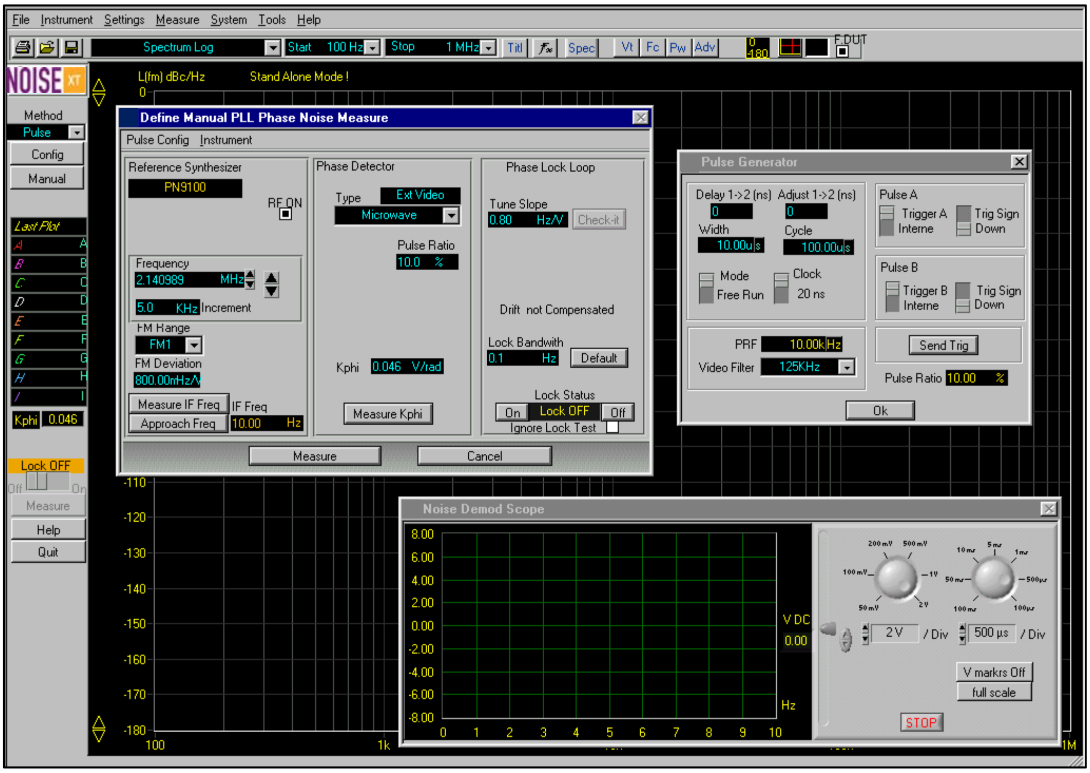
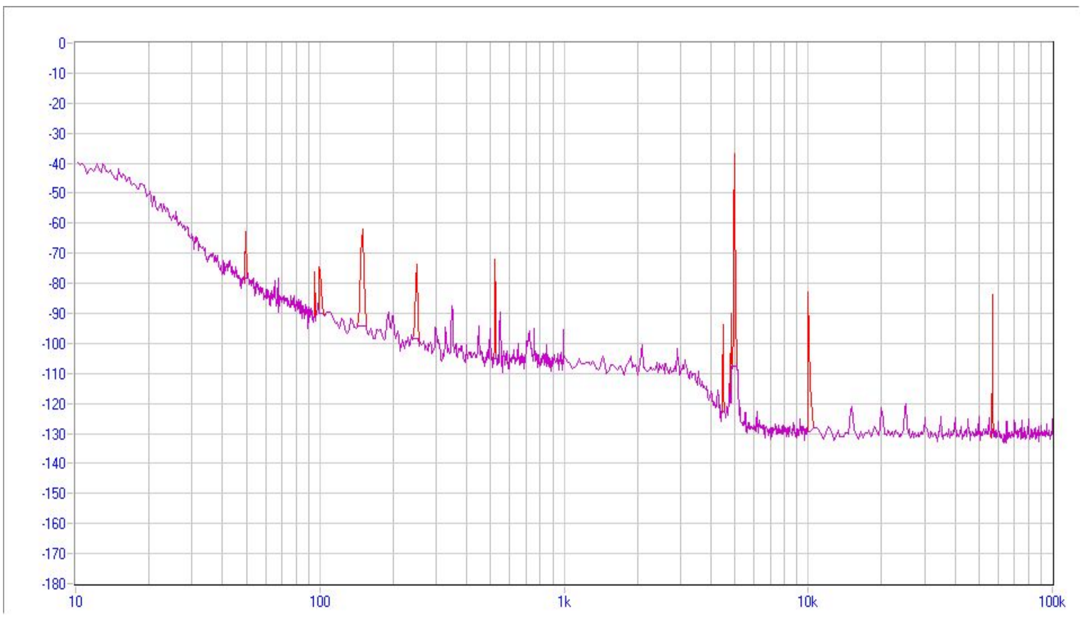
The specialist of Phase noise Measurements

PN9000

PULSED CARRIER MEASUREMENTS





Carrier frequency: 2.7 GHz - PRF: 5 kHz – Duty cycle: 1%

Introduction

When measuring a pulse modulated signal the PN9000 must cope with the following problems:

1. **Loss of power**

   The power of a pulsed signal decreases as function of the duty cycle of the pulse. The exact power loss is given by the formula 20 log x duty cycle. For example, for 10 % duty cycle the power of the modulated signal is 20 dB lower than in CW, and for 1% duty cycle it is 40 dB lower (100 times lower !). As a result, the detected phase noise will be also lower with the same ratio.

   To display the real noise of the modulated signal and to control the measurement process (such as the lock control), the software will have to compensate it by computing an offset corresponding to the duty cycle. It is why the software menu needs to know the duty cycle value.

   As a consequence of loss of power, the system residual noise will increase in the same proportion. In general it doesn't make problem because the pulsed sources are mostly in MW range and have higher phase noise than RF sources. However, attention must be paid to it.
   The system has also to compensate the loss of the phase lock loop sensitivity due to the duty cycle.

   With lower input power, calibration of the phase detector could be tricky. To prevent that, the PN9000 software includes gain adjustment, used for measurement parameter adjustments and calibration only.

2. **Bessel response spurs**

   The power of a pulsed signal is split around the carrier on the fundamental and harmonics of the pulse signal, this is easy to see with a spectrum analyzer. These "spurs" are very powerful and can saturate the LNA used to bring the phase noise, which is low by nature, to the operating input level of the A/D converter. A filter, called video or PRF filter, will be connected between the phase detector output and the LNA input. The optimized cut-off value for this filter is half of the PRF, because this is the useful frequency range of a pulsed signal without aliasing problem.

3. **DC offset of the detected phase noise signal**
   When the reference source is in CW mode and the DUT is in pulse mode, the DC offset voltage at the output of the phase detector can be larger than the useful beat signal , sometimes this beat signal never cross the zero voltage needed to calibrate and to lock the reference . The PN9000 software includes a special function (DC offset compensation) to solve this problem.
   Using a reference source in CW mode is very useful because this simplifies the operating mode, no need to pulse and trigger the reference .

Measurement advice

In addition to the above phenomena, the jitter (or phase noise) of the pulse generator can contribute to increase the noise of the pulse modulated signal, although this is difficult to quantify.

The **PN9815** option, in a single slot module, has been designed to prevent this problem. It includes two functions: a pulse generator and a microwave pulser.
The pulse generator is driven from of a crystal oscillator and digital circuits to adjust PRF and duty cycle from the PN9000 software. **The use of the PN9815 is strongly recommended** to generate a low noise pulse waveform.

The microwave pulser, driven by the pulse generator, can be used for two purposes:

- To pulse modulate a CW signal.
- To generate a pulse window allowing measurement at in specific place of the initial DUT pulse. Example: if the noise contribution of the rising and falling edge has to be removed, the PN9815 can be programmed with a smaller pulse width in order to remove this part of the initial pulse.

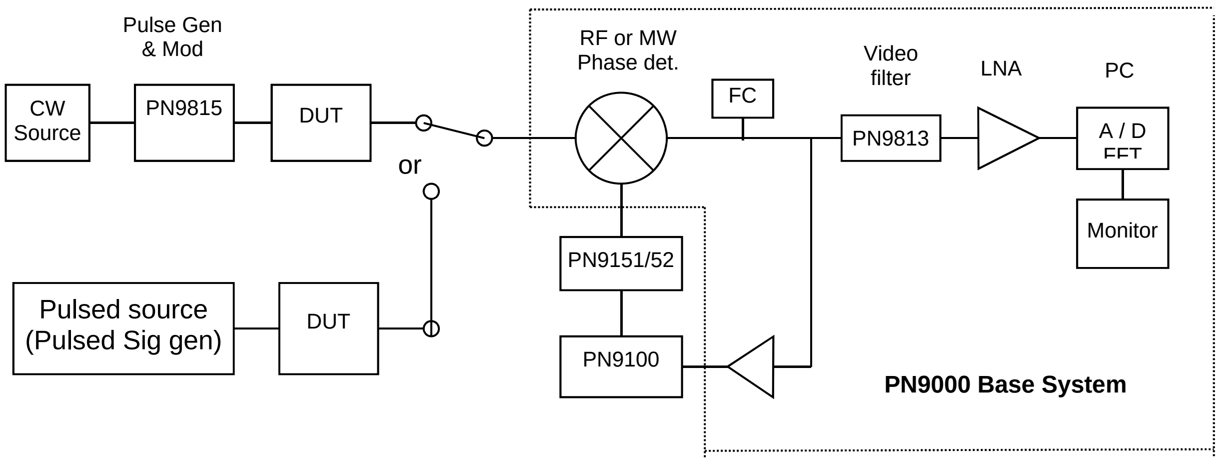
The **PN9813** option, in a single slot module, offers 5 video filter values, selected from the software. The values must be specified by the customer when ordering the system. Additional values can be provided in a second module, at any time.

The **PN9341** phase detector option must be used, because it includes the SMA connectors on the front panel to connect the video filter.

Care must be taken of the increase of the residual noise due to power reduction. For example, if the MW phase detector is used, base system residual noise is – 165 dBc/Hz at 10 kHz offset with + 6 dBm CW RF and LO inputs. With a 10 % duty cycle pulsed signal, the base system residual noise will increase by 20 dB, i.e. – 145 dBc/Hz, which still allows to measure very clean radar sources. With 1 % duty cycle it will be reduced to – 125 dBc/Hz.

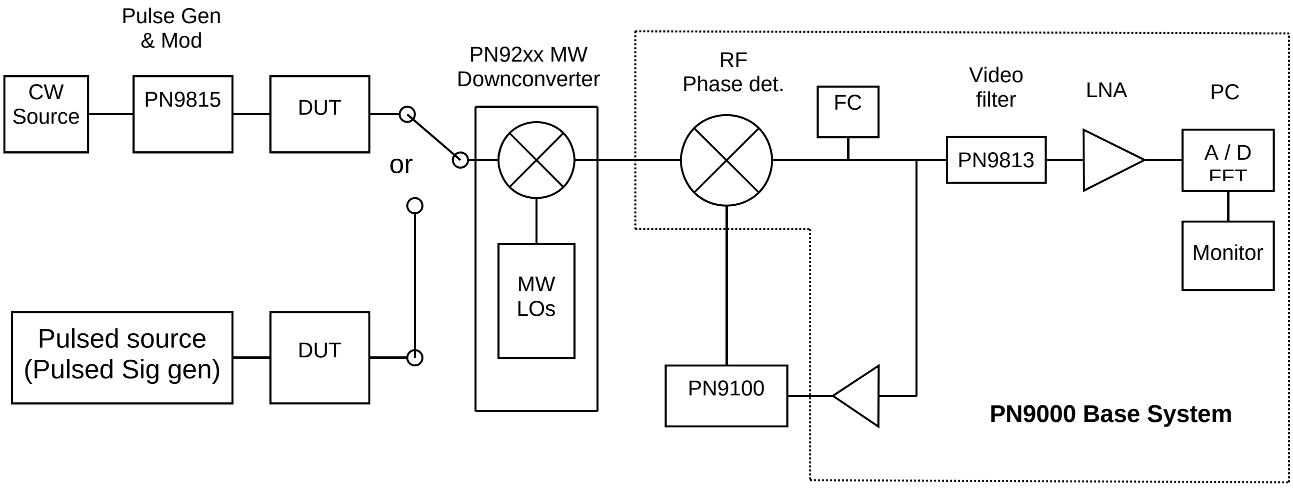
Measurement Methods

1. RF or MW DUT with Direct Phase Noise detection



This diagram will be used for RF source measurements up to 1.8 GHz with the standard RF phase detector and with the MW phase detector up to 4.5, 9.0 and 18.0 or 26.5 GHz, depending on the PN9100 options implemented in the system.
When the MW phase detector is used, the built-in counter will not measure MW RF and LO inputs, it will measure the IF beat only with a maximum value of 400 KHz. If the beat value is higher than 400 KHz, an external counter or a spectrum analyzer must be used to know about the DUT MW frequency.

2. MW signal downconverted to the RF Frequency range



This method uses a MW downconverter, PN952/55, PN9253/54 or PN9273/74, to downconvert the MW DUT signal to the RF frequency range of the PN9000 base system. This configuration, used for low noise MW source phase noise measurements, provides two advantages:

- Lower residual noise (noise floor), see the PN9253/54 and PN9273/74 datasheets for the specs,
- The built-in counter will measure RF, LO inputs up to 2 GHz and IF beat output of the standard RF phase detector. This makes LO tuning to the RF input frequency much easier.

Measurement Process

Whatever the used method is, direct or downconversion, the measurement process will be the same as for an RF or CW signal with some additional settings due to the pulse modulation. It will include:

- Signal connections,
- Parameter settings,
- Tuning LO to the DUT frequency signal, directly or through the MW downconverter,
- Adjust a beat for phase detector calibration and display V marks on the scope,
- Phase detector calibration.
- Phase locking LO on RF signal,
- Measurement.

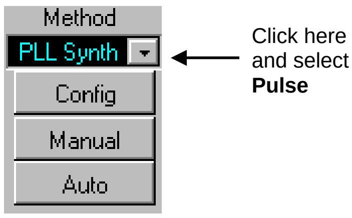
1. Connections & Input Levels

To make easy measurements, a good level of the DUT signal is 0 to +10 dBm for duty cycle > 5 % and + 5 to + 10 dBm min. for duty cycle < 5 %.

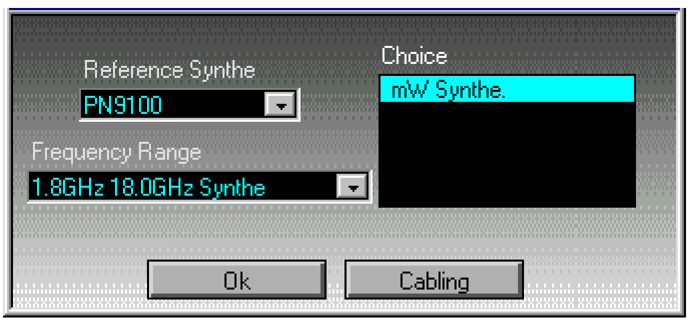
- Connect the DUT signal to the “CW RF input” of the PN9815 (If needed) ,
- When direct phase noise detection is used, connect the “Pulsed RF output” of the PN9815 to the “RF input” of the PN9341 phase detector,
- When a downconverter is used, connect the “Pulsed RF output” of the PN9815 to “DUT input” of the MW downconverter, and “IF output” to the “RF input” of the PN9341 phase detector,
- Connect the PN9100 output to the PN9341 LO input. Output level of the PN9100 is +10 dBm.
- Connect “Tune voltage” of noise output module to “Fc Tune” of PN9100 module,
- Connect “External input” of the PN9341 phase detector to the “Video Input” of the PN9813 video filter and the output to the “2nd LO input” of the PN9341 phase detector.

Example of connections for a MW measuring configuration
Including two PN9100 frequency doublers

2. Measurement Configuration



- Click on the button below "**Method**" and select "**Pulse**"
- Click on "**configuration**" and select "**Source**", for "carrier" phase noise measurement.



Then this window will appear. It shows that the MW method installed in the system uses a PN9100 with the PN9151 and PN9152 to extend the frequency range to 18 GHz. If a MW downconverter is installed, select it.

Measurement Parameter Settings

- Click on "**Manual**", below Method.

Three windows will appear: See the image of page 1.

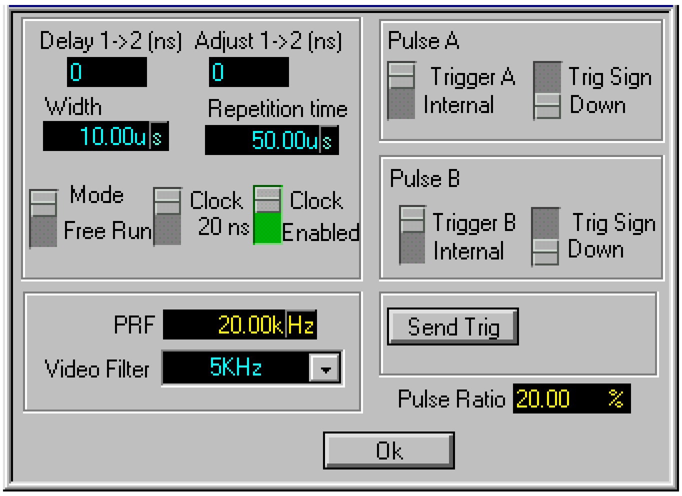
- **Define Manual PLL Phase Noise Measurement**,
  It will be used to tune the reference source to the same frequency as the DUT, to calibrate the phase detector, to set the loop parameters and achieve phase locking of the reference.

- **Pulse Generator**
  To be used to set the pulse parameters, pulse mode and start pulse, etc …

- **Noise Demod Scope**
  The scope is connected to the output of the phase detector. It shows the beat until phase locking is achieved. When the reference is phase locked, it shows the DC voltage control of the reference. For small pulse ratio, and low PRF, the scope will be very useful to make sure that phase locking is stable during the measurement process.

3. Pulse Parameter Settings

a) The PN9815 is used to pulse modulate the carrier :
Width, cycle, trigger A, Mode, Clock and Video filter values must be filled in. PRF and pulse ratio are computed and displayed automatically. Click on "Send Trig" to start the pulse generator.



b) The Carrier is already Pulsed :
Width and repetition time (PRF) values must be filled in, so that the software knows the pulse ratio and will adjust the noise level accordingly. The pulse ratio (or duty cycle) is shown at bottom right of the above wizard and also in the second section of Manual measuring wizard. Also Video filter value must be selected, half of PRF value.

For standard pulsed carrier measurements "**delay**" and **Pulse B** are not used.

Width is the pulse duration, **Cycle** is the duration of one period of the PRF. The ratio width/cycle determines the duty cycle. Enter first **Cycle** value, **PRF** is displayed (PRF = 1/duty cycle), then enter **width** and **Pulse Ratio** is displayed automatically. For the first measurement adjust a pulse ratio of 5 or 10 % and PRF of 5 kHz or more. **Pulse A** must be **Internal.**

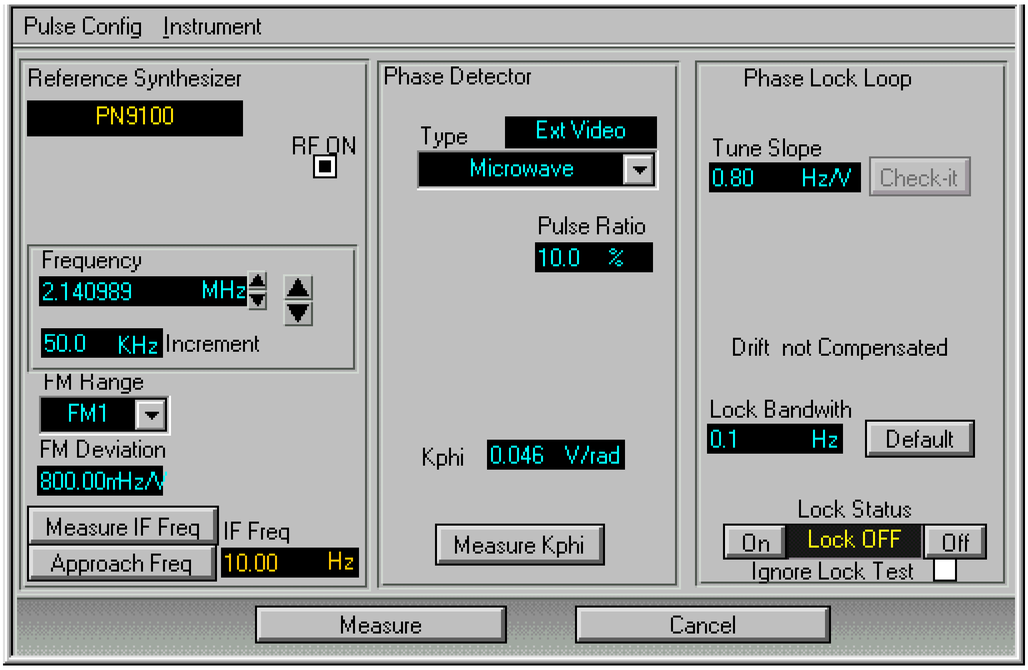
Mode must be **Free Run** and **Clock** at 20 ns for PRF ≥ 5 kHz and 200 ns for PRF ≤ 5 kHz.
Click on "**Send Trig**" before leaving the menu.

Enter the **Video Filter** value corresponding to the selected **PRF.** Should it is not available, an additional module can be provided by Noise XT.

4. Reference Frequency Tuning.

a) Direct Phase noise detection in MW

This window is displayed for direct phase noise detection using the PN9100 and the PN9151 & PN9152 doublers and the MW phase detector.



This window includes 3 sections:

- The left one "Reference Synthesizer" is used to tune the PN9100 to the same frequency as that of the DUT.

- That in the middle is used to select the gain according to the duty cycle (click on Measure Kphi) and to calibrate the phase noise detector,

- The right one is used to adjust the loop parameters and phase locking the PN9100 on the DUT signal.

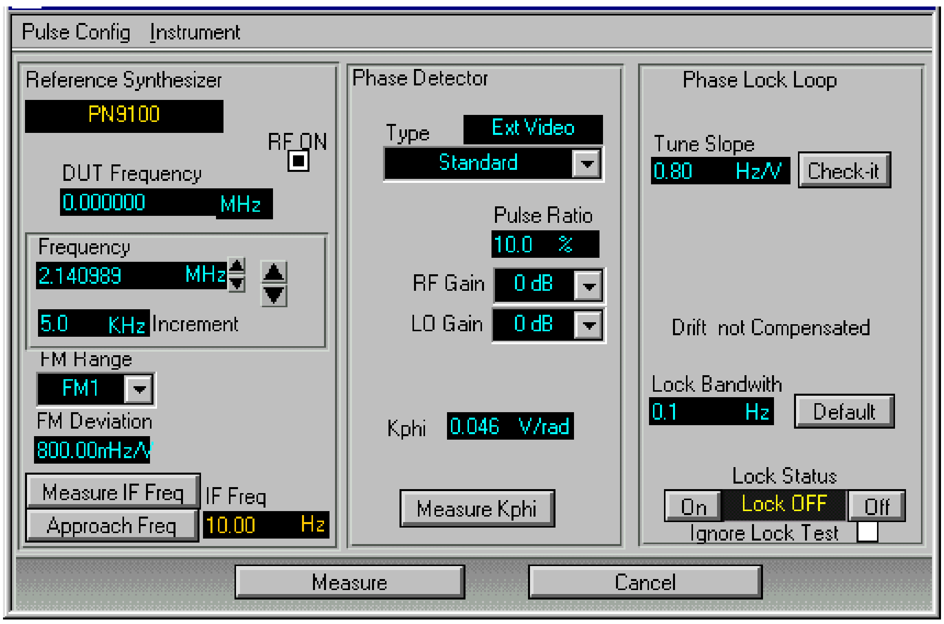
Tune the PN9100 to the DUT frequency value:

- Click on the window **frequency** and enter DUT frequency value.
- Select the FM range, **FM1** for clean carriers and **FM2** for noisier sources (for small PRF and small duty cycle the software will allow FM1 only).
- Click on "**Measure Kphi**" and adjust **Gain:** 20 dB for pulse ratio ≥ 10%, 30 dB for 5 to 10% and 40 dB for ≤ 5%. These are average values, optimized values will depend on the pulse signal power. When Kphi is higher than 0.3 Volt/radian, this gain can lowered or the RF signal level to be decreased.
- Adjust the **Large increment** at about 1/10 of the PRF value. In any case, it must be lower than half of the PRF value; otherwise the beat signal wouldn't go through the filter.
- **Measure IF**. The frequency counter will measure the beat between pulsed RF and LO inputs as far as the beat is lower than the selected video filter. It means that the DUT frequency must be known with an error lower than PRF/2. When IF is measured,
- Click on "**Approach frequency**" to fine tune the PN9100 reference to the same frequency as the DUT. The beat must be a few Hertz.

NB : *When fine tune using "approach freq" fails, use the large and small increments and the scope to achieve it. Look at the beat on the scope; it is possible that the beat includes mixing pulse products which do not allow the counter to properly measure the beat. Make a few large increments up or down and try again. In case of this doesn't fix the problem, increase pulse ratio to 60 or 80 % or cancel Pulse modulation to get a CW signal (do not forget to reduce Gain in "measure Kphi". Then, tune carefully the LO frequency to DUT. When done, pulse the signal again, re-adjust Gain in Kphi and with the large increments find a beat value which will show a clean signal on the scope and then measure Kphi. Be careful to not forget how many increments have been made to come back to the fine tuning. It takes more time to explain it than to do so when you have some practice.*

b) A PN92xx MW downconverter is used

- Enter the DUT frequency value in the "**DUT frequency**" window. The MW downconverter will automatically select the nearest fixed MW frequency and will tune the PN9100 on the IF beat of the downconverter output. The software will select the standard RF phase detector, since the IF is in the RF frequency range.
- The advantage of this method is that RF gain is now available and also the counter can measure RF and LO inputs of the phase detector. This provides more flexibility for the level and frequency adjustments.

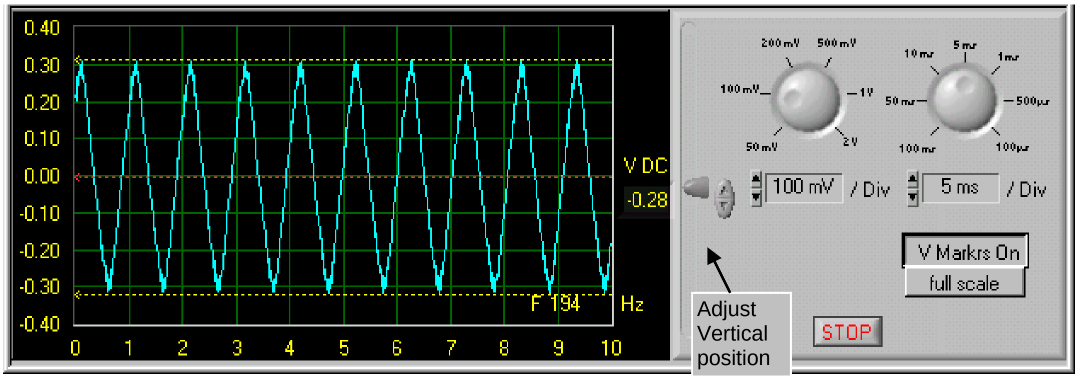


The process to tune the PN9100 LO to the DUT frequency is the same as for the item a), refer to above paragraph. Make the same adjustments for FM range, large increment, gain, etc.

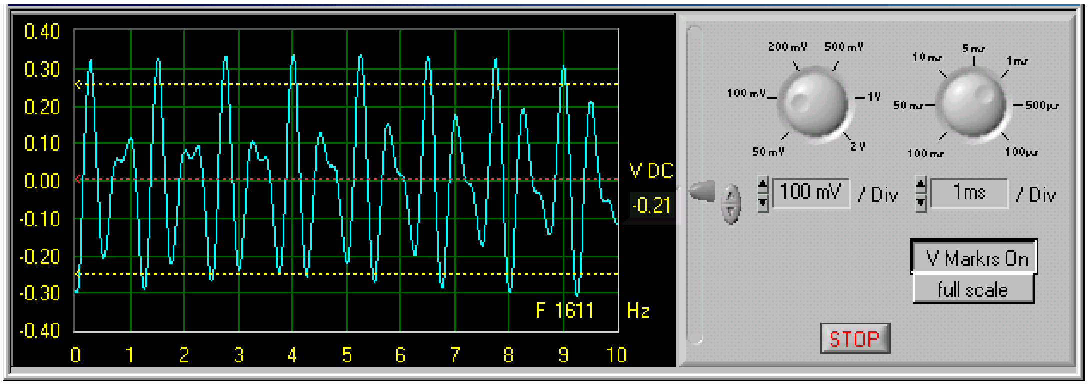
5. Measure Kphi

From a low IF beat (a few Hz), obtained in clicking on “Approach frequency”, make one or a few large increments (a few hundred Hz each (don’t forget that it must remain lower than PRF/2) and adjust amplitude, sweep and DC offset of the scope up to getting a nice beat as shown below. The optimized figure is generally obtained for a beat close to 1/10 of the PRF value.

Maximum and minimum must symmetrical to zero. When achieved, press “**V Marks On**”. Upper and lower lines will show the limits for phase locking DC voltage. The red line is the reference for the DC voltage when phase locking is done. See image of next page.



The window below shows a bad beat for calibration. Make additional increments and change the increment value if necessary, until getting something like the upper image, while remaining in the range of 1/10 to ½ PRF.



- Cancel the increment set to get the clean beat, while reminding well its value and enter it in the increment window. For example, if 3 steps up of 200 Hz have been used to get a clean beat, make 3 steps down and enter 0.6 kHz in the increment window. This increment will be automatically set when “Measure Kphi/Measure” will be clicked. It is also possible to cancel the beat just clicking “approach frequency” and enter the beat value in “increment” window.
- Click on “**Measure Kphi**” and select the mode “Beat slope” and “both (mean) “.
- Click on “**measure**”. The above increment is added the LO frequency and the resulting beat is used to calibrate the phase noise detector.
  - If the power is too low, the message “**RF too low**” will appear, increase the gain in “Measure Kphi” window, or increase the DUT output level and run a new calibration.

On the calibration signal, check if the two slopes, negative and positive (in green and in red), are detected, if not, run a new measurement. In any case run several measurements to make sure that the detected slope is stable. If the system fails to show clean slopes, change the beat frequency in adjusting a smaller or larger increment value, but still in the range of ½ PRF to 1/10 PRF . Adjust the “Scope” parameters to see the beat and adjust its value until a clean beat is obtained and measure Kphi again.

The software detects the DC offset of the beat signal and compensates it automatically. The display shows only the AC part and report the DC value in the menu. At this point the system knows the DC offset at the output of the phase detector, and will able to compensate its effect on the measurement process.

6. Phase Locking the reference LO on the DUT signal

- Make sure the beat is very low, in any case much smaller than the locking bandwidth. If it is not, click on “**Approach frequency**” to get a beat of a few Hz.
- Click on “**Default**” Lock Bandwith,
- Click on “**ON**” of Lock Status
- Watch the scope and wait until the trace is stabilized. If it is a straight line, phase locking is achieved, but the trace is probably not in the middle, close to the red line. Should it is above, click on the small increments up, waiting until full effect before clicking a new one, up to the trace is close in to the red line. Wait a little to make sure it is stabilized, then, click on **Measure**.

The “Scope” can show three situations:

- The “Scope” still displays a beat signal, the system is unlocked, the lock process failed.
- The “Scope” displays a DC voltage, but far from the average value (red line), the system is locked but far from the quadrature, the lock process failed.
- The “Scope” displays a DC voltage closed to the average line (red line), the system is locked and is in quadrature, the lock process is ok.

If lock process fails try several times (open and close the loop).
If lock process still fails , either the two sources are too far from each other, use “approach” to cancel the beat, or the loop bandwidth is too small. In that case, try FM2.

7. Measurement.

Run the spectral analysis.
The useful span is up to half of the PRF values, however a wider span can be set, but a PRF filter value must be used accordingly.

NOTE: Video Filter

Video filters specifications:

- Filter type: Low-pass , 4 or 6 poles .
- Load impedance: 200 Ohms .
- Cut-off frequency: ½ PRF (pulse repetition frequency) .

The video filters are used to reduce the PRF spurs during the spectral analysis of the pulsed phase noise. 40dB attenuation at the PRF offset is needed, only not to saturate the low noise amplifier.
The valid span analysis is half the PRF, example PRF= 100KHz , use the video Filter
100KHz in the menu "DESIGN/PULSE" . The valid span analysis is then 50KHz.

About Pulsed Carrier Measurements

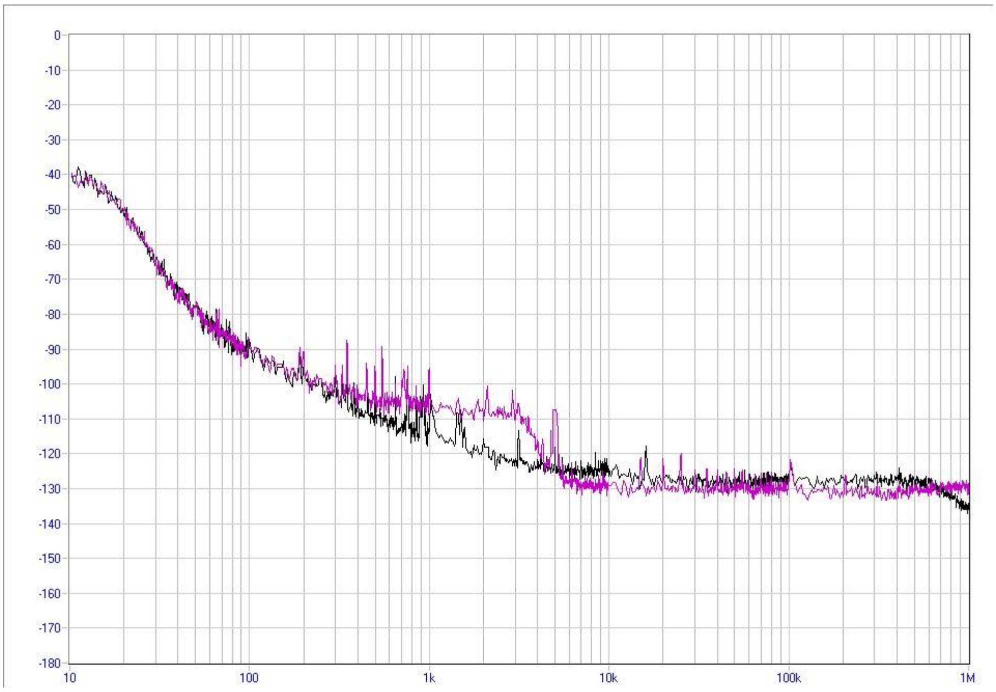
1. How the PN9000 can measure a Pulsed carrier using a CW LO reference?

It can do it for several reasons:

- The PN9000 LNA is not saturated with a reasonable DC offset. In addition, the software and hardware include functions which measure DC voltage offset due to the duty cycle of pulse modulation and compensate it automatically.
- The PN9341 phase detector module includes switches and connectors to implement video filters (LPF filters with cut-off frequency at PRF/2) which will drop the pulse spurs and transcients up to 40 dB at PRF value.
- Amplifiers are implemented behind the phase detectors to compensate the loss of power for frequency tuning and phase detector calibration.
- Special tools, such as the “scope”, “small” and “large” LO increments, built-in counter, “approach frequency” (or LO fine tuning) allow easy and accurate adjustments to make measurements of pulsed carriers with PRF as low as 1 kHz and pulse ration of 1% and less.

2. How to make sure that a Pulsed carrier measurement is OK?

The best way to make sure that a measurement of a pulsed carrier is good and reflects the actual phase noise of the pulse signal is to make first a measurement of the same carrier in CW and store it. When the two measurements are performed, display both as shown below.



The fact that both measurements show the same phase noise close in to the carrier means that the pulse mode measurement has been conducted properly. But, from about 300 Hz from the carrier, phase noise is higher in pulse mode than in CW mode. The reason is that in pulse mode the noise of the carrier combines (one could say there is a kind of overlapping) with the noise of the PRF spur and the result is a higher noise. For this measurement a Low Pass Filter of 3 kHz was used, this why the phase noise above 3 kHz offset has no meaning.

Low noise Pulse CW and Add Pulse Noise measurements require low jitter pulse generator and high ON/OFF pulsers (MW switches).

The PN9815A (master) includes:
- A xtal oscillator clock, for low noise jitter.
- A Pulse generator, to generate the trigger and the pulse waveform.
- A MW Pulser to switch on/off a microwave carrier.

The PN9815B (slave) is used to generate a second pulse modulator for the measurements which require the same pulse CW signal on the RF and LO phase detector inputs.
The PN9815B uses the same clock as the PN9815B. An internal connection in the PN9000 mainframe provides the clock the PN9815B. In case of this option is supplied separately, a mainframe modification is necessary.

This microwave pulser can be connected to the output of the PN9100 or PN9253/54 to generate a pulsed CW source.

Both modules are controlled from the menu "**Design/Pulse".**

The pulse generator output (TTL 50 Ohms) can be used to switch on/off an external DUT.
The "trigger out" can be used to trig the external DUT.
The "trigger in" can be used to trig the PN9000 microwave pulser from an external system.
If the two sources are pulsed: the reference source and the DUT, the two pulses should synchronize**.**

SPECIFICATIONS

Clock, internal	:	20 and 200 ns
Trigger	:	Internal or external.
Trigger output,	:	TTL positive/50 Ohm. Duration: 20 or 200 ns.
Cycle/PRF	:	Min : 40 or 400 ns (2.5 MHz or 25 KHz). Max : 20 ns x 65536 = 1.3 ms or
	:	200 ns x 65356 = 13 ms
Pulse width	:	Min : 20 or 200 ns
Pulse out	:	TTL positive/50 Ohm.
Pulse RF output	:	Same level as the input signal, must be loaded on 50 Ohm. During **OFF** period, the RF signal is internally loaded on 50 Ohm. The pulse signal is internally connected to the SPDT.
Delay 1 to 2	:	delays the master trigger for the PN9815B slave, to adjust the output pulse according delays in the DUT and connectors. Min delay: 0 Max delay: 20 or 200 ns x 256.

14 February 2011