

Request:

Please read this document before trying to use the program or asking me questions about it. If it does not answer your questions, I would like to know so that I can improve it. Thanks!

Introduction

Testing IIP3 or OIP3 of circuits or modules can be very tedious and prone to human error. The software described in this document was designed to automate the process, allowing engineers to obtain more consistent and detailed data in a shorter period of time with a minimum of manual steps.

Features:

- Testing of Gain/ IIP3/OIP3 at constant output power level per tone across frequency
- Testing of Gain/IIP3/OIP3 at constant input power level per tone across frequency
- Testing of Gain/IIP3/OIP3 for mixers/converters:
 - Fixed input frequency, swept LO, swept output frequency (TX upconverter as an example)
 - Fixed output frequency, swept LO, swept input frequency (RX downconverter as an example)
 - Fixed external LO, swept input, swept output (block converter or testing of a product with an internal LO)
- User parameters:
 - Type of test (described above)
 - Test and calibration description text
 - Instrument GPIB addresses and instrument model types
 - Power input/output per tone
 - Power output per tone Tolerance / On screen leveling tolerance for constant input power case (this is odd, feel free to ask me about this one)
 - Tone spacing
 - Start frequency, stop frequency
 - # of points (2-100 valid)
 - Calibration info (described later)
 - **There is only a very basic level of error checking on the inputs, so think about how you would run a manual test when specifying sweep ranges, etc.**
- File input /output
 - The main output report is in a Comma Separated Values (CSV) format which is easy to read into excel and other applications. A template for graphing the results is provided, simply copy all the report output and paste it into the template. The output also captures the users description, the test specifications, and the spectrum analyzer model/revision/serial number, and is time stamped.

- The “snapshot” output is a capture of the final spectrum analyzer screen shot at each frequency in the sweep, i.e. the one that measurements are derived from. This was originally included for debugging, but it may be useful for identifying other odd behaviour such as identifying poorly behaved nonlinearities or spurious signals in the DUT. This is also written in “CSV” format and a graphing template is provided.
- All test settings and calibration info can be stored in a configuration file so that tests can be repeated exactly by simply reopening the file.
- Calibration:
 - “Manual”
 - “Gain” between Generator 1/Generator 2 and the input to the DUT¹ are specified by the user (typically this is a loss, but in some cases it could be a gain. **To avoid confusion, “gain” is always used in specifying these quantities**)
 - “Gain” between the DUT output and the spectrum analyzer input.
 - “Automatic” (only available in the “Normal” mode, i.e. no mixer measurements allow automatic calibration)
 - For this mode, the Spectrum analyzer is considered the “trusted” entity. All measurements and calculations assume that the spectrum analyzer is accurately reporting power levels.
 - The starting point for this mode is the manual calibration constants used for the “manual mode”, hence they should be set first to get the system into the ballpark.
 - The automatic calibration mode can handle up to +/- 4-5 dB of gain slope across the sweep range in the current implementation because the analyzer is put in 1 dB/ Vertical division mode for best accuracy of measuring the tone levels.
 - The calibration process involves two steps:
 1. The user connects the cable that normally goes to the DUT input directly to the spectrum analyzer input. The software sweeps the generators across the whole frequency range of the test to be run in order to determine the “gains” in the power combiner and the cables², and for any offset in the signal generator output levels. See Figure 5.
 2. The user next connects the spectrum analyzer input “network” which will consist of a cable and perhaps an attenuator or directional coupler. The software again sweeps the generators across the frequency range of interest (at this point they’ve been calibrated to be approximately equal), measuring the “gain” of the path between the DUT output and the spectrum analyzer. See Figure 6

¹ DUT stands for “Device Under Test”, an amplifier, mixer, attenuator, anything that an IP3 test is meaningful for.

² It is perfectly reasonable to insert gain between the generators and the power combiner or the power combiner and the DUT input, just make sure of two things: First, make sure you adequately estimate the gain of the network (more later in the automatic calibration section of this document). Second, make sure that at the power levels that the amplifier is operating that it does not contribute significant intermodulation distortion to the system.

Compatibility

The software runs under Windows 2000 (and perhaps other windows operating systems) using National Instruments GPIB interfaces. The software (including all instrument drivers) was written completely from scratch in Microsoft Visual C++, the low level GPIB interface routines from the National instruments Language Interface /DLL for Microsoft C were used. Other than this software package, you will only need to have a National Instruments hardware interface product and drivers installed. Microsoft Excel is also recommended for using the graph templates.

The initial release of the software, while rough around the edges, is functional and supports the following test equipment:

Spectrum analyzer: HP856x series (tested with HP8562A, 8563E, 8565E)

Signal generators: HP8656A/B, HP8648 series, HP 83711/712 series, Anritsu 3631/3632 series.

Disclaimer:

This software is provided totally "as is". Use at your own risk. If you do have problems with the software, I would like to hear about it but I make no guarantee that it will be fixed if I do not have access to the same type of equipment or I cannot duplicate the problem.

Users may wish to use this software to test high power equipment. It is YOUR responsibility to ensure that your equipment (such as the spectrum analyzer) is protected from damage. Always assume that the signal generators could be set to maximum or the wrong frequency and that the spectrum analyzer could be set to an inappropriate level of attenuation. Facilities for easily incorporating attenuators/couplers in the setup are provided for this reason.

Walkthrough for a simple amplifier measurement

For more advanced tests, it is suggested that the user experiment with the program themselves.

We will progress from the upper left of the program window (See Figure 1) across and then down through the settings like text is normally read on a page.

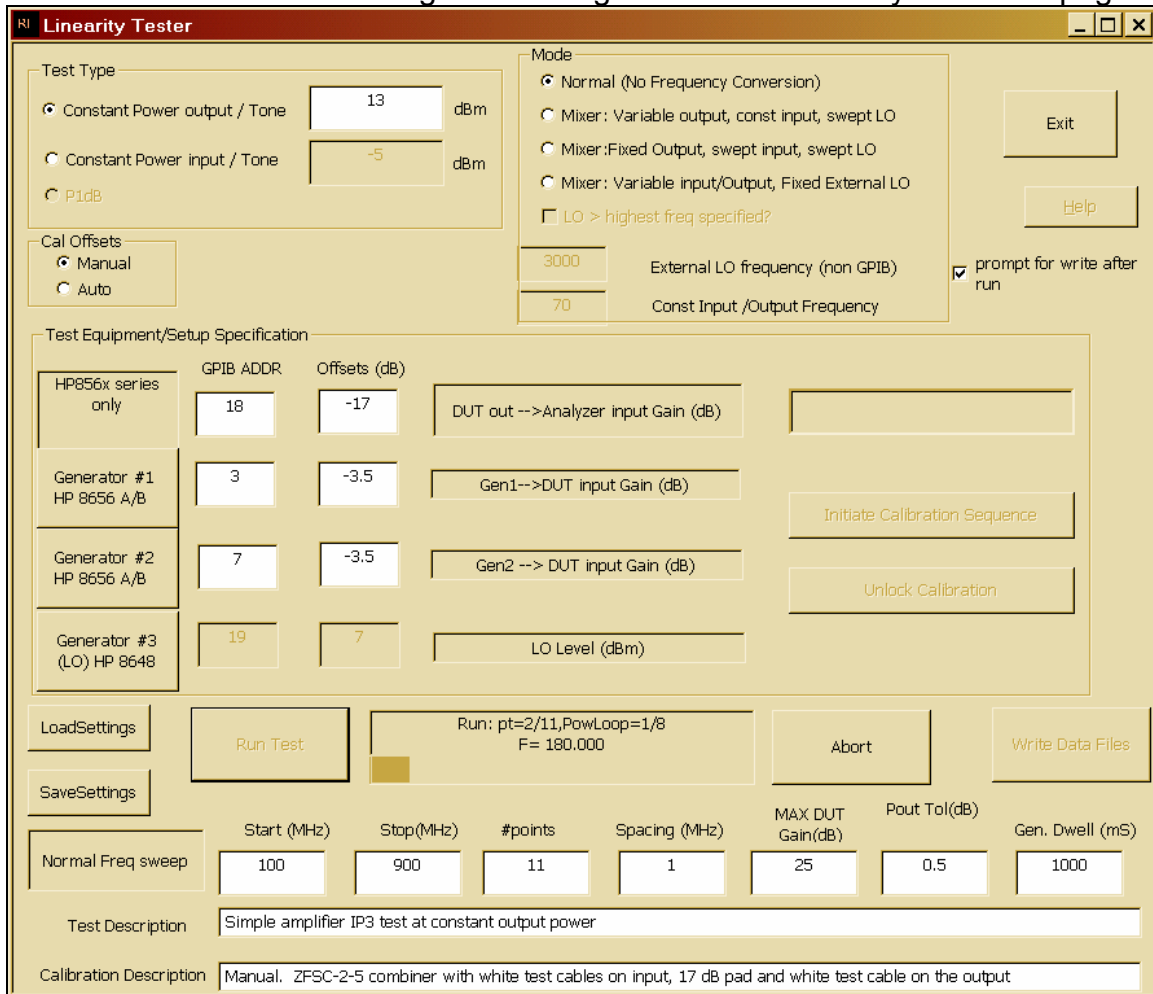


Figure 1: Main application window

1. Select the test type and set the power level parameter (note this is at the DUT input/output, the calibration offsets take care of delivering/setting the power level to this point). You should know what you're testing in the sense that you need to select this power level based on knowing that 3rd order intermodulation distortion can actually be observed on the screen. Beware, the software does manipulate the "Maximum Mixer Level" setting in the spectrum analyzer to achieve the best strong signal handling

- capability, so the noise level may appear higher than you are used to, masking the intermodulation you are trying to see.
2. Select the test mode (leave it in “Normal” mode for an amplifier test)
 3. Select Manual Calibration in the “Cal/Offsets” group
 4. Select the instrument types you have available on your GPIB bus and set the addresses correctly. The instrument model is selected by clicking on the button for each generator. If you do not know the GPIB addresses, consult the equipment documentation.
 5. Set the offsets. See Figure 2 for a typical setup. *The Cal offsets represent the items in the boxes.* I recommend using an attenuator at the spectrum analyzer input, I have some surplus 17 dB microwave attenuators so that explains the “-17 dB” setting in Figure 1. I typically use a mini-circuits ZFSC-2-5 power splitter/combiner in my setup and the “gain” of this from each generator to the DUT input is typically -3 to -4 dB.
 6. Skip over the next few buttons and set the Start, Stop frequency, the number of points and the tone spacing. I recommend Tone spacings of 0.1 MHz to 10 MHz as they will execute in a reasonable amount of time.
 7. Set the maximum DUT gain. This just helps the software to estimate the appropriate drive level on the first pass to get the desired output (for constant output power cases) or to set the reference level appropriately (for constant input power cases). The software will always adapt to what the DUT actually has for gain (currently this loops 8 times to do this), but it will save time to have this estimate either exact (at the starting frequency), or to have the estimate a little high for gain.
 8. Set Pout tolerance. For constant output power cases I do not recommend setting this much below 0.5 dB, certainly not much below 0.25 dB as the spectrum analyzer resolution is not much better than this in the normal sweep mode (we could change settings for the leveling, but this adds little value and would take longer). For constant input power cases I recommend setting this to >1 dB (3dB would probably be fine and may make some measurements run considerably faster). The leveling that is done here is similar, but it merely tries to get the two main output tones at the same point on the spectrum analyzer screen so that the detector is operating in the same region.
 9. Set the generator dwell time. This is the time in milliseconds that the software waits between setting the generators on the new frequency/level and taking a picture of (measuring) the output with the spectrum analyzer. Different generator types take different amounts of time to switch frequency and level (such as when attenuators kick in and synthesizers settle).
 10. Write text descriptions in the Test and Cal boxes
 11. If you think you may want to repeat this test, click the “save settings” box and you will be prompted with a dialog box that helps you to select the location and name of the settings file. The “Load settings” button is used to recall previous settings.

12. Hook up the DUT and run the test! If you have the “Prompt for write after run” box checked (upper right of the program window), you will be prompted for the file name and location of the output when the test is done. If you feel that the test is going wrong in any way, you can hit the “abort” button at any time. It will abort relatively shortly after you hit it. A progress bar and text description are provided while the sweep is running(in the lower middle of the screen next to the run button), but I think it’s more fun to watch the equipment. The “Write data files” button is there if you don’t want to be prompted at the end of the test and would prefer to initiate this yourself.
13. The report files (report and snapshot) can be opened to review the output. For graphs, just select all the text of the report and paste them into the Excel templates provided in the installation directory (shortcuts are made to these). The resulting graphs for this sweep can be found in Figure 3 and Figure 4 . Note that if the leveling loop fails, an ERROR term is shown in the output report and on the output graph labeled “Error_chart”. The leveling works well, but still fails occasionally for some reason. A flaky DUT will definitely cause it to fail, as will specifying levels which cannot be achieved. OIP3H/L are the OIP3 based on the high tone/IM3 product and Low tone and IM3 product. Significant imbalance in these should raise a warning flag.

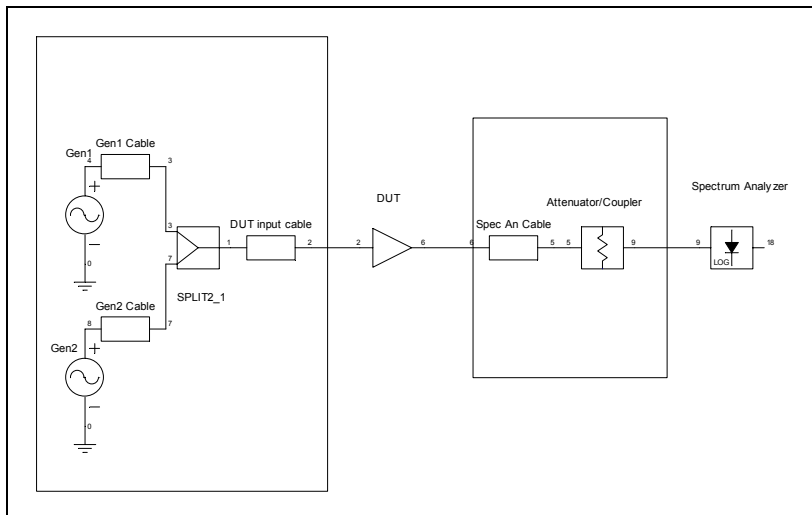


Figure 2: Basic two-tone linearity test setup

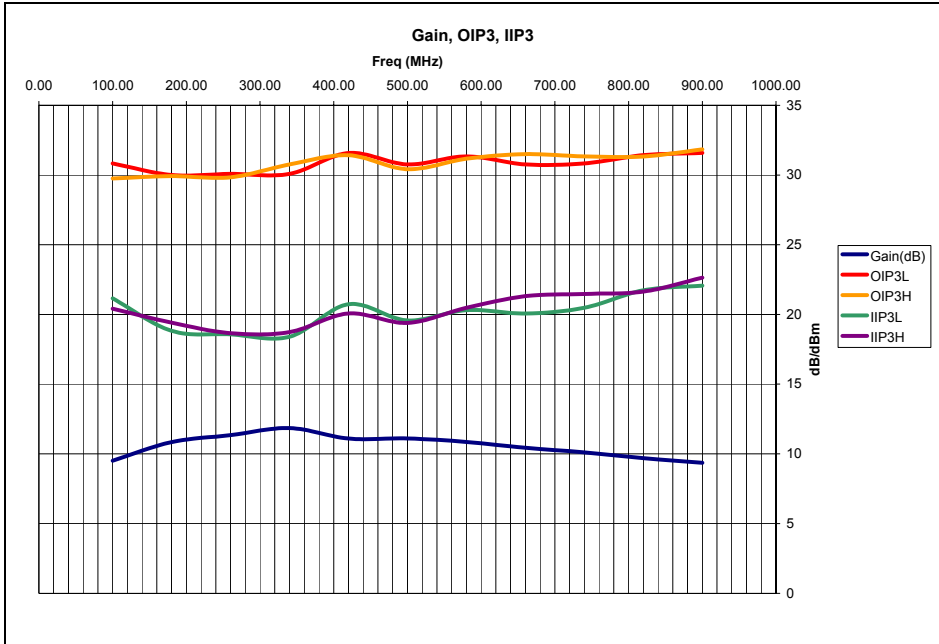


Figure 3: 11 point sweep of an AH1 amplifier prototype

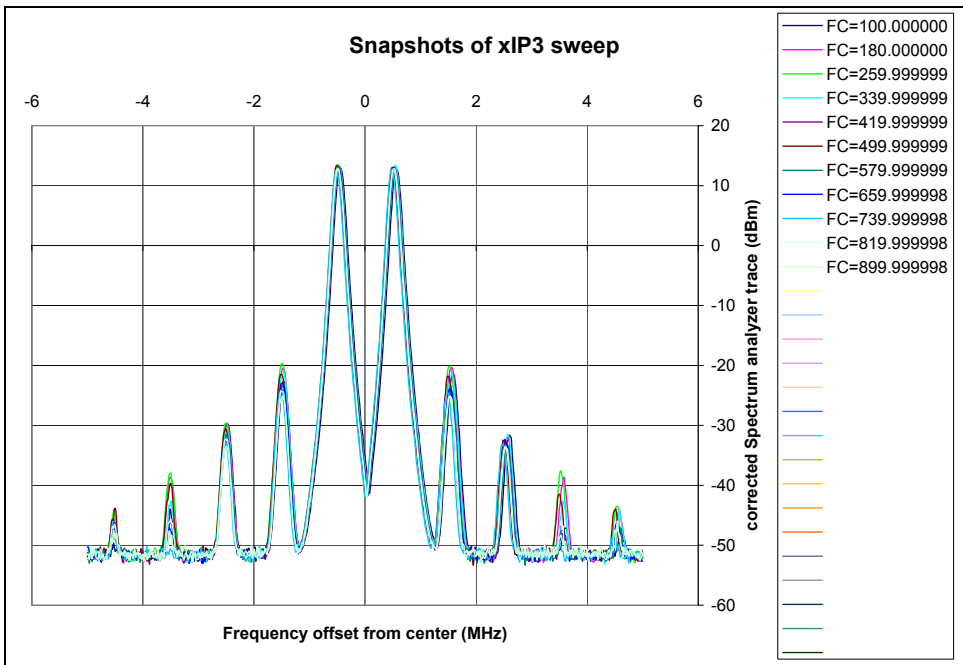


Figure 4: "Snapshots" taken during the sweep

Automatic calibration

The Automatic calibration mode, described above, is handy for higher accuracy measurements or measurements where the setup has a frequency response which is not flat over the sweep range. To enter this mode, follow the following steps:

1. click "Auto" in Cal Offsets.
2. Write an updated description of the test setup in the Cal description string
3. Hit "Initiate Calibration sequence" on the right portion of the screen.
4. Follow the prompts, connecting the equipment as specified BEFORE hitting "OK". The setup connections for the first and second prompts are shown in Figure 5 and Figure 6 respectively (they are also described in the dialogs). **Important note: as of the time that this document was written, the power level that is used for calibration (delivered to the spectrum analyzer input) is hard coded to -20 dBm. This was chosen as a compromise. Specifically most generators + splitter losses + attenuators at the input of the analyzer would still allow – 20 dBm to be delivered without hitting the upper limit of most signal generators output power range. This may be made an option later, but to keep things simple and accommodate most cases, this level was chosen.**
5. Once done, if you have the "prompt for write after run" box checked, you will be prompted to save the calibration and sweep information in a settings file. This is highly recommended because as long as you don't change your cables/attenuators/etc, this calibration should be reasonably valid.
6. As a sanity check you can verify the calibration (or see how good it is) by leaving the setup configured as is shown in Figure 6, then running a test (with an appropriate power level set, perhaps much less than you intend to run with a high gain DUT). There certainly shouldn't be any distortion, but you can see how flat the gain is. I did this in my setup while preparing this document; the results are shown in Figure 9.
7. To keep users from mistakenly invalidating their calibrations, once a successful auto calibration is done, the start/stop frequencies and the number of points are locked out (grayed out, but still visible). I am assuming that tone spacing and power levels are still safe to change after calibration. You can always go to manual cal mode, but if you want to change your auto cal calibration, you must hit the "Unlock Calibration" button which will blow away the current cal after you are prompted to make sure that's what you want to do.

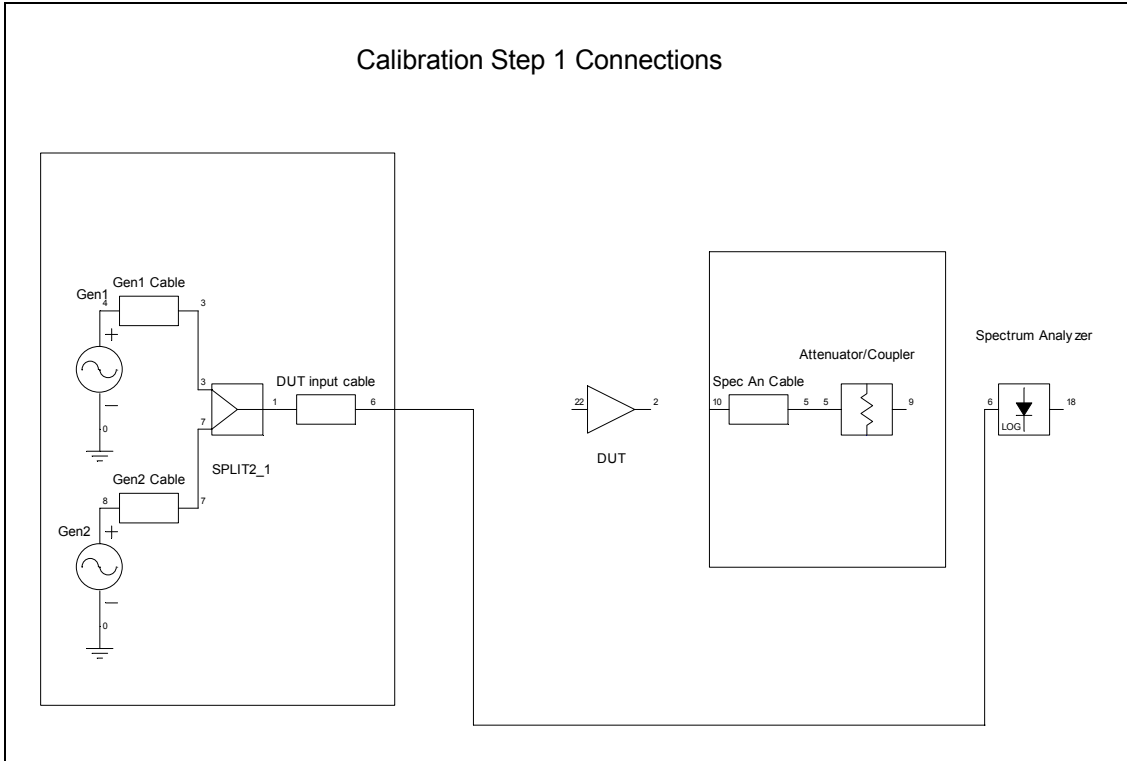


Figure 5: calibration step 1

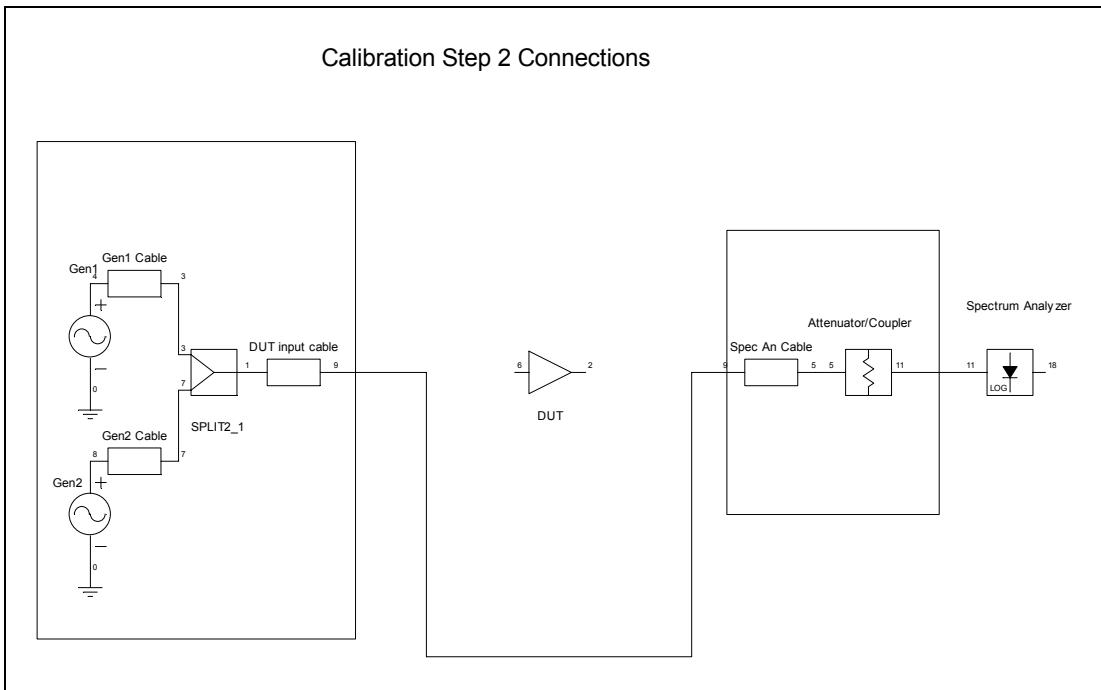


Figure 6: calibration step 2

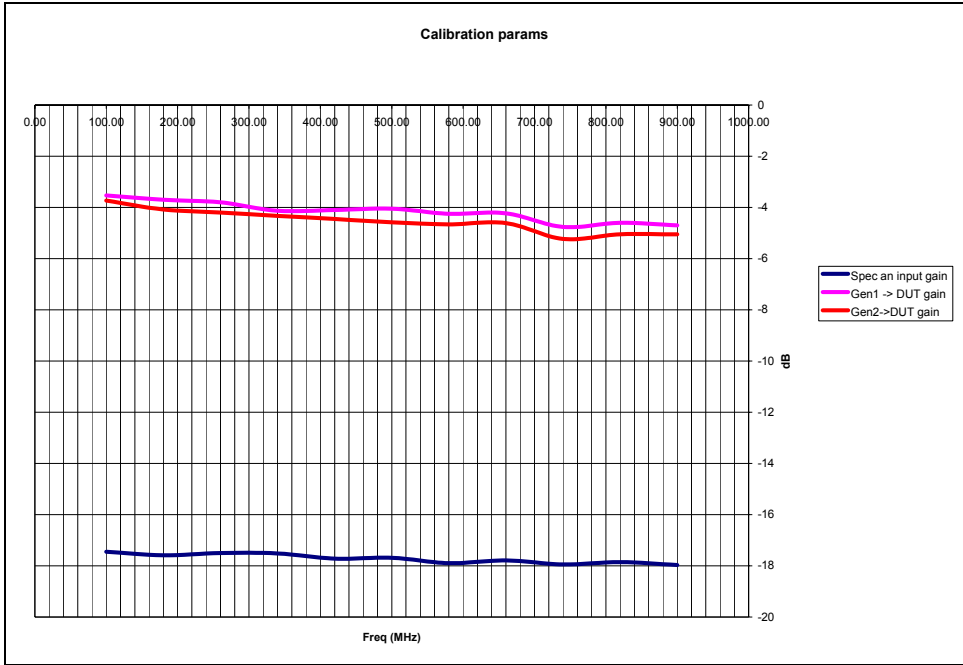


Figure 7: Auto calibration Cal values written to the report. Note, one of my generators has a rear panel connector so I need a longer cable for it to reach the splitter, explaining the increasing loss vs. frequency when compared to the other.

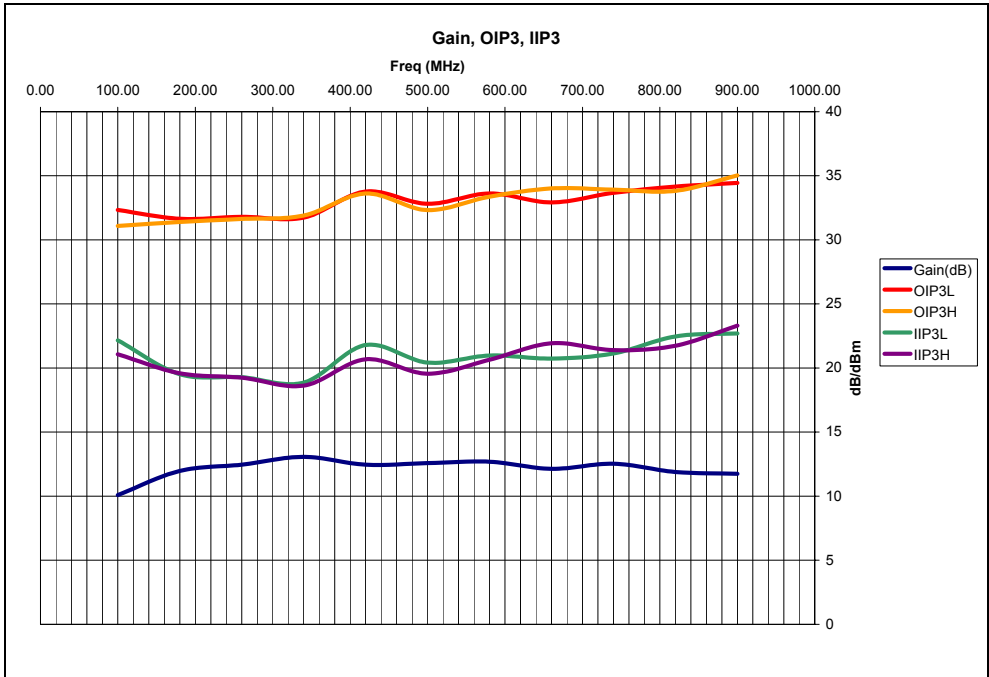


Figure 8: Test case with Auto Calibrated setup. Note that the gain is shown to be more flat than that in Figure 3 because of the variable correction applied.

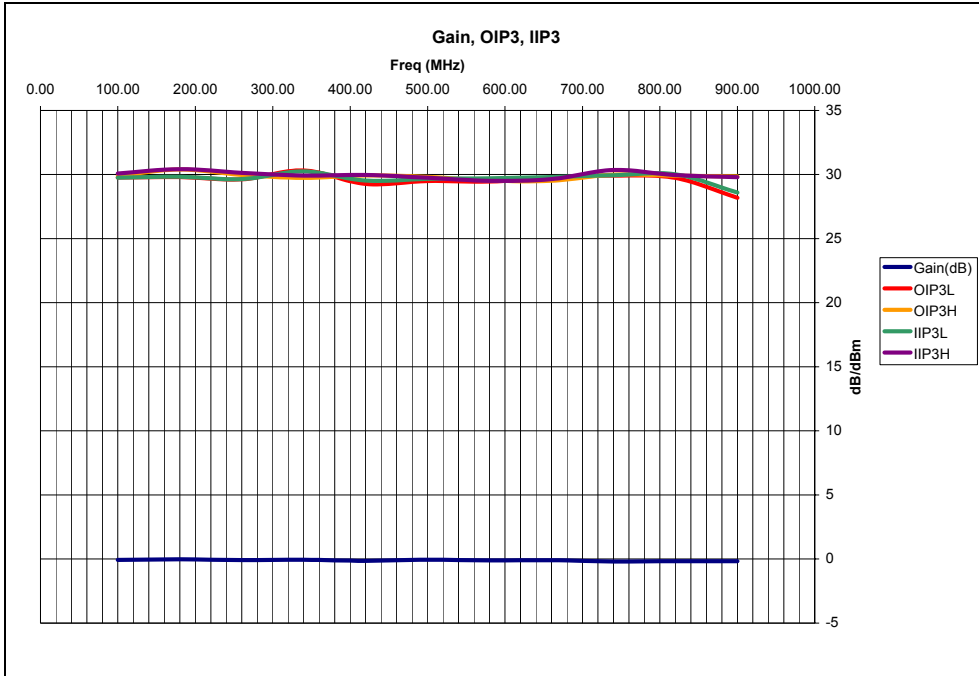


Figure 9: Auto calibration verification with a barrel connector and Pout/Tone set to 0 dBm. The gain is flat, as we hope. In my setup the gain error was about -0.2 dB maximum. Your luck may vary depending on the equipment and various settings.

Mixer modes (this section is very rough)

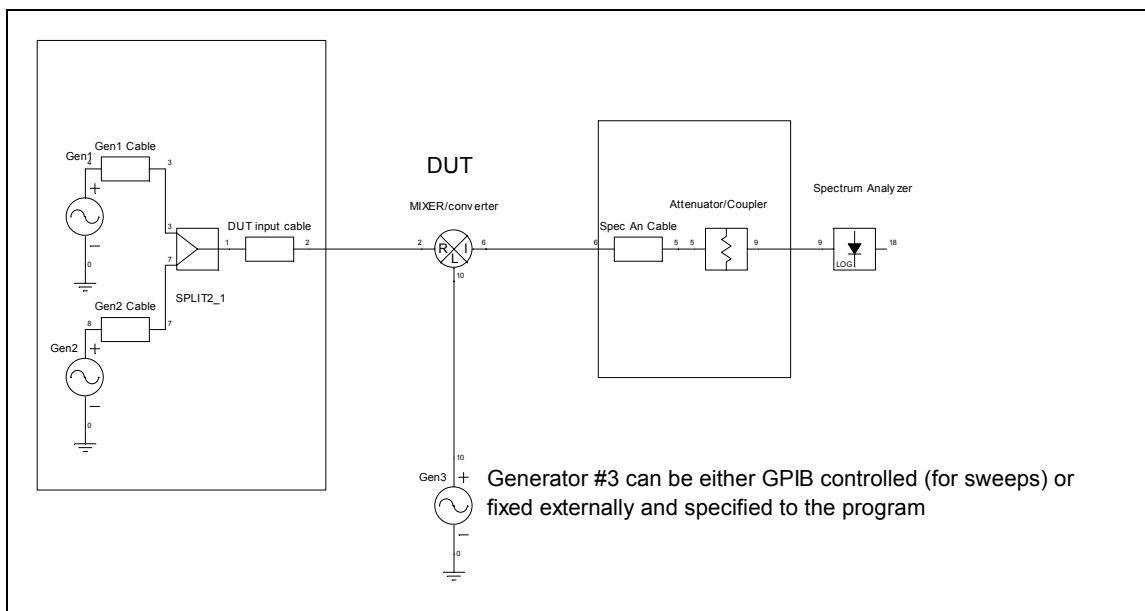


Figure 10: measurement setup with frequency translation

The mixer/converter modes can be a little bit confusing. There are a number of nuances to the operation that may be best clarified by simply providing a table of examples. As previously stated, there is very little error checking on all of the various inputs to the program, so please think about the settings as you enter them (using Table 1 as a template guide).

Also realize that some features of the main program window (Figure 1) change as buttons are clicked, i.e. in the case of the mixer modes various parameters are locked out, and description text changes (such as the text next to the frequency sweep parameters).

Note: in the case of the external LO that is GPIB controlled, the "level" setting is exactly what the signal generator is set to, no calibration or offset is available.

Table 1: Mixer / Converter example summary

Test example Description	Linearity Tester Mode	User specifies range	User specifies constant input/output frequency	LO > Highest frequency specified box checked?	LO frequency	Input frequency	Comments
Upconverter with fixed IF and swept LO Fin = 100 MHz Fout= 500-550 MHz LO = low side injection	"Mixer: Variable output, constant input, swept LO"	Mixer output frequency (500-550 MHz)	Input (100 MHz)	No, the highest frequency specified is the output	400-450 MHz	100MHz +/- Tone spacing /2	
Upconverter with fixed IF and swept LO Fin = 100 MHz Fout= 500-550 MHz LO = high side injection	"Mixer: Variable output, constant input, swept LO"	Mixer output frequency (500-550 MHz)	Input (100 MHz)	Yes, the highest frequency specified is the LO	600-650 MHz	100MHz +/- Tone spacing /2	

Test example Description	Linearity Tester Mode	User specifies range	User specifies constant input/output frequency	LO > Highest frequency specified box checked?	LO frequency	Input frequency	Comments
Downconverter with fixed IF output, swept LO Fin=500-550 IF out = 100 MHz LO= Low side injection	"Mixer: fixed output, swept input, swept LO"	Mixer input frequency (500-550 MHz)	Output frequency (100 MHz)	No, input frequency is highest specified	400-450 MHz	500-550 MHz	
Downconverter with fixed IF output, swept LO Fin=500-550 IF out = 100 MHz LO= High side injection	"Mixer: fixed output, swept input, swept LO"	Mixer input frequency (500-550 MHz)	Output frequency (100 MHz)	Yes, LO frequency is highest specified	600-650 MHz	500-550 MHz	

Test example Description	Linearity Tester Mode	User specifies range	User specifies constant input/output frequency	LO > Highest frequency specified box checked?	LO frequency	Input frequency	Comments
<p>Upconverter with fixed external LO (1000 MHz), variable input/output.</p> <p>Desired output 1200-1300 MHz</p> <p>Input below LO.</p>	<p>“Mixer: Variable input/output, Fixed external LO”</p>	<p>Mixer output frequency (1200-1300 MHz)</p>	<p>User specifies fixed LO frequency = 1000 MHz (box is enabled for this mode)</p>	<p>(Note: in this case the box description reads “input frequency > external LO”)</p> <p>No, the input is below the external LO.</p>	<p>Fixed external</p>	<p>200-300 MHz</p>	
<p>Upconverter with fixed external LO (1000 MHz), variable input/output.</p> <p>Desired output 1200-1300 MHz</p> <p>Input above LO.</p>	<p>“Mixer: Variable input/output, Fixed external LO”</p>	<p>Mixer output frequency (1200-1300 MHz)</p>	<p>User specifies fixed LO frequency = 1000 MHz (box is enabled for this mode)</p>	<p>(Note: in this case the box description reads “input frequency > external LO”)</p> <p>Yes, the input is above the external LO.</p>	<p>Fixed external</p>	<p>2200-2300 MHz</p>	

Test example Description	Linearity Tester Mode	User specifies range	User specifies constant input/output frequency	LO > Highest frequency specified box checked?	LO frequency	Input frequency	Comments
<p>Downconverter with fixed external LO (1000 MHz), variable input/output.</p> <p>Desired output 200-300 MHz</p> <p>Input above LO.</p>	<p>“Mixer: Variable input/output, Fixed external LO”</p>	<p>Mixer output frequency (200-300 MHz)</p>	<p>User specifies fixed LO frequency = 1000 MHz (box is enabled for this mode)</p>	<p>(Note: in this case the box description reads “input frequency > external LO”)</p> <p>Yes, the input is above the external LO.</p>	<p>Fixed external</p>	<p>1200-1300 MHz</p>	
<p>Downconverter with fixed external LO (1000 MHz), variable input/output.</p> <p>Desired output 200-300 MHz</p> <p>Input below LO.</p>	<p>“Mixer: Variable input/output, Fixed external LO”</p>	<p>Mixer output frequency (200-300 MHz)</p>	<p>User specifies fixed LO frequency = 1000 MHz (box is enabled for this mode)</p>	<p>(Note: in this case the box description reads “input frequency > external LO”)</p> <p>No, the input is below the external LO.</p>	<p>Fixed external</p>	<p>800-700 MHz</p>	