Vector measurements in MilliLab

1. General

Millimetre wave vector network analyser (MVNA) measurements are typically used to characterise various kinds of components used in building instruments such as millimetre wave receivers or their subsystems. These instruments are designed for radioastronomy, remote sensing etc. to be used on the ground or space-borne in satellites. For example, when a filter has been designed and manufactured, its response is usually verified by a network analyser measurement. With suitable accessories, a network analyser can also be used to measure the radiation pattern of an antenna or to determine the dielectric properties of some material. Measuring the gain of an amplifier is another emerging application because, thanks to the rapid development of transistor technology, also amplifiers are now being developed for the millimetre wave band. Sometimes a millimetre wave network analyser can also be used simply as a signal generator for some receiver test when other signal generators are not well available.

MilliLab's MVNA 8-350 is a millimetre-wave vector network analyser manufactured by AB Millimètre, Paris, France. In general, a network analyser can be used for measuring electrical characteristics of a device under test, in short: a DUT. For performing this, the DUT has to be connected to the test ports (= "measurement ports") of the network analyser. In the case of MilliLab's MVNA, these test ports are available via waveguide flanges. Measurements can be transmission or reflection measurements. The vector measurement capability of MVNA indicates that both the amplitude and the phase of a transmission or a reflection response can be measured. In the following, a short description of MVNA and measurements with it in MilliLab is given. (More data of measurement options are available in a table in MilliLab's web pages describing measurement services. Of course, you can always contact MilliLab for verifying any detail etc.)

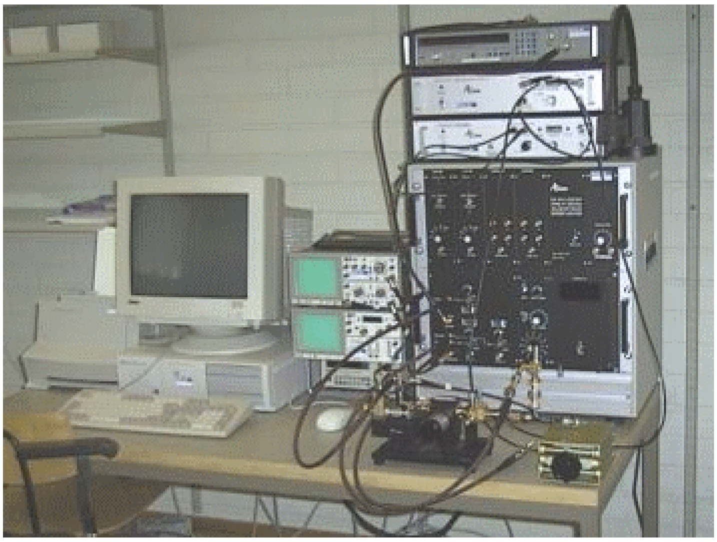

Figure 1. MVNA system in MilliLab (all extensions not available in this picture).

2. Basic measurement principle (for transmission)

A transmission measurement is the most typical application of MVNA's capability. This measurement is based on generating a test signal, transmitting it through the DUT, receiving, and then detecting the amplitude and the phase of the signal. Because the amplitude and the phase need to be referred to something to be meaningful, the measurement system is calibrated before the measurement of the DUT. Baseline correction is a simple form of calibration.

There are different multipliers and harmonic mixers available as signal source and detector devices. Basically, each matching source-detector pair is to be used in some preferred specified frequency range as is common practice with all waveguide devices. A simplified block diagram of MVNA setup is shown in Fig. 2 and, as an example, D-band source and detector units are shown in Fig. 3.

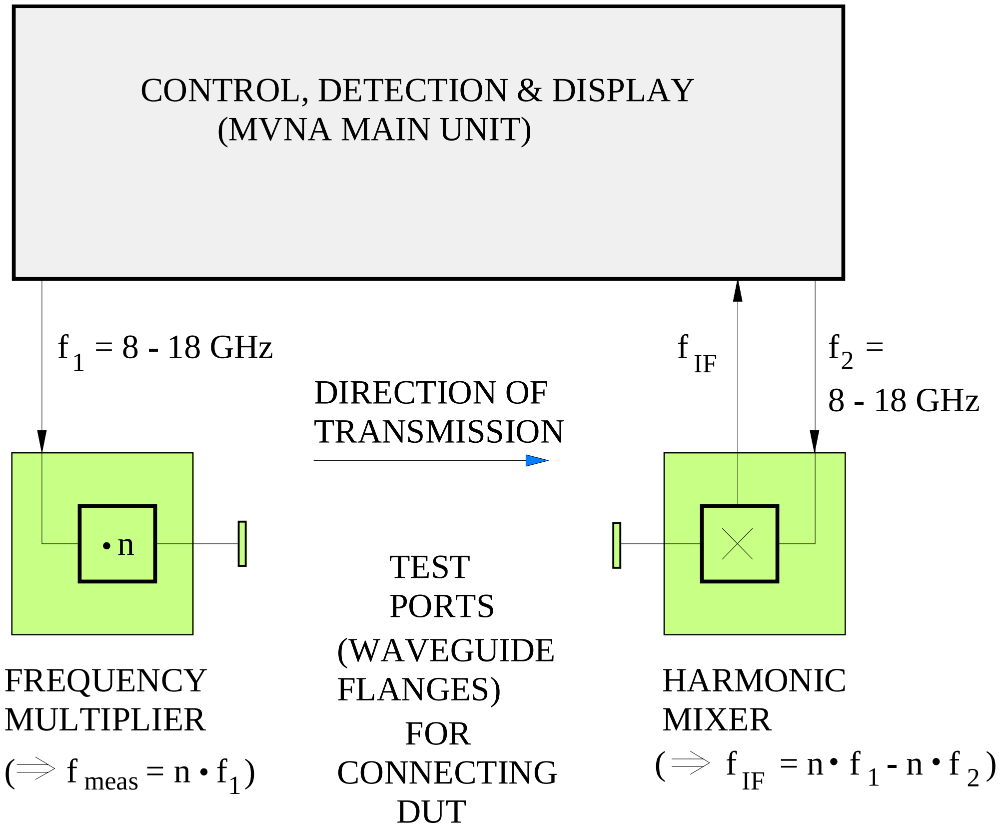

Figure 2. Simplified block diagram of MVNA setup (for a measurement of transmission type) at frequencies up to 220 GHz. Harmonic number n is selected suitably according the frequency of interest. Up to 170 GHz isolators are used to minimise reflections at test ports. Above 170 GHz a high-pass filter is used at the output of the frequency multiplier. Frequency sweeps are possible. Baseline correction is used as a means of calibration. Thus measurement results with DUT are normalised to results taken previously without any DUT connected. The DUT can be any device with suitable ports to be connected to the test ports.

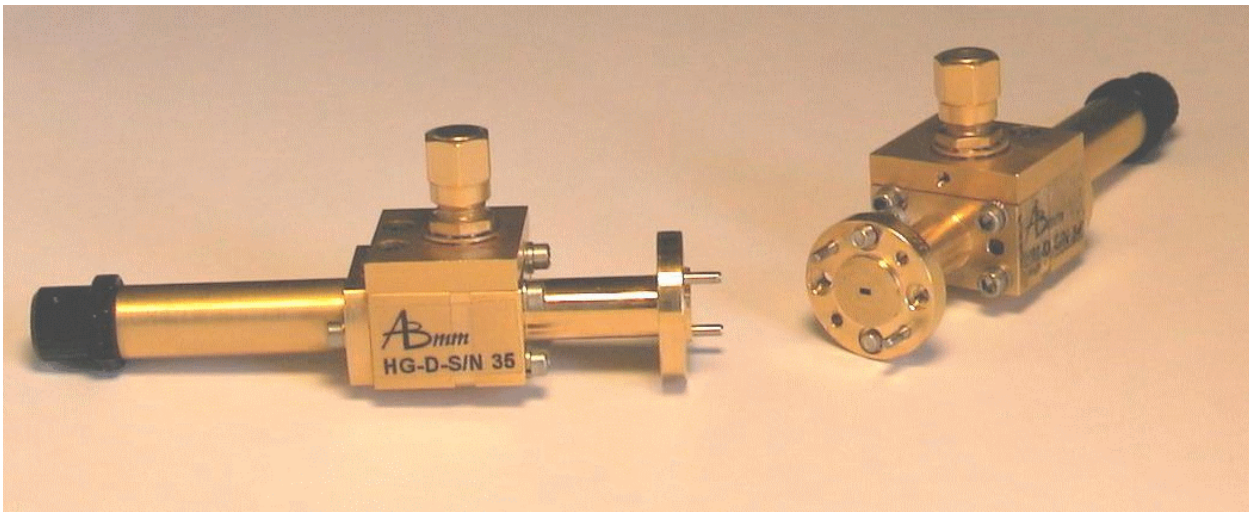

Figure 3. As an example of MVNA components: D-band (110 - 170 GHz, waveguide WR-6: 1.65 mm x 0.83 mm) source and detector. The detector is used also above 170 GHz. Waveguide test ports can be seen (without possible isolators etc. here now). Cables to MVNA main unit will be connected to top SMA connectors (which are shown here with static electricity protective short circuit terminations). Black adjusting knobs seen in the ends are for backshort tuning (useful for optimisation of operation).

3. Generation of a test signal

MVNA (main unit) generates a test signal by using a relatively low-frequency ($f_1 = 8 - 18$ GHz) oscillator to feed a frequency multiplier. A frequency component with a suitable harmonic number n from the multiplier output harmonics is selected for measurement use. Due to this selection, the MVNA system controls the frequency difference between the two oscillators properly to satisfy the f_{IF} requirement needed for detection (see formula for f_{IF} in Fig. 2).

The power in the harmonic signal components gets smaller with increasing frequency and this has on effect on the dynamic range (here meaning: distance in dB from signal level to noise level) available for measurements. Above 150 GHz, MilliLab's ESA-1 extension to MVNA increases the signal level and widens the dynamic range and useful frequency range. Sometimes an external high-power source can be used also, but this requires a more complex system setup than the one shown in Fig. 2. Also the setup with ESA-1 extension is relatively more complex although the basic principle of signal generation is always the same.

4. Reception of the test signal

MVNA receives the test signal with a harmonic mixer (of course, after the signal has been affected by the DUT if a measurement is going on). It is to be noticed that, taking into notice the harmonic number n for the harmonic mixer, MVNA concurrently has a proper tuning of the local oscillator fundamental frequency f_2. Thus the test signal is converted in the mixer to a fixed intermediate frequency (IF). This IF is low enough for easy amplification and detection inside MVNA's main unit. Amplitude and phase information can be extracted for display.

Similarly as in the case of frequency multipliers, the performance of harmonic mixers deteriorates with increasing signal frequency. To reduce this problem when using the highest frequencies (*i.e.*, above 260 GHz), MilliLab's MVNA has an extension called ESA-2. ESA-2 is a very sensitive receiver that considerably lowers the limit for useful signal levels. Thus it also widens the dynamic range and useful operational frequency range. ESA-1 and ESA-2 extensions are targeted at the very highest of frequencies and due to this they utilise Gunn oscillators working at around 100 GHz. The frequency relations that are needed for proper operation are controlled by the MVNA main unit but with the help of some separate control units associated to the extensions. Thus, similarly as happens with ESA-1 extension on the source side, the use of ESA-2 extension on the detector side also slightly complicates the setup from what is seen in Fig. 2. The ESA-1 and ESA-2 setup is described in Fig. 4.

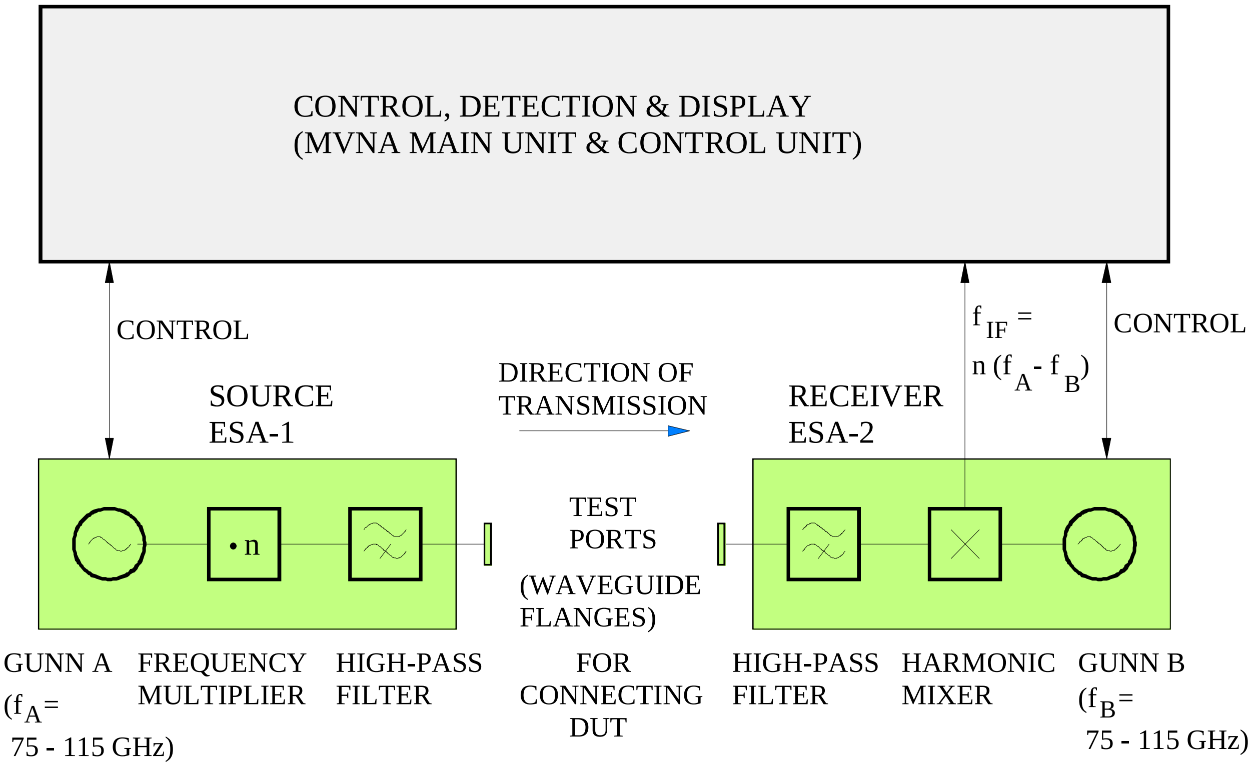

Figure 4. Simplified block diagram of MVNA measurement setup at frequencies up to 700 GHz. ESA1- and ESA-2 extensions are used. (At low frequencies a WR-6 waveguide harmonic mixer is usable instead of the ESA-2 receiver shown here). Harmonic number n is selected suitably. First all signals are tuned to phase lock at each measurement frequency point, then measurements can be made resulting in amplitude and phase values. Frequency sweeps are limited to electrical tuning range of Gunn times multiplication factor. Baseline correction used: Measurement results with DUT are normalised to results taken previously without DUT.

5. Calibration for transmission measurement

For a transmission measurement, a *baseline correction* (other names perhaps more often used: response calibration, normalisation) is a simple calibration which is done by first making a calibration measurement without any DUT while still recording the results. During the calibration, test ports are directly connected to each other. Then later the measurement results with the DUT are divided by the recorded results of the calibration measurement. The final outcome of this procedure is that the MVNA system can display the transmission response (both amplitude and phase) of the DUT. Ideally the transmission response would be directly related to the scattering parameter S_{21} of the DUT. However, in practice, due to the limitations of real-world equipment, some case-dependent errors will remain in the displayed response. The sources of these errors are, for example, the reflections between the DUT and the test ports of the network analyser. In many cases isolators or attenuators in the test ports can be used to reduce these errors if considered necessary.

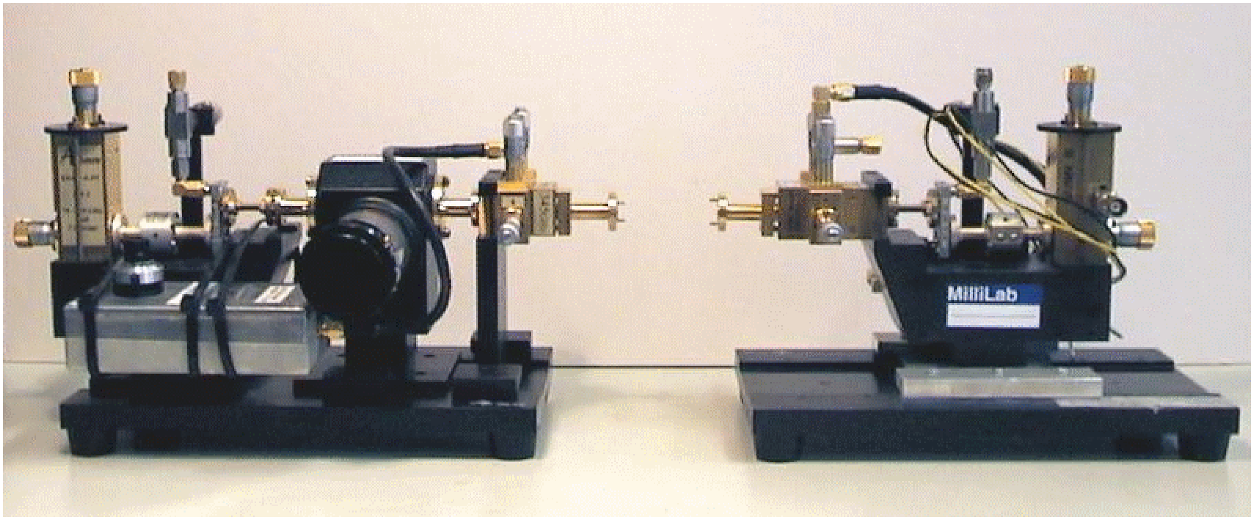

Figure 5. Source extension ESA-1 and detector extension ESA-2 are shown. Test ports can be seen in the middle. Cable connections to the rest of required MVNA setup will be added in practice but for clarity they are not shown here.

There exist more effective ways of calibration than the one used in the MVNA system in MilliLab. However, these calibration procedures would require a considerably more complex network analyser system. This is not yet possible in our case at the high frequencies that are available for measurements with our MVNA.

6. Reflection measurement

When a directional coupler is available for use at the measurement frequency, it is possible to make a measurement of the reflections at the ports of the DUT. The directional coupler is then used to couple the reflected signal to the receiving test port of the network analyser as shown in Fig. 6. Only the reflections of a single DUT port at a time can be measured with MilliLab's MVNA. The measurement gives a reflection response which is related, for example, to the scattering parameter S_{11} of the DUT if we are measuring port 1 of the DUT. (Of course, matched loads connected to all other ports of the DUT will be required for getting true S_{11} parameter values.)

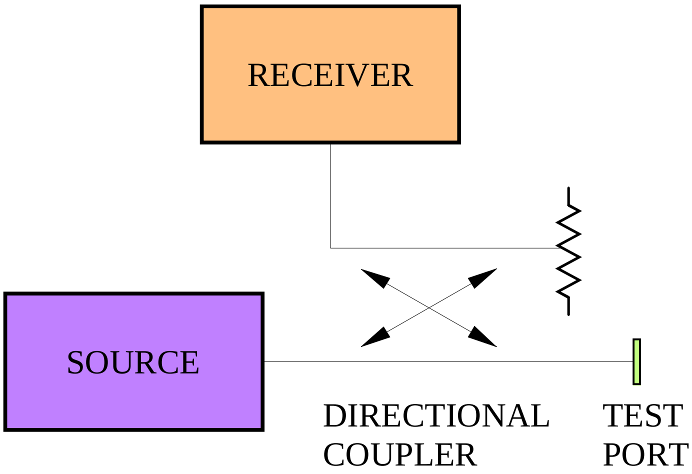

Figure 6. Setup for reflection measurements using a directional coupler (waveguide couplers are available up to 325 GHz in MilliLab). A simple calibration is possible by briefly using a short circuit at the test port. The required port of the DUT will then be connected to the test port for the measurement proper.

7. Calibration for reflection measurement

As usual, a calibration of MVNA is needed first when a reflection measurement of a DUT is to be made. In principle this calibration is very similar to the case with the transmission measurement described above but the practical realisation is slightly different. A suitable reference for the reflections of the DUT is easily obtained by making the calibration measurement with a short circuit as a calibration load. This follows from the fact that a short circuit in the test port of MVNA reflects quite precisely all of the test signal. Again, in practice, some errors will remain in the final measurement result and this is mostly due to the limitations of the equipment. In order to correct for these and depending on the estimated accuracy requirements, a more complicated calibration technique can be used if calibration loads other than only a short are available. In MilliLab’s MVNA such loads are available up to 170 GHz.

8. Availability of two simultaneous measurements

In the lower end of the available frequency range for measurements, MilliLab’s MVNA is equipped with two receiving test ports while one signal source is available. Then, with a suitable connection of the DUT, two measurement channels can be used to measure simultaneously one reflection response and one transmission response.

9. Some final remarks

Vector network analyser measurements at frequencies of several hundreds of gigahertz easily seem to be more demanding than similar measurements at considerably lower frequencies. Due to this, some increase in uncertainties is to be expected in measurement results when moving up in frequency. In addition, some waveguide modes other than the fundamental mode might also occur and cause some variation in the measured response.

MilliLab’s MVNA (with its extensions) provides a capability for measurements in a very broad frequency range, even getting near to 1 THz. Also the dynamic range (even up to 120 dB) is very large for most measurement applications. However, measurements with instantaneous wide-band frequency sweeps are mostly not available. This is especially true when using the extensions because the equipment has to be tuned for each new frequency point. Then an automatically system controlled frequency sweep bandwidth could be in the order of 1 GHz or less. Larger sweeps are possible at low frequencies with the basic MVNA system only or, to some extent, by using some suitable external free-running generator together with the MVNA system. The use of an external generator with MVNA, under an extension option called FESA, is in some ways similar to ESA-1 extension.

For measurements with an extremely high dynamic range MilliLab has some relatively high power BWO millimetre wave sources which can be associated with the MVNA system. This happens with FESA extension or by using some extra devices for ESA-1 type source control but without final frequency multiplication. Usually this association and the related dynamic range will have to be verified first in each case as there may occur some power or response limitations at some frequencies.

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