By identifying the problems and improving the understanding of receiver behaviour while pushing the limits of dynamic range performance, one can better understand how to properly configure the system for maximum dynamic range while minimising measurement uncertainty. At the heart of the discussion is the concept of receiver linearity and how it impacts calibration and measurement accuracy. While other papers describe in more detail the accuracy issues of non-linear calibration [1], this article note describes the practical aspects of configuring a VNA system for maximum dynamic range while limiting measurement uncertainty.

Defining dynamic range

System dynamic range of a VNA is defined as the difference between the measurement power available at the test port and the noise floor of the receiver. In situations where dynamic range is pushed to the limits, it is important to clearly understand the parameters of test port power and receiver capabilities. For example, test port power level is defined in a number of different ways. The power level is sometimes defined as the maximum power available from the source. It also is defined at the source test port power level when the receiver is at the 0.1 dB compression point. Furthermore, it may even be defined at some arbitrary value above the 0.1 dB compression point. And note that if the power level is defined for the maximum available power from the test set, there may be no assurance that the available power level is below the 0.1 dB compression point. Specifying at the 0.1 dB compression point is the most useful and practical method since it limits the linearity errors to a known value.

At the receiver end, the noise floor can be defined at different IF bandwidths (10 Hz is commonly used) and includes the method of statistical analysis (RMS, with or without averaging, etc.). When comparing noise floor specifications, be sure that the IF Bandwidth, averaging, and method of analysis are similar. Also, be aware that some VNAs specify a 10 Hz noise floor specification that is derived mathematically from a higher IF bandwidth. This method has limitations due to the possible existence of spurs, harmonics and other leakages that may not be evident at the higher noise floor.

Optimal dynamic range consideration

Since system dynamic range is defined as the difference in the source power level and receiver noise floor, the first objective is to set the test set source power for optimal power output. The most important aspect of determining the optimal source power level is consideration of the compression level of the receiver. So as not to introduce non-linear calibration errors and ensure best accuracy, the source power should be set well below the 0.1 dB compression point, typically about 3 – 4 dB below.

If the maximum available power of the source is well under the compression range of the receiver, then setting the source to maximum available power will provide the widest dynamic range. One point of caution is to confirm that the harmonic content at the maximum level is within the range of acceptability of the device under test (DUT). If the harmonic level is too high, contributions may affect the measurement accuracy (e.g. measuring amplifier gain compression points).

When considering noise level, the most useful tool available to the user is the IF filter bandwidth setting and/or averaging. Dynamic range specifications are often cited with an IF bandwidth setting of 10 Hz. While this may give useable numbers of dynamic range performance, a 10 Hz setting will often result in an unacceptably slow sweep speed. Setting the IF filter to a higher bandwidth, 1 kHz for example, will significantly improve the sweep speed at the expense of a higher noise floor. Changing from a 10 Hz setting to a 1 kHz setting will result in a nominally 20 dB higher noise floor. In most cases this degradation may be acceptable, but it is best to confirm acceptability before performing a full calibration. Also be aware that changing the IF bandwidth settings may have an effect on high level trace noise due to noise skirt conversions in the down-converters.

Accuracy considerations when configuring test port power levels

As mentioned, the input power level to the receiver needs to be below the 0.1 dB compression point for best accuracy. When measuring passive devices, assumptions are sometimes made that the DUT insertion loss will attenuate the power well below the 0.1 dB
Two primary concerns emerge regarding system dynamic range when utilising the harmonic down-conversion method; conversion efficiency and harmonic N factor. As a general rule, harmonic mixers tend to have better conversion efficiency when compared to harmonic mixers, especially at higher frequencies (~> 30 GHz). Utilising the advantage of better conversion efficiency and incorporating optimum LO design structure, VNAs using harmonic sampling can be designed for a higher compression point and improved signal to noise performance and thereby provide better system dynamic range.

Harmonic N factor also contributes to the overall dynamic range performance of a VNA system. In general, harmonic conversion loses efficiency as the harmonic number increases. This is especially true with harmonic mixers due to the nature of the roll off in the LO comb response which can begin as low as 20 GHz. An example of the amount of line error that can exist after calibrating the VNA under varying degrees of compression is demonstrated in Fig. 2. The topmost trace is the linearity error after calibration at the 0.2 dB compression point of the receiver. As shown in the graph, a S11 measurement of an 8 dB return loss device can have as much as 6% error after calibrating the VNA at the 0.2 dB compression level. This clearly demonstrates the need to identify the 0.1 compression point of the receiver and to set the power level well below that point in order to ensure maximum accuracy.

For applications where maximum dynamic range is critical, trade-offs between linearity accuracy and noise uncertainty may need to be considered. For example, if a wide dynamic range filter is being measured, it may be tempting to raise the power level of the source in order to maximise system dynamic range. Although this may increase the dynamic range capability of the VNA, the resultant linearity errors will dramatically affect measurement accuracy in the pass-band region of the filter.

Steps for configuring the VNA for maximum dynamic range performance

- Determine the 0.1 dB compression level point of the receiver. This should be your guideline for maximum power input to the receiver while still maintaining good accuracy. Remember, input power at the 0.2 dB compression point can induce errors up to 6%.
- Consider test port cable losses and optimum dynamic range performance. If the test port cables or fixtures located behind the test ports present significant insertion loss, then the power level can be increased and still operate within the linearity region of the receiver. However, care must be taken when attempting this; it is possible the receiver enters compression at lower power levels in lower frequency bands. This method, properly executed, can provide additional dynamic range without an increase in compression errors, especially at

![Fig. 2: The normalised resulting measurements of a DUT based on the six calibrations (different power levels) are shown here. Even though the receiver was only compressed 0.2 dB at most, nearly 0.4 dB of error occurred in the measurement.](image)
For applications where two devices need to be measured simultaneously, using direct receiver input loops provides a low noise floor for optimum dynamic range capabilities. The overall benefit of the NLTL harmonic sampling technique coupled with a line harmonic sampler architecture is the excellent isolation between test ports even above 50 GHz. At frequencies above 40 GHz, the transfer function of the SRD method typically begins to roll off. At 50 GHz the roll off is enough to significantly affect the dynamic range performance of the system. In the area above 50 GHz, the SRD method provides a challenging situation where high input power capabilities are required before compression. The VNA with higher non-compensated test port power will have a better signal to noise ratio and will not have to rely on a narrow IF bandwidth filter to minimise noise effects. Consequently, the VNA with higher non-compensated test port power can produce faster measurements with more accuracy.

The MS4610A VectorStar VNA optimises broadband dynamic range performance by utilising non linear transmission line (NLTL) technology in the harmonic sampler architecture. This technique, also known as shock-line transmission, substantially minimises the effects of harmonic N roll-off and thereby provides the widest possible dynamic range at high frequencies. Fig. 3 illustrates the typical differences in conversion efficiency between a standard SRD-driven harmonic sampler and a NLTL-driven sampler for a given LO frequency. At frequencies above 40 GHz, the transfer function of the SRD method typically begins to roll off. At 50 GHz the roll off is enough to significantly affect the dynamic range performance of the system. In the area above 50 GHz, the SRD method provides a challenging situation where the LO frequency may need to be constantly modified to minimise the loss in dynamic range performance. A final benefit of the NLTL shock-line harmonic sampler architecture is the excellent isolation between test channels which further improves effective noise floor performance. The overall benefit of the NLTL harmonic sampling technique coupled with other design considerations is a VNA with high compression levels and a low noise floor for optimum dynamic range capabilities.

Using direct receiver input loops provides maximum flexibility for custom test setups. The loops provide the opportunity to increase the maximum available power by adding external power amplifiers. When used to bypass the couplers, insertion loss to the receiver is reduced by 10 dB or more which in turn improves the noise floor of the system. However, utilising the access loops to improve noise performance requires careful consideration in order to stay within the parameters of the test set. Accessing the loops not only lowers the noise floor of the system, it also lowers the compression point of the receiver. So care must be used to ensure the test setup does not push the receiver into compression due to the lower compression level. When specifying system dynamic range of the VNA using access loops, the specification often includes the maximum available power and the minimum system noise floor when bypassing the test set couplers. While this will result in improved dynamic range numbers, it can result in the receiver operating far into compression if care is not taken during test configuration. This is why a VNA data sheet will often have two different sets of dynamic range specifications; one for the system test set and one for the receiver. System dynamic range, as mentioned at the beginning, includes available test port power when operating in a non-compressed mode, to the noise floor at the coupler input.

Receiver dynamic range, on the other hand, describes the range from the noise floor at the port bypassing the internal coupler to the maximum signal input to the receiver port. And even though this may look like a better number, it may not guarantee accuracy due to compression errors. A final factor that can have an impact on measurement accuracy when operating in the direct access mode is the differences in match of the different ports. Since some situations utilising direct access do not include full 12 term calibration, the variances in match between ports can lead to an increase in measurement uncertainty.

Summary
Optimising the VNA for maximum dynamic range performance requires consideration of linearity accuracy as well as noise floor limitations. For best accuracy, set the power level of the source well below the 0.1 dB compression point (~ 3 – 4 dB). For cases where the widest possible dynamic range is a must, use external loop access to bypass the internal couplers for direct access to the samplers. Be sure to use caution and avoid compression during the calibration process. Remember that calibrating the VNA at the 0.2 dB compression level can have as much as 6% measurement error due to receiver linearity errors.

Contact Georges Lenferna, Etecsa,
Tel 011 787-7200, glenferna@etecsa.co.za