Introduction

LTE-A continues to rapidly evolve, providing even faster data rates and supporting more mobile devices. Meeting those expectations requires the use of high-performance RF components in base transceiver stations (BTS) and handsets. As a result, test requirements are very stringent for devices such as BTS filters and handset filters, and this makes it difficult to ensure fast, accurate testing in manufacturing. For example, measurements of filter devices need much wider dynamic range - at least 10 dB more than currently available - to enable fast, accurate measurements in the deep rejection bands of steep-skirted filters. In high-volume manufacturing, significant improvements in throughput are needed to meet aggressive ramp-up schedules.

The essential measuring instrument is a vector network analyzer (VNA). This application note offers suggestions for optimizing analyzer settings and ensuring better measurements of BTS and handset filters. It covers basic settings such as intermediate frequency bandwidth (IFBW) and power levels, and it also describes how operators can utilize advanced features such as segment sweep to help increase testing yields.
Scanning Current and Future Test Requirements

As the global uptake of smartphones continues, the demand for leading-edge LTE-A BTS equipment is on the rise. This translates into tougher testing requirements to ensure that new equipment is able to provide stable performance at continually increasing data speeds. The frequency range for BTS filter testing has two stages: tuning and final test (Figure 1).

In the tuning stage, operators adjust the filter characteristics. On the VNA, they select a wider IFBW to get real-time display updates that track along with manual adjustments. In this configuration, the VNA has dynamic range of 80 to 90 dB, and the filter’s rejection band is below the noise level. The last step is to set a narrower IFBW and check the rejection bands. At this stage, the required dynamic range is 110 to 120 dB.
Final test is automated, relying on a test program and switch box. Once operators connect a filter to the switch box, the test program automatically measures the filter and makes a go/no-go decision. These systems typically include a 9 GHz VNA to measure the second harmonic, or a 14 GHz VNA to measure around 13 GHz, which is required by the 3GPP specification.

In the case of handset filters and duplexers, RF components have become more sophisticated with tighter specifications for blocking and isolation. Components must also be of sufficient quality to ensure the desired increase in functionality.

This test process also has two stages: in-process test and final test (Figure 2). In-process testing is performed by probing individual devices on a silicon wafer. These tests are typically fast and simple, checking only the fundamental frequency.

After the individual devices have been cut from the wafer and packaged, detailed final testing is performed. Measurements are typically made at a wide enough span to cover the second harmonic and at a dynamic range of 70 to 90 dB.

Because these devices are produced in such high volumes, manufacturers are always seeking ways to optimize measurements and increase test throughput. These needs extend to the front-end modules (FEMs) used in high-end smartphones. An FEM is a highly integrated multiport DUT that includes switches, filters and amplifiers. Achieving fast throughput and maintaining high accuracy requires a VNA solution that provides speed and dynamic range even when making measurements with a multiport test set.
Balancing dynamic range and measurement speed

In the manufacturing of LTE-A devices, cost-effective characterization requires tradeoffs between attributes such as dynamic range and test time. Fortunately, a few basic analyzer settings can help engineers adjust the dynamic range and measurement speed of their VNA: using a higher power level will increase dynamic range; if the VNA already has wide dynamic range, using a wider IFBW will increase measurement speed.

The first step is to know the analyzer’s maximum measurement dynamic range, which is the difference between its maximum output power and its noise floor at a 10 Hz IFBW. Table 1 compares the results for Keysight’s cost-effective ENA (E5080A and E5071C) vector network analyzer.

Table 1. Dynamic range equals the difference between maximum output power and the noise floor at 10 Hz IFBW.

<table>
<thead>
<tr>
<th></th>
<th>E5080A, typical</th>
<th>E5071C, typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum output power</td>
<td>+17 dBm</td>
<td>+10 dBm</td>
</tr>
<tr>
<td>Noise floor at 10 Hz IFBW</td>
<td>-130 dBm</td>
<td>-125 dBm</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>147 dB</td>
<td>135 dB</td>
</tr>
</tbody>
</table>

The effective dynamic range is calculated by power setting and table 2.

Table 2. The effective noise floor is calculated by IFBW and a noise floor at 10 Hz IFBW.

<table>
<thead>
<tr>
<th>IFBW</th>
<th>Noise floor of E5080A</th>
<th>Noise floor of E5071C</th>
</tr>
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<tbody>
<tr>
<td>1 kHz</td>
<td>-110 dBm</td>
<td>-105 dBm</td>
</tr>
<tr>
<td>30 kHz</td>
<td>-95 dBm</td>
<td>-90 dBm</td>
</tr>
<tr>
<td>70 kHz</td>
<td>-92 dBm</td>
<td>-87 dBm</td>
</tr>
<tr>
<td>100 kHz</td>
<td>-90 dBm</td>
<td>-85 dBm</td>
</tr>
<tr>
<td>500 kHz</td>
<td>-83 dBm</td>
<td>-78 dBm</td>
</tr>
<tr>
<td>1 MHz</td>
<td>-80 dBm</td>
<td>-75 dBm</td>
</tr>
</tbody>
</table>
Figure 3 shows two different approaches that both achieve 110 dB of dynamic range but result in very different measurement speeds. The example on the left uses +15 dBm power and 30 kHz IFBW. The example on the right achieves the same dynamic range using 0 dBm and 1 kHz IFBW. Of course, the best choice depends on the DUT: if it can accept higher input power, a wider IFBW setting can be used.

Achieving better results in less time

Keysight addresses LTE-A measurement needs with a common platform for RF and microwave vector network analyzers (VNAs), which includes its cost-effective ENA Series.

The E5080A ENA provides best-in-class performance, flexible functionality and advanced usability. With its intuitive, touch-based interface, the new ENA is designed to help users streamline their measurement flow and achieve better results in less time.

On the production line, improved analog performance ensures faster throughput. In the R&D lab, better performance enables greater design margins, and enhanced usability helps ensure greater confidence in results and faster time-to-market.

Figure 4. The Keysight E5080A ENA Series network analyzer can be configured with two or four ports and a frequency range of 9 kHz to 4.5, 6.5 or 9.0 GHz. Typical performance includes 147 dB dynamic range and speeds as fast as 3 ms for a 401-point measurement.
While wider IFBW settings result in faster measurements (Figure 5), they also generate more trace noise and create a higher noise floor, which reduces dynamic range. As a rule of thumb, a ten-fold reduction in IFBW equates to a 10 dB reduction in the noise floor.

A few additional tips can be used to help optimize test performance:

- Choose smaller spans: testing should cover only the frequency spans necessary to characterize the DUT
- Use the minimum number of sweep points: for most analyzers, sweeping with fewer points reduces the time per sweep
- When possible, use swept mode rather than stepped mode
- When possible, turn off the display update: the drawing of the display consumes CPU cycles
- Use the widest IFBW with acceptable dynamic range and trace noise
- Use the highest source power level that overloads neither the device nor the VNA
- Accelerate data transfers under remote control: use a HiSLIP\(^1\) connection and multiple data transfer SCPI commands with multiple traces

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1. HiSLIP (High Speed LAN Instrument Protocol) is a protocol for TCP-based instrument.
Using Advanced Settings to Improve Measurement Speed

Applying the concepts from the preceding section, engineers can adjust their measurement settings to best suit the needs of specific segments in the DUT response, as illustrated in Figure 6. Narrow dynamic range is sufficient in the passband, but much wider dynamic range is needed in the stopband.

IFBW can be wide when high dynamic range is not necessary (i.e., shorter sweep time) and narrow when high dynamic range is required.

As deeper background, the following characteristics of filters and duplexers can be used to guide the required measurement setup:

- **Passband**: Because the measured value will be around 0 dBm, tweaking the settings for greater dynamic range is not necessary and wider IFBW settings can be used.
- **Stopband**: Some of the latest filters provide 70 to 90 dB of blocking, and BTS duplexers achieve more than 100 dB of blocking. Thus, achieving maximum dynamic range in the VNA is required to measure this part of the response.
- **Filter skirts**: Because characteristics range from 0 dBm to approximately –90 dBm, detailed measurements that use the stepped-sweep mode are useful.

To maximize throughput, users must also understand which mode—stepped or swept—is most suitable for each segment\(^2\). In stepped mode, the frequency is changed in a stepwise manner and sampling is performed at a fixed rate for each measurement point. In contrast, swept-mode sampling is performed with the frequency always swept for each measurement point. In general, swept mode is the faster choice but it is less accurate than stepped mode.

\(^2\) E5080A equips auto sweep mode instead of swept mode. This mode chooses automatically fastest sweep mode either swept or stepped.
To further optimize speed and dynamic range, stepped and swept modes can be combined using a function called segmented sweep. Each segment can have stop and start frequency, number of data points, IFBW, and power level. Data resolution can be increased where needed (more data points) and decreased where not needed (fewer data points); and specific areas can be skipped where no data is needed.

Another way to gain speed is to use different IFBW settings on each port. Currently, this capability is unique to the ENA and it provides a speed advantage, even when measuring duplexers. The slower alternative is to use only a narrow IFBW for the full frequency span, or create another channel that uses a different IFBW setting.

In this example, the transmitter/antenna path is a passband but the antenna/receiver path is a rejection band (Figure 7). Using a wider IFBW for only the transmitter/antenna path will enable a faster sweep.

![Figure 7. Dividing the responses into subsegments (seven, in this case) is a key step toward optimizing the measurement settings.](image-url)
Improving Measurement Quality

Trace noise can have a significant effect on measurement quality, potentially altering test results in the passbands. This is especially true when testing handset filters: when trace noise is high, increased failures in go/no-go testing will result in lower yields. Although users can overcome this issue by selecting a VNA that has inherently low trace noise, this generally equates to slower measurement speeds.

Once again, the optimum solution can be found in the interplay between output power and IFBW. The key idea is to check trace noise and keep it small in the required frequency range. Because high-level trace noise is proportional to the square root of the IFBW value, a narrow IFBW setting helps reduce trace noise.

This is illustrated by the four measurement traces shown in Figure 8. In these examples, trace noise is highest at -20 dBm and a 100 kHz IFBW (lower left). Increasing the power from -20 dBm to 0 dBm provides a noticeable improvement in trace noise (upper left). Leaving output power at -20 dBm but reducing IFBW from 100 kHz to 1 kHz provides a similar improvement (lower right). Here, the combination of 0 dBm output power and a 1 kHz IFBW provides the greatest reduction in trace noise (upper right).

![Figure 8. Higher output power and a narrower IFBW results in lower trace noise, as shown in the upper-right trace.](image)

On a production line, an instrument often runs continuously to produce the planned number of devices. However, the ambient environment tends to fluctuate, and this can cause measurement instability. Also, the measurement uncertainty caused by instrument instability must be added to the tolerances of the go/no-go test limits along with the dispersion of the DUT.

To get a stable measurement result, it is vital that the instrument have superior stability performance. Unstable instruments need frequent recalibration, and this requires that the line be stopped until the calibration is complete. This is an issue with some competitive VNAs that require calibration every two hours to guarantee the specs. With its superior stability, the E5080A requires calibration just once a day.
Conclusion

To deliver on LTE-A’s promise of reliable connectivity, high data throughput and seamless handoffs, all BTS components must be fully optimized in design and on the production line. Any weaknesses will become apparent during thorough testing—and fine-tuning of even the most basic settings of a VNA will enable useful tradeoffs between essential parameters such as dynamic range and measurement speed.

In addition to necessary, basic VNA capability, Keysight’s cost-effective ENAs provide advanced features such as segmented sweeps. By reducing the effect of issues such as trace noise, testers will be able to ensure their devices meet the high specifications set forth in the LTE-A standard, both now and in the future.

Every Keysight vector network analyzer is the ultimate expression of the company’s expertise in linear and nonlinear device characterization. On the production line, the ENA Series provides the throughput, repeatability and reliability needed to create accurate, dependable test stations—and transform parts into competitive components. In R&D, the ENA streamlines the measurement flow and enables better results in less time. With the ENA Series, engineers and their organizations are equipped to drive down the cost of test.

Related information

- Application brief: Deploying the Ideal Test Solution for Handset Filters and Duplexers, publication 5992-0472EN
  http://literature.cdn.keysight.com/litweb/pdf/5992-0472EN.pdf
- Application brief: Improving Speed and Accuracy in the Testing of BTS Filters and Duplexers, publication 5992-0457EN
- Application note: Drive Down the Cost of Test with ENA Series Network Analyzers, publication 5992-0195EN
  http://literature.cdn.keysight.com/litweb/pdf/5992-0195EN.pdf
- Brochure: E5080A ENA Series Network Analyzer, publication 5992-0290EN
- Data sheet: E5080A ENA Series Network Analyzer and E5092A Configurable Multiport Test Set, publication 5992-0291EN
- Configuration guide: E5080A ENA Series Network Analyzer and E5092A Configurable Multiport Test Set, publication 5992-0292EN

Web resources

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