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Phase Noise PN9000

PHASE NOISE DATAMATE

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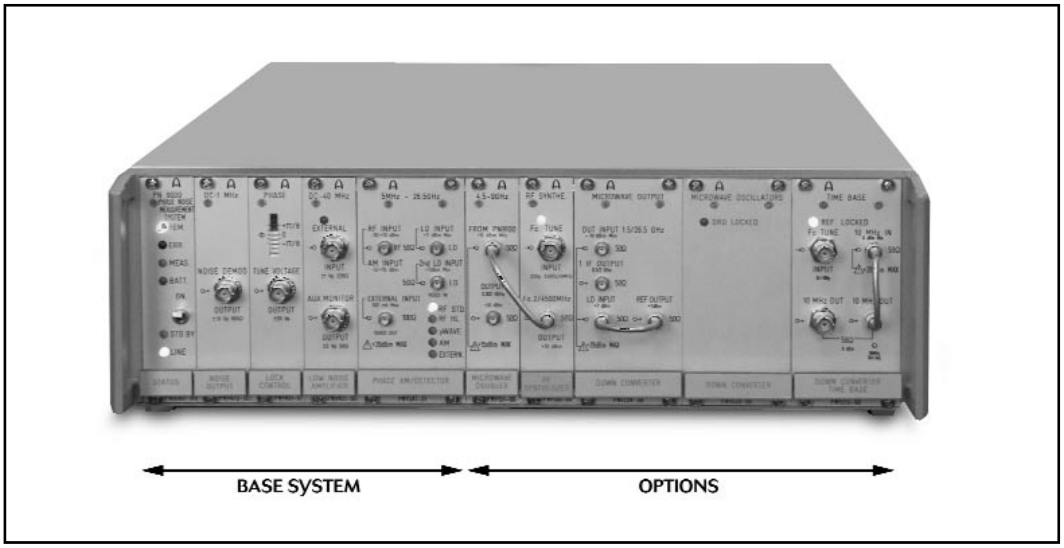
PN9000 Phase Noise Measurement System



The Modular design of the PN9000 provides versatility and flexibility to setup the appropriate configuration to measure any kind of frequency source from 2 MHz to 140 GHz.

TECHNIQUES:

Phase Lock Loop

Delay line (option)

Added phase noise (option)

Amplitude Noise (option)

Plug-in optional modules:

Internal phase detectors up to 40 GHz

Low Noise Built-in DC FM Reference Synthesizer

MW down-converters for stable and free-running Sources

mmW external harmonic mixers/diplexers to extend the frequency coverage up to 140 GHz

Pulse generator and modulator

Software:

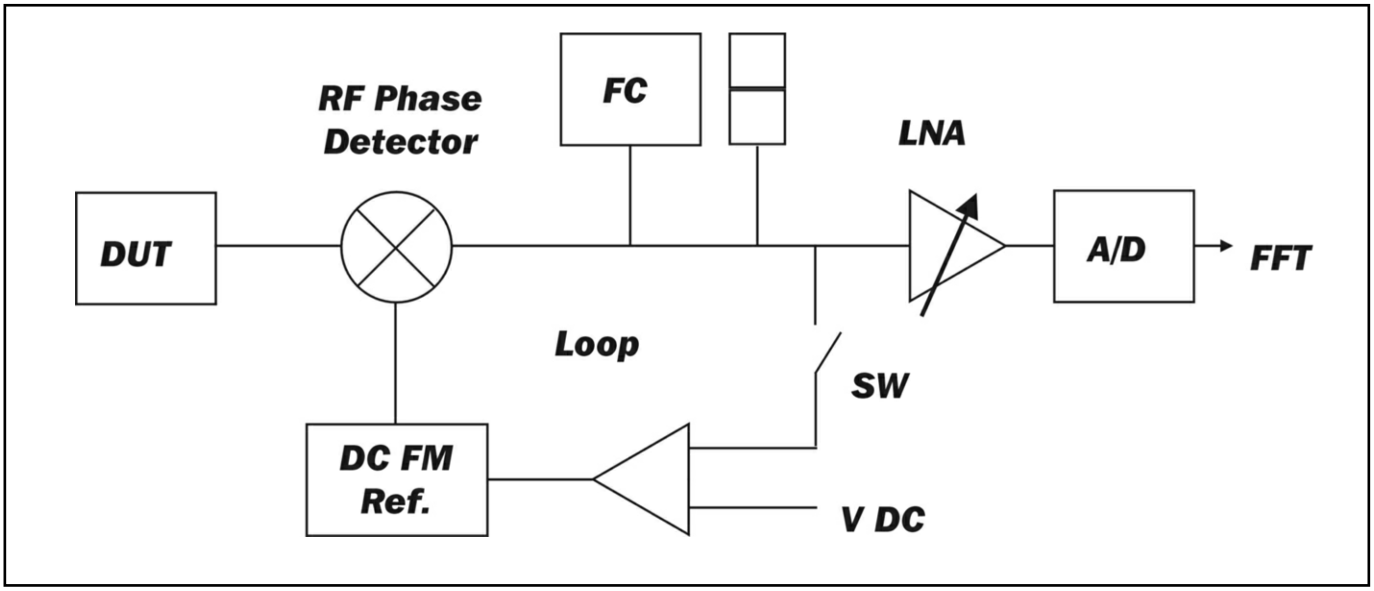
WPN9000: Windows based graphical user interface with file management

Remote control option through Ethernet or GPIB

The base system is the core of any measurement configuration. It includes hardware and software, except the reference source, to measure stable sources from 2 MHz to 1.8 GHz.

Note: All the options are described and specified in separate datasheets.

PN9000 System Basic Capabilities



Base System Operating Diagram

Using the built-in frequency counter, in open loop, the DC/FM reference source is manually or automatically tuned on the DUT frequency. The beat signal between DUT and reference is used to measure the demodulation factor of the phase detector using multiples techniques allowing non-linear operation of the detector.

Loop bandwidth and reference FM deviation (or tune slope) will be adjusted depending on the expected noise and stability of the DUT. For most of PLL and synthesizers a few hundred Hz is an average convenient value. Then, closing the loop, the reference source will be phase locked on the DUT signal and RF/LO phase detector inputs will be set automatically in phase quadrature, providing at the output of the detector the combined phase noise of the DUT and the reference. The bar graph located on the lock control module will allow a quick visual check of the loop status (the bar graph should be centered and steady). When the reference's phase noise is 6 dB better than the DUT's one, its contribution to the detected noise is 1 dB only.

The LNA, with auto-gain feature, will adjust the noise level to the optimum dynamic range of the digitizing board housed into the computer. FFT calculation process is done in the computer and displayed on the monitor (not represented on the diagram). Loop bandwidth is fully compensated to display phase noise down to 0.01 Hz from the carrier.

In PLL measurements, the system residual noise, or noise floor, will be the reference oscillator's phase noise.

PN9000 Base System

PN9000 mainframe including:
- PN9470 Noise output module
- PN9451 Phase lock control module
- PN9421 LNA module
- PN9330 Standard and High level RF phase detectors
- PN9025 Power Supply

Personal Computer including:
- TFT flat screen monitor
- Digitizing board
- Set of Cables
- OS, Software and manual

PN9000 BASE SYSTEM SPECIFICATIONS

Frequency Input Range	: 2 MHz to 1.8 GHz
Offset Analysis	: 0.01 Hz to 1 MHz
Measurement Accuracy	: ± 2 dB up to 1 MHz offset, ± 3 dB above 1 MHz offset
Reference Tuning Voltage	: ± 20 Volt with 5 mV resolution
Phase Lock Loop Gain	: Proportional and Integral (DUT drift compensation)
Loop Compensation	: Automatic (can be disabled)

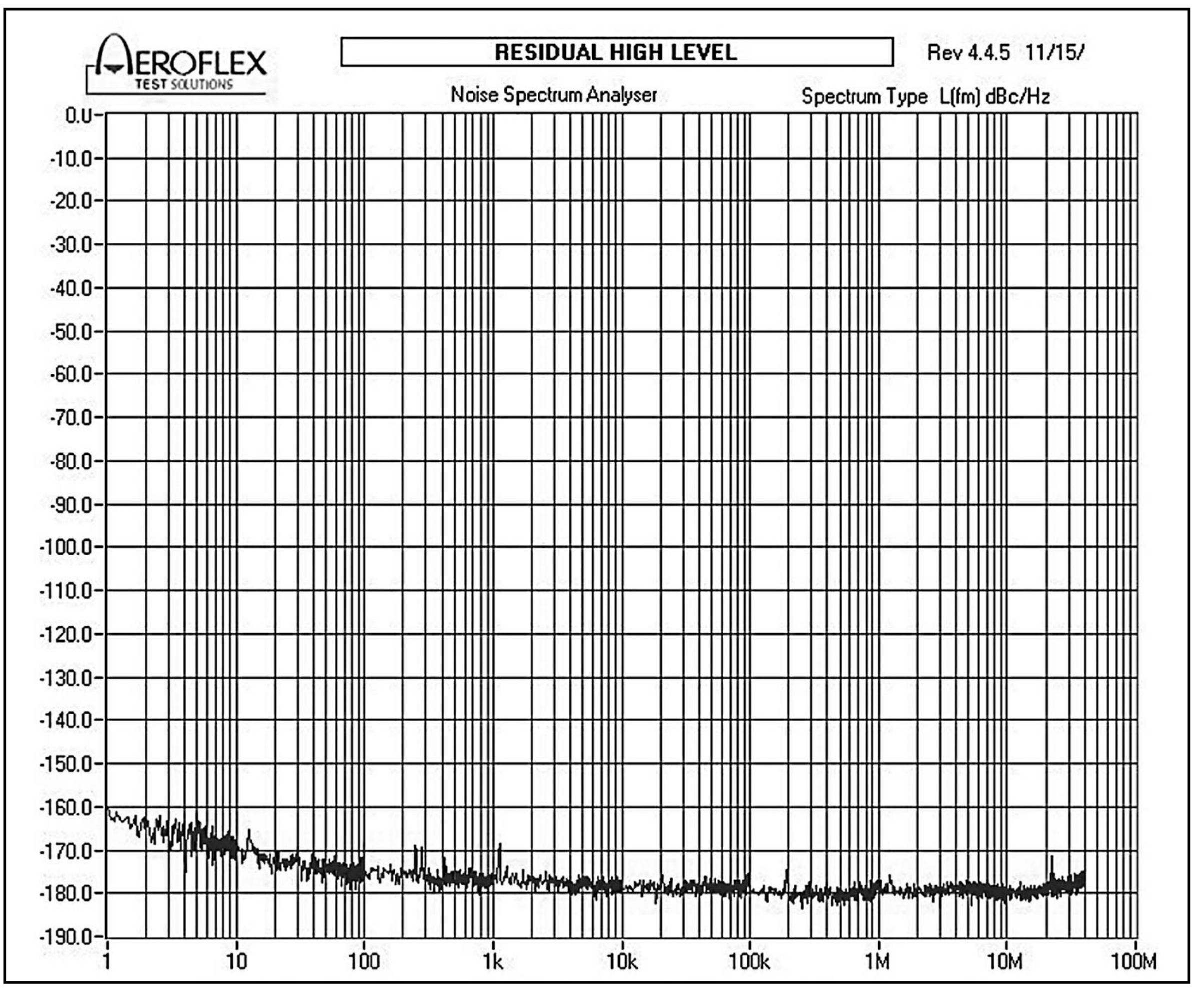
PARAMETERS	STANDARD RF	HIGH LEVEL RF
Frequency range, GHz	0.002 to 1.8	0.002 to 1.6
RF Input min. dBm	- 20	+ 10
RF input max. dBm	+ 10	+ 20
LO input min. dBm	0	+ 10
LO input max. dBm	+ 10	+ 20
RF input Gain, dB	-10, 0, 10, 20	None
LO input Gain, dB	0, 10	None
Noise floor, in dBc/Hz at		
1 Hz offset	- 130	- 140
10 Hz	- 140	- 150
100 Hz	- 150	- 160
1 kHz	- 160	- 170
10 kHz	- 168	- 178
100 kHz & beyond	- 168	- 178
Nominal RF input level, dBm	+ 6	+ 16
Nominal LO input level dBm	+ 7	+ 17

For specified values add + 3 dB (± 2 dB accuracy). For RF levels < nominal value, the noise floor will increase by the number of dB below the nominal value. For example, for 0 dBm RF input, instead of +6, the typical system residual noise is, at 10 kHz offset : -168 dBc/Hz - 6 dB = - 162 dBc/Hz.

Spurious level	: - 110 dBc
Built-in Counter, RF and LO ports	: 2 MHz to 2 GHz
IF/Beat	: 0.3 Hz to 400 kHz
Mechanical Dimensions:PN9000A	: HxWxD :13.3 x 38.5 x 68.5 cm or 5.25"x17.72"x26.97"
PN9000B	: HxWxD :23.6 x 38.5 x 35 cm or 10.47"x17.72"x15.16"
Temperature & Humidity , operating	: 0 to + 50 °C
Storage	: - 40 to + 75 °C. Up to 95 % non condensing.

PN9000 TYPICAL PHASE AND AMPLITUDE DETECTORS OPTIONS SPECIFICATIONS

Parameters	***MW (option) Std level***	***MW (option) High level***	***MW (option) PN9361-02***	***AM (option)***
Frequency range, GHz	1.6 to 26.5	1.6 to 26.5	5 to 40 GHz	0.01 to 26.5
RF Input min. dBm	- 10	+ 10	- 10	- 5
RF input max. dBm	+ 15	+ 20	+ 15	+ 15
LO input min. dBm	+ 7	+ 10	+ 7	None
LO input max. dBm	+ 15	+ 23	+ 15	None
RF input Gain, dB	None	None	None	None
LO input Gain, dB	None	None	None	None
Noise floor, in dBc/Hz at				
1 Hz offset	- 120	- 128	- 125	None
10 Hz	- 130	- 138	- 135	None
100 Hz	- 140	- 148	- 145	- 142
1 kHz	- 150	- 158	- 155	- 150
10 kHz	- 160	- 168	- 168	- 160
100 kHz & beyond	- 168	- 174	- 168	- 160
Nominal RF input level, dBm	+ 6	+ 13	+ 6	+ 10
Nominal LO input level dBm	+ 10	+ 20	+ 10	None



Residual noise with high-level phase detector option

WPN9000 Software

The Windows software provides a friendly interface to the system:

MEASUREMENT METHOD CONTROL

Selection of measurement method, depending on the DUT

PLL Synth for reference synthesizer method, for stable sources
PLL Xtal for crystal sources
VCO (delay line) for free running sources
AM noise
Noise voltage for voltage sources
ADD NOISE added noise for two port devices
PULSE for pulsed sources or pulsed two ports devices (PM, AM, Added noise)

Photographic based cabling help to guide the user in wiring settings

System configuration, file management, phase detector, frequency range, down-converter, … selections

Store and display up to ten measurements or specifications lines with direct access memories. Plot export as text, BMP or JPEG file to any windows accessible storage device.

MEASUREMENT MODE - AUTOMATIC AND MANUAL

Automatic Measurement are based on embedded expertise that guides the user through the measurement process. In most of the cases, a single click is enough.

Manual Measurement for reference LO selection and tuning, phase detector calibration factor measurement, loop bandwidth and reference tune slope, reference phase locking

DATA PROCESSING

Noise/Spurious differentiation	: Spurs expressed and displayed in dBc.
Display functions	: Smooth, spec-line, frequency & level markers, spurs list
Data Computation	: A ± B, N*A, A:N, A±N*B, A±NdB
Integrated power	: in dBc, radian rms, radian^2, degree rms, degree^2, Hz rms, Hz^2
Variance	: Allan,True, Modified and Tvar
Jitter	: Secrms ,Secpp ,UIpp
FFT / Spectrum Analysis	: L(f) dBc/Hz, Power dBv2/Hz, M(f) dBc/Hz
Plot Printing	: Any windows supported printers
External synthesizer driver	: User defined IEEE-488 control menu to set up most of commercial signal generators

PN9100 BUILT-IN LOW NOISE DC/FM FREQUENCY SYNTHESIZER 2 MHz TO 4.5/18 GHz

The reference frequency source is the keystone of easy phase noise measurements with low residual noise and high dynamic range. As a matter of fact, the residual system noise will be that of the reference source, in FM mode, since the base system residual noise is much lower.

Most commercial DC/FM signal generators can be used as the external reference source, controlled from the PN9000 software (through the use of user defined drivers). However, the appropriate signal generator will depend on the expected noise of the DUT. Should the DUT noise be low, close-in or far away from the carrier, the reference synthesizer noise will have to be clean, close-in or far away, accordingly. Unfortunately, most commercial RF signal generators do not provide both close-in and far away low noise. Thus, depending on the DUT applications, two signal generators often have to be used, which is not convenient. It takes too much space and immobilizes an instrument with many functions which are not used for phase noise measurements.

The PN9100 is designed to provide simultaneously low phase noise, close-in and far away from the carrier. It is housed in the PN9000 mainframe, it makes the system smaller, lighter and easier to move.

Optional doublers extend the base frequency range to 9 and 18 GHz. Low frequency synthesis is obtained by dividing the core frequency band (2.048 to 4.380 GHz). It enables the phase noise to go down to the residual noise of the dividers, about -152 or -155 dBc/Hz. It is often better than many crystal oscillators.

CW and DC FM Range 1 - TYPICAL SSB PHASE NOISE IN dBc/Hz (WITH STANDARD TIME BASE)

Frequency Range, MHz	Slope Hz/V	FM Max	1 Hz	10 Hz	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz	10 MHz
17360 - 18000	3200	FM1	- 30	- 60	- 81	- 103	- 105	- 105	- 124	- 150
8680 - 17360	3200	FM1	- 30	- 60	- 81	- 106	- 112	- 112	- 130	- 150
4340 - 8680	1600	FM1	- 36	- 66	- 87	- 112	- 118	- 118	- 136	- 156
2048 - 4340	800	FM2	- 42	- 72	- 93	- 118	- 124	- 124	- 142	- 162
1024 - 2048	400	FM2	- 48	- 78	- 99	- 124	- 130	- 130	- 148	- 152
512 - 1024	200	FM2	- 54	- 84	- 105	- 130	- 136	- 136	- 152	- 152
256 - 512	100	FM3	- 60	- 90	- 111	- 136	- 142	- 142	- 152	- 152
128 - 256	50	FM3	- 66	- 96	- 117	- 142	- 148	- 148	- 152	- 152
64 - 128	25	FM3	- 72	- 102	- 123	- 148	- 152	- 152	- 152	- 152
32 - 64	12.5	FM3	- 78	- 106	- 129	- 152	- 152	- 152	- 152	- 152
16 - 32	6.25	FM4	- 84	- 114	- 135	- 152	- 152	- 152	- 152	- 152
8 - 16	3.12	FM4	- 90	- 120	- 141	- 152	- 155	- 155	- 155	-
4 - 8	1.56	FM4	- 96	- 126	- 147	- 152	- 155	- 155	- 155	-
2 - 4	0.78	FM4	- 102	- 132	- 152	- 152	- 155	- 155	- 155	-

The DC/FM ranges FM2/3/4 are not always available. It depends on carrier frequency.

DC FM Range 2 - TYPICAL SSB PHASE NOISE IN dBc/Hz (WITH STANDARD TIME BASE)

Frequency Range, MHz	*Slope Hz/V*	*1 Hz*	*10 Hz*	*100 Hz*	*1 kHz*	*10 kHz*	*100 kHz*	*1 MHz*	*10 MHz*
4340 - 4500	16000	- 18	- 48	- 78	- 112	- 118	- 118	- 136	- 156
2048 - 4340	8000	- 24	- 54	- 84	- 118	- 124	- 124	- 142	- 162
1024 - 2048	4000	- 30	- 66	- 96	- 124	- 130	- 130	- 148	- 152
512 - 1024	2000	- 36	- 66	- 96	- 130	- 136	- 136	- 152	- 152
256 - 512	1000	- 42	- 72	- 102	- 136	- 142	- 142	- 152	- 152
128 - 256	500	- 48	- 78	- 108	- 142	- 148	- 148	- 152	- 152
64 - 128	250	- 54	- 84	- 114	- 148	- 152	- 152	- 152	- 152
32 - 64	125	- 60	- 90	- 120	- 148	- 152	- 152	- 152	- 152
16 - 32	62.5	- 66	- 96	- 126	- 152	- 152	- 152	- 152	- 152
8 - 16	31.2	- 72	- 102	- 132	- 152	- 155	- 155	- 155	-
4 - 8	15.6	- 78	- 108	- 138	- 152	- 155	- 155	- 155	-
2 - 4	7.8	- 84	- 114	- 144	- 152	- 155	- 155	- 155	-

DC FM Range 3 - TYPICAL SSB PHASE NOISE IN dBc/Hz (WITH STANDARD TIME BASE)

Frequency Range, MHz	*Slope Hz/V*	*1 Hz*	*10 Hz*	*100 Hz*	*1 kHz*	*10 kHz*	*100 kHz*	*1 MHz*	*10 MHz*
256 - 512	10000	- 36	- 66	- 96	- 121	- 138	- 142	- 152	- 152
128 - 256	5000	- 42	- 72	- 102	- 127	- 144	- 148	- 152	- 152
64 - 128	2500	- 48	- 78	- 108	- 133	- 152	- 152	- 152	- 152
32 - 64	1250	- 54	- 84	- 114	- 140	- 152	- 152	- 152	- 152
16 - 32	625	- 60	- 90	- 120	- 146	- 152	- 152	- 152	- 152
8 - 16	312	- 66	- 96	- 126	- 152	- 155	- 155	- 155	-
4 - 8	156	- 72	- 102	- 132	- 152	- 155	- 155	- 155	-
2 - 4	78	- 78	- 108	- 138	- 152	- 155	- 155	- 155	-

CW and DC FM Range 4 - TYPICAL SSB PHASE NOISE IN dBc/Hz (WITH STANDARD TIME BASE)

Frequency Range, MHz	*Slope Hz/V*	*1 Hz*	*10 Hz*	*100 Hz*	*1 kHz*	*10 kHz*	*100 kHz*	*1 MHz*	*10 MHz*
16 - 32	6250	- 50	- 80	- 110	- 135	- 152	- 152	- 152	- 152
8 - 16	3120	- 56	- 86	- 116	- 141	- 155	- 155	- 155	-
4 - 8	1560	- 62	- 92	- 122	- 147	- 155	- 155	- 155	-
2 - 4	780	- 68	- 98	- 128	- 152	- 155	- 155	- 155	-

Frequency range	: 2.0 MHz to 4.5 GHz : 2.0 MHz to 9.0 GHz with PN9151 option : 2.0 MHz to 18 GHz with PN9151 + PN9152 options
Output level	: + 13 dBm ± 2 dB
Frequency resolution	: 1 Hz up to 1024 MHz : 2 Hz from 1024 to 2048 MHz : 4 Hz from 2048 to 4500 MHz : 8 Hz from 4.5 to 9.0 GHz : 16 Hz from 9.0 to 18 GHz
Harmonics	: - 20 dBc up to 512 MHz : - 10 dBc above 512 MHz
Sub-Harmonics	: - 90 dBc up to 1024 MHz : - 30 dBc above 1024 MHz
Non Harmonics (Excepted line spurs)	: - 80 dBc up to 1024 MHz Increases by 6 dB for each above range

FM Mode:

The DC FM oscillator is designed to bring the lowest contribution to the noise of the output signal. For FM range 1, used for clean stable sources, there is no contribution at all. For the other ranges, the closing noise increases with the selected FM deviation, specifically close-in the carrier.

FM Deviation:

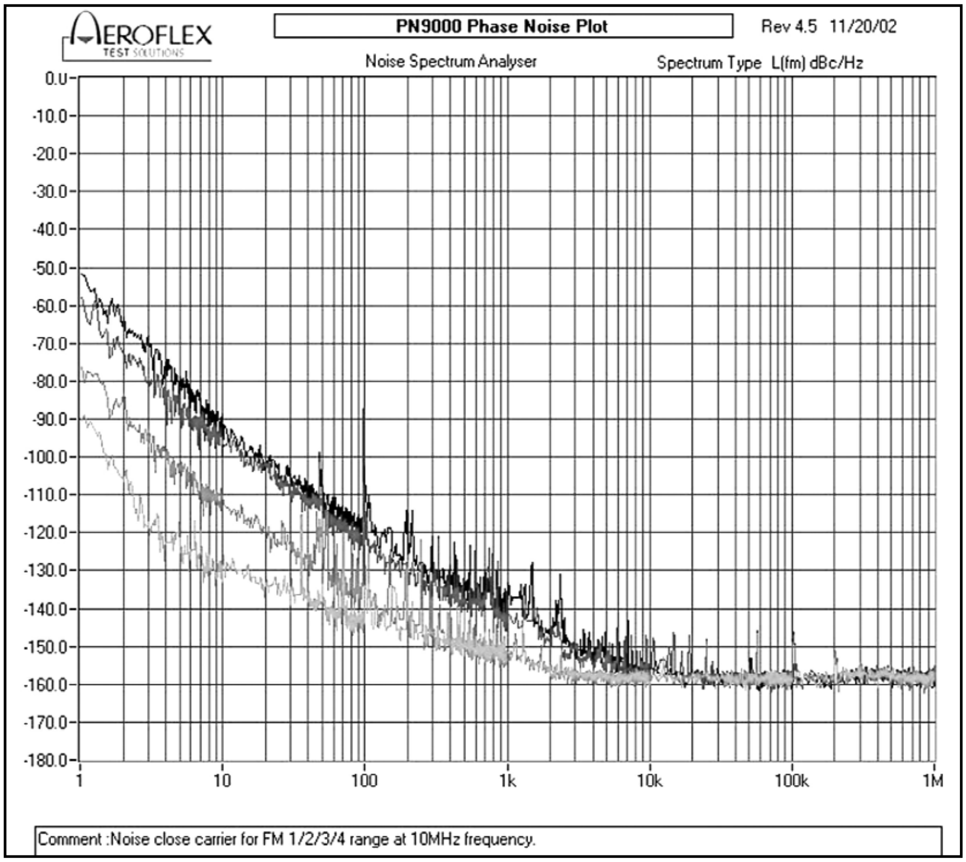
Four FM deviation ranges (FM1, FM2, FM3, FM4) can be selected to comply with noise and phase/frequency fluctuation of the DUT. FM range 1 provides close residual noise as the CW mode, making the PN9100 the ideal reference source for any kind of stable source phase noise measurements.

Tables on page 7 show for each frequency range tune slope and SSB phase noise. Values are for 1 V peak. Input voltage range is ± 5 V, then for each frequency range full FM deviation is 10 times the slope/V. For Range 2 add 10 times more. FM deviation value is automatically set when selecting FM range and transferred to the loop parameters.

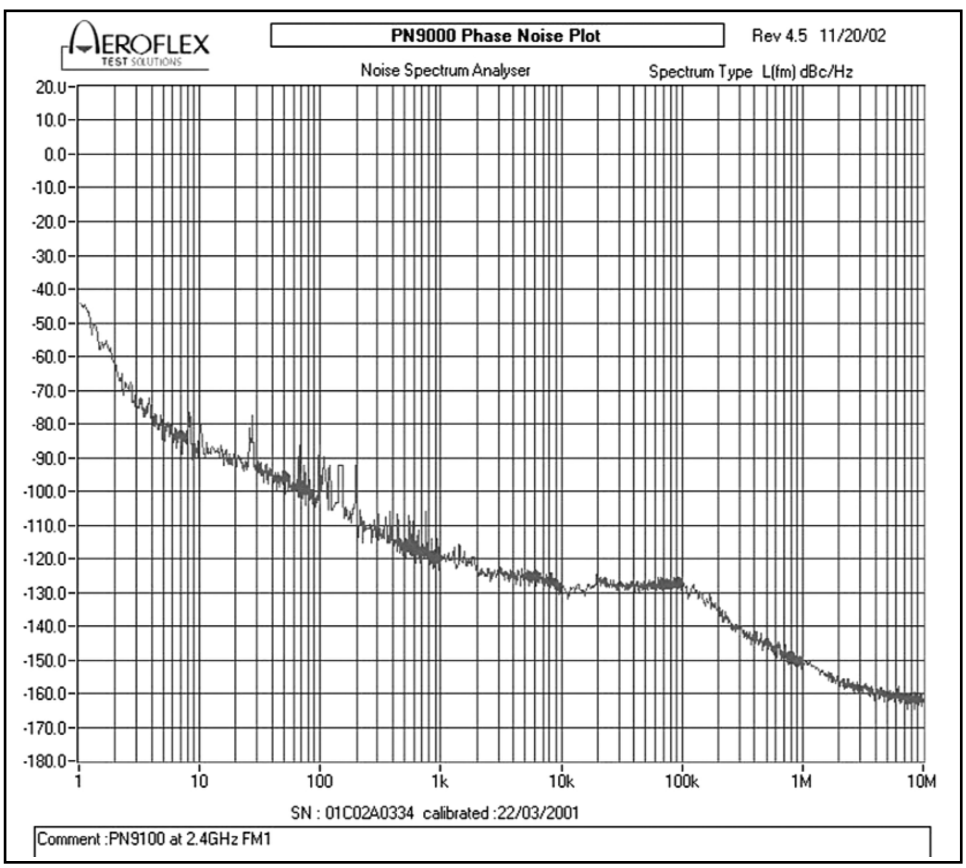
All figures are typical values, for specified values add + 3 dB.

The PN9100 is made of three shielded modules housed in the back of the PN9000 mainframe, a PN9100 single slot output module located on the front of the PN9000 chassis and the PN9211 double size slot module reference time base.

When the configuration includes the PN925x or PN927x MW down-converter, the PN9211 is removed and replaced by the PN9213 or PN9214, a shared time base.



Noise close to carrier depends on the FM range, example on a 10 MHz carrier



Example of a PN9100 measurement at a frequency of 2.4 GHz

PN925x and PN927x MICROWAVE DOWN-CONVERTERS FOR STABLE SOURCES MEASUREMENTS

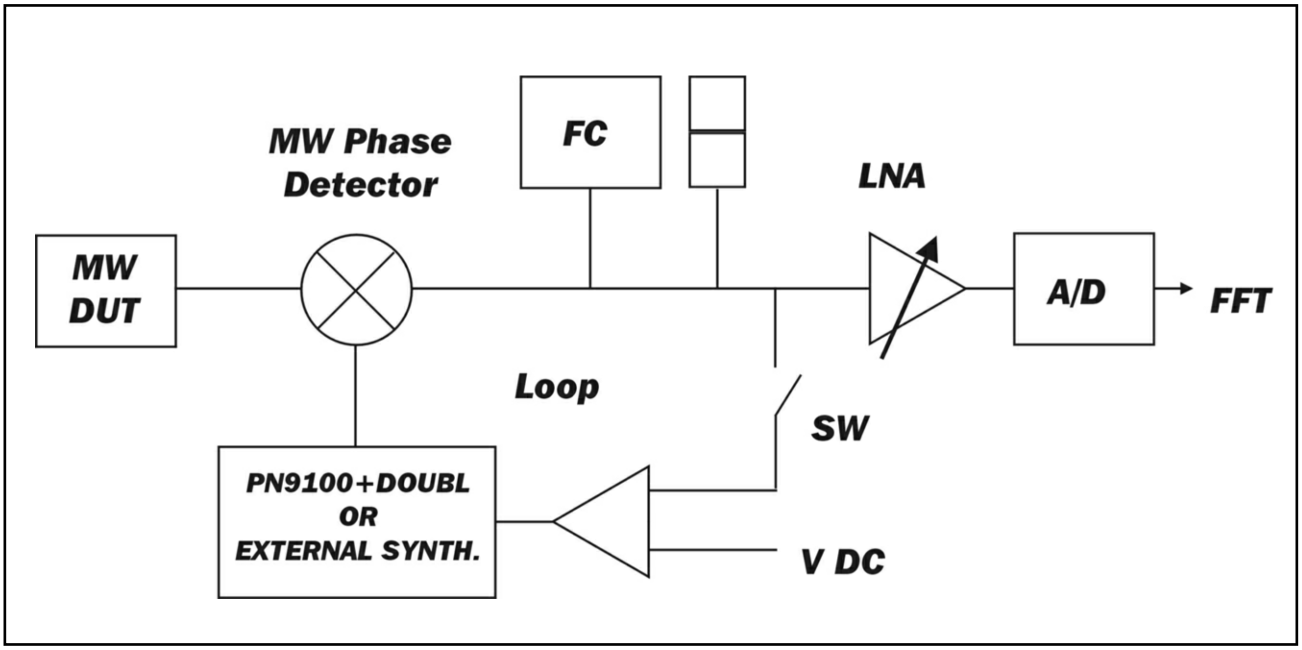
Two methods can be used:

Direct MW phase noise detection, phase locking a DC FM MW reference source

DUT signal down-conversion to the RF frequency range of the PN9000 Base System

A comparison table is available, labeled "PN9000 MW MEASUREMENTS".

DIRECT PHASE NOISE DETECTION IN MW RANGE



This is the simplest and least expensive method. The PN9100 with PN9151 & PN9152 doublers, housed in the PN9000 mainframe, is the ideal solution as long as the phase noise of the PN9100 is lower than that of the DUT signal.

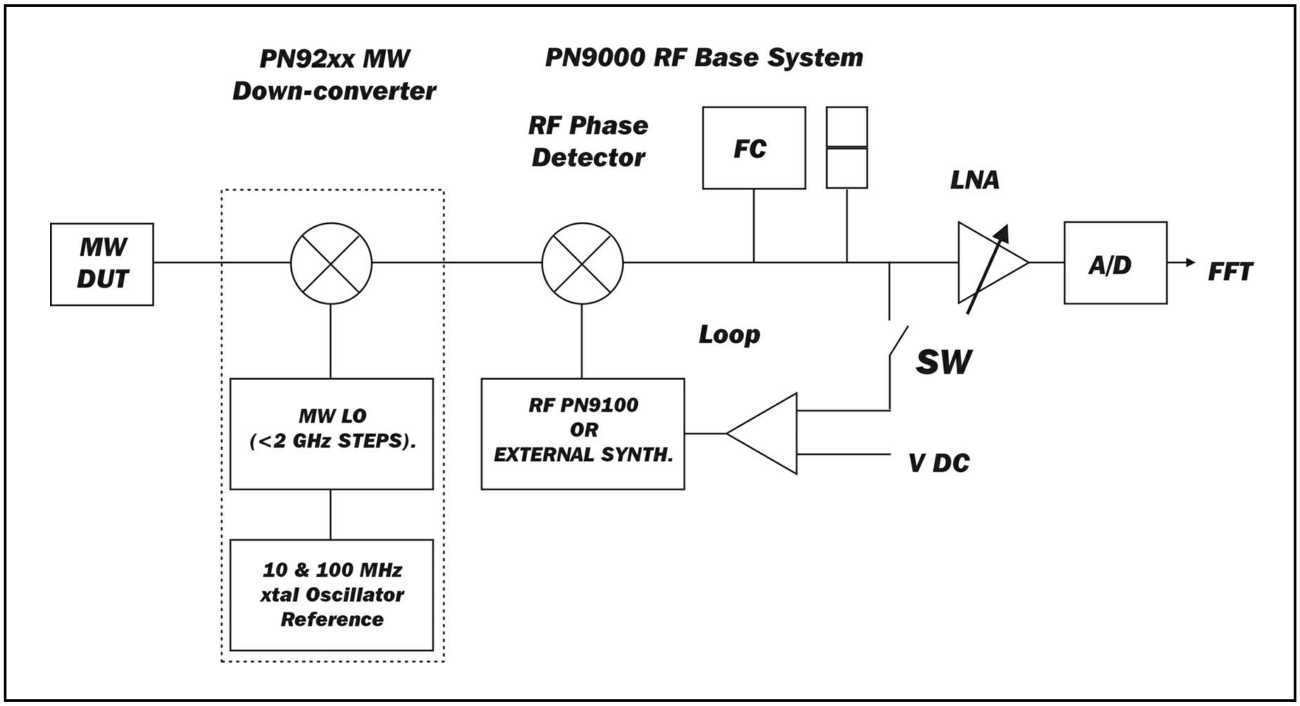
Residual noise of this solution, at 10 kHz offset of the carrier, is - 112 dBc/Hz at 9 GHz and - 105 dBc/Hz at 18 GHz (see PN9100 specifications).

SPECIFICATIONS

When this method is used, the base system specifications are those of the PN9000 Base System with the Microwave Phase detector (see PN9000 System datasheet) and the system residual noise will be that of the PN9100 built-in RF synthesizer with the PN9151 & PN99152 doublers (see the PN9100 data sheet). Should it be an external RF DC FM synthesizer, look carefully at its phase noise floor.

DUT SIGNAL DOWN-CONVERSION

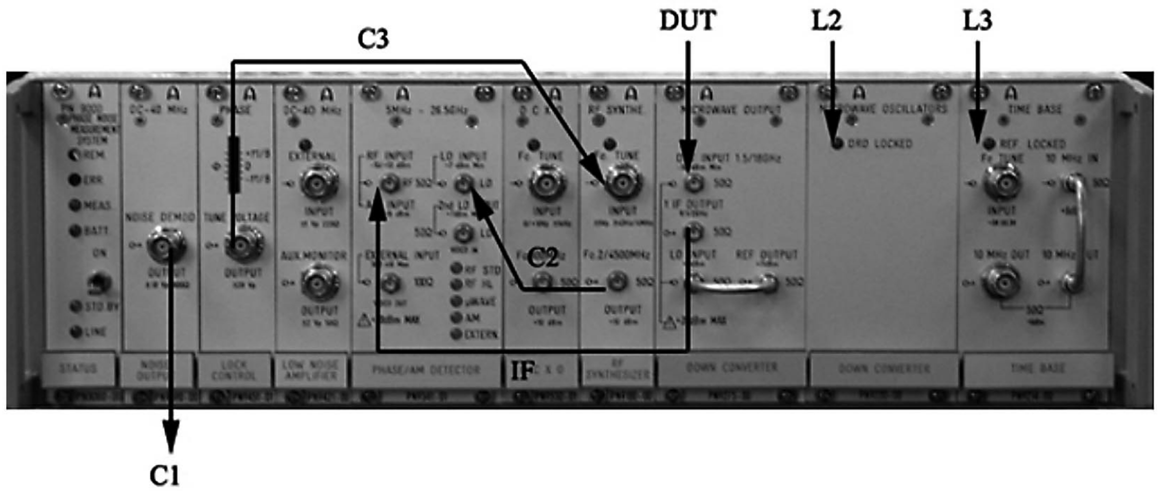
There is no wide-band and high resolution DC FM synthesizer available for the measurement compatible with Ultra-Low Noise MW Radar Sources. The only solution is to mix down the DUT signal with clean fixed frequencies, providing an IF signal in the range of the PN9000 RF base system.



MW Down-conversion Operating Diagram

The PN9000 down-converters include a MW Mixer and MW DROs phase locked on a 1 GHz SAW oscillator, phase locked on a 100 MHz crystal oscillator, phase locked itself on a 10 MHz crystal oscillator, in order to provide a low noise reference close-in and far away from the carrier. The same reference is used for the PN9100.

Setting in the software the MW DUT frequency, the closest LO frequency will be selected and the RF reference source will be automatically tuned on the IF frequency value. Then the measurement process is as simple as for an RF source measurement (see PN9000 base system).



MICROWAVE STABLE SOURCE DOWN-CONVERTER SPECIFICATIONS

Input Frequency range

PN9273 / PN9253 : 1.5 to 18 GHz

PN9274 / PN9254 : 1.5 to 26.5 GHz

MW Signal Input Level : - 10 to + 0 dBm (- 20 dBm with RF phase detector gain)

LO Fixed Frequencies

PN9273 / PN9253 : 2.0; 3.8; 4.2; 7.6; 8.4; 11.4; 12.6; 15.2; 16.8 GHz

PN9274 / PN9254 : 2.0; 3.8; 4.2; 7.6; 8.4;(11.4 - 12.6)H3; 15.2 ; 16.8 GHz
19.0 ; 21; (22.8 & 25.2)H3 GHz

The right LO frequency will be selected manually or automatically.

LO fixed Frequencies Output Level : All > + 7 dBm

IF Output Frequency/Level : 50 MHz to 1.8 GHz / -10 to 0 dBm

Spurious response : <- 50 dBc from 1 Hz to 1 kHz offset
<- 80 dBc above 1 kHz offset

Residual Phase Noise : Down-converter residual noise is the noise of the fixed LOs.

STANDARD PN9253 - PN9254

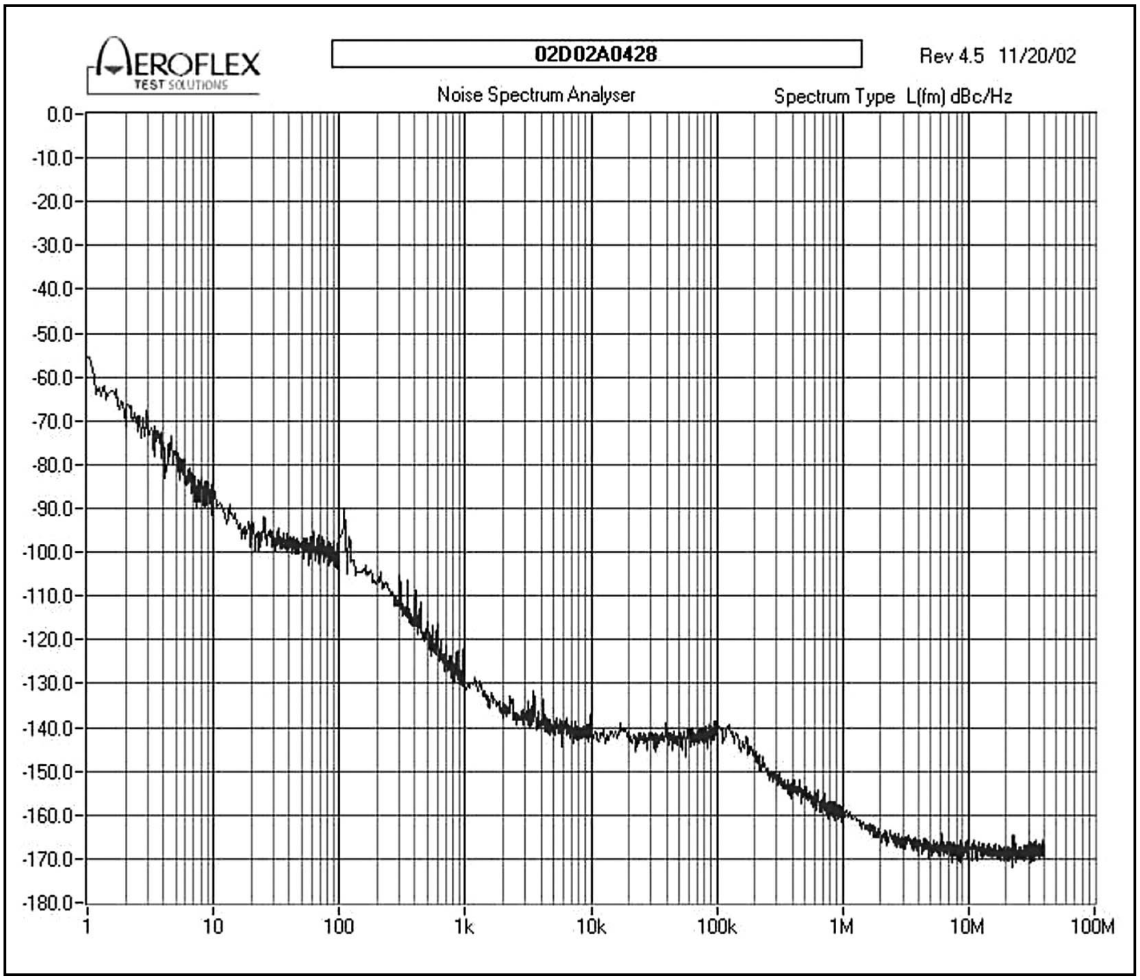
Offset (GHz)	***2***	***3.8/4.2***	***7.6/8.4***	***11.4/12.6***	***15.2/16.8***	***19.0/21.0***	***22.8/25.2***
1 Hz	- 49	- 43	- 37	- 34	- 31	- 29	- 28
10 Hz	- 79	- 73	- 67	- 64	- 61	- 59	- 58
100 Hz	- 99	- 93	- 87	- 84	- 81	- 79	- 78
1 KHz	- 129	- 123	- 117	- 114	- 111	- 109	- 108
10 KHz	- 136	- 130	- 124	- 121	- 118	- 116	- 115
100 KHz	- 141	- 135	- 129	- 126	- 123	- 121	- 120
1 MHz	- 160	- 152	- 146	- 143	- 140	- 138	- 136
10 MHz - 160	- 163	- 157	- 153	- 151	- 149	- 147	

LOW NOISE PN9273 - PN9274

Offset (GHz)	***2***	***3.8/4.2***	***7.6/8.4***	***11.4/12.6***	***15.2/16.8***	***19.0/21.0***	***22.8/25.2***
1 Hz	- 64	- 58	- 52	- 49	- 46	- 44	- 42
10 Hz	- 92	- 86	- 80	- 77	- 74	- 72	- 70
100 Hz	- 108	- 102	- 96	- 93	- 90	- 88	- 86
1 KHz	- 132	- 126	- 120	- 117	- 114	- 112	- 110
10 KHz	- 144	- 138	- 132	- 129	- 126	- 124	- 122
100 KHz	- 145	- 139	- 133	- 130	- 127	- 125	- 123
1 MHz	- 160	- 152	- 146	- 143	- 140	- 138	- 136
10 MHz	- 160	- 163	- 157	- 153	- 151	- 149	- 147

The figure shown is typical values, for specified values add + 3 dB. The frequencies are those of the fixed frequency MW LO (DROs). For configuration residual noise see also the noise of the RF reference synthesizer tuned at the IF output. For example, 8.4 MW LO will be used to measure a 10 GHz DUT, an will generate a 1.6 GHz IF.

REAL MEASUREMENT OF A 4.2 GHz LO FROM THE PN9273 & PN9274



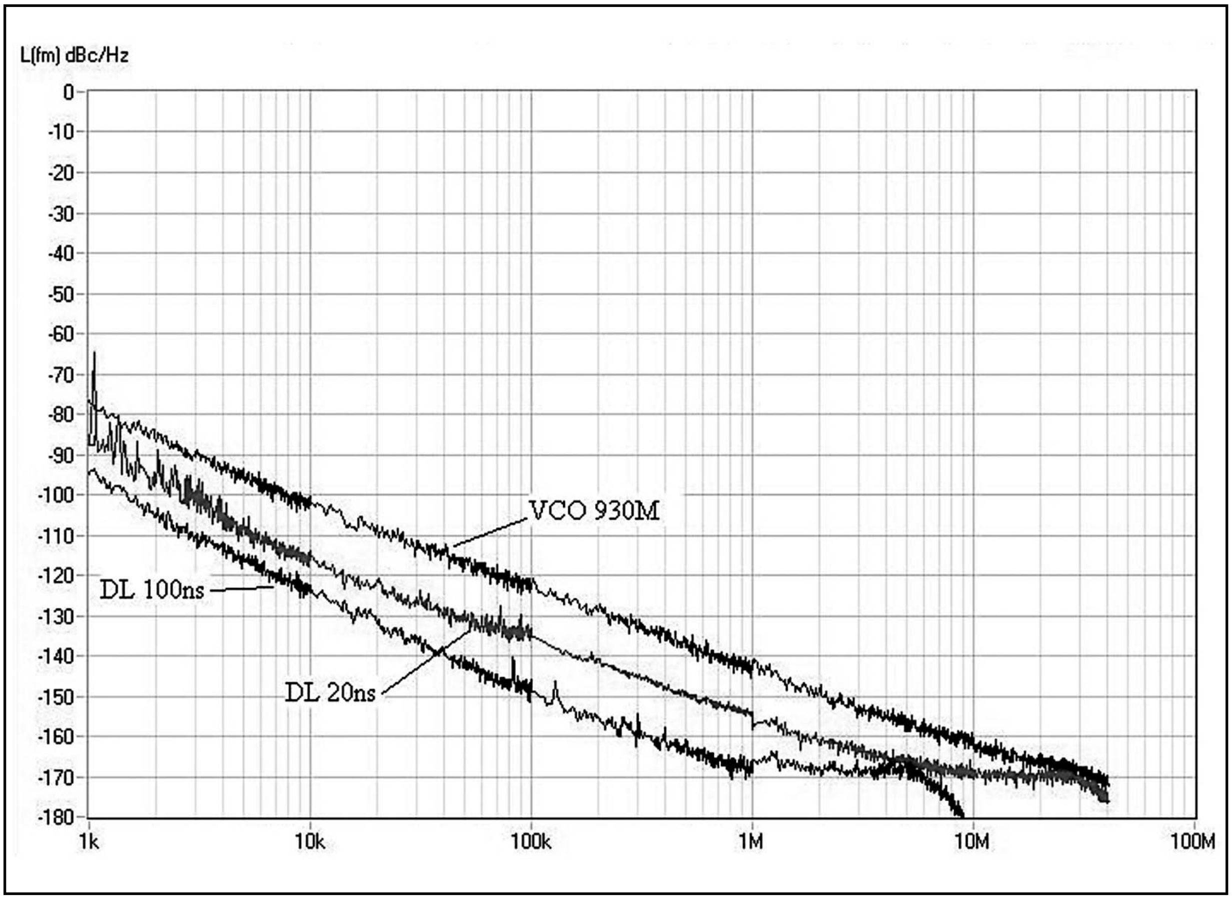
MILLIMETER WAVE PHASE NOISE MEASUREMENTS

For devices above 18 or 26.5 GHz Aeroflex quotes optimized solutions based on Harmonic Mixer down-conversion, up to 140 GHz (see mmW data sheet).

Two optional methods can be used to detect phase noise, reference phase locking or delay line. Delay line is the most convenient and the least expensive. As a matter of fact, the reference phase locking method requires two LOs, one from 5 to 9 GHz for the Harmonic Down-conversion, and the other, in the RF range, phase locked on the IF signal to detect phase noise. The delay line method needs the MW LO only, since the IF phase noise is detected by the delay line.

The optimized solution for mmW phase noise measurements includes a harmonic mixer, a diplexer-amplifier, the PN9100 built-in synthesizer with the PN9151 doubler option and PN9715 delay line. All options are housed in a PN9000 standard mainframe. Refer to mmW note/datasheet.

PN9000 DELAY LINES FOR RF AND MW FREE-RUNNING SOURCE PHASE NOISE MEASUREMENTS (FROM 100 MHz TO 100 GHz)



To make easy measurements of the new generation of VCOs for mobile communications, Aeroflex has designed this new delay line to provide higher phase noise detection sensitivity and lower noise floor up to :

-130 dBc/Hz at 20 kHz offset with the 100 ns.

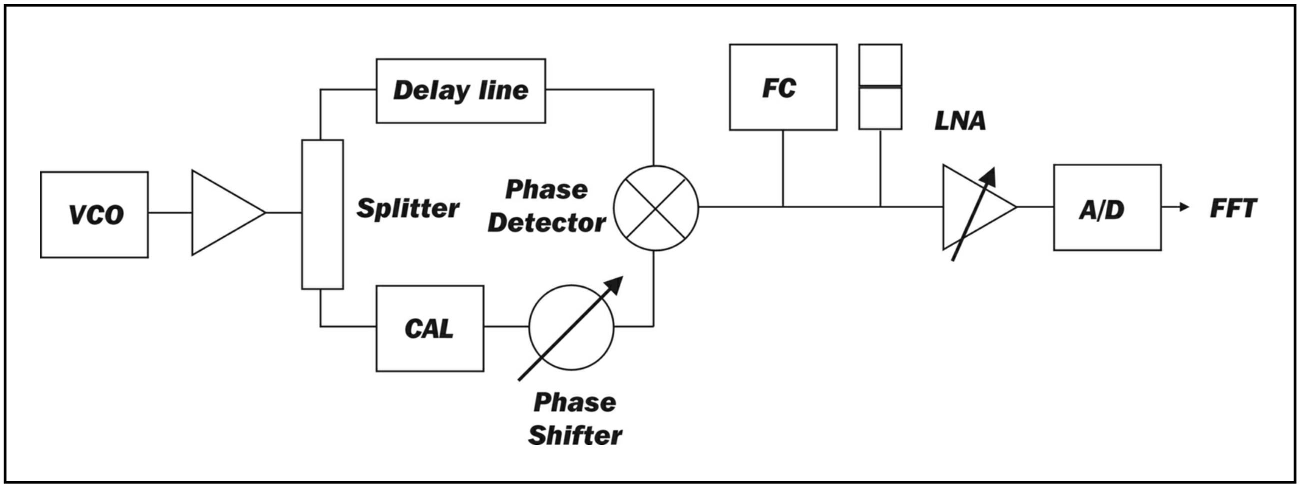
-170 dBc/Hz at 20 MHz offset with the 20 ns.

The above plot shows the residual noise, or noise floor, of the 20 and 100 ns delay lines measuring a 1 GHz very low noise SAW oscillator whose phase noise is lower. These plots include the phase noise of the 1 GHz SAW oscillator itself (SAW noise floor : 168 dBc/Hz at 2 MHz offset).

The upper plot shows a real 930 MHz GSM VCO. It shows that the residual noise is low enough to measure "state of the art" new generation VCOs.

PN9000 DELAY LINE OPERATING DIAGRAM

The phase noise of Free-run frequency sources, such as VCO, DRO or YIG oscillators, cannot be easily measured using the reference phase locking method. Their frequency drift and phase/frequency fluctuations are generally too high to allow phase locking a DC FM reference source. Fortunately, another method can be used to obtain phase quadrature between RF and LO inputs of the RF phase detector of the PN9000 base system. Its principle of operation is shown below.



The DUT signal is connected to the power splitter through the input amplifier-conformer to compensate insertion loss of the delay line and the phase shifter. The power splitter outputs are connected to the RF input of the phase detector through the delay line and to the LO input through the calibrator and the phase shifter, which can adjust fine phase quadrature.

One button launches a complete measurement sequence.

The delay line operates as a frequency discriminator, since a delay line provides linear phase shift as a function of the frequency. When phase quadrature is achieved, the VCO's frequency fluctuations are converted into a noise voltage at the output of the phase detector. After spectrum analysis, the data is converted into the equivalent phase spectrum and displayed as a phase noise plot.

The demodulated signal, or noise voltage, is given by the following formula :

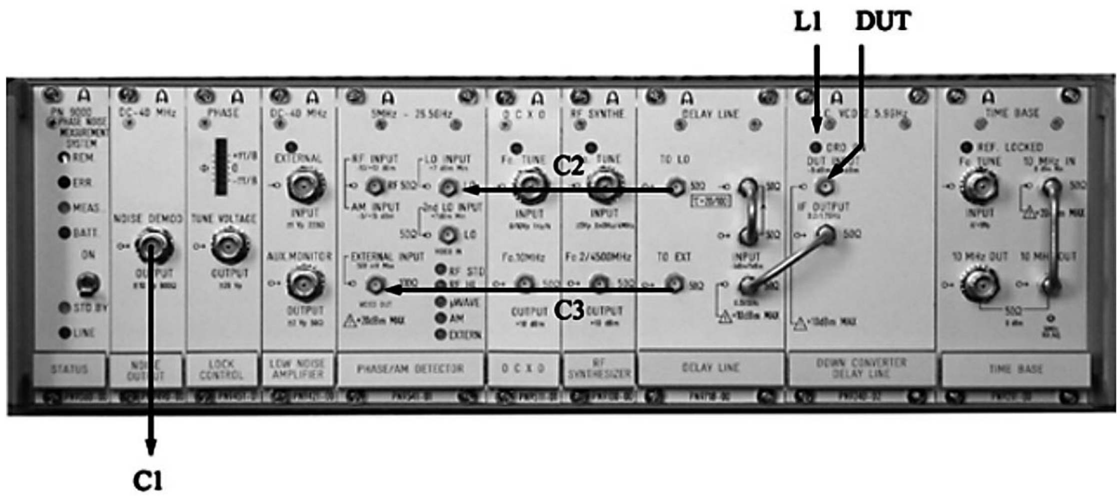
$$V_{noise}(f_m) = K_\Phi \, 2\pi\tau \, \Delta f(f_m) \, [\sin(\pi\tau f_m) / (\pi\tau f_m)]$$

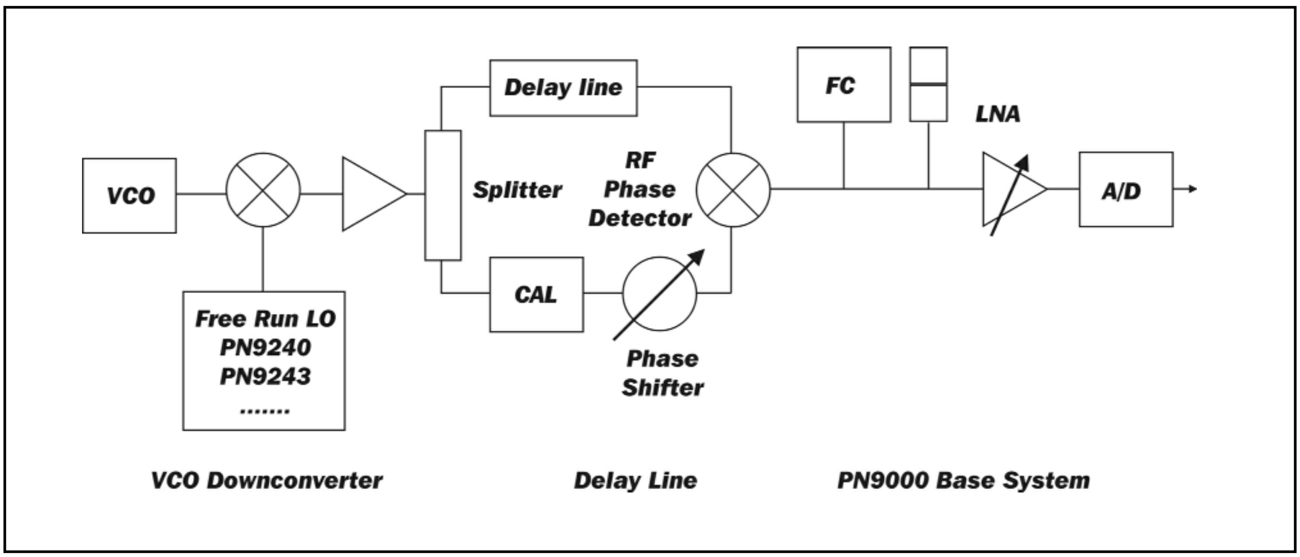
KF is the sensitivity of the the phase detector, expressed in Volt/radian. The term sin(x)/x provides first null response of a delay line at 1/t offset, then the appropriate delay must be selected depending on the desired offset analysis, taking into account the residual noise depending on length of the delay line (see table below) The PN9000 software compensates for the sin(x)/x response to provide accurate measurements up to 5 MHz for 100 ns delay, 30 MHz for 20 ns.

Note: Unlike the reference phase locking method, the delay line provides poor AM noise rejection. As a consequence, when AM noise is significant compared to phase noise, the measurement result will show a combination of both. This is why the delay line method is dedicated for free running oscillators with no or low AM noise.

Operating frequency range is 250 MHz to 2 GHz (need MW phase detector for the PN9715). A family of VCO Up/Down converters extends the frequency range from 2 GHz to 18 GHz. From 18 GHz to 100 GHz, Harmonic mixers driven by the MW LO source down-convert mmW free-run sources to the operating range of the delay lines. (see mmW note)

PN924x DOWN-CONVERTERS FOR MEASUREMENTS FROM 2 TO 18 GHz WITH THE DELAY-LINE





Free-running local oscillators are required to down-convert MW free-run sources. As a matter of fact, the noise floor of phase locked sources is generally higher than the noise of free run sources far away from the carrier.

For example, the noise floor of clean PLL or synthesizers is rarely lower than -150 dBc/Hz at 1 MHz when last VCO generation provides -160 dBc/Hz at 1MHz and lower than -165 dBc/Hz at 10 MHz. The residual noise of the PN9240 down-converter, for VCOs from 2 to 5.9 GHz, is as low as -168 dBc/Hz at 10 MHz offset, due to the use of free-running DROs.

THE FAMILY OF VCO UP/DOWN-CONVERTERS INCLUDES:

PN9908 100 MHz to 2 GHz frequency doublers, allows measurements from 125 MHz

PN9906 500 MHz to 2.2 GHz, dynamic range extender

PN9240 2.0 to 5.9 GHz

PN9242 2.0 to 10 GHz

PN9243 2.0 to 18 GHz. See mmW note for devices above 18 GHz.

All work in their specifications with an input level of -5 to +5 dBm / 50 Ohm.

Residual System Phase Noise

The residual phase noise of the system will be the combination of the delay line residual noise and the Local Oscillators of the down-converters.

PN9715 & PN9718 DELAY LINE SPECIFICATIONS

Two delay lines are available, the PN9715 and the PN9718. Both have the same specifications, except for the residual noise or noise floor. The PN9718 has been designed for the new generation of VCOs for mobile phone base stations. The PN9718 module includes the appropriate phase detector.

Frequency Range : 250 MHz to 2 GHz (need MW phase detector for the PN9715)

RF Input Level : - 5 to + 5 dBm / 50 W

Delay : 20 and 100 ns

Offset Analysis : 30 MHz for 20 ns delay
5 MHz for 100 ns delay

Residual Phase Noise : Depends on the selected delay and the noise of the down-converter LO. See table below.

	100 ns		***20 ns***	
Offset	***PN9715***	***PN9718***	***PN9715***	***PN9718***
1 KHz	- 90	- 95	- 80	- 82
10 KHz	- 120	- 125	- 106	- 112
100 KHz	- 140	- 148	- 126	- 135
1 MHz	- 160	- 168	- 146	- 157
5 MHz	- 165	- 170	- 160	- 167
10 MHz	NA	NA	- 165	- 170
20 MHz	NA	NA	- 165	- 170
30 MHz	NA	NA	- 165	- 170

Typical figures for Frequency range : 250 MHz up to 1 GHz and Level > - 3 dBm.
For specified values add + 3 dB .
For Frequency > 1 GHz, residual noise increases as a function of the frequency :
- For 100 ns delay line : 20 log Fdut/1 GHz, example at 2 GHz add + 6 dB
- For 20 ns delay line : 10 log Fdut/1 GHz, example at 2 GHz add + 3 dB
For Level < - 3 dBm residual noise increases as a function of the Level:
-example for - 5 dBm add + 2 dB

VCO µW Down-converter with PN9715

	2 GHz-5.9 GHz		10 GHz		18 GHz	
Offset	***100 ns***	***20 ns***	***100 ns***	***20 ns***	***100 ns***	***20 ns***
1 kHz	- 79	- 78	- 75	-75	- 70	- 70
10 kHz	- 110	- 105	- 108	-104	- 102	- 102
100 kHz	- 132	- 125	- 127	-124	- 121	- 121
1 MHz	- 152	- 145	- 152	-145	- 144	- 144
5 MHz	- 163	- 159	- 158	-156	- 152	- 152
20 MHz	NA	- 162	NA	-158	NA	- 152

Typical values expressed in dBc/Hz
Specified add 3 dB

VCO µW Down-converter with PN9718

	2 GHz-5.9 GHz	***10 GHz***	***18 GHz***
Offset	***100 ns/20 ns***	***100 ns/20 ns***	***100 ns/20 ns***
1 kHz	- 79	-75	- 70
10 kHz	- 110	-108	- 103
100 kHz	- 132	-127	- 122
1 MHz	- 155	-152	- 147
5 MHz	- 163	-158	- 152
20 MHz	NA /-162	NA /-158	NA /-152

Typical values expressed in dBc/Hz
Specified add 3 dB

PN9281 with PN9293-xx MMW PHASE NOISE MEASUREMENT

DOWN-CONVERSION TO THE RF FREQUENCY RANGE

As for the MW sources, the mmW sources must be down-converted to the operating range of the PN9000 system. The most convenient way to do this is to use a Harmonic Mixer. These devices are designed to work with LO harmonic ranks as high as 11 to 13, providing an IF signal of - 30 dBm or higher so that it is possible to down convert a mmW signal of 20 to 140 GHz with an LO source of 4 to 9 GHz.

PHASE NOISE DETECTION METHODS

When converted to the RF range the phase noise of the DUT signal can be detected by the mean of two methods: the Reference phase locking method or Delay line method.

The Reference Phase Locking Method will be used, as for the RF and MW devices, for clean phase locked mmW sources. As shown below, it requires a MW LO in the range of 4 to 9 GHz depending on the mmW signal frequency and an RF reference synthesizer up to 2 GHz.

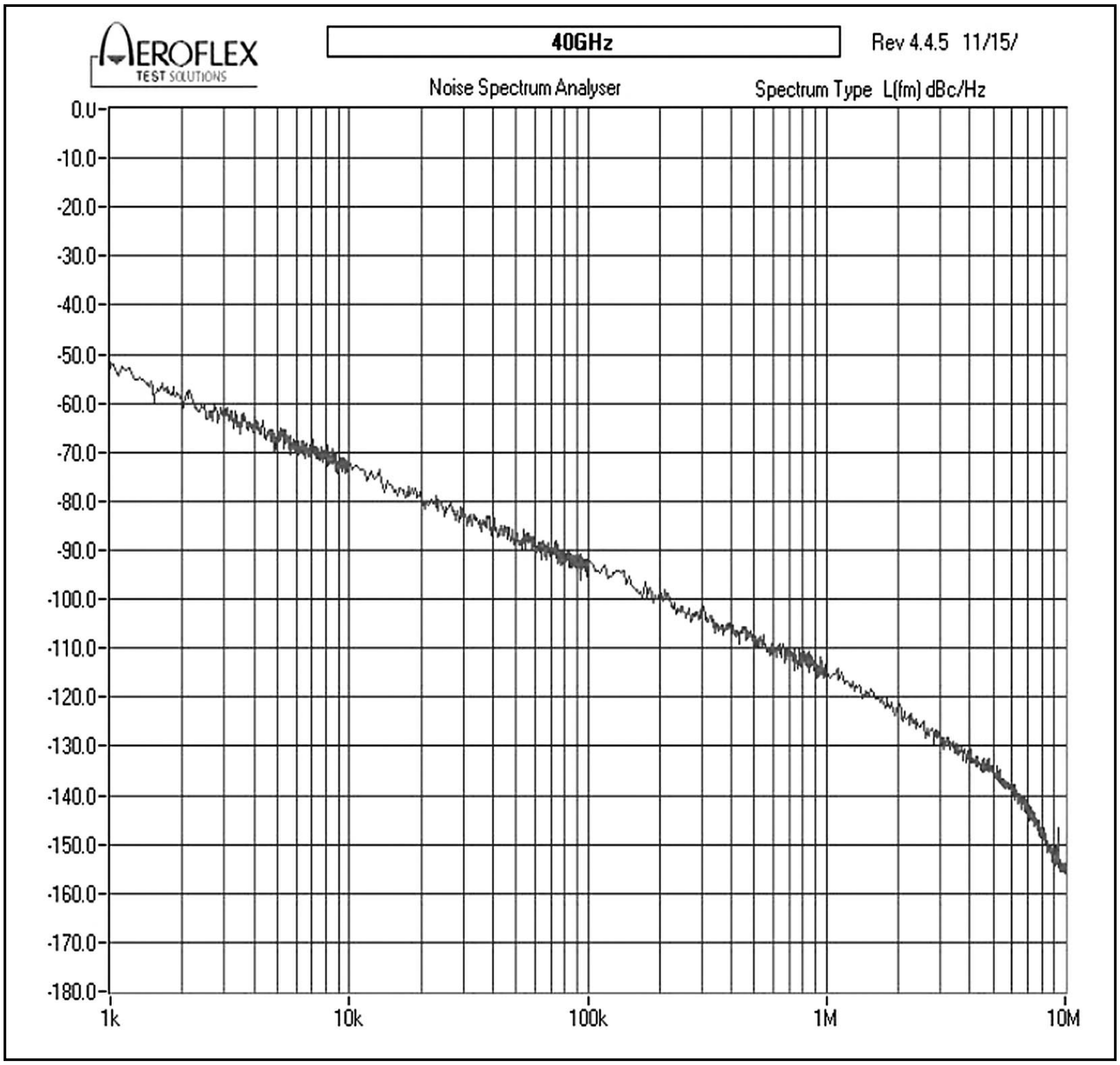
The Delay Line Method will be used for the noisy phase locked and free running sources.

However, it appears that the residual noise of the PN9000 delay lines is lower than that of most of the phase locked mmW sources, so that they can be measured using the delay line method.

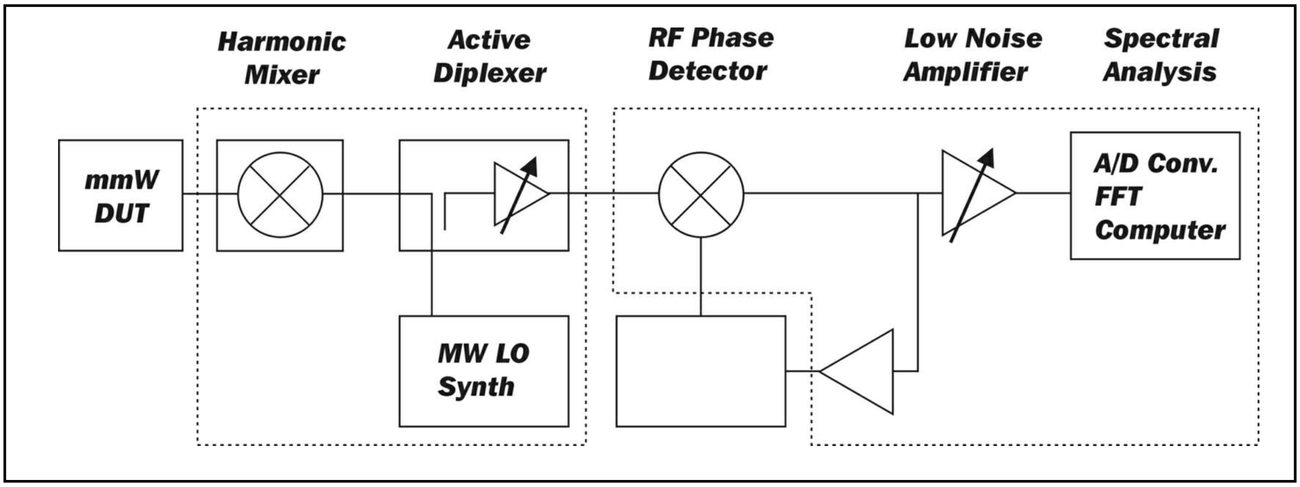
The Delay Line method offers two main advantages:

Only one LO synthesizer is required for the mmW down conversion.

The PN9000 delay lines include automatic process for phase quadrature adjust and calibration.

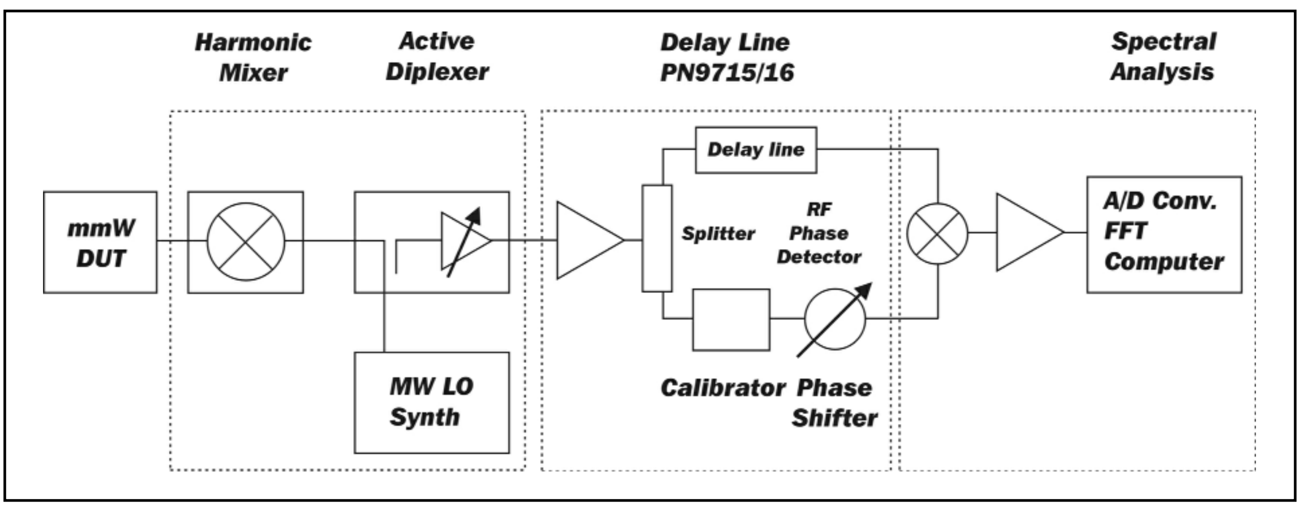


REFERENCE PHASE LOCKING METHOD



The mmW harmonic mixer is selected according to the DUT frequency. As a general rule they cover an octave. PN9000 options cover 20 to 140 GHz. At first measurement it is recommended to connect a spectrum analyzer to the output of the diplexer and tune the LO synthesizer to optimize the IF level and frequency, and adjust the gain to get between 0 and + 10 dBm at the input of the RF phase detector. Then the major steps to make a measurement are: tune the RF Reference synthesizer to IF value from the diplexer, measure the beat at the output of the phase detector, calibrate the phase detector, execute phase lock, and measure. The RF Reference synthesizer can be the PN9100 or any appropriate external signal generator.

DELAY LINE METHOD



Use the same procedure as above to optimize IF Level and Frequency. Then, just run the delay-line automatic measurement process. This method allows easy and fast measurements.

Note: The PN9000 harmonic mixer options cover the following ranges: 18-26, 26-40, 33-50, 40-60, 75-110, 90-140, 50-75, 60-90 and 90-140 GHz. When existing harmonic mixers include a diplexer, the PN9281 diplexer is removed. However the PN9281 controlled amplifier is recommended to adjust the IF output level at the operating amplitude range of the phase detector.

Most of the problems which occur when performing phase noise measurements come from:

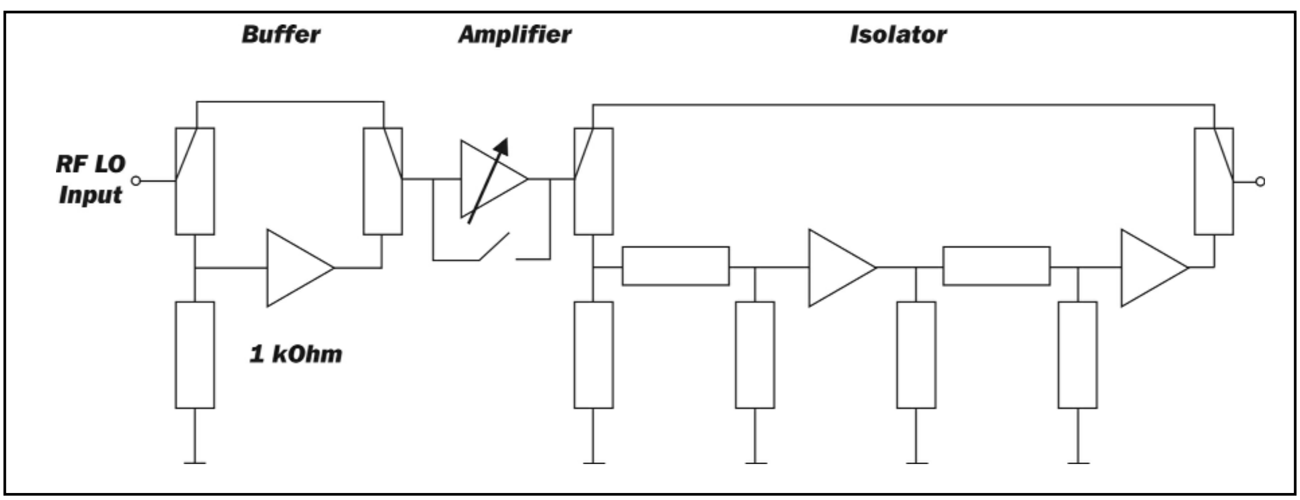
- Low DUT output level,
- High DUT output impedance (TTL output), connected to 50 Ohm PN9000 RF input,
- Poor isolation between the oscillator and the output of the DUT, which is at the origin of DUT locking injection from the Reference source through the RF and LO inputs of the phase detectors.

The solutions consist in providing input gain, impedance adaptation and isolation between the RF and LO inputs of the phase noise detector. That is what the Aeroflex PN9820 option provides. It is housed in a standard PN9000 double slot module. The three functions and parameters are controlled from the PN9000 software. Thus, it is possible to select the appropriate functions depending of the DUT source parameters.

The PN9820 is a dual channel Buffer - Amplifier - Isolator, with full software control. One channel is for the DUT source and the other one is for the LO source. They have separate software control.

PN9820 SPECIFICATIONS

Frequency Range	: 5 MHz to 1.8 GHz	
Amplifier Nominal Gain	: F < 1 GHz	: 0 - 10 - 20 - 30 dB
	F > 1 GHz	: 0 - 7 - 14 - 21 dB
Insertion loss	: F < 100 MHz	: 1.3 dB
	F < 1 GHz	: 3 dB
	F> 1 GHz	: 7 dB
Noise factor	: amplifier only	: 5 dB
	Isolator only	: 15 dB
Buffer	: 1 kOhms	: F < 100 MHz, gain = 7 dB
	100 Ohms	: F < 1 GHz, gain = 0 dB
Isolator	: F < 100 MHz, 50 dB	
	1 GHz, 70 dB	



Note: One channel only is represented

Switches controlled by the software allow selection of the desired functions and adjust the gain of the amplifier to provide the optimized output levels for the RF and LO inputs of the phase detectors (0 to +10 dBm for the RF input and +6 to +10 dBm to the LO input.)

PN9908 FREQUENCY DOUBLER ISOLATOR

This option has been designed for two purposes. The first is to prevent injection between the reference source and the DUT through the phase detector; the second is to increase the system measurement dynamic range.

ISOLATION AGAINST INJECTION LOCKING, BETWEEN REFERENCE AND DUT SOURCES IN PLL MODE

Due to low isolation between the RF and LO input of the phase detector, the DUT and Reference can synchronize on each other when they are tuned on the same frequency instead of phase locking the reference on the DUT. Without phase locking, there is no phase quadrature and no phase noise detection. This problem happens often with small TTL or ECL devices having high output impedance. This phenomenon is known as "injection locking".

There are two solutions to provide isolation between the DUT and reference.

The first is to insert attenuators between the DUT output and RF input and the Reference output and LO input. However, if more than 10 dB are needed, the RF and LO input levels will be too low. Then amplifiers will have to be inserted between the attenuators. Aeroflex has designed such an option, the PN9820 Amplifier Isolator.

The second solution is to double the DUT and Reference signals. In this case, the DUT and Reference sources do not see their fundamental frequency through RF/LO leakage of the phase detector. The PN9908 provides in consequence a virtual (but real) isolation between the DUT and Reference sources.

INCREASE THE SYSTEM DYNAMIC RANGE USING THE DELAY LINE METHOD

For exmple, if the system residual noise is - 160 dBc/Hz at 1 MHz offset and the expected noise of the DUT is - 163 dBc/Hz. The system will of course measure - 160 dBc/Hz and not the actual noise of the DUT.

The PN9908 will double the DUT signal frequency and, its phase noise will increase by 6 dB (20LogN) to - 157 dBc/Hz, i.e. 3 dB above the delay line residual noise. The software includes a function to deduct the 6 dB added to the measured values. The PN9000 has a reference offset function to do this automatically.

SPECIFICATIONS PN9908

Frequency range	: 100 MHz to 1 GHz, 1 GHz to 2.2 GHz (2 bands selectable by software)
Input level	: -5 to + 5 dBm/50 Ohm.
Function	: Low noise Frequency Doubler
Size	: 1 single PN9000 slot module

PN9906 WIRELESS DYNAMIC RANGE EXTENDER

This option has the same purpose than the PN9908. Its main purpose is to extend the dynamic range.

This is a x 4 multiplier for the 500 MHz to 1 GHz band providing 12 dB of dynamic range extention and a doubler for the 1 to 2.2 GHz band.

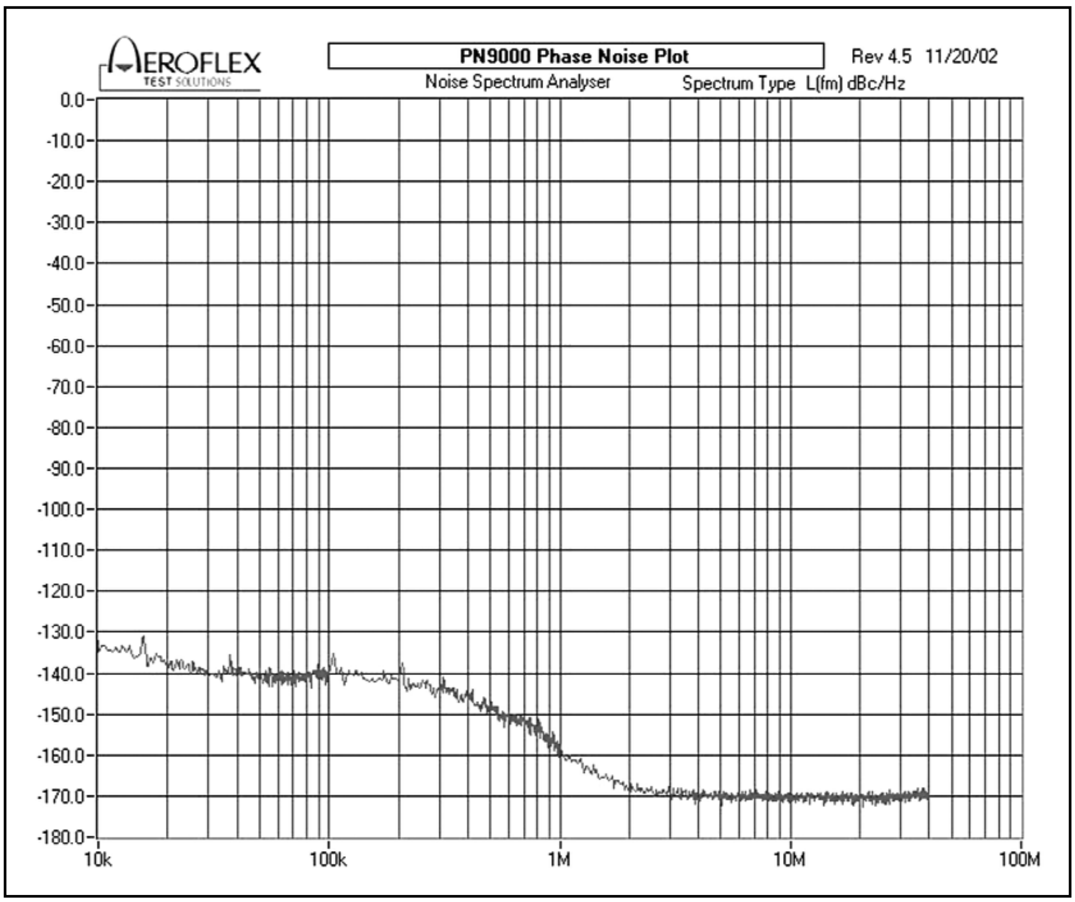
SPECIFICATIONS PN9906

Frequency range : 500 MHz to 1 GHz, 1 GHz to 2.2 GHz (2 bands selectable by software)

Input level : -5 to + 5 dBm/50 Ohm.

Function : Low noise Frequency Doubler (6 dB extender)
Quadrupler (12 dB extender)

Size : 1 single PN9000 slot module



Example:

PN9906 GSM 900 MHz source measurement with PN9100 synthesizer reference at 3.6 GHz

PN95XX REFERENCE CRYSTAL OSCILLATORS

All stable frequency sources, such as synthesizers used in radar, satellites, digital and mobile communication systems, utilize reference crystal oscillators. Their phase noise, often very low, must be measured to make sure it doesn't affect the performances of the whole system they drive. However, it is often difficult to find another reference good enough to measure them. Aeroflex offers a selection of very low and ultra low noise reference crystal oscillators housed in standard PN9000 modules, making the measurements easy and accurate.

In addition to the following standard catalog devices, Aeroflex will quote on request customized frequencies.

Parameters	***PN9510*** ***Very low noise***	***PN9511*** ***Ultra low noise***	***PN9530*** ***Very low noise***	***PN9531*** ***Ultra low noise***
Frequency	10 MHz	10 MHz	100 MHz	100 MHz
Output level, typical	+ 10 dBm	+ 13 dBm	+ 10 dBm	+ 13 dBm
Long term stability	5.10^{-10} / day after 3 months operating	NA	NA	1.10^{-9} / day after 1 month operating
Frequency tuning				
- Mechanical	NA	2 ppm	NA	± 2.5 ppm
- Electrical	2 ppm	2 ppm	10 ppm	± 0.2 ppm
- Tune voltage	0 to + 10 V.	0 to + 10 V	0 to + 10 V	± 5 V
- Average tune slope	2 Hz / Volt	2 Hz / Volt	150 Hz / V	4 Hz / V
Phase noise, dBc/Hz				
10 Hz	- 132	- 134	- 95	- 100
100 Hz	- 142	- 162	- 125	- 130
1 kHz	- 148	- 172	- 155	- 162
10 kHz	- 152	- 174	- 168	- 178
100 kHz	- 152	- 174	- 168	- 178
1 MHz	- 152	- 174	168	- 178

- All figures are typical values, add + 5 dB for specified values.
- Other frequencies are available, such as 26, 70, 140 MHz. Request for quotation.
- All are housed in standard single size PN9000 modules.

PN9562 REFERENCE SAW OSCILLATOR 1GHz

This oscillator provides, due to the SAW resonator, a very low phase noise signal. Running at 1 GHz, its phase noise is at the order of magnitude of that a 100 MHz crystal oscillator. It provides much better phase noise than a 100 MHz crystal oscillator multiplied 10 times.

Such a low noise 1 GHz source has a lot of applications. It can be used as a reference for MW PLLs and converters. It can also be used as a reference for phase noise measurements. As a matter of fact, it is one of the best 1 GHz frequency source available today.

PN9562 SPECIFICATIONS

Frequency : 1 GHz

Tune Range : ± 300 KHz

Tune Voltage : 0 to + 5 V

Output Power : + 10 dBm typical, + 7 dBm min.

Output Impedance : 50 Ω

Phase Noise, in dBc/Hz :	- 80	at 100 Hz offset
	- 112	1 KHz
	- 135	10 kHz
	- 160	100 kHz
	- 168	1 MHz
	- 168	10 MHz

Size : single PN9000 slot

Operating temperature : 0 to + 50° C.

All phase noise figures are typical values, add + 5 dB for specified values

PN9815 PULSE GENERATOR AND MODULATOR

Low noise Pulsed CW in PLL and and Added Noise measurements require a low jitter pulse generator and high ON/OFF pulse modulators (MW switches).

The PN9815-00 (master) includes :

- A crystal oscillator clock, for low noise jitter
- A Pulse generator, to generate the trigger and the pulse waveform
- A MW Pulse modulator to switch on/off the microwave carrier

The PN9815-01 (slave) is used to generate a second pulse modulator. Some measurements require the same pulsed CW signal on the RF and LO phase detector inputs.

The PN9815-01 slave uses the same clock as the PN9815-00 master. An internal connection in the PN9000 mainframe provides the clock to PN9815-01. In case this option is supplied as a later add-on, 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.

The pulse generator output (TTL 50 Ohms) can be used to switch on/off an external DUT.

The "trigger out" can be used to trigger the external DUT .

The "trigger in" can be used to trigger the PN9000 microwave pulse modulator from an external system.

If the two sources are pulsed (the reference source and the DUT), the two pulses must be synchronized.

PN9815 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 time, 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 PN9815 slave, to adjust the output pulse according to delays in the DUT and connectors.

Min delay : 0

Max delay : 20 or 200 ns x 256

PN9841 FOR ADDED PHASE NOISE MEASUREMENTS

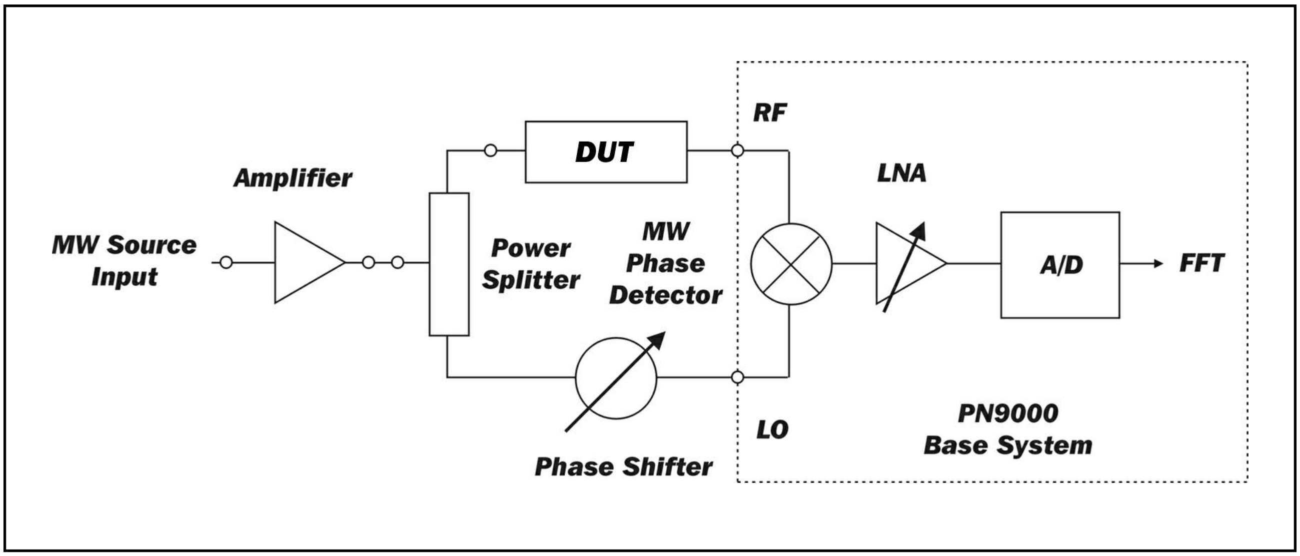
The PN9841 option includes, in a two-slot module:

An amplifier, connected when the input level is too low.

A power splitter to split the input signal in two paths, one to the RF phase detector input through the DUT and the other to the LO phase detector input through the phase shifter.

A phase shifter, manual or motorized trombone.

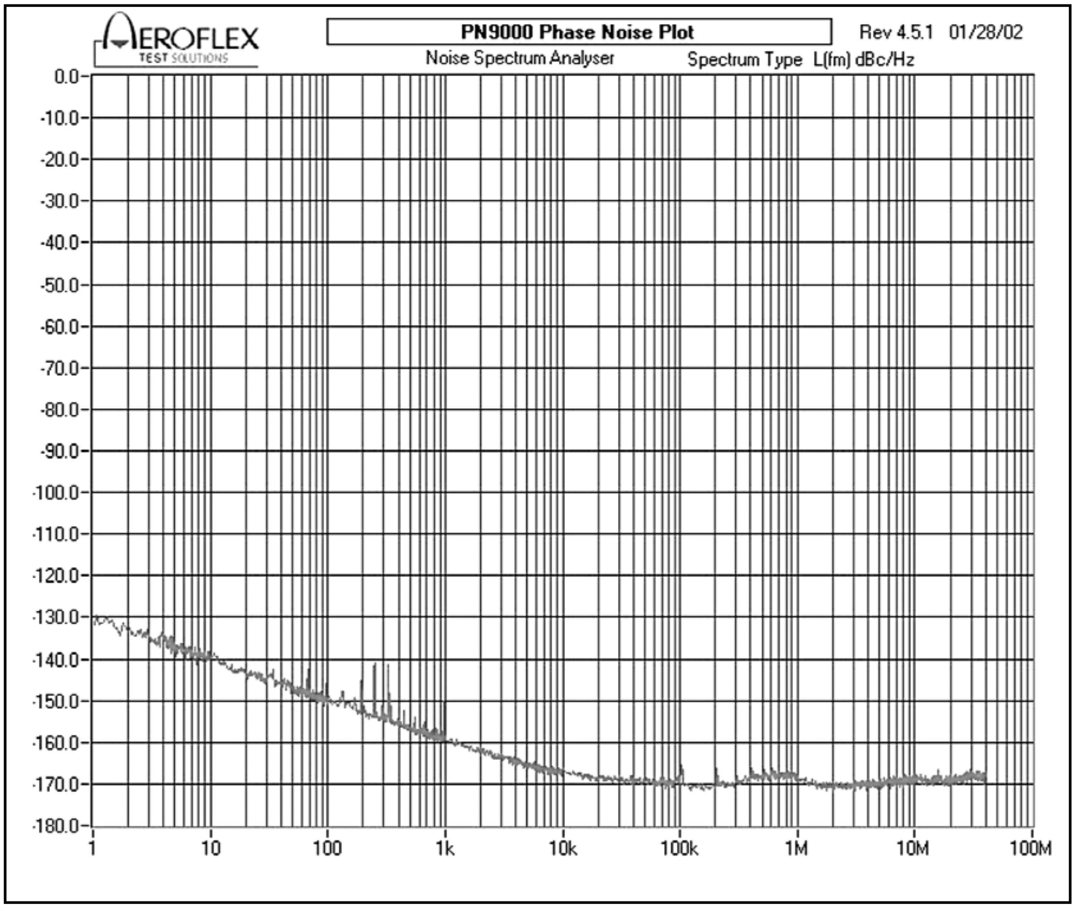
The other components, MW phase detector, FC, bar graph, LNA, etc. are part of the base system.



PN9841 SPECIFICATIONS

Frequency range	: 2 to 18 GHz depending on phase shifter
Input amplifier level	: 0 dBm min. for maximum measurement dynamic range
Input amplifier gain	: 15 / 20 dB
Phase shifter output level to LO	: +7 dBm min
Output level to DUT input	: + 12 to +15 dBm

The output level of the DUT should be adjusted to the nominal value of the RF input port (0/+6 dBm for phase adjust calibration mode and up to the maximum power input).



Residual Added Noise Measurement at 10 GHz

For principle of operation, see "ADDED PHASE NOISE MEASUREMENT" application note.

For measurement process, see "PULSE CW MEASUREMENTS" technical note.

For Pulse modulation option, see PN9815 datasheet.

Added phase noise residual specification :

10 Hz	***100 Hz***	***1 kHz***	***10 kHz***	***100 kHz***	***1 MHz***	***10 MHz***
- 130	- 135	- 140	- 155	- 160	- 160	- 160

MEASUREMENTS IN MW FREQUENCY RANGE

When the DUT signal frequency exceeds the operating frequency range of the PN9000 base system, 1.8 to 2 GHz, the measurement solution will depend on the nature of the DUT stable or free running source. Stable sources are PLL or synthesizers. Free running sources are those with no phase locking on a reference crystal oscillator.

FOR THE STABLE SOURCES, THE PN9000 OFFERS TWO SOLUTIONS:

The PN9273 & PN9274, 18 & 26.5 GHz down-converters

They include low noise oscillators and a MW mixer to provide an IF signal connected to the RF input of the PN9000 base system. The phase noise is detected using the PN9100 as the LO reference.

This solution provides the lowest residual noise, due to the low noise fixed frequencies used to down convert the DUT to the RF frequency range and the low noise of the PN9100.

The direct phase noise detection up to 4.5, 9.0, 18 & 26.5 GHz

The standard PN9330 RF phase detector is replaced by the PN9341 MW phase detector. To the PN9100 RF reference synthesizer will be added the PN9151, 4.5 - 9.0 GHz and the PN9152, 9.0 - 18.0 GHz doublers. Each one increases the phase noise by two times or 6 dB, i.e. 12 dB between 4.5 and 18 GHz. For the range from 18 to 26.5 or 40 GHz (PN9361), the MW phase detector works on the third harmonic of the LO.

FOR UNSTABLE OR FREE RUNNING SOURCES

These sources are not phase locked. Their short and long term stability depend on their frequency range, component quality and technology. In general, their drift and frequency fluctuations are too high to phase lock a reference, the delay line method is the only way to detect their phase noise. (See Delay line method in the PN9000 description and Delay line datasheet.)

The maximum direct input frequency range of the delay lines is 2.0 GHz. Then, to measure free running sources at a higher frequency, the MW DUT signal must be down converted to the operating range of the delay lines.

Phase locked MW sources such as the PN9273/74 MW down-converter and PN9100 + PN9151/52 can be used, however, the noise floor of a free running oscillator is generally lower than that of a phase locked oscillator due to the noise of the loop components, digital divider, amplifier and varactor. This is why, to measure the phase noise of a MW free run source, the LO used to down convert it must also be a free run source.

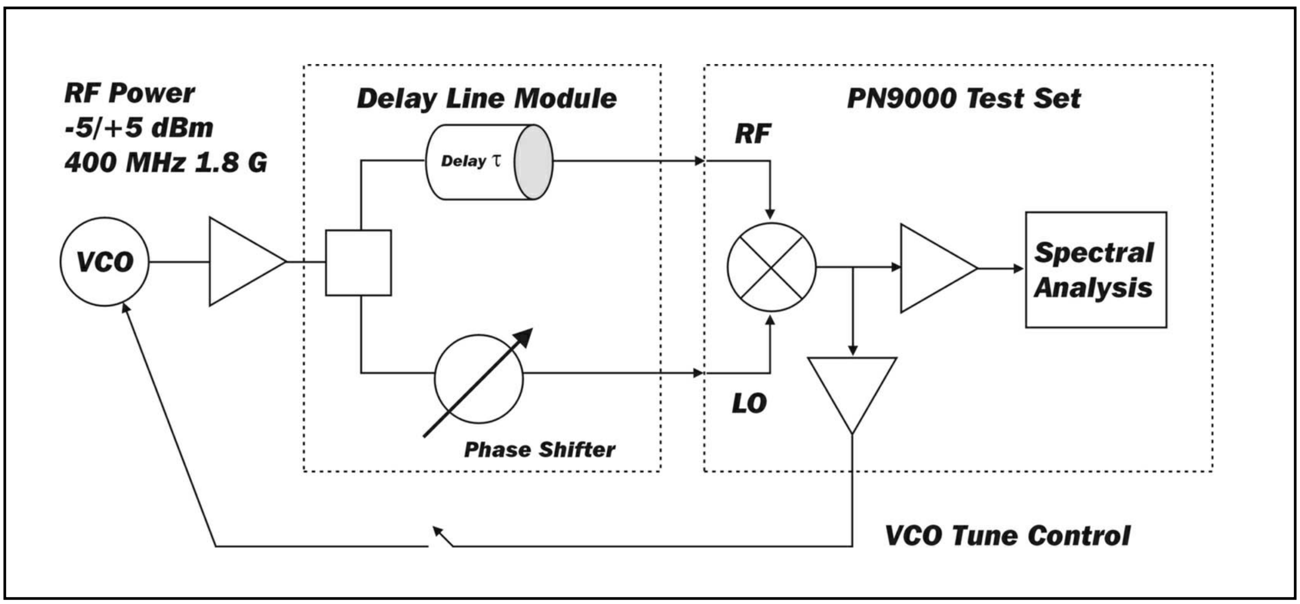
The PN9240 to PN9245 provide free running LOs and built-in mixers, to down-convert free running sources from 1.6 to 18 GHz.

Residual Phase Noise Comparison table between the MW Measurement Solutions

Offset	***PN9273 (PLL)***	***9 GHz*** ***PN9100 (Synth.)***	***PN9242 (Free run)***	***PL9273 (PLL)***	***18 GHz*** ***PN9100 (synth.)***	***PN9243 (Free run)***	***PN9274 (PLL)***	***26 GHz*** ***PN9100 (H3)***	***PN924X (Free run)***
1 Hz	- 52	- 30	NA	- 46	- 30	NA	- 42	- 20	NA
10 Hz	- 80	- 60	NA	- 74	- 60	NA	- 70	- 50	NA
100 Hz	- 96	- 81	NA	- 90	- 81	NA	- 86	- 71	NA
1 KHz	- 120	- 106	- 75	- 114	- 103	- 70	- 110	- 96	NA
10 KHz	- 132	- 112	- 108	- 126	- 105	- 103	- 122	- 102	NA
100 KHz	- 133	- 112	- 127	- 127	- 105	- 122	- 123	- 102	NA
1 MHz	- 144	- 130	- 152	- 138	- 124	- 147	- 136	- 120	NA
10 MHz	- 157	- 150	- 158	- 151	- 150	- 152	- 147	- 140	NA

Residual noise is in dBc/Hz. For other frequencies, refer to the option data sheets.

VCO Measurements



The Delay line method acts as a frequency discriminator. Since a delay is a linear phase shift with frequency, the frequency fluctuations of the VCO are converted into a noise voltage at the output of the phase detector. After the spectral analysis has been performed, the system transforms the frequency spectrum into the equivalent phase spectrum and displays the curve in the same format as with the direct phase demodulation method. The conversion is inversely proportional to the offset frequency squared, 1/f2 . Due to this conversion, the residual white noise of the test set is transformed into a 1/f2 noise. The sensitivity of this demodulation decreases by 20 dB per decade as the offset frequency of measurement decreases (see curve).

This method is very useful for measuring sources that have a high amount of frequency drift, such as free running VCO. A 100 nsec delay line allows 250 kHz frequency drift without affecting the measurement accuracy. It also enables the measurement of a source without a lower noise reference source, but if the residual noise shape of the delay line method is adapted to a VCO phase noise spectrum, it is not an adequate method for synthesized sources which present lower close in phase noise.

The demodulation is proportional to the length of the Delay Line (τ):

$$\text{Noise Voltage } (f_m) = K_\Phi \, 2\pi\tau \, \Delta f\,(f_m)\,[\sin(\pi\tau\, f_m) / (\pi\tau\, f_m)]$$

KF = phase detector demodulation factor

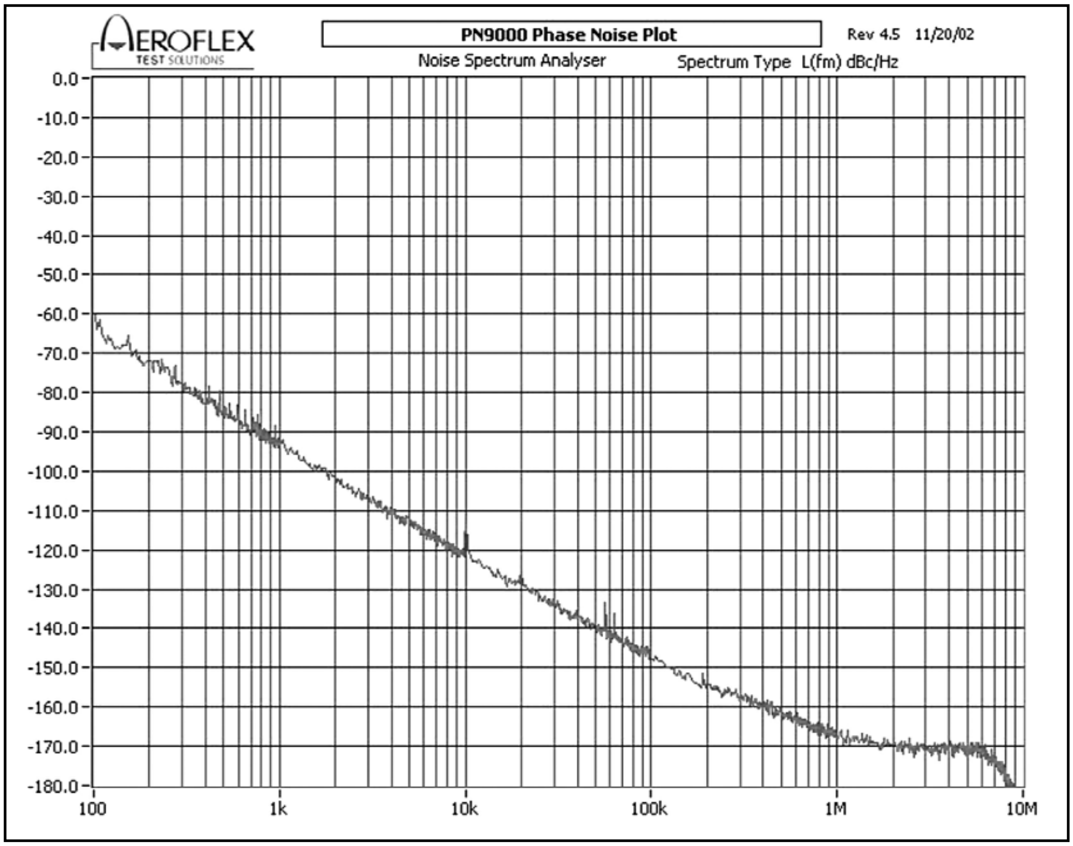
$\Delta f\,(f_m)$ = frequency fluctuations of the VCO, function of the offset.

The PN9000 software corrects the $[\sin(\pi\tau\, f_m) / (\pi\tau\, f_m)]$ transfer function up to about fm = $1/2\tau$

$$\text{Noise Voltage } (f_m) = K_\Phi \, 2\pi\tau \, \Delta f\,(f_m) \quad \text{up to } f_m = 1/2\tau\ .$$

The compromise of this method is between the sensitivity proportional to τ and the maximum offset frequency of the measurement inversely proportional to τ. The PN9000 system proposes different values for the delay line:

- 100 nsec: sensitivity -148 dBc/Hz at 100 kHz offset, Foffset max = 5 MHz, VCO drift 250 kHz
- 20 nsec: sensitivity -135 dBc/Hz at 100 kHz offset, Foffset max = 25 MHz, VCO drift 1.25 MHz
- 20 nsec: sensitivity -170 dBc/Hz at 20 MHz offset.



MEASUREMENT PROCESS

The VCO is connected to the Delay Line module input and the signal is amplified to +20 dBm with a limiting power amplifier.

The phase detector demodulation factor expressed in Volts per radian has to be measured to refer the spectral density of the phase noise to 0 dBc/Hz, which represents the carrier power or 1radian rms of phase jitter.

In case of a two-source configuration, a beat note frequency is set between the two paths RF and LO. The system then measures the phase slope at 0Volt crossing, corresponding to the quadrature condition. For the Delay Line configuration with only one source, one of the easiest solutions is to adjust the two paths in quadrature and move the phase between the two paths, RF and LO, by a calibrated amount DF and measure the DC voltage DV at the output of the phase detector:

Demodulation factor $K_{\Phi} = \Delta V / \Delta\Phi = \Delta V / 2\pi F_o \Delta\tau$

With F_o the VCO carrier frequency.

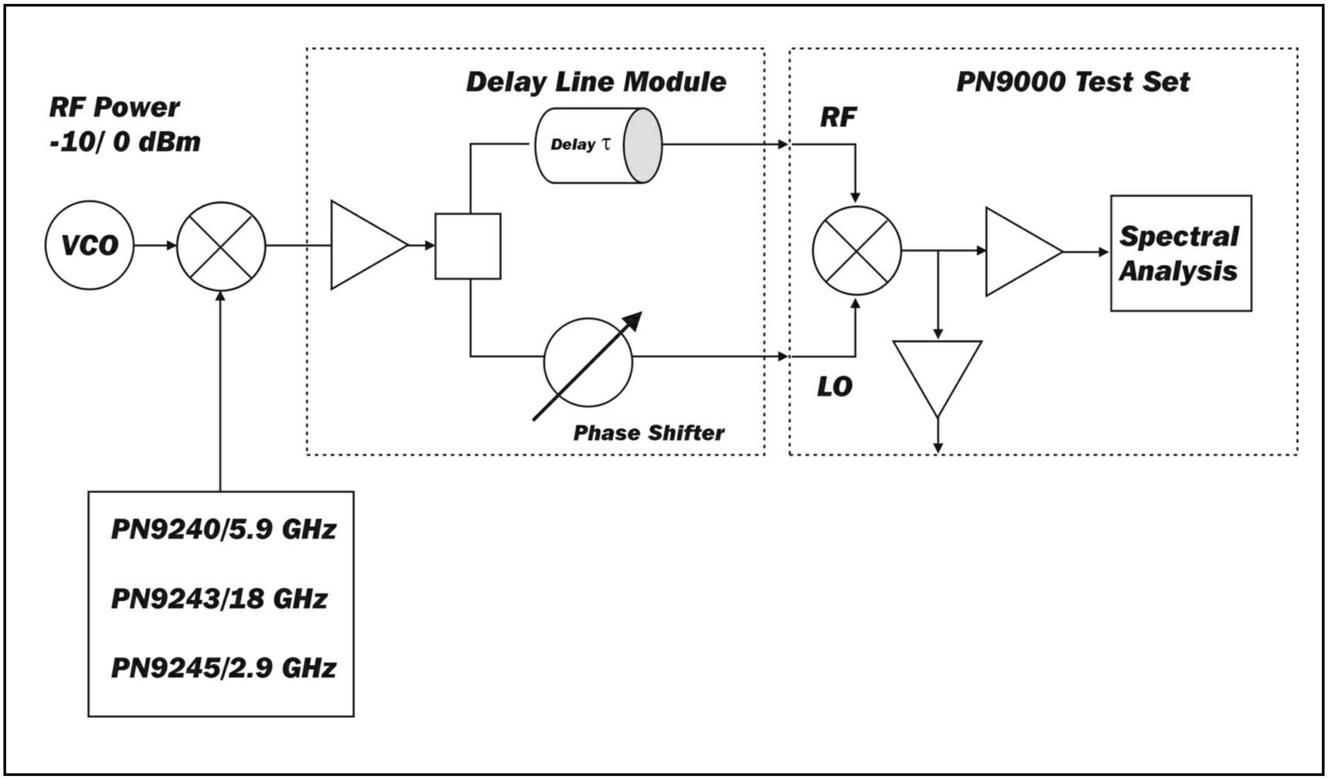
F_o is measured with the internal RF frequency counter.

The electronic phase shifter operates automatically this quadrature adjustment and measurement.

The losses of the Delay Line are proportional to the carrier frequency. Above 1 GHz the sensitivity decreases by 20 log (1 GHz / Fo GHz).

In case of large frequency drift, the VCO can be locked by the Voltage Control to maintain the quadrature condition without affecting the spectrum above 100 Hz offset.

Down-conversion VCO measurement



The standard input frequency range of the Delay line modules is 250 MHz to 2 GHz. The microwave frequency range has to be down-converted to this base band. A family of VCO down converters are available. Their free running LO provides a very low residual noise far away from the carrier (see Delay line datasheet).

In addition, when available, the PN9100, a 2 MHz to 4.5 GHz synthesizer, or the PN9273/4 or PN9253/4 Microwave down converter can also be used to down-convert a microwave VCO/DRO signal up to 26.5 GHz. Considering 2 GHz as the maximum beat frequency, the PN9100 can down convert VCO up to 6.5 GHz.

PHASE NOISE SPECTRUM CONSIDERATIONS:

The phase noise spectrum has to be compatible with the VCO specifications. It is important to consider the standard shape of the phase noise spectrum. A free running VCO presents mainly two slopes: 30 dB (close to the carrier) and 20 dB per decade.

DROs, Dielectric Resonator Oscillators, have the best phase noise, provided they are free running (no DC voltage frequency control).

The global phase noise spectrums of the PN924x reference sources are perfectly appropriate for VCO measurements.

A synthesized source presents lower noise close to the carrier (<10 kHz), but higher phase noise far from the carrier (>100 kHz). This spectrum is not perfectly adapted to VCO specifications. Generally a large pedestal noise floor due to the synthesis provides a phase noise rise in the range of 100 kHz from the carrier.

Conclusion: In terms of phase noise spectrum adapted to free running VCO phase noise measurements, the PN924x family provides the lowest phase noise. However, the PN9100 (up to 4.5 GHz) or the PN9273/74 (up to 18/26.5 GHz) can be used taking into account their phase noise specifications in the offset range of 100 kHz to 10 MHz offset from the carrier.

INTERMODULATION CONSIDERATIONS:

The input of the mixer generates intermodulation mainly because it is a wide band mixing scheme.

Intermodulation spurious can occur between the VCO and the reference source, but also with all the harmonics. One standard solution to reduce these spurious is to operate with a low input signal to optimize the mixer intermodulation, but this condition is opposite with low noise floor measurement. Another solution is to slightly move one of the frequencies (VCO or reference source) to reject the spurious out of the measurement span.

ADVANTAGES / DISADVANTAGE FOR VCO MEASUREMENTS :

PN924x family: frequency range up to 18 GHz. Good spectrum adapted to the shape of VCO. Fixed value not tunable in case of intermodulation.

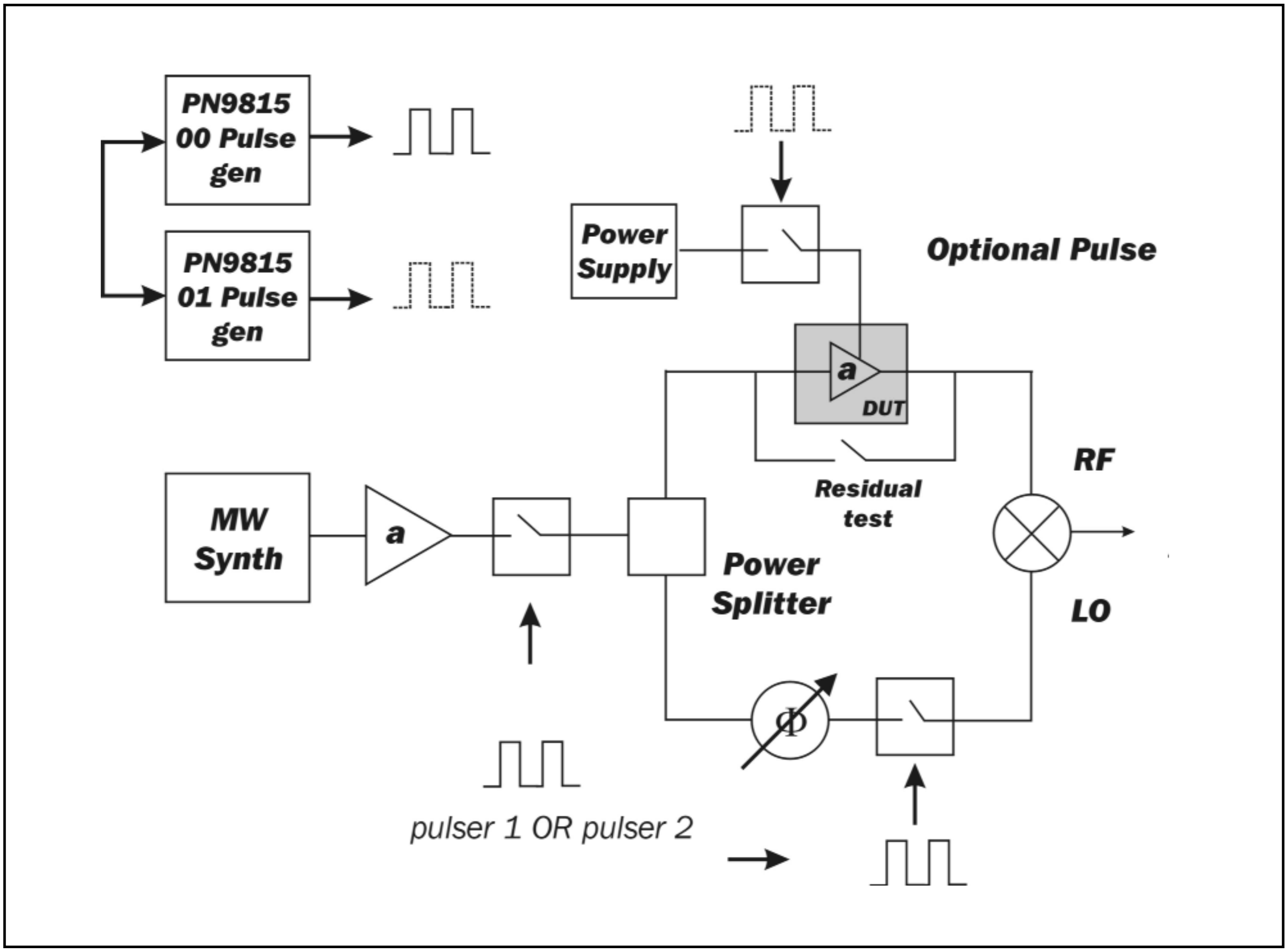
PN9100: frequency range up to 4.5 GHz with variable frequency tunable. In case of intermodulation, the PN9100 frequency can be moved to reject the intermodulation out of the span. Good spectrum close to the carrier.

Phase noise limited to -124 dBc/Hz at 100 kHz from the carrier at 4 GHz.

Source compatible with very low noise synthesized sources measured with the phase demodulation method.

PN927x / PN925x: frequency range up to 18 GHz or 26.5 GHz on option. Good spectrum close to the carrier. Source compatible with very low noise synthesized microwave sources measured with the phase demodulation method.

Phase noise limited to -139 dBc/Hz at 100 kHz from the carrier at 4 GHz.



Depending on the measuring configuration, pulse modulator 1 or 2 are used. When no signal is connected to their input, they are ON (CW mode).

This method quantifies the amount of noise added to a signal as it passes through a DUT.

The technique of measurement is the same as the Residual Test of the phase detector method, determining the noise floor of a system.

A Residual Test (DUT bypassed) is performed by dividing the source output with a power splitter "Sp" and phase shifting one path "Ps" by 90°. The two signal paths RF and LO enter the mixer in quadrature with correlated phase fluctuations. The measured noise is only generated by the test set itself as long as the delay difference of the signal paths is minimized to reject the Source frequency (or phase) noise.

In case of Added Noise measurement, the DUT is inserted in the RF path so that the measured noise is the sum of the residual noise (DUT bypassed) and the added noise of the DUT.

This measurement can be performed under CW or Pulsed conditions.

The different parts of the setup are:

Source (microwave synthesizer)

The Source is at the test frequency. Its absolute phase noise is reduced by the correlation factor given by 20 log ($2 \pi \tau F_m$).

With τ = delay difference of the two paths, F_m = frequency offset

Example: absolute phase noise of the Source = -50 dBc/Hz at 100 Hz from the carrier, t = 10 ns and Fm = 100 Hz, correlation factor = -104 dB, the noise floor only due to the Source is -50 dBc/Hz -104 dB = -154 dBc/Hz at 100 Hz from the carrier.

Another caution is the AM noise of the Source, the phase detector has approximately only 30 dB AM rejection. AM contribution can be estimated by setting the two paths in phase. In this condition the mixer demodulates the AM noise. From this noise only 30 dB reduction can be achieved when the two paths are in quadrature.

Power Amplifier "A" (+20 dBm)

To achieve a good dynamic, the PN9000 has a high level phase detector requiring LO power >+15 dBm and RF power >+10 dBm which correspond to approximately +20 dBm before the power splitter. A power amplifier is needed because the majority of the microwave sources don't provide +20 dBm output power.

Pulser "Pu"

If the DUT is operating under pulsed conditions it is better to provide pulsed signal on the two paths. This way the DC offset and the internal phase noise of the phase detector are minimized.

Isolator "Is"

An isolator can be inserted in the RF path to prevent bad SWR at the input of the DUT.

Phase shifter "Ps"

The phase shifter can be mechanical or electrically tunable. This phase shifter is used for two purposes: to adjust the phase to measure the demodulation factor and to adjust the phase to set the quadrature. An electrical phase shifter presents two limitations: its internal added noise can be too large and the maximum input power can be too low to be compatible with the high-level phase detector

The PN9000 provides three main advantages when testing Added Phase Noise under pulsed conditions:

A PRF video filter can be inserted between the phase detector and the low noise amplifiers.
The low noise amplifiers support a large voltage swing.
The High Level mixer provides a high demodulation factor.

These features permit the best dynamic under pulsed conditions.

The process of measurement is the same as CW, except that in the calibration process the video filter has to be selected. The system takes into account the loss of sensitivity due to the Duty Cycle and the spectrum is then normalized.

Hardware Configuration

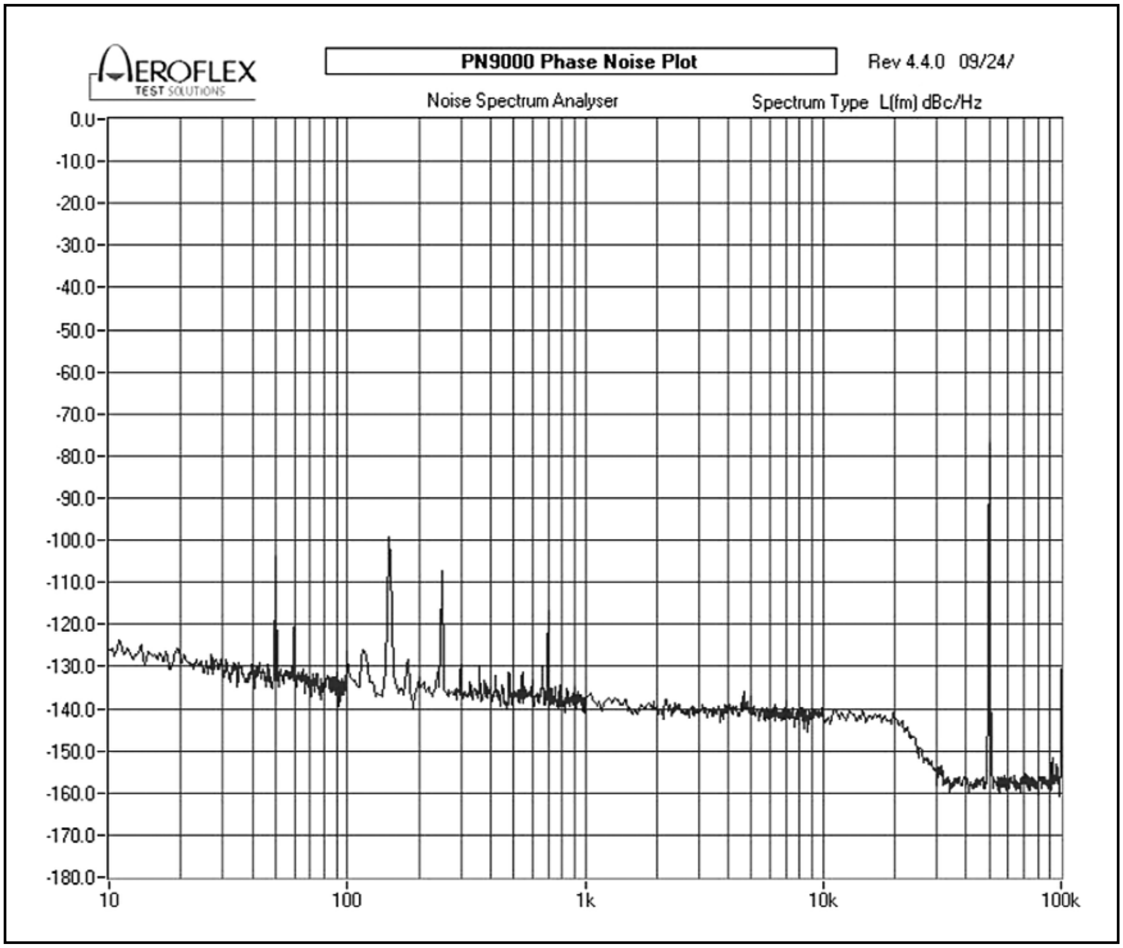
The PN9000 family offers an "ADDED NOISE" option including:

A Power Amplifier, a Pulser, a Power Splitter, a Phase Shifter, a Pulse generator with low jitter and video filters. The pulse generator includes an external trigger and auxiliary output to drive the DUT with a programmable delay 20 ns to 1 ms between the microwave pulse and the DUT pulse.

The PN9100 Low noise synthesizer is the adequate Source providing the lowest phase and amplitude (AM) noise.

The phase noise test set PN9000, the Added noise module and the PN9100 are housed into a standard 3U chassis, offering a compact system including all the hardware to perform Added noise measurements.

Pulsed CW Source phase noise



This plot shows the measurement of a 3.5 GHz signal modulated by the PN9815. PRF is 50 kHz and the duty cycle is 5%.

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

LOSS OF POWER

The average, or rms power, decreases as a function of the duty cycle of the pulse signal. The exact same process happens to the demodulation factor. Its variation is given by the formula 20 log (duty cycle). Thus, for 10 % duty cycle the demodulation factor (and noise floor) is 20 dB lower (higher) than it is in CW, and for 1% duty cycle it is 40 dB difference (add +40 dB to a CW residual noise floor !). To display the real noise of the modulated signal the software will have to compensate by computing an offset corresponding to the duty cycle. This is why the software menu needs the duty cycle value (or also called "pulse ratio")

In general this is not a problem because pulsed sources are mostly in MW range and have higher phase noise than RF sources. However, attention must be paid to it.

The system also has to compensate for the loss of 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 additional gain adjustment, used only for calibration.

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 amplify 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 problems.

DC OFFSET OF THE DETECTED PHASE NOISE SIGNAL

When the reference source is in CW mode and the DUT is on pulse, the DC offset voltage at the output of the phase detector can be larger than the useful beat signal. Sometimes this beat signal never crosses 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. There is 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, a single slot module, has been designed to prevent this problem. It includes two functions: a pulse generator and a microwave pulse modulator.

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 waveforms.

The microwave pulse modulator, driven by the pulse generator, can be used for two purposes: to generate a pulsed signal from a CW signal and to generate a pulse window allowing measurement with a shorter duration than 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.

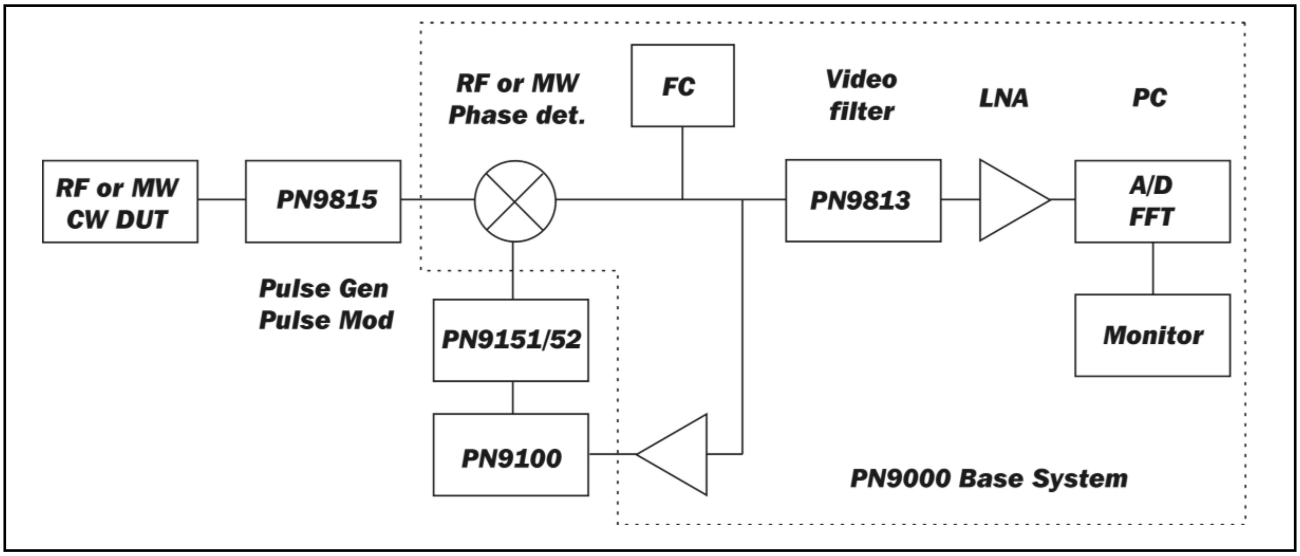
The PN9813 option, a single slot module, offers 5 video filter values, selected from the software. The values must be specified by the customer when ordering the system. Additional values can be provided in a second module, at any time.

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 about 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 CW signal, the base system residual noise will increase by 20 dB, i.e. - 145 dBc/Hz, which still measures very clean radar sources. With a 1% duty cycle it will be reduced to - 125 dBc/Hz.

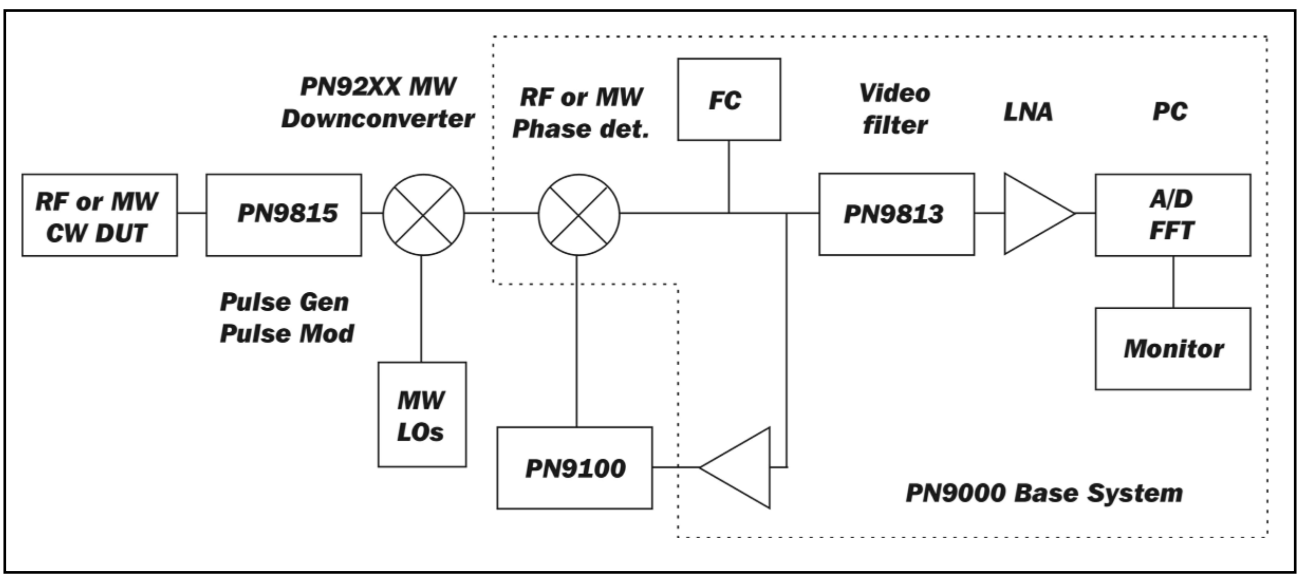
MEASUREMENT METHODS

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 GHz depending on the PN9100 options implemented in the system.

MW signal down converted to the RF Frequency range



This method uses a MW down converter, PN9273/74, to down-convert 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 PN9273/74 datasheets for the specs,
- The built-in counter will measure RF, LO inputs and IF beat output of the standard RF phase detector. This makes LO tuning to the RF input frequency much easier.

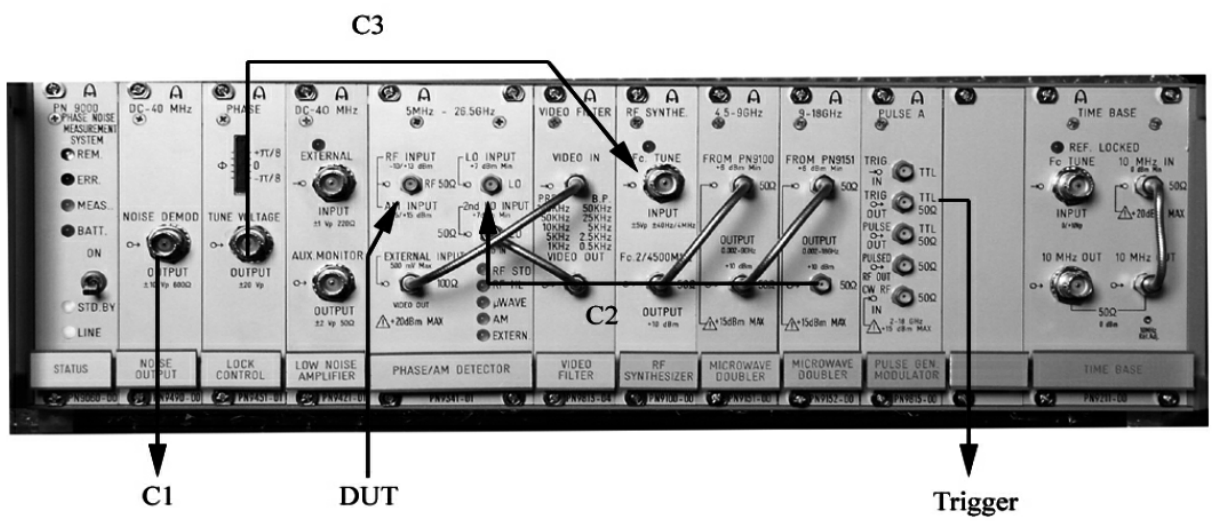
If the DUT is already a pulsed signal, the PN9815 can be removed, but the pulse generator waveform of the PN9815 can still be used to drive the DUT pulse modulator.

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. 40 dB attenuation of the PRF is needed, to not saturate the low noise amplifier.

The valid span analysis is half the PRF, example PRF= 100 kHz, use the video filter 50 kHz in the menu "System/Pulse". The valid span analysis is then 50 kHz.



Example of a configuration with direct phase noise detection

Note: The PN9100 output is connected to the input of a PN9151 doubler, extending the range of the PN9100 to 9.0 GHz. A PN9152 would extend it to 18 GHz. Obviously, if the configuration includes a MW down converter, the PN9100 output is connected directly to the LO input of the phase detector.

The DUT signal is already pulse modulated

In that case, the DUT signal will be connected to the Phase detector input, in case of direct phase noise detection, or to the MW DUT input when a down converter is used. Then it is possible to use the PN9815 to pulse modulate the LO reference also. This has the advantage to suppress the DC offset. The PN9815 will use an external trigger and delays will be used to synchronize the RF and LO pulses. The duration of the two pulses must be the same. A dual trace scope might be necessary to achieve these adjustments. For more details, see the PN9815 datasheet.

Phase Noise

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