THE MSA IN MODES 1G, 2G AND 3G

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A Quick Review

The Modular Spectrum Analyzer (MSA) contains PLO1, which generates the LO1 signal roughly in the 1-2 GHz range, PLO2, which generates a fixed LO2 signal typically at 1024 MHz, and optionally PLO3, which generates the LO3 signal, which is typically set to 10.7 MHz above LO1. These signals and the input signal are mixed in various combinations:

Mixer 1: Mixes the input signal with LO1 to produce the first IF (IF1), typically at 1013.3 MHz.
Mixer 2: Mixes IF1 with LO2 to produce the second IF (IF2), typically at 10.7 MHz.
Mixer 3: Mixes LO2 with LO3 to produce the tracking generator (TG) signal, normally 0-1000 MHz.
Mixer 4: Mixes LO1 with LO3 to produce the VNA phase reference signal, typically at 10.7 MHz.

Mixer 3, Mixer 4 and PLO3 are not present in the basic MSA build, which provides only spectrum analyzer (SA) capabilities.

Summary of the Modes

With all three modes, it is possible for the MSA to operate to approximately 3 GHz. The details of the three modes are given below, but that may be more than many people want to know. Here is the executive summary.

1G. The normal mode is 1G mode, and covers approximately 0-1000 MHz. In this mode, the plain spectrum analyzer (SA), spectrum analyzer with tracking generator (SA/TG) and vector network analyzer (VNA) operation is possible.

3G. With no hardware changes, the MSA can operate in 3G mode, covering approximately 2-3 GHz.

2G. To cover the in-between frequencies of 1-2 GHz with 2G mode requires some minor hardware changes. This can be done by moving a couple of cables. It is more convenient to add a diplexer board and provide for switching to 2G mode with an external jumper. 2G mode can be improved by adding an external connection for the LO3 signal, which is used as the TG signal in 2G mode. The regular TG signal contains a significant LO3 component, so it is possible to use 2G mode with just the regular TG. The regular TG can be enhanced as described below to contain a larger LO3 component. In 2G mode, SA, SA/TG and VNA operation are all possible, though plain SA operation creates double images of input signals, separated by 2*IF2. For some purposes those double images may be confusing, but for many purposes they are easy to deal with.

As of this date, the released software (version 114) does not explicitly support 2G and 3G modes. These modes will work, but the displayed frequencies do not represent the true signal frequencies. The current version of the next release does support 2G and 3G modes, and the sample scans shown in this document were produced using that version.

If that is all you need to know for now, skip to the “Sample Scans” section near the end to see some actual scans in 2G and 3G mode.

Normal (1G) Mode

Assume the standard MSA configuration where LO2 is 1024 MHz and the final IF2 filter is 10.7 MHz. This makes IF1 equal to 1013.3 MHz, the center frequency of the cavity filter.

In normal operation, the MSA tunes to a particular frequency F by setting LO1 to a frequency 1013.3 MHz above F. When the input frequency F is mixed with LO1 in Mixer 1, the difference frequency 1013.3 MHz is produced, and passes through the cavity filter and on to Mixer 2, where it is mixed with LO2 (1024 MHz) to produce the final IF2 of 10.7 MHz.

Because LO1 is always set to 1013.3 MHz above the target frequency F, varying LO1 between 1013.3 MHz and 2013.3 MHz covers the input frequency range 0-1000 MHz. Because the limit of normal operation is approximately 1 GHz, we call the basic mode of operation 1G mode.

3G Mode

Note that whenever LO1 is 1013.3 MHz above the frequency F, it is also 1013.3 MHz below another frequency, that frequency being F+2026.6 MHz (more generally, F+2*IF1). That higher frequency can also mix with LO1 in Mixer 1 to produce the difference frequency of 1013.3 MHz. This means that when the MSA tunes to frequency F, it may also be picking up F + 2026.6 MHz. (Mixer 1 may be less efficient at mixing with this higher frequency, but will nevertheless be very responsive.) This gives an additional tuning range of 2026.6-3026.6 MHz, corresponding to F=0 to 1000 MHz. Because the limit of this additional range is approximately 3 GHz, we call this 3G mode.

As far as the MSA is concerned, it will respond simultaneously to signals in the 1G and 3G ranges. However, it is usually in the user's interest to be sure that when targeting signals in one range, signals in the other range are filtered out. Also, the user wants the graph to display the actual signal frequency. Therefore, the user specifies whether to graph in 1G mode or 3G mode, and applies to the input signal whatever filtering is needed. In 3G mode, if the true target signal frequency is TrueFreq, the MSA hardware will "think" it is tuning to frequency TrueFreq-2026.6 MHz (more generally, TrueFreq-2*IF1), but the display will show the actual target frequency, TrueFreq.

Note that 3G mode uses exactly the same hardware as 1G mode, except for any external input filtering attached by the user. Even the basic MSA build (without TG or VNA) can be operated in 3G mode as a spectrum analyzer.

To obtain a tracking generator signal in 3G mode, a software trick is required. Normally we obtain the TG signal by mixing LO2 and LO3, with LO3 set to TrueFreq+LO2. We then use the LO3-LO2 mixing product. For 3G mode, we need to use the LO3+LO2 mixing product, and set LO3 to TrueFreq-LO2. This will provide the necessary test signal to operate in SA/TG mode. It also causes LO3 to be IF2 below LO1 instead of the usual IF2 above LO1, which maintains the difference between the two necessary to generate a valid VNA phase reference signal.

2G Mode

There is one additional mode of operation that covers the range between 1G and 3G modes, and is called 2G mode. This mode is implemented by skipping the cavity filter and Mixer 2, and using the Mixer 1 output as the source of the final IF2 (typically 10.7 MHz). This requires a cabling change, discussed below. Both the SA and VNA can operate in 2G mode. But in 2G, even operating just in SA mode requires the presence of Mixer 3 and PLO3, so the MSA build must include the tracking generator modules.

For the VNA, this requires using LO3 as the test signal source, since LO3 is always equal to LO1 + IF2. Thus, when the portion of LO3 that survives the DUT is mixed with LO1 in Mixer 1, the result will be a difference frequency of IF2. It is actually not critical that a pure LO3 signal be used as the test source; the regular tracking generator output contains a substantial LO3 component. Nevertheless, a pure LO3 signal has advantages. To obtain such a signal, it is necessary to tap into one of the two LO3 lines by means of a splitter or directional coupler, and amplify that signal, using an amplifier with good reverse isolation.

In VNA/2G mode, when the hardware acts as though it is tuning to frequency F, LO1 is set as usual to F + IF1, and LO3 is set as usual to F+IF1+IF2. Since we use LO3 as the test frequency, the actual targeted frequency is LO3=F + IF1 +IF2, which also equals F+LO2. Accordingly, in 2G mode we want the graph to be labeled with those higher values.

For the SA in 2G mode, the MSA will respond to signals that are IF2 above or below LO1, which includes F+IF1+IF2 and F+IF1-IF2. The former is exactly the same frequency that is targeted in VNA/2G mode. The latter frequency is 2*IF2 (typically 21.4 MHz) below that main frequency, and represents an extra image on the graph. In SA/2G mode, every signal will appear twice on the graph, if the graph range is broad enough. When viewing widely spaced signals, this double image does not create a significant problem; we simply ignore the lower frequency image. The only way the image creates problems is when it appears on top of another signal of interest. Thus, if you have a mass of signals in the 1500-1530 MHz range, each creates a lower image 21.4 MHz below the main signal, and some of these images will overlap other signals of interest. But if you are viewing harmonics of a 100 MHz fundamental, the signals of interest will be spaced 100 MHz apart, and each will have an image 21.4 MHz below itself. In that case it is easy to identify and ignore the lower images.

The frequency range of 2G mode depends on the range of LO1 and LO3. The low end is approximately 950 MHz. The high end depends on the tuning voltage supply to the VCOs. With the standard MSA supply of about +19V, the high end will be about 2050 MHz. With a +22V supply it will be about 2200 MHz. In either case it can be thought of roughly as 1-2 GHz.

Software Adjustments for 2G and 3G Modes

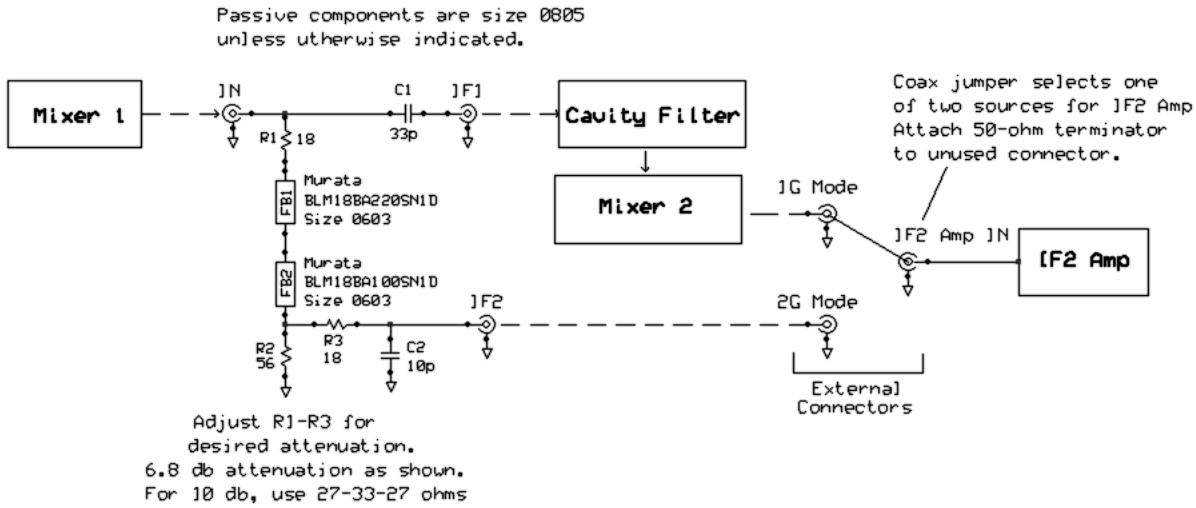
The MSA software must maintain two internal frequencies for each scan point. One corresponds to the actual signal frequency, as set by the user; call this TrueFreq. The other is the one which is used to actually command the hardware, which always acts as though it is in 1G mode. This latter frequency, which is stored internally in the array datatable(), is called the Equivalent 1G Frequency. The conversion is made as follows:

1G Mode: Equivalent 1G Frequency = TrueFreq
2G Mode: Equivalent 1G Frequency = TrueFreq-LO2
3G Mode: Equivalent 1G Frequency = TrueFreq-2*IF1

In addition, to use the tracking generator in 3G mode, LO3 needs to be set to TrueFreq-LO2, rather than the normal TrueFreq+LO2.

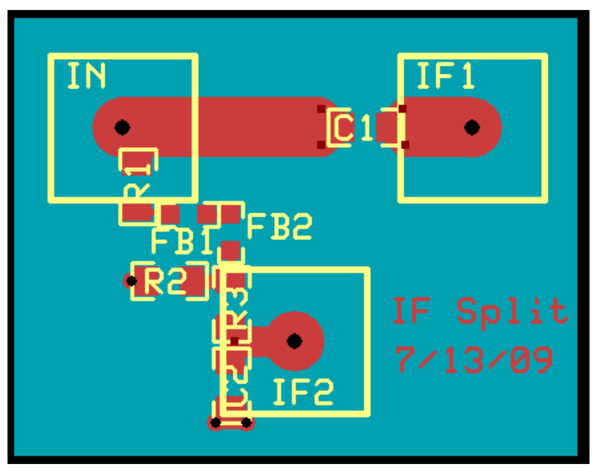
Hardware Modifications for 2G Mode

1G and 3G modes use exactly the same hardware arrangement. 2G mode, however, needs to bypass the cavity filter and Mixer 2. To make it easy to switch into and out of 2G mode, a diplexer board was devised. The diplexer allows the cavity filter to remain connected even when it is not being used. Switching between 1G and 2G modes then involves moving a single external jumper. Here is the switching scheme, including the diplexer board.



In 1G mode, the Mixer 2 output is jumpered to the IF2 amp input. In 2G mode, that amp takes its input directly from the diplexer board. Switching between modes requires only moving a single jumper, located on the outside of the MSA box. To be fancy, an RF switch could be used, provided it has very high isolation.

Here is the ExpressPCB layout of the diplexer board:



With a hardline coax soldered to the input, this board can be attached directly to the Mixer 1 output, and supported just by that hardline.

The other hardware modification that is useful for 2G mode is the creation of an external LO3 output to use in lieu of the tracking generator output. I did so by running one of the PLO3 outputs to an active splitter, which provides an external 10 dBm LO3, a far stronger signal than is needed for this purpose. A simpler method would be to run one of the PLO3 outputs through a directional coupler such as the Mini-Circuits SYD-20-33, and then attenuate the tapped output by 10 db and amplify it by 20 db. This would provide an LO3 signal of about -12 dBm, as well as providing decent isolation between the various LO3 lines.

An alternative to the separate LO3 output is to use the LO3 component that is present in the normal TG output. It might be useful to strengthen that component, however. One way to do so is to attenuate the LO2 signal in Mixer 3, producing a 20 db weaker TG signal (with an unchanged LO3 component), and then amplify the weakened TG by 20 db. This will increase the LO3 component by 20 db, as well as improving the isolation between LO3 and LO2 (which is impaired by leakage in Mixer 3). Other benefits of this approach are that the TG output signal can have a much better return loss (depending on the amplifier), and the output of Mixer 3 becomes isolated from the DUT, so the characteristics of the DUT do not affect the level of the Mixer 3 output. (More on that issue elsewhere.)

<u>Filtering in 1G and 3G Modes</u>

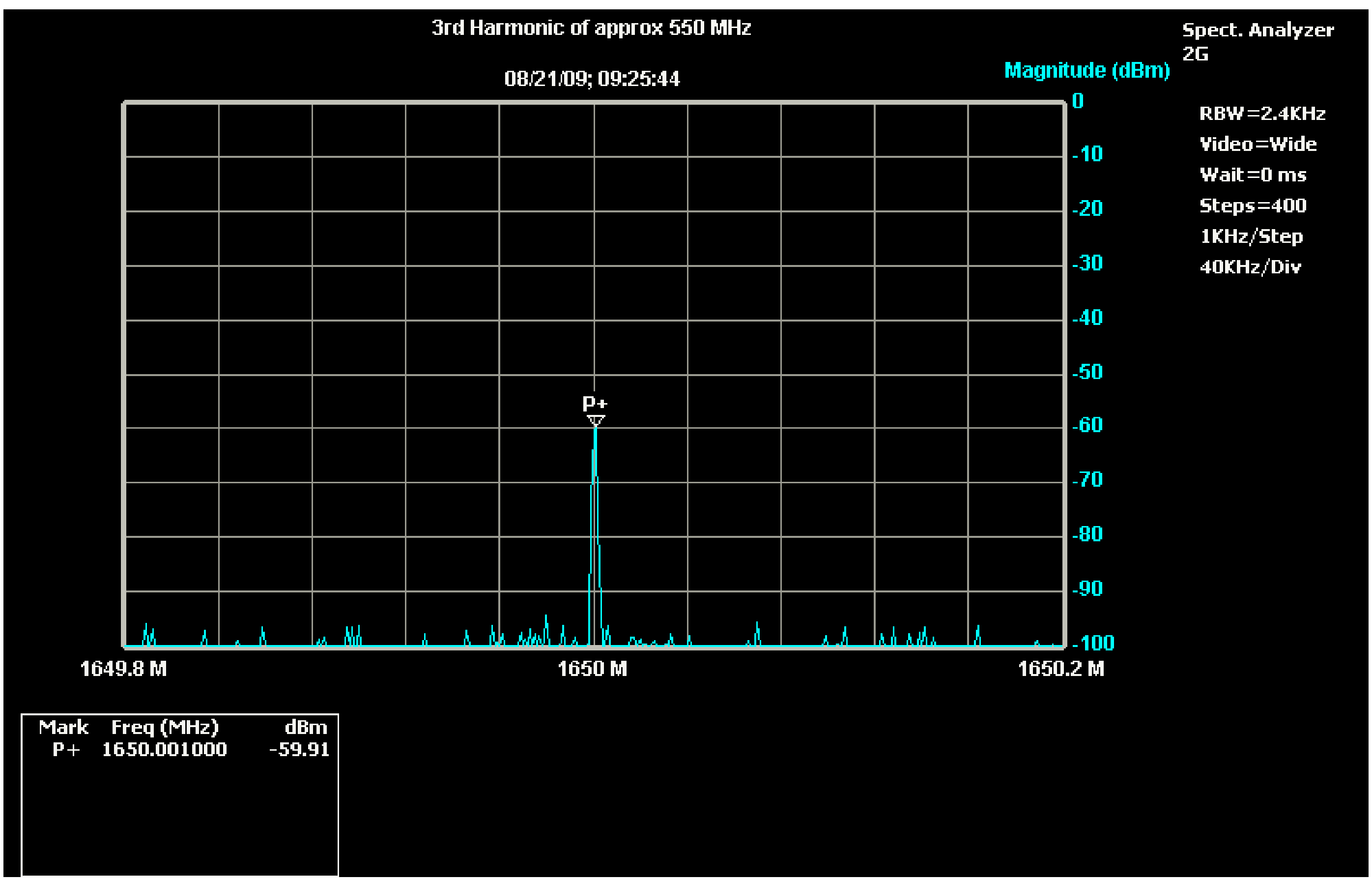
As noted above, the MSA will automatically respond to 1G and 3G signals simultaneously, whether in 1G mode or 3G mode. It is generally desirable to filter out the untargeted signal range. This is usually not necessary when operating the SA/TG or VNA, because the odds are low of the test signal containing 1G and 3G components that will show up in the same place.

For the SA in 1G mode, 3G signals of frequency F will appear on the 1G graph at F-2*IF1. They can be eliminated with a lowpass filter with a cutoff around 1.2 GHz, though for other reasons (primarily, elimination of any IF1 signal from the input) it may be desirable to use a lower cutoff. A Mini-Circuits LFCN-630 is generally a good choice for this purpose, though it will affect response in the 900-1000 GHz range as well.

For the SA 3G mode, 1G signals of frequency F will appear in the 3G graph at F+2*IF1. They can be filtered out with a highpass filter with a cutoff near 1.9 GHz. One suitable high pass filter is the Mini-Circuits HFCN-1910. If very strong 1G signals are present, additional filtering may be desired, such as cascading two HFCN-1810 filters.

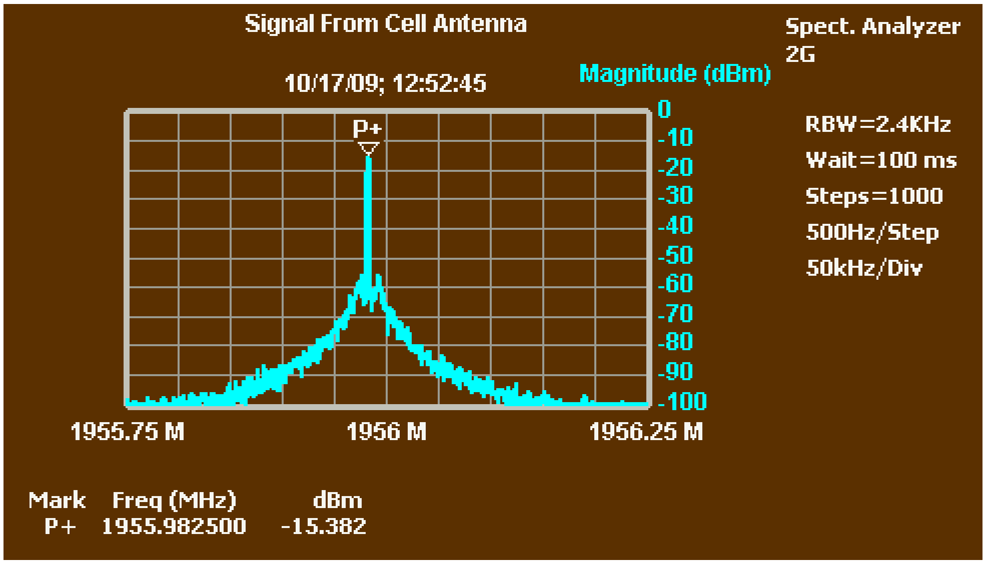
<u>Sample Scans in 2G and 3G modes</u>

The following scan was produced in 2G mode by inputting a signal very near 550 MHz and examining its third harmonic.



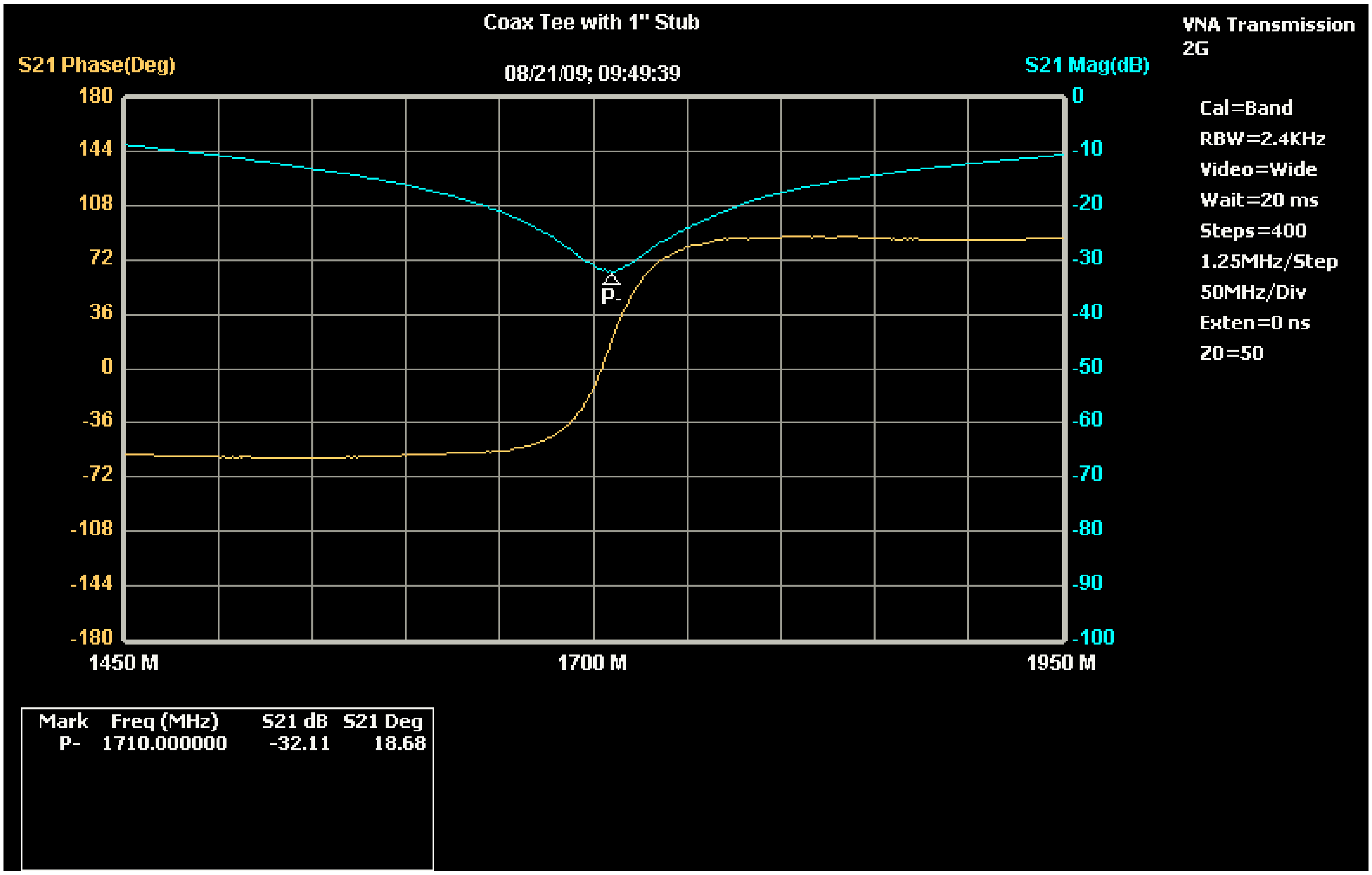
(Note that the mode is displayed near the upper right of the screen as “2G”). The image of this signal also appears 21.4 MHz below 1650 MHz, but by focusing on a narrow range we avoid that distraction.

The following 2G scan shows a signal amplified from LO3 of the MSA, and run through a piece of wire draped over a cell-phone booster antenna.



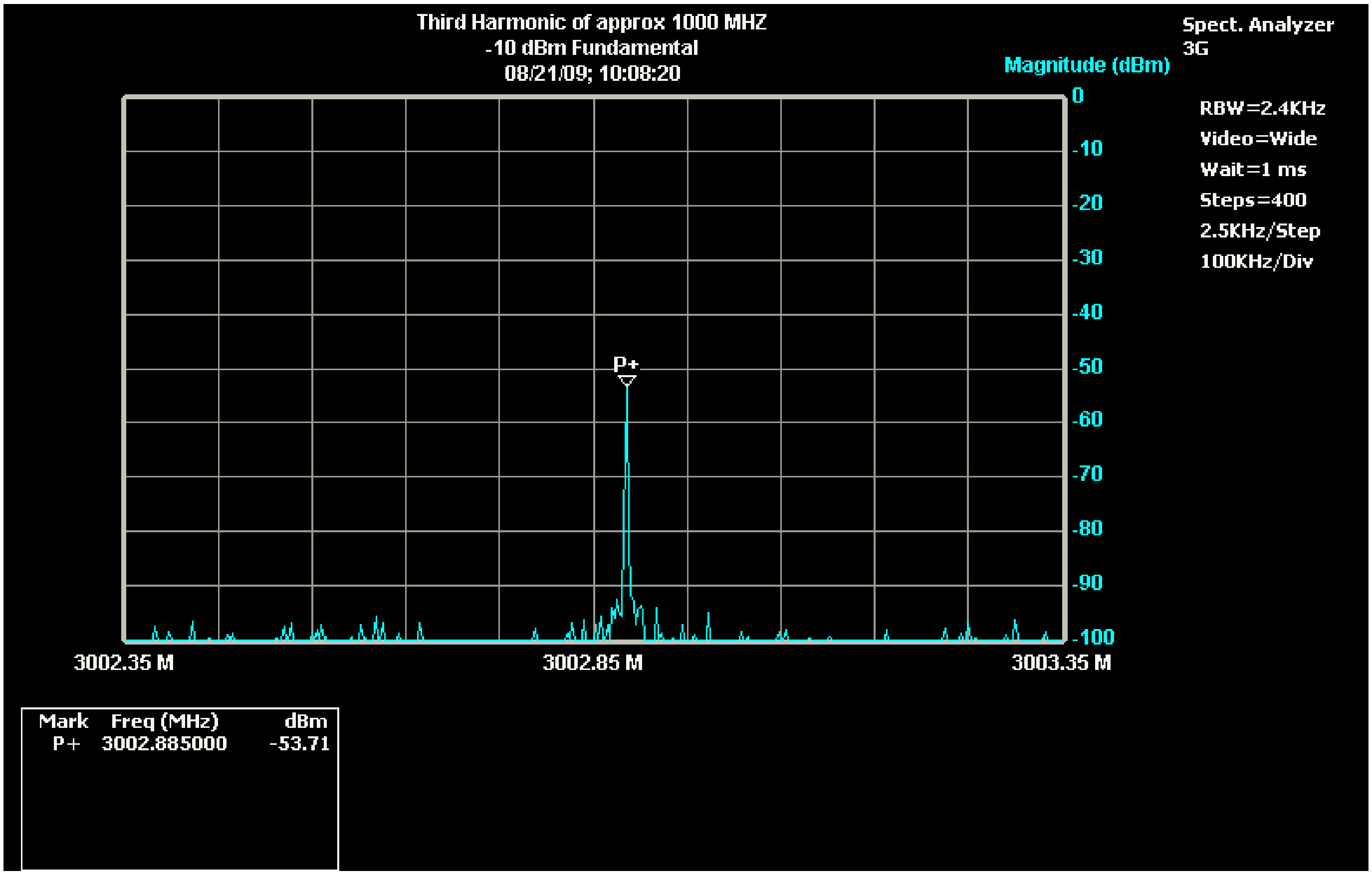
The LO3 signal is very strong and shows that the MSA has very good dynamic range in 2G mode.

The following scan was produced with the VNA in 2G mode, scanning the transmission of a coax tee with a 1” coupler attached to the third leg, acting as an open stub:



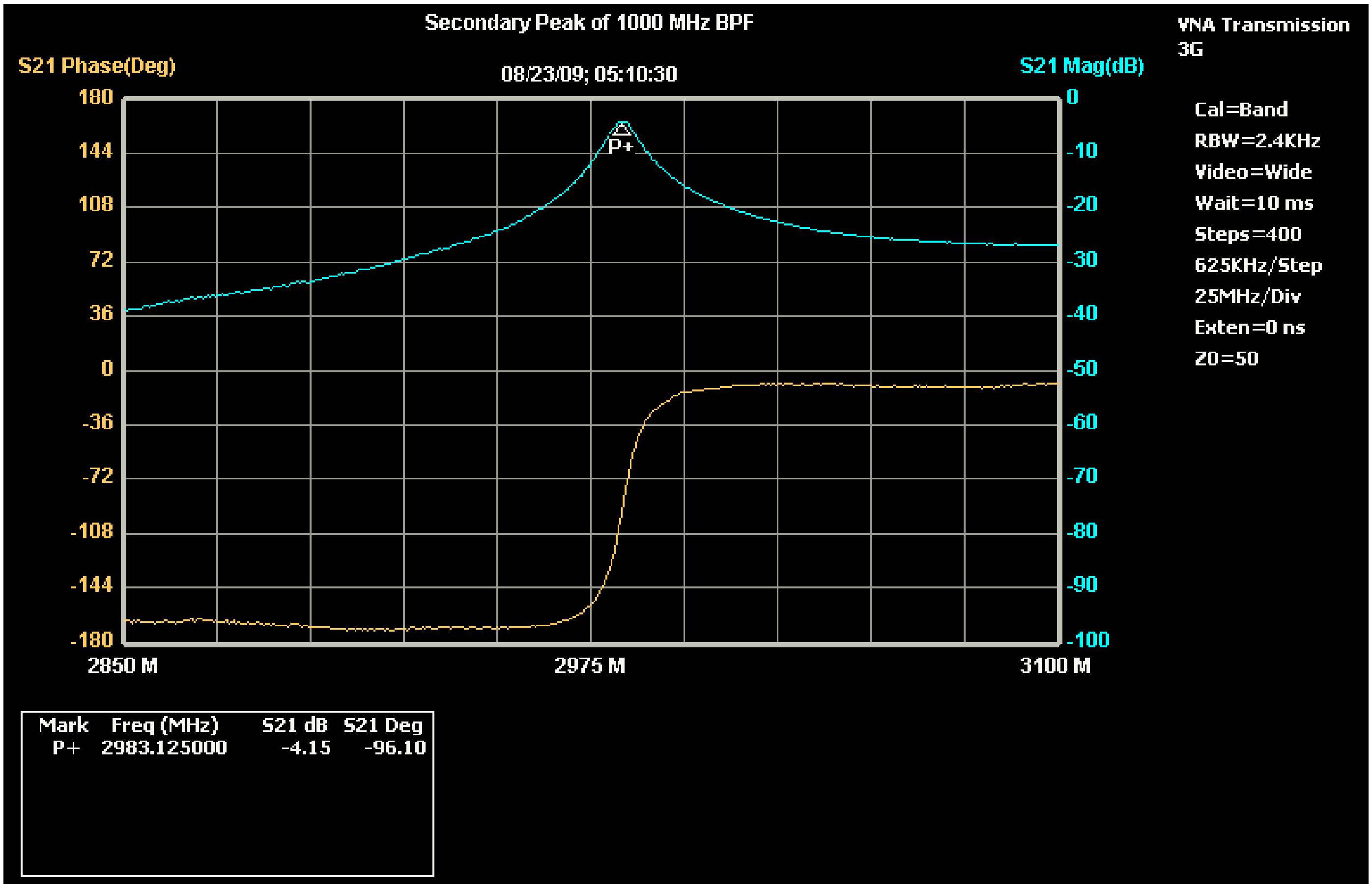
In VNA/2G mode, there is no issue of an image, because the possible image frequency is not present.

The following scan was taken with the SA in 3G mode, using an input signal of about 1001 MHz, and examining the third harmonic.



No input filtering was used, which means the fundamental of 1001 MHz would also appear on the 3G graph at 3027.6 MHz (F+2*IF1). This would create a false image if we were to extend the range of the above graph past that frequency. But with this narrow scan, it was not necessary to filter out the fundamental.

Finally, we have a scan with the VNA in 3G mode. The DUT was a bandpass filter tuned to 1000 MHz. The design of the filter causes periodic behavior, so it has a secondary peak at approximately 3 times the fundamental. The capacitor used for tuning causes the peaks to be not perfectly periodic, so the secondary peak appears at 2983 MHz.



Secondary Peak of 1000 MHz BPF
S21 Phase(Deg)
08/23/09; 05:10:30
S21 Mag(dB)
VNA Transmission 3G
Cal=Band
RBW=2.4KHz
Video=Wide
Wait=10 ms
Steps=400
625KHz/Step
25MHz/Div
Exten=0 ns
Z0=50
180
144
108
72
36
0
-36
-72
-108
-144
-180
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
P+
2850 M
2975 M
3100 M
Mark Freq (MHz) S21 dB S21 Deg
P+ 2983.125000 -4.15 -96.10