Anritsu

Global Power Sweep

Scorpion® Standard Feature

Application Note

Power Sweep Measurements for Amplifiers, Mixers and Integrated Circuits

Linking the World

Introduction

The power sweep mode allows a collection of newer measurement possibilities in the Scorpion system with reasonable speed and simplicity. While swept power gain compression was available previously, the new global power sweep provides for many more measurements:

- Easier AM-PM measurements
- Gain compression measurements of mixers, sweeping the LO and/or the RF sources
- Reflection coefficients vs. power
- Mixer isolation vs. LO power
- Swept power harmonic measurements
- Swept power IMD and mixer IMD measurements

Power sweep within alternate sweep, noise figure, and frequency translating group delay is not supported at this time although they may be in the future. The purpose of this note is to explore the operation of this global sweep mode, discuss setup issues, and to illustrate with a variety of examples.

Setup Parameters and General Issues

As with frequency sweep, one must select a start and stop value (or alternatively center/span). In power sweep, a step size is selected directly instead of a number of points. Since the number of points must be the same for all driven sources (so that the sweep can be coordinated), the step size will be adjusted when the user enters a new start or stop power to keep the number of points constant. If one then desires to change the step size, the number of points will be changed for this and for ALL other sources.

To summarize: *The number of power points will be held constant until the user explicitly changes the step size.*

In addition, any of the sources can be set to single power (analogous to CW but in the power domain) while the others are sweeping. This may be useful, for example, if one wants to sweep the RF on a mixer measurement while keeping the LO at constant power.

An important question is over what range can the internal sources be swept. Any segment of the ALC range is allowed but a step attenuator is not allowed to move during the sweep. The guaranteed ALC range is from -15 dBm to either +5, +7 or +10 dBm depending on model/options. It is often possible to exceed the guaranteed ratings on the high side over limited frequency ranges by several dB: up to +20 dBm may be entered for the upper limit but ALC unleveled errors are possible. The lower limit may not be set lower than -15 dBm. A step attenuator may be set to achieve lower power levels but will not change during the sweep due to lifetime issues (since the step attenuators are mechanical). As a result the maximum guaranteed power sweep range will be 20-25 dB. Note that the X-axis of the display is currently always the Source 1 ALC range; in more complicated sweep scenarios one must check the power control menus to see which source is sweeping where and with what absolute port power.

Examples:

1) -10 to +5 dBm	set the attenuator to 0 dB set start=-10 dBm, stop = +5 dBm
2) -25 to -5 dBm	set the attenuator to 10 dB set start=-15 dBm, stop=+5 dBm
3) -55 to -30 dBm	set the attenuator to 40 dB set start=-15 dBm, stop=+10 dBm (only guaranteed to be leveled for some models)

Another question of some importance is the frequency of operation. Normally, the system is run in CW with the only independent variable being power and this will be indicated under the frequency menu. As in frequency sweep CW, the allowed CW frequencies are determined by the start and stop frequencies together with the number of frequency points which were last set while in frequency sweep mode. If a specific CW frequency is necessary, it may be necessary to go back to frequency sweep mode and change the start/stop frequencies and/or the number of frequency points. It is important to note that the number of frequency points and the number of power points are different variables.

It is also possible to disable CW operation while in power sweep. In this state, the system will multiplex sweeps: perform the power sweep at the first frequency point, perform the next sweep at the second frequency point, and so on. The start/stop frequency and the number of frequency points as discussed above set the available frequencies. This state may be useful, for example, in qualitatively determining if the compression characteristics of a device are radically different at some frequencies as opposed to others. It may also be useful in quickly getting both power and frequency sweep data acquired when running the system remotely either via GPIB or ethernet.

EXAMPLE: TURN OFF CW, suppose the system is set for M frequency points and N power points (P1…PN)

Sweep 1	Freq point 1	system will sweep power from P1 to PN
Sweep 2	Freq point 2	system will sweep power from P1 to PN
....		
Sweep M	Freq point M	system will sweep power from P1 to PN
Sweep M+1	Freq point 1	system will sweep power from P1 to PN
Sweep M+2	Freq point 2	system will sweep power from P1 to PN
...		

Linear Power Cals

Of considerable interest in a power sweep measurement is the accuracy of the port power. The standard ALC calibration (performed at the factory and, optionally, by the user or calibrator at future points in time) provides an accuracy of +/- 1 dB (typically +/- 0.5 dB). If this is not adequate, there is a LINEAR POWER CAL available, analogous to the flat test port power cal available in frequency sweep, that can greatly increase port power accuracy. A power meter is required and the sensor must be connected to the relevant measurement port(s), which may be at the end of a cable or other network. The frequency and power sweep parameters should be set in advance. The linear power cal will proceed to correct the port power at EVERY FREQUENCY AND POWER POINT SELECTED, so it may be thought of as a two dimensional calibration as opposed to the flat test port power cal which calibrates at only one power level but all frequencies. Note that there is a limitation on the total number of points that can be calibrated so it may be necessary to reduce either the number of frequency or power points (for example, one cannot do 1601 frequency points and 1601 power points).

Note that if CW mode is on while in power sweep, the linear cal will proceed at only one frequency but all power points. If CW mode is off, the cal will proceed at all frequency and power points. This selection is made at a special menu item on the power menu ('CW mode in linear cal').

Since there may be many frequency and power points, this calibration may take awhile depending on the power meter used. Depending on power meter accuracies, the port power accuracy will generally be < +/- 0.1 dB for some period of time after the cal is performed.

External Sources

The various GPIB-controlled sources are still accessible from multiple source control and the mixer control menus while in power sweep. At this time, however, power sweep of external sources is not allowed. Be sure the external sources are under positive control either by turning them on prior to booting the Scorpion system or using the multiple source menu to probe the GPIB system (see the Multiple Source Control Application Note for more information).

Main Measurement Calibrations

Most of the individual application calibrations proceed in an intuitive fashion and will be discussed in the examples section. The receiver cal is sufficiently global, however, that it will be discussed here.

The purpose of the receiver cal is to establish what 0 dBm looks like for a given receiver port. Because of excellent receiver linearity, this is enough to establish an absolute power measurement capability for the given receiver port. While in frequency sweep mode, one connects a thru line from a given transmit port to a given receive port and the system will sweep across the given frequency range with the ALC set to 0 dBm and the step attenuator set to 0 dB. A flat power cal can be used to improve accuracy. In power sweep, the ALC and attenuator will be set the same and the cal will basically proceed as before. If in CW state, the receiver cal will be done at one frequency. If not in CW, the receiver cal will be done over the programmed frequency range. When moving between frequency and power sweep, the system will do the best it can to apply the calibration based on the frequency points for which it has calibration data. In general, it can be good practice to perform one receiver cal over the full frequency range of the instrument (or the full range that will be used for the class of devices under test) with many frequency points and then apply it for all measurements.

Trace Memory

Since the dependent variables and sweep parameters are so different between frequency sweep and power sweep, the data cannot be shared. As a result, any stored trace memory will be cleared when moving between sweep modes.

Examples

The remainder of the document will consist of a series of examples showing how various power sweep measurements can be made. The main objectives will be to discuss any additional setup issues, illustrate the general cal procedures, and provide example data.

Standard T/R examples

For a standard (non-mixer) T/R measurement, any of the usual calibration techniques may be applied (1 port, 12 term,….). Most of the measurements in this category will be akin to AM-AM or AM-PM conversion analysis and are useful for studying compression effects on linear parameters.

Figure 1 illustrates a typical AM/PM measurement. A simple forward frequency response cal was performed (while in power sweep), and then the amplifier DUT was connected. The amplifier output was padded to avoid compressing the receiver.

Setup Summary for Figure 1

- ✓ Power sweep with CW mode (1.000 GHz)
- ✓ Sweep power (src 1) from -15 to +5 dBm
- ✓ Perform frequency response cal (forward only) while in power sweep
- ✓ Select LogMag+Phase graph type, single channel display (ch 3, S21 usually)
- ✓ Select IFBW/averaging to suit

Figure 2 shows S11 and S21 for an amplifier during power sweep. A full 12-term cal was performed, while in power sweep, to enable this measurement. Again the amplifier output was padded to avoid compressing the receiver (normal specification for the MS462X is 0.1 dB compression at 10 dBm receiver port power depending on model).

Setup Summary for Figure 2:

- ✓ Power sweep with CW mode (0.9940 GHz) display (ch 3, S21 usually)
- ✓ Sweep power (src 1) from -15 to +10 dBm
- ✓ Perform full 12 term cal (isolation not required) while in power sweep
- ✓ Select dual channel overlay display (ch 1 and 3) with channel 1 set for S21 (LogMag graph type) and channel 3 set for S11 (LogMag graph type)
- ✓ Select IFBW/averaging to suit

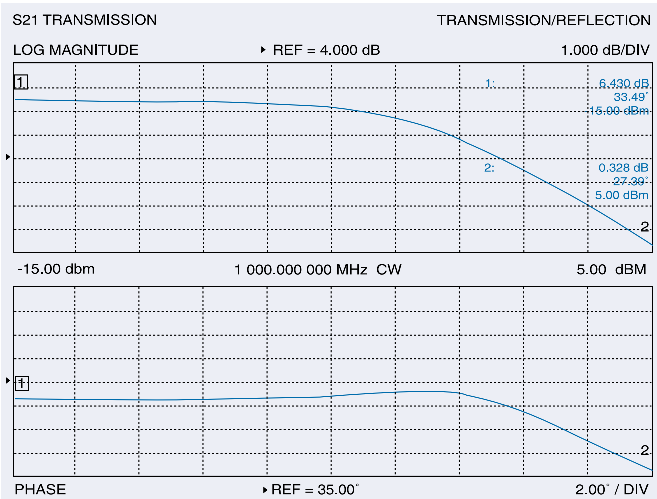

Figure 1. *An AM/PM measurement of an amplifier is shown here. A frequency response cal was used, one could additionally use trace memory to normalize the results to low power values if desired.*

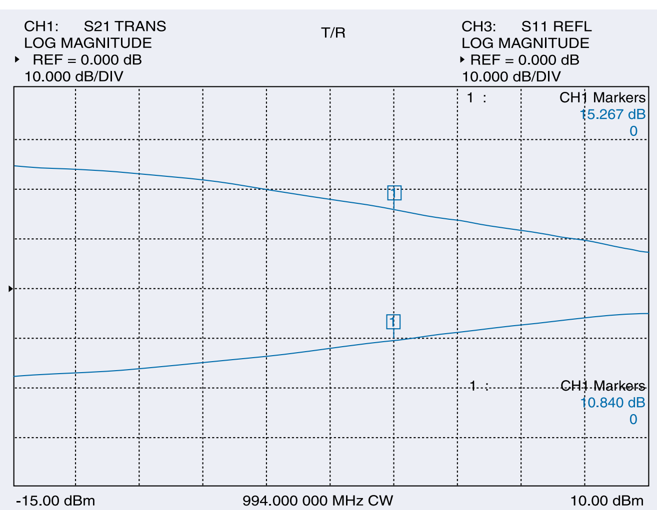

Figure 2*. |S21| and |S11| for an amplifier vs. power are shown here. A full 12-term calibration was used. The measurement was meant to illustrate that the input match as well as gain is changing very rapidly with power above a certain level.*

Mixer T/R Examples

The usual T/R cals apply to non-frequency translating mixer measurements and the receiver cal, discussed earlier, can apply to conversion gain measurements. There are a number of choices as to which sources are sweeping and how, which complicates the setup a bit, but provide for substantial flexibility. It is important to note that the X-axis power variable always refers to source 1. Many of the measurements in this category are AM-AM in nature although many effects of LO starvation/overdrive are also of interest. Since conversion measurements are unratioed, a direct AM-PM measurement cannot be made.

Figures 3 and 4 show the compression of conversion loss for a passive mixer with RF and LO sweeping, respectively. For these measurements, source 1 (1.1 GHz, driving port 1) is used as the RF while source 2 (1.0 GHz, driving port 3) is used as the LO. The IF (100 MHz) receive port is port 2. In Fig. 3, the LO is fixed at +10 dBm and the 1-dB compression point appears to occur when the RF is near +1 dBm.

Setup Summary for Figure 3:

- ✓ Select user-defined measurement parameter b2/1 (starting with S21 on ch 3 usually) single channel display LogMag
- ✓ Select power sweep with CW mode (1100 MHz)
- ✓ Sweep power (src 1) from -15 dBm to 5 dBm, Src 2 fixed at 10 dBm
- ✓ While in standard mode, connect a thru line and perform a thru normalization to trace memory (a receiver cal can have been done previously, disable CW to allow coverage between 100 and 1100 MHz at least)
- ✓ Enable mixer mode, LO as src 2, CW at 1000 MHz, Down conversion
- ✓ Connect the mixer to measure (IF to port 2, RF to port 1, LO to port 3)
- ✓ Select IFBW/averaging to suit

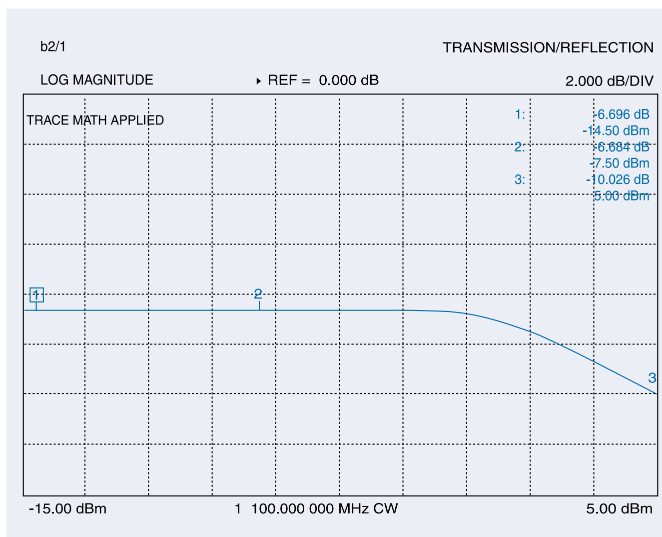

Figure 3. *Mixer conversion loss compression with the RF sweeping is shown here. All frequencies are CW and the LO is fixed at +10 dBm. Receiver cal and trace memory normalization were used to make the measurement.*

Setup Summary for Figure 4:

- ✓ Select user-defined measurement parameter b2/1 (starting with S21 on ch 3 usually) single channel display, LogMag
- ✓ Select power sweep with CW mode (1100 MHz)
- ✓ Sweep power (src 2) from -15 dBm to 10 dBm, Src 1 fixed at -5 dBm
- ✓ While in standard mode, connect a thru line (1->2) and perform a normalization to trace memory (a receiver cal can have been done previously, disable CW for coverage between 100 and 1100 MHz at least)
- ✓ Enable mixer mode, LO as src 2, CW at 1000 MHz, Down conversion
- ✓ Connect the mixer to measure (IF to port 2, RF to port 1, LO to port 3)
- ✓ Select IFBW/averaging to suit

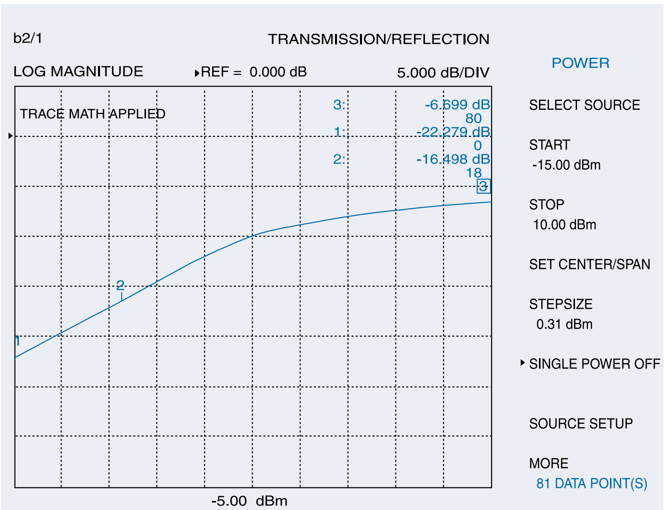

***Figure 4.**.Mixer conversion loss compression with the LO sweeping is shown here. The RF is fixed at -5 dBm and all frequencies are CW. The LO sweep range can be determined from the menu bar at the right (-15 dBm -> + 10 dBm or 2.5 dB/div). As is consistent with Fig. 3, the mixer is only operating 'normally' when the LO power is approximately 10 dB greater than the RF power.*

Another mixer measurement that is often of interest is isolation. Sometimes when the mixer is being driven weakly, imbalances become more obvious and leakage can change. In the case of Fig. 5, the RF is fixed and the LO power swept (over the same -15 -> +10 dBm range as in Fig. 4). As one can see, the RF->IF isolation is indeed a function of LO drive. Many other isolation measurement combinations are possible.

Setup Summary for Figure 5:

- ✓ Select S21 as the measurement parameter, No conversion, single channel display, LogMag
- ✓ Select power sweep with CW mode (1100 MHz)
- ✓ Sweep power (src 2) from -15 dBm to 10 dBm, Src 1 fixed at 0 dBm
- ✓ Perform a frequency response cal
- ✓ Enable mixer mode, LO as src 2, CW at 1000 MHz, No conversion
- ✓ Connect the mixer to measure (IF to port 2, RF to port 1, LO to port 3)
- ✓ Select IFBW/averaging to suit

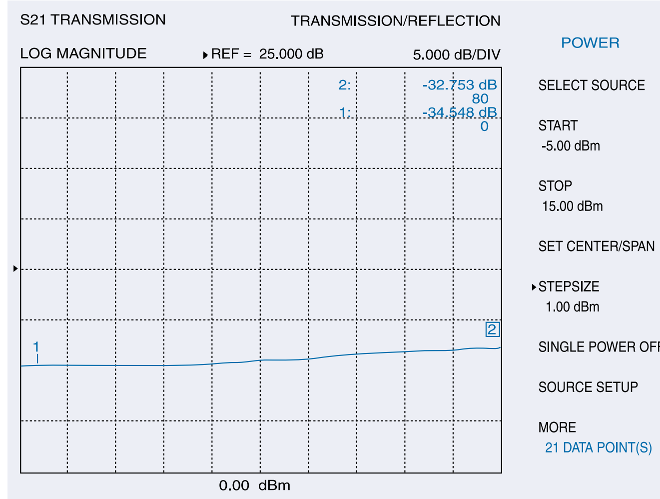

***Figure 5.**.Mixer isolation as a function of LO drive is shown here. A simple frequency response cal was used.*

Swept Power Harmonic Measurements

Since harmonic output is often a strong function of drive power, this is an interesting measurement and may often be used as a coarse analysis of distortion. Both scalar and enhanced measurements are possible where scalar measurements are often made with trace memory normalization to achieve values relative to the fundamental. The enhanced calibration removes the effects of source harmonics. Since the source harmonics are a strong function of power level, it is critical and mandatory that this calibration be performed while in power sweep mode.

Figure 6 illustrates a simple scalar harmonic measurement. Trace memory normalization was used (memory stored when harmonic=1, then switch to harmonic=2) to produce the desired relative output. As is the case in frequency sweep, very low level scalar harmonic measurements may be limited by source harmonics but these are quick measurements to make.

Setup Summary for Figure 6:

- ✓ Setup for power sweep, CW mode at 1 GHz, parameter HS21, single channel display LogMag
- ✓ Sweep power (src 1) from -15 dBm to 5 dBm
- ✓ Select swept harmonics (not CW rcvr) with harmonic=1 and connect DUT
- ✓ Store data to memory for normalization
- ✓ Switch to harmonic=2
- ✓ Select IFBW/averaging to suit

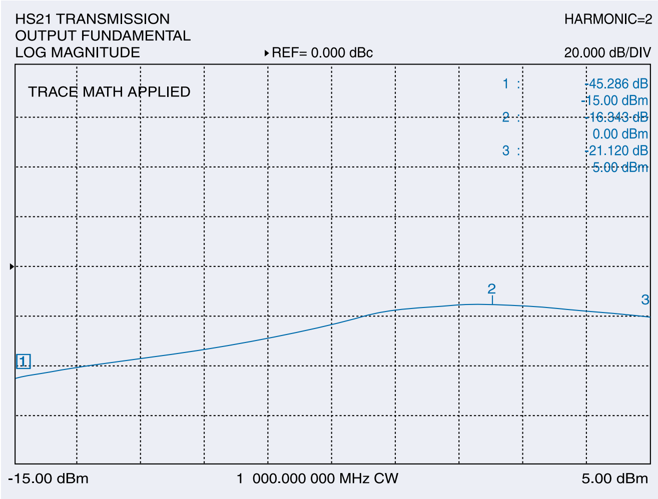

Figure 6. *A scalar second harmonic measurement of an amplifier is shown here. The results are in dBc relative to the fundamental due to a trace memory normalization.*

The next example shows the application of the harmonic enhancement cal within power sweep. As with the frequency sweep version, the enhancement cal removes the effects of source harmonics in a vectorial fashion. In Fig. 7, the 2nd harmonic of an amplifier is shown. If one were to use a scalar measurement on this amplifier, the error would have been 2-3 dB at the low end (for more information see the Harmonics Application Note). Approximately 60 dB of dynamic range is available when using this calibration.

Setup Summary for Figure 7:

- ✓ Go to power sweep, CW 1.120 GHz, Harmonics referenced to output fundamental, harmonic=2, measure HS21
- ✓ Single channel display, LogMag
- ✓ Sweep power (src 1) from -15 dBm to +5 dBm
- ✓ Perform a harmonic enhancement cal
- ✓ Connect the DUT
- ✓ Select IFBW/averaging to suit

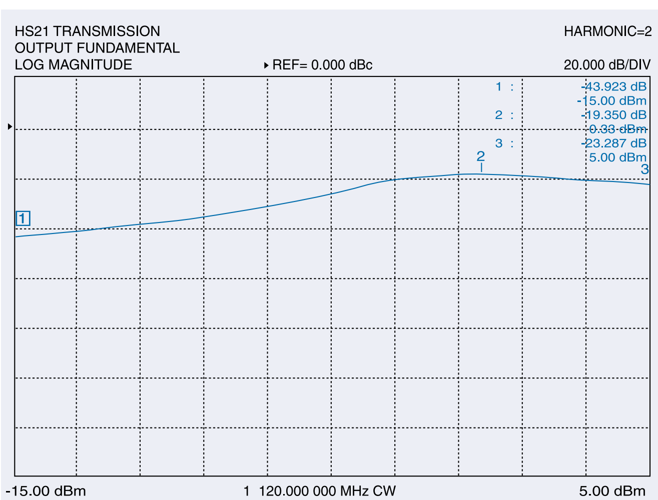

Figure 7. *An enhanced 2nd harmonic measurement of an amplifier is shown here. The results are referenced, as is common, to the output fundamental.*

Swept Power Intermodulation Distortion (IMD) and Mixer IMD measurements

All IMD products and intercepts can be computed during a power sweep and can provide a powerful tool for distortion analysis. The receiver cal, as discussed before, is available as is the IMD cal for use in input-referred measurements. The latter cal should be performed while in power sweep. It is often useful to examine IMD products versus power, since they rarely follow the simplistic linear power dependence due to the presence of multiple non-linearities of a given order and the interaction of different order non-linearities. See the IMD Application Note for more information.

The first example in this section is of the 3rd through 9th intermodulation products (odd orders only) of an amplifier. Only a receiver cal was used for this measurement, but even it is probably unnecessary. Above about -5 dBm input power, this amplifier is extremely non-linear as is evidenced by the magnitude of the intermodulation products. The shapes of the higher order product curves during power sweep are of particular interest in optimizing amplifier performance.

Setup Summary for Figure 8:

- ✓ Go to IMD with power sweep, CW at 1 GHz, swept mode (not CW RCVR), product, referenced to tone 1, output referred, offset at 1 MHz
- ✓ Connect combiner and DUT (port 1 and 3 to combiner inputs, DUT output to port 2)
- ✓ Sweep power (src 1 and src 2) from -15 to +5 dBm
- ✓ Select a four channel display; in ch1 select IMD3, ch2 select IMD5, ch3 select IMD7, and ch4 select IMD9, LogMag graph types at 20 dB/div
- ✓ Select IFBW/averaging to suit

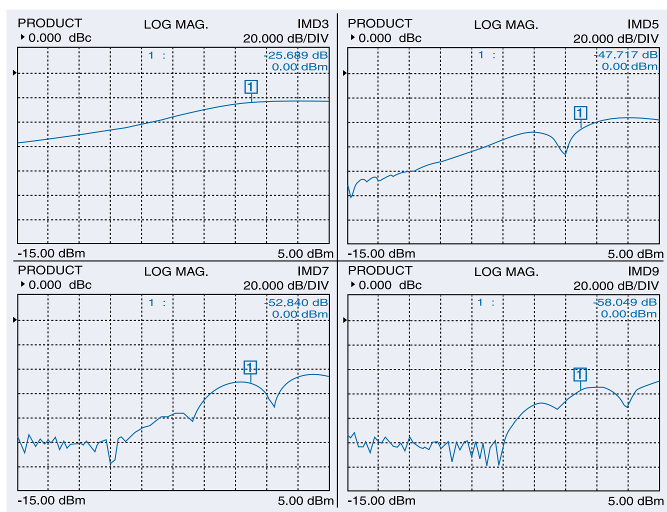

Figure 8. *The 3rd through 9th (odd) order intermodulation products of an amplifier are shown here. Two equal tones were applied (X-axis refers to the power of tone 1) with a tone 1 frequency of 1 GHz.*

As is obvious, the curves are not simple straight lines that one may expect from a naive analysis. This, of course, impacts the interpretation of an intercept calculation, which is a simple single point extrapolation. Such an intercept measurement is shown in Fig. 9. The displayed intercept is calculated from the intermodulation product (and main tone power) at that given power point using a linear model. For this reason, the intermodulation product curves of Fig. 8 are often preferred for analysis.

Setup Summary for Figure 9:

- ✓ Single channel LogMag display in IMD power sweep, CW at 1 GHz, offset at 1 MHz, intercept referenced to tone 1, input referred, 3rd order
- ✓ Sweep power (src 1 and src 2) from -15 to +5 dBm
- ✓ Connect combiner output directly to port 2 and perform IMD cal
- ✓ Connect DUT between combiner and port 2
- ✓ Select IFBW/averaging to suit

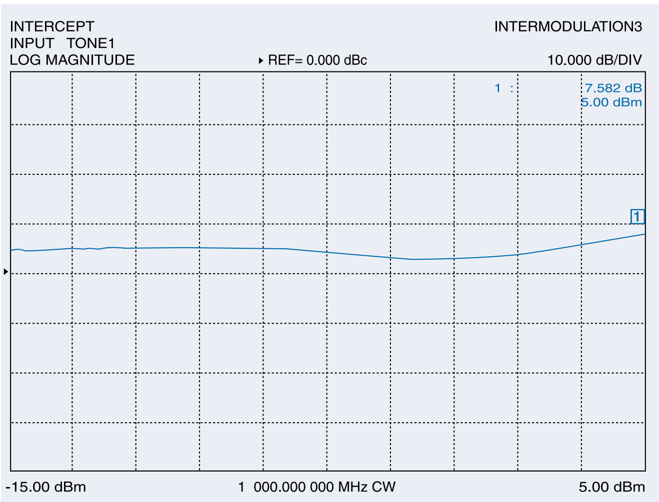

Figure 9. *An input-referred third order intercept point plot is shown here where the IMD calibration was done while in power sweep. If the amplifier was weakly non-linear, one may expect this power sweep to be flat. As the power level increases, the extrapolation used in computing the intercept becomes increasingly power dependent.*

In both of the previous examples, tone 1 and tone 2 swept over the exact same power ranges. Sometimes, a more general sweep is desired (may be required by a given standard) and almost any linear relationship is possible (as long as both sources remain in their respective ALC control ranges). Figure 10 contains a plot of the 3rd order IMD product when source 2 sweeps at a fixed offset of -5 dB relative to source 1. It is also possible for the sources to sweep over entirely different ranges with different step sizes as long as the number of power points are the same. Both IMD products are shown in Fig. 10 since they will not be the same in this case. The upper curve is the upper sideband (relative to tone 1) while the lower curve is the lower sideband relative to tone 2. The effect of the asymmetry is quite clear.

Setup Summary for Figure 10:

- ✓ IMD power sweep, CW at 1.12 GHz, offset at 3 MHz, product output referred, 3rd order on channels 1 & 3
- ✓ Sweep power (src 1) from -10 to +5 dBm, (src 2) from -15 to 0 dBm
- ✓ Connect combiner and DUT as in Fig. 8 setup
- ✓ Select dual channel overlay display (ch 1 and 3), ch1 reference to tone 1, ch 3 reference to tone 2, LogMag on both channels
- ✓ Select IFBW/averaging to suit

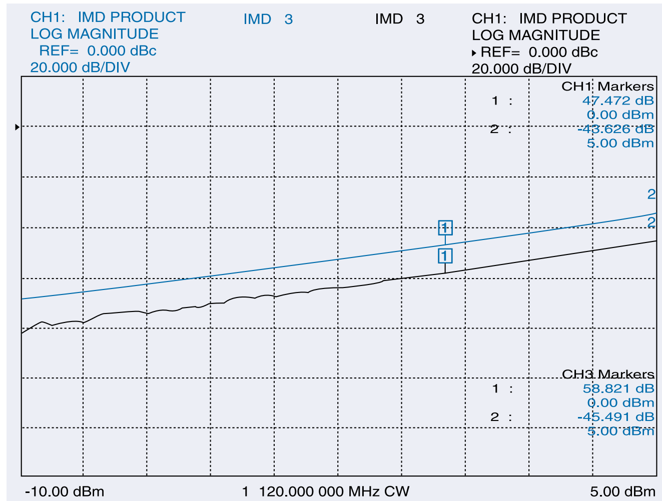

Figure 10. *The upper and lower IMD3 products for asymmetric drive are shown here. Tone 2 is swept at a -5 dB offset relative to tone 1 although any linear relationship is allowed.*

In mixer IMD measurements, usually the RF will be swept and the corresponding IMD/IP products observed. Sometimes it may be interesting to sweep the LO alone (or in combination with sweeping the RF) to observe the effects of LO starvation or due to some power coupling of the practical signal sources. In all of the mixer examples to follow; a simple, passive doubly-balanced mixer was employed. Because of current control restrictions, the examples are setup so that the external synthesizer is not sweeping power.

Figure 11 shows the case of a fixed LO (source 3, an external synthesizer) at 900 MHz and +10 dBm. The two RF tones, from sources 1 and 2, are swept (equal amplitude this time) and the IMD3 product is plotted. As might be expected from the earlier conversion loss compression measurements, the distortion increases significantly as the RF power gets within about 10 dB of the LO power for this passive mixer.

Setup Summary for Figure 11:

- ✓ IMD power sweep, CW at 1 GHz, offset at 3 MHz, product, output referred, reference to tone 1, 3rd order
- ✓ Mixer mode; source selections: tone1=src1, tone2=src2, LO=src3; LO CW at 900 MHz, downconvert
- ✓ Single channel (usually ch 3), LogMag
- ✓ Power sweep (src 1 and src 2) -15 to +5 dBm, src 3 fixed at +10 dBm
- ✓ If src3 is not under GPIB control, manually set it for +10 dBm, 900 MHz
- ✓ External reference selected on rear panel menu (be sure to connect 10 MHz cable to external synthesizer)
- ✓ Connect combiner and mixer DUT, combiner output is connected to DUT RF, src 3 is connected to DUT LO, port 2 is connected to DUT IF
- ✓ Select IFBW/averaging to suit

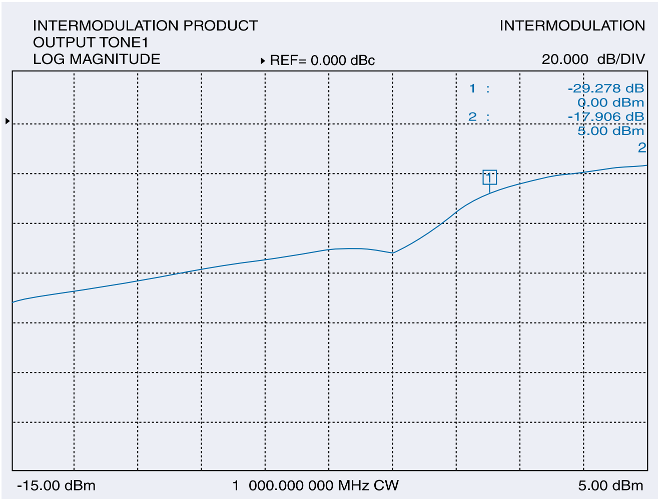

Figure 11. *The IMD3 product for a passive mixer with fixed LO drive (+10 dBm) is shown here. The two RF tones are swept as shown (equal amplitude).*

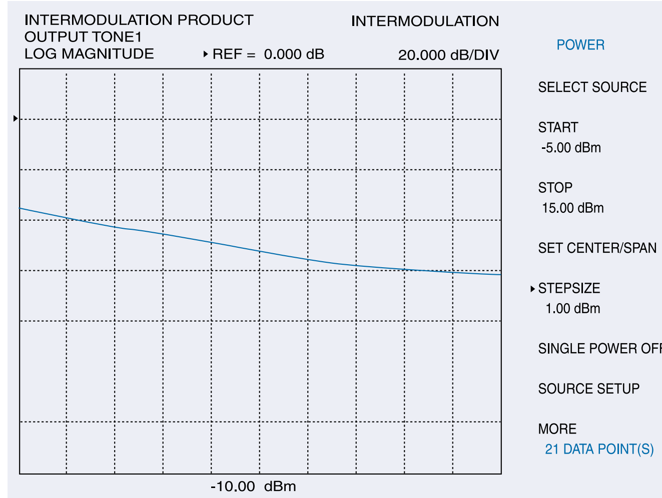

Figure 12. *The IMD3 product for a passive mixer with fixed RF tones (-10 dBm) is shown here. The LO power is swept from -5 to +15 dBm and all frequencies are CW.*

Another option is to fix the RF tones (at 1 GHz and 1.003 GHz respectively, -10 dBm each) and sweep the LO power. Sources 1 and 3 were used for the RF tones and source 2 was used as the LO in this case although that is not a requirement. Again an IF of 100 MHz is used for this example mixer. The LO sweep range is indicated in the menu at the right and although guaranteed port power is only +10 dBm for this instrument, 15 dBm was available at this frequency (maximum power and frequencies at which unlevelled errors occur may vary). The distortion asymptotes to a reasonably low value as the LO drive reaches a sufficiently high level.

Setup Summary for Figure 12:

- ✓ IMD power sweep, CW at 1 GHz, offset at 3 MHz, product, output referred, reference to tone 1, 3rd order
- ✓ Single channel display (usually ch 3), LogMag
- ✓ Mixer mode; source selections: tone1=src1, tone2=src3, LO=src2; LO CW at 900 MHz, downconvert
- ✓ Power sweep (src 2) from -5 to +15 dBm if possible (may need to drop high end to avoid unleveled errors depending on model), src 1 and src 3 fixed at -10 dBm
- ✓ If src 3 is not under GPIB control, manually set it for -10 dBm, 1003 MHz
- ✓ External reference selected on rear panel menu (be sure to connect 10 MHz cable to external synthesizer)
- ✓ Connect combiner and mixer DUT, port 1 and src 3 are connected to combiner inputs, combiner output is connected to DUT RF, port 3 is connected to DUT LO, port 2 is connected to DUT IF
- ✓ Select IFBW/averaging to suit

Summary

This note has discussed the implementation of the new global power sweep in the Scorpion family of instruments. The setup is analogous in many ways to frequency sweep with a slightly different handling of power calibrations and point count control. Most of the application calibrations translate directly and most measurement applications can invoke the power sweep to perform useful measurements.

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