency of the passband is now in the center of the Smith chart, and there is no capacitive shift in the impedance as there is in the single-ended data. The output impedance shows similar characteristics. The differential match is different from the single-ended matches because the two sides of the balanced pairs are not isolated from each other.

The transmission characteristics now show the loss of this device when it is driven differentially. When inserted into a differential system, the data shows that the filter will have an insertion loss of about 8.9 dB. The single-ended transmission characteristics, by comparison, showed a loss of 14.5 dB.

The characteristics of the filter with a common-mode stimulus and a common-mode response are shown in the quadrant in the lower right. Both the input and output ports show a very high reflection (less than –0.1 dB return loss). As a result, the insertion loss is very high (greater than 60 dB). The ratio of the differential-mode gain to the common-mode gain gives the common-mode rejection of this device, which is greater than 50 dB in the passband as shown in figure 6.

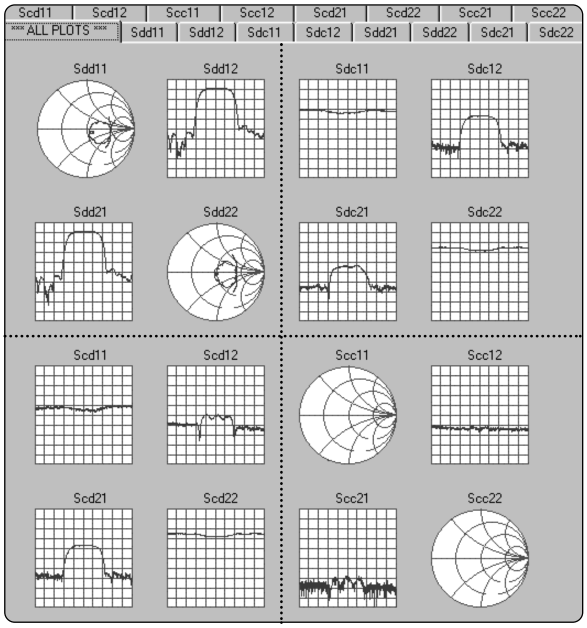


Figure 5. Mixed-mode S-parameters of the 700Ω device

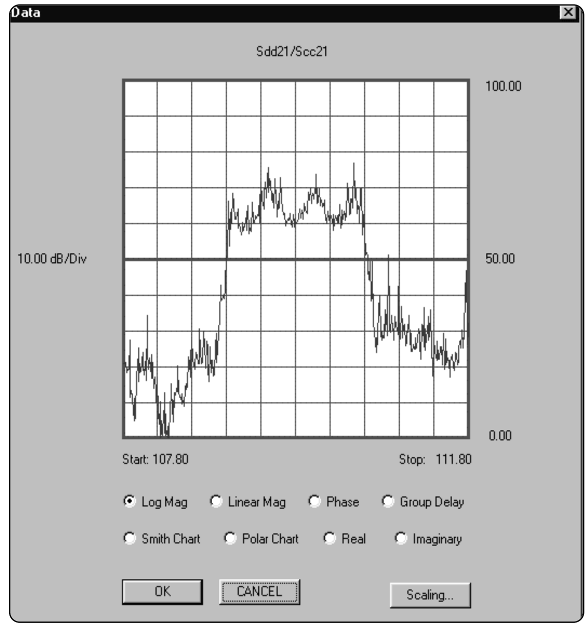


Figure 6. Common-mode rejection ratio (CMRR) greater than 50 dB

The lower left quadrant and the upper right quadrant in Figure 5 show the mode-conversion performance of this device. All of these parameters are very small, indicating that this filter is extremely symmetrical.

If a differential signal is applied to the input of this filter, there will be a large differential output signal, and a very small common-mode output signal arising from the very good, yet imperfect, symmetry. The ratio of the magnitudes of these two components is greater than 25 dB, as shown in Figure 7. Therefore, very little common-mode signal is inadvertently generated in this device.

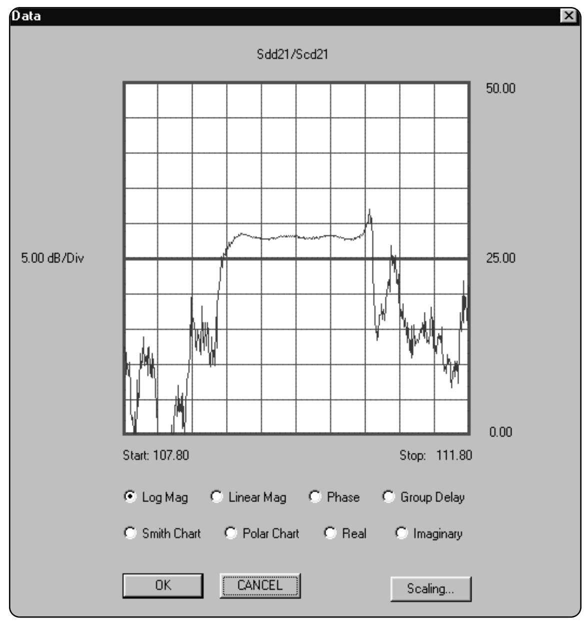


Figure 7. Ratio of differential-mode output to common-mode output, with differential-mode stimulus

Non-ideal SAW filter performance

The previous example showed the characteristics of a SAW filter with excellent performance. Examining less ideal devices helps to illustrate the insight that Agilent's balanced-measurement systems can provide. The single-ended S-parameters of one such device are shown in Figure 8.

This device is designed for 100Ω differential on the input port, and 500Ω differential on the output port. The single-ended matches on the two input terminals are very different, and it is clear that there is a problem with the filter on port 3. The two output terminals look similar to each other, but since the filter is designed for 500Ω, the traces are near the edge of the Smith chart. The transmission characteristics also indicate the problem on port 3 since S23, S32, S34, and S43 all show excess insertion loss compared to the other transmission parameters.

As with the previous example, looking at the data in the proper impedance system brings the matches on the output terminals closer to the center of the Smith chart and reduces the insertion loss, as shown in Figure 9.

Finally, the mixed-mode data in Figure 10 needs to be considered. The differential-mode quadrant (upper left) of the mixed-mode S-parameter matrix shows that the input is not properly matched to 100Ω differential, but is closer to 40Ω + j15Ω because of the problem on port 3. The output is well matched to 500Ω differential, and the transmission characteristics can be seen in the SDD21 parameter.

The common-mode performance (lower right quadrant) shows a high reflection on the output port. The problem on the input port also shows up in the common-mode reflection at the input.

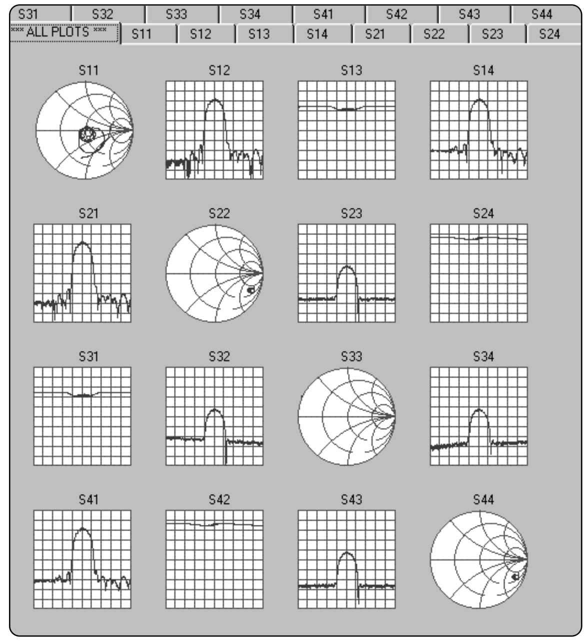


Figure 8. Single-ended S-parameters

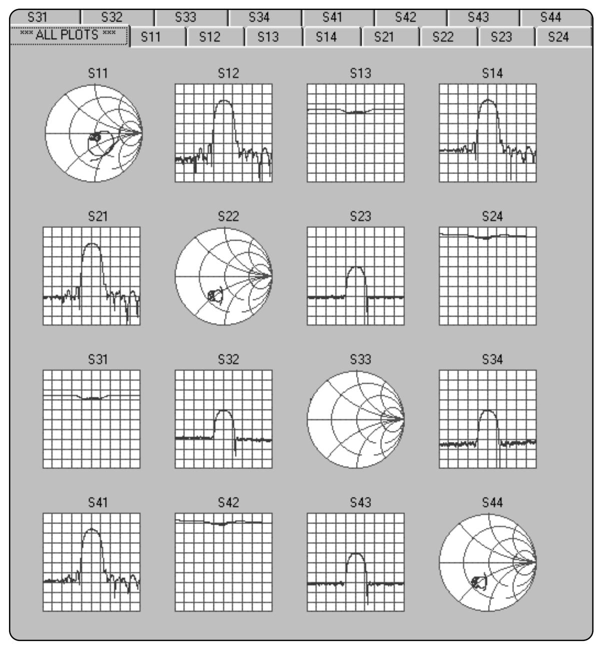


Figure 9. Insertion loss reduction

By examining the mode-conversion quadrants we can begin to see the additional affects that this filter will have on system performance. With a differential stimulus at the input of the filter (lower left quadrant), the filter will cause a considerable amount of common-mode signal to be reflected back into the system as the parameter SCD11 shows. There is not a large common-mode component generated in forward transmission (SCD21), but in reverse transmission, the common-mode component will be almost as large as the differential-mode component.

With a common-mode stimulus on the filter input (upper right quadrant), there will be a large differential-mode signal reflecting back into the system. In forward transmission, a common-mode input will convert to a large differential-mode signal at the output of the filter. In the reverse direction, the common-to-differential mode conversion is very low.

Therefore, even though there is very little differential-to-common mode conversion in forward transmission, there is very high common-to-differential mode conversion in this direction. The common-to-differential mode conversion indicates a susceptibility of the system to EMI caused by this device.

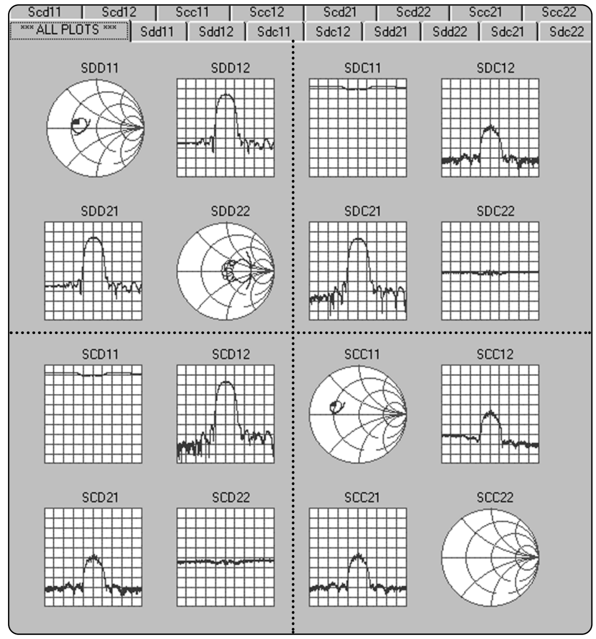


Figure 10. Mixed-mode data

Conclusion

These examples illustrate some of the benefits of Agilent's balanced-measurement systems. Some of the key features that are helpful in understanding the performance of a SAW filter include the ability to:

- Measure devices with multiple ports
- Define arbitrary reference impedance on each port
- View mixed-mode S-parameters
- Specify user-defined parameters

These features allow balanced devices such as SAW filters to be easily and comprehensively characterized and designed into high performance differential systems.

Related literature

Agilent Balanced Measurement Example: Baluns, Application Note 1373-6,
literature number 5988-2924EN

Agilent Balanced Measurement Example: Differential Amplifiers, Application Note 1373-7,
literature number 5988-2923EN

Measurement Solutions for Balanced Components, Product Overview, literature number 5988-2186EN

Key web resources

For more information on Agilent's balanced solutions please visit:

www.agilent.com/find/balanced

Visit our component manufacturer industry area at:

www.agilent.com/find/component_test

By internet, phone, or fax, get assistance with all your test & measurement needs

Online assistance:

www.agilent.com/find/assist

Phone or Fax
United States:
(tel) 1 800 452 4844

Canada:
(tel) 1 877 894 4414
(fax) (905) 282-6495

China:
(tel) 800-810-0189
(fax) 1-0800-650-0121

Europe:
(tel) (31 20) 547 2323
(fax) (31 20) 547 2390

Japan:
(tel) (81) 426 56 7832
(fax) (81) 426 56 7840

Korea:
(tel) (82-2) 2004-5004
(fax) (82-2) 2004-5115

Latin America:
(tel) (305) 269 7500
(fax) (305) 269 7599

Taiwan:
(tel) 080-004-7866
(fax) (886-2) 2545-6723

Other Asia Pacific Countries:
(tel) (65) 375-8100
(fax) (65) 836-0252
Email: tm_asia@agilent.com

Product specifications and descriptions in this document subject to change without notice.

Printed in USA September 17, 2001
5988-2922EN

Agilent Technologies