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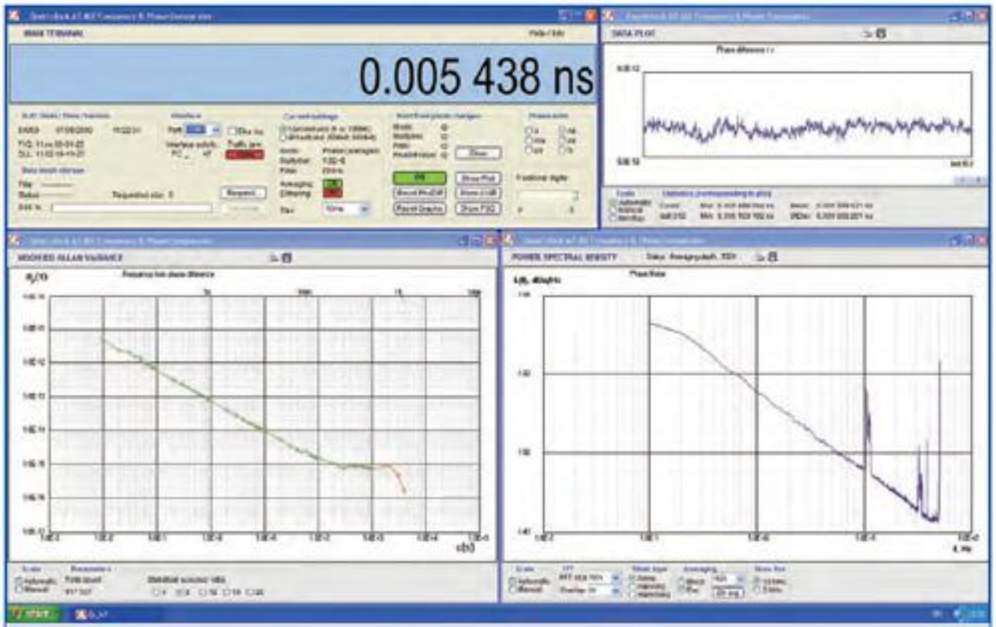
Quartzlock Signal Stability Analyzer Model A7-MX Has Lowest Noise Level Available in Easy to Use Flexible Package

By Quartzlock

The A7-MX is a bench or rack mount instrument which interfaces with most notebook or desktop PCs, using an RS232 or USB interface on the computer. The instrument includes a differential multiply and mix chain, and a 2 channel digital phase comparator. An analogue meter shows frequency offset or phase difference.



All displays, Phase data, Stability/Allan Variance & Close-in Phase Noise may be maximized

There are 2 inputs on the front panel. One of these is for the phase/frequency reference which will often be an atomic frequency standard. The reference frequency can be 5 or 10MHz with automatic switching. The other input is for the measurement signal, also 5 or 10MHz, also with automatic switching.

There are push-button controls for phase/frequency mode, multiplier ratio, filter selection, sampling rate (tau) and phase reset. There are also a number of controls which adjust the analogue meter function. There are indicator lights to confirm that the reference and measurement inputs are at the required level, and that the internal phase locked multipliers are locked. The analogue meter shows fractional frequency difference with full scale ranges from +/-1x10-7 to +/-1x10-12, and phase differences with full scale ranges from +/-10us to +/-100ps.

When the instrument is connected to a PC, the control positions are read by the PC and displayed on the virtual control panel.

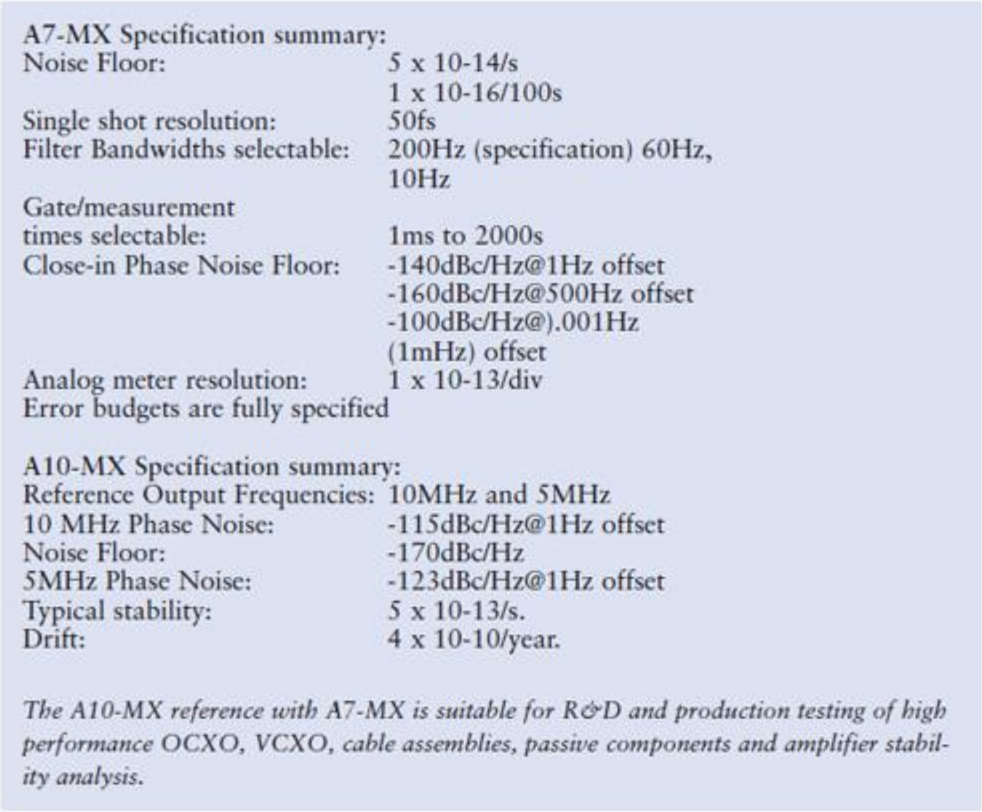
On the rear panel is the broadband frequency input which can be between 50 kHz and 65 MHz. Also on the rear panel are outputs to an external timer/counter, and a switch which adjusts the analogue meter time constant.

The instrument has two main modes; narrowband, high resolution; and broadband. The selection between these modes is made on the PC virtual control panel.

In narrowband, high resolution mode, the measured signal must be at 5 or 10MHz. In this mode, the instrument uses multiply and mix techniques to increase the fractional frequency difference (or phase difference) between the measured input and the reference. This improves the resolution of the digital phase comparator, and results in a theoretical phase resolution of 0.125fs. The actual resolution is noise limited to about 50fs. The corresponding fractional frequency resolution is 1x10-13 in one second of measurement time.

In broadband mode, the multiply and mix is not used. The digital phase comparator makes direct phase measurements with a resolution of 12.5ps. This is comparable to the fastest frequency counters and gives a fractional frequency resolution of 3x10-11 in one second of measurement time, or 2x10-12 with averaging switched on.

When connected to a PC, the software provides 4 scalable windows. One of these is the virtual panel and digital display. The other 3 are data plot, Allan variance plot, and phase spectral density (phase noise) plot.



A7-MX Specification summary:

Noise Floor:	5 x 10-14/s 1 x 10-16/100s
Single shot resolution:	50fs
Filter Bandwidths selectable:	200Hz (specification) 60Hz, 10Hz
Gate/measurement times selectable:	1ms to 2000s
Close-in Phase Noise Floor:	-140dBc/Hz@1Hz offset -160dBc/Hz@500Hz offset -100dBc/Hz@).001Hz (1mHz) offset
Analog meter resolution:	1 x 10-13/div

Error budgets are fully specified

A10-MX Specification summary:

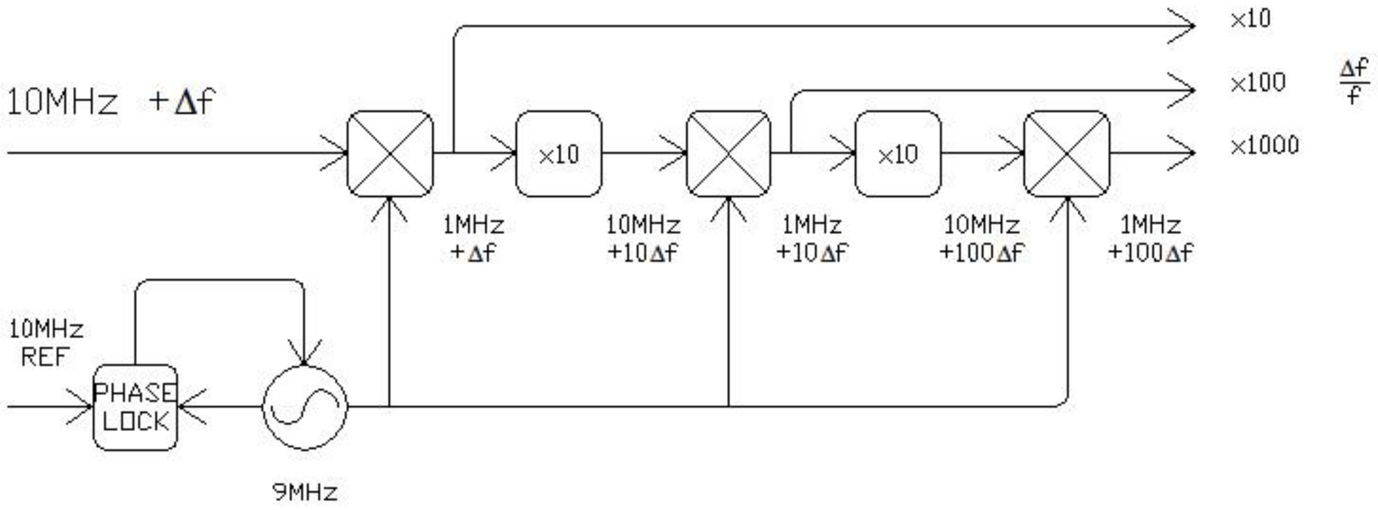
Reference Output Frequencies:	10MHz and 5MHz
10 MHz Phase Noise:	-115dBc/Hz@1Hz offset
Noise Floor:	-170dBc/Hz
5MHz Phase Noise:	-123dBc/Hz@1Hz offset
Typical stability:	5 x 10-13/s.
Drift:	4 x 10-10/year.

The A10-MX reference with A7-MX is suitable for R&D and production testing of high performance OCXO, VCXO, cable assemblies, passive components and amplifier stability analysis.

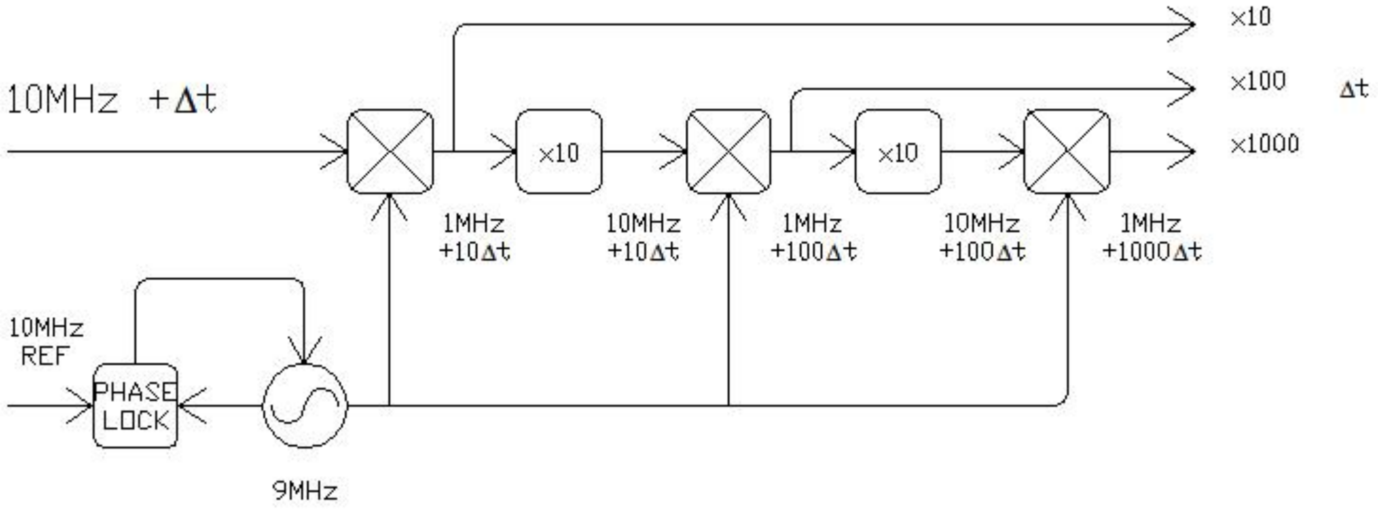
A7-MX Technical Description

The principle behind the A7-MX is to increase the resolution of a digital phase meter. This is achieved by multiplying the frequency to be measured to a higher frequency, and then mixing it down to a lower frequency using a local oscillator derived from the frequency reference. The principle is illustrated in **Figure 1**, and has been made the basis of a number of instruments in the past. The relationship is shown for signals down the mix/multiply chain for an input signal with a difference of delta f from the reference, and also for a signal with no frequency difference, but with a phase difference of delta t. (An important clarification is that phase difference between two signals can be measured either in time units or angle units. A measurement in time units does not specify or imply the frequency of the signals. A measurement in angle units (radians) needs a prior knowledge of the frequency. (Throughout this description, phase will be measured in time units). It should be noted that a frequency multiplication multiplies a frequency difference but leaves a phase difference unchanged. Conversely, a mixing process leaves a frequency difference unchanged, but multiplies a phase difference. When the frequency differences are converted to fractional frequency differences by dividing by the nominal frequency, it will be seen that the multiplication factors for frequency and phase are the same.

The big disadvantage in the simple approach shown in **Figure 1** is that phase drift with temperature will be excessive. As rate of phase drift is equal to the fractional frequency difference, the measurement of the frequency of an unknown device will be in error. For example, a drift rate of 10ps per second in the first multiplier in the **Figure 1** diagram will be multiplied to 1ns per second at the output. This is equivalent to a 1 x 10-12 frequency error due to drift. Phase drift may occur in mixers and multipliers, but especially in multipliers. If harmonic multipliers are used, drift will occur in the analogue filters that are used to separate the wanted harmonic from the sub harmonics and unwanted mixer products. If phase lock multipliers are used, phase drift will occur in the digital dividers.



Typical Mix/Multiply Chain Showing Frequency Relationships



Typical Mix/Multiply Chain Showing Phase Relationships

Figure 1

To overcome the drift problem, the multiplier/mixer chain is made differential, i.e. the reference signal is processed in an identical way to the unknown. When the two channels are subtracted, any drift in the multipliers will cancel. The method of doing this can be seen from the functional block diagram of the A7-MX, **Figure 2**. The first stage of the processing for both the reference and measurement channels is a multiplication by 10 (20 for 5MHz inputs). The multipliers are phase locked loops with a VCXO of 100MHz locked to the input by dividing by 10 (20 for 5MHz inputs). The phase detectors used are double balanced diode mixer type phase detectors. These exhibit the lowest phase drift with temperature. The dividers used are ECL types with very small propagation delays. The outputs of the dividers are re-clocked using a D type flip-flop clocked by the 100MHz VCXO signal. In this way, the divider delay is made equal to the propagation delay of one

D type, approx 500ps. As a further refinement, the re-clocking D types for the reference and measurement channels are closely thermally coupled. As the divider propagation delays are equal to the re-clocking flip-flop delays, the tracking between the reference and measurement channels is exceptionally good.

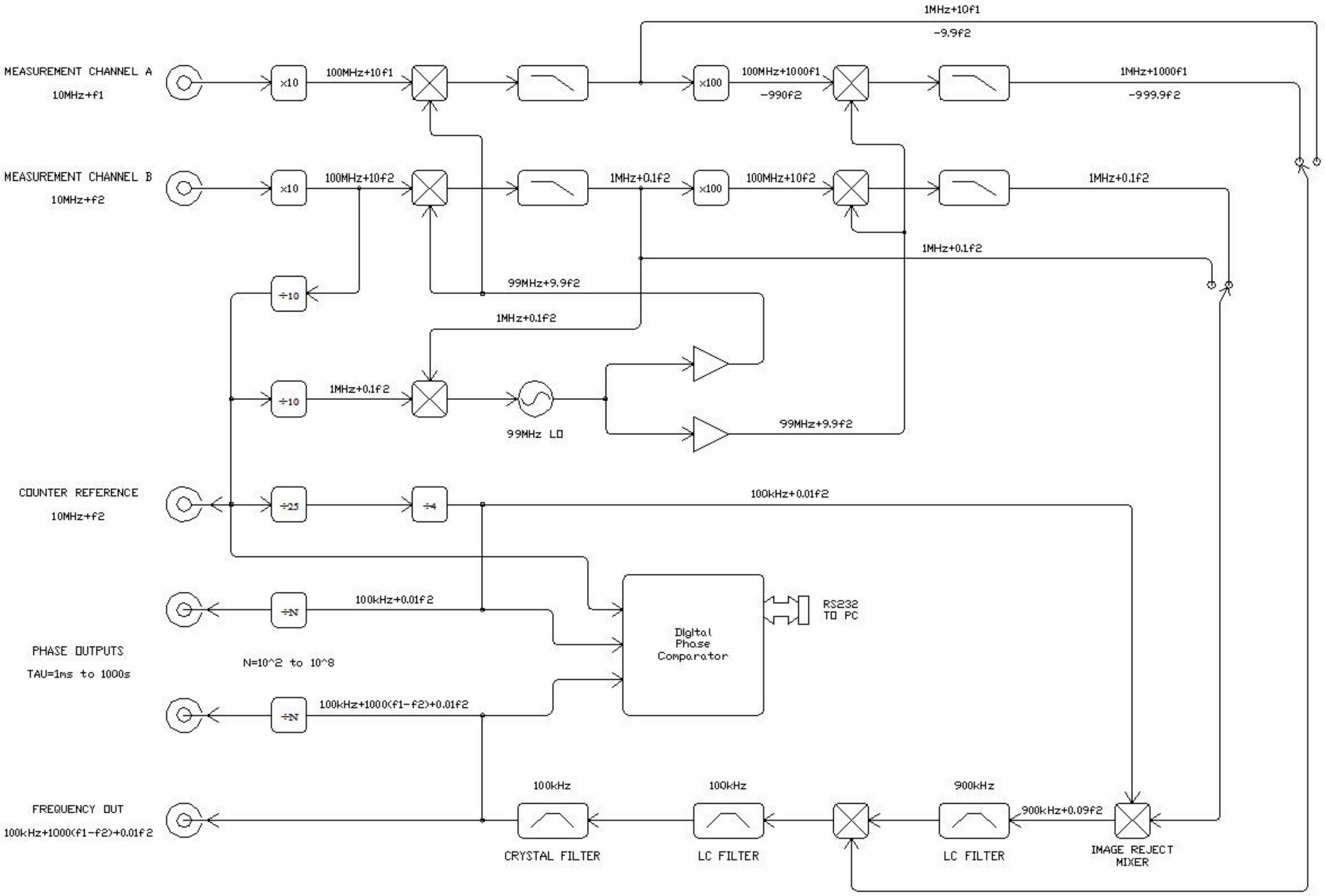


Figure 2

The VCXO signals at 100MHz also drive double balanced FET mixers for the first down conversion to 1MHz. The 99MHz LO is common to both the reference and measurement channels, and is obtained from a 2 way passive inductive type power splitter. The output from the mixers is filtered by diplexer type filters to remove the image at 199MHz and the signal and LO feed through at 100MHz and 99MHz, respectively. The wanted IFs at 1MHz are passed without further processing to the second multipliers. The avoidance of IF amplifiers at this point avoids drift, which could be substantial as the propagation delay of the IF amplifier could be several 100 nanoseconds. IF amplifiers are used for the first IF take off points to the IF processing board. The first IFs are used when a multiplication of 103 is selected.

The second multipliers are nearly identical to the first multipliers, with the difference that the phase lock loop dividers divide by 100. This multiplies the first IF of 1MHz to the second VCXO frequency of 100MHz. The second down convert is identical to the first, with the second IFs being passed to the IF processing board.

The first and second multipliers/mixers for the reference and measurement channels are built symmetrically on one PCB (Printed Circuit Board). In order to ensure the best possible temperature tracking between the channels, the PCB is in good thermal contact with a thick metal base plate. This minimizes rapid temperature changes between the channels.

The two pairs of IF signals (sine wave) are passed to the IF processing PCB. The two pairs are the outputs from the first and second down convertors. They correspond to final multiplication factors of 103 and 105. Also on the IF processing board is the 99MHz LO generation and phase lock. A 10MHz un-multiplied signal is passed to the IF processing board from the reference channel on the multiplier board.

The 1MHz IFs could be divided down and measured directly by the frequency counter, which would make a time difference measurement between the measurement and reference IF signals. In this way, the difference between the channels would be measured and any drift would cancel. Although this would work for a phase measurement, there would be no way of making a conventional frequency measurement. The IFs cannot be directly subtracted in a mixer as they are both nominally 1MHz, and the nominal difference frequency would be zero. In order to avoid this problem, the multiplied reference IF is frequency shifted to 900 kHz using an LO of 100 kHz derived from the un-multiplied reference. The 900 kHz is then mixed with the 1MHz measurement channel IF to give a final IF of 100 kHz. This final IF contains the multiplied frequency difference, but drift in the multipliers and phase noise in the common 99MHz LO will have been cancelled out.

The detailed process is as follows:

The 10MHz reference from the multiplier board (this is derived from the reference input without multiplication) is divided by 25 to 400 kHz. The 400 kHz is then divided by 4 to give two quadrature signals at 100 kHz. These signals are filtered using low pass filters to give 100 kHz quadrature sine waves. The 1MHz multiplied reference IF (after limiting) is delayed by 250ns to give quadrature square waves. These operate dual switching mixers with the 100 kHz quadrature sine waves as the linear inputs. The outputs are combined to form an image reject mixer, with the wanted sideband at 900 kHz and the unwanted sideband at 1.1MHz. The 900 kHz sideband is filtered in an LC band pass filter to further remove the unwanted sideband and the 1MHz feed through. This output is used as the linear input to a further switching mixer which down converts the 1MHz multiplied measurement IF (after limiting) to the final IF of 100 kHz. The final IF is filtered in an

LC band pass filter to remove the unwanted sideband at 1.9MHz and any other mixer products. The measurement and reference channels have now been combined into a single IF of 100 kHz with the drift and LO instabilities removed. This IF is now further processed to provide the counter outputs as will be described in the next paragraphs.

The measurement bandwidth of the system has been defined up to this point by the loop bandwidths of the phase lock multipliers and the bandwidth of the 100 kHz LC filter. The 3dB bandwidth is about 8 kHz. This means that Fourier frequencies further displaced from the carrier of greater than 5 kHz will be attenuated. The phase measurement process essentially samples the phase of the unknown signal relative to the reference at a rate determined by the selected tau (selectable from 1ms to 2000sec). As with any sampling process, aliasing of higher frequency noise into the baseband will occur. Thus, further band limiting of the 100 kHz IF is desirable before measurement takes place. The A7-MX has a crystal filter following the LC filter with selectable bandwidths of nominally 10Hz, 60Hz, and 200Hz. For most Allan variance plots at least the 200Hz filter should be used. The use of a filter will reduce the noise floor of the instrument, which is desirable when measuring very stable active sources and most passive devices.

After the crystal filter, the 100 kHz IF is limited to a square wave by a zero crossing detector. This output is made available to the counter A channel when frequency mode is selected. Both the 100 kHz IF containing the multiplied frequency difference information and the 100 kHz un-multiplied reference are divided in identical divider chains down to 1 kHz to 1 MHz in selectable decade steps. The output of the dividers trigger digital (clocked) monostables to generate 10us pulses which are routed to the counter A and B channels when phase mode is selected.

When the internal digital phase comparator is in use, the phase of both the 100 kHz reference and the 100 kHz multiplied IFs are measured relative to the un-multiplied 10MHz reference. The digital phase comparator then calculates the resulting phase difference or fractional frequency offset depending upon the selected mode. The digital phase meter also applies averaging if selected. It has internal storage sufficient for 32768 measurements. The RS232 interface to the computer uses full handshaking to prevent data loss. The internal phase comparator has a resolution of 12.5ps, obtained by using an analogue pulse expander circuit.

The meter circuit also uses the 100 kHz IF and 100 kHz reference. The basis of the circuit is a differential frequency to voltage convertor. However, in order to increase the resolution of this circuit, a further stage of multiplication and mixing is employed. The 100 kHz reference is divided down to 500Hz. This frequency is then multiplied to 4.9995MHz using a phase lock loop with a divider of 9999. The 100 kHz measurement IF is multiplied to 5MHz, also using a phase lock loop. Finally, the 5MHz signal and the 4.9995MHz signal are mixed together to give an IF of 500Hz. An additional fractional frequency multiplication of 104 results. On the least sensitive meter range this 500Hz IF varies in frequency from 0Hz to 1 kHz. The 500Hz measurement IF and the 500Hz reference both trigger digital monostables which produce very accurate fixed width pulses. These pulses are used to gate an accurate positive and negative current into a chopper stabilized summing amplifier. The output of the summing amplifier is a voltage which drives the moving coil centre zero meter. The meter circuit has 4 decade ranges which, in conjunction with the 2 multiplication factors of the main comparator, results in 6 meter ranges with full scale deflections of 10-7 to 10-12.

The meter time constants are linked to the meter range, however they may be increased if desired using a switch mounted on the rear panel.

The virtual panel provides control of measurement rate (tau), and mode (narrowband, high resolution; or broadband). Repeater indicators are provided to show the settings of controls on the physical instrument. It is possible to store blocks of measurements up to 32768 measurements into a computer file. Once a measurement is started, the instrument will store the complete measurement block internally, provide power is maintained. This makes certain that data is never lost, even if the computer crashes and has to be restarted. In order to make sure that a long measurement run is not interrupted by a power failure, the instrument may be powered from a battery supply of 24V. This will automatically be used if line power should fail.

The digital display shows phase or fractional frequency offset, depending upon mode. The units and number of significant digits is adjustable.

Averaging mode may be selected from this window. If averaging is off, the digital phase comparator makes single measurements at the selected sampling rate. If averaging is on, the comparator operates at the maximum sampling rate of 1ks/s. A block average reduces the data rate to the selected sampling rate.

Dither mode may be selected from this window. Dither is a technique which reduces unavoidable internally generated spurii to below the noise floor, at the expense of an increase in noise floor. (For further details, see operating manual).

The data window shows real time accumulation of the data as a graph. The last 8 to 32768 data points may be shown on the graph. A statistics display shows max, min mean, and standard deviation for the data shown on the graph. The scaling of the y axis may be auto, manual, or max/min.

The Allan variance window shows calculated Allan variance for all data accumulated since the start of a run. If averaging is off, single phase measurements are made at the requested sampling rate and the statistic is true Allan variance. If averaging mode is on, the statistic becomes modified Allan variance. The graph title correctly indicates this.

The Phase Spectral Density (PSD) window shows phase noise as a graph of L(f) in units of dBc against offset frequency on a log scale. Various window functions and averaging modes are provided. The routines are identical to those used in the industry standard software Stable32.

The user can select the basic length of the FFT, and also the degree of overlap. As data is accumulated, new FFTs are performed on a mix of old and new data, depending on the overlap parameter.

Each FFT result can either replace the last graph, be added to a block average, or be used in a continuous or exponential average.

All FFTs are correctly normalized for bin bandwidth, window ENBW, window coherent gain, and nominal frequency.

Frequency data always has a fixed offset removed before being used for the FFT calculation. Phase data has a fixed slope ramp removed by linear regression. This avoids a large component in the lower frequency bins which will distort the result, even when windowing is used.

A mode is provided for the measurement of discrete components (spurii). In this mode, the scale is changed from L(f), dBc/Hz to Power, dBc. Corrections for bin bandwidth and window ENBW are removed. A flat top window is provided for measurement of discretes, with scallop loss of only 0.01dB.

Original article: - http://www.mpdigest.com/issue/Articles/2010/feb/quartz/Default.asp