A7-MX

Frequency, Phase & Phase Noise Measurement System

OPERATION

MANUAL

Contents

1 Safety Considerations

1.1 General

This product and related documentation must be reviewed for familiarisation before operation. If the equipment is used in a manner not specified by the manufacturer, the protection provided by the instrument may be impaired.

1.1.1 Before Applying Power

Verify that the product is set to match the available line voltage and the correct fuse is installed.

1.1.2 Before Cleaning

Disconnect the product from operating power before cleaning.

WARNING
Bodily injury or death may result from failure to heed a warning. Do not proceed beyond a warning until the indicated conditions are fully understood and met.

CAUTION
Damage to equipment, or incorrect measurement data, may result from failure to heed a caution. Do not proceed beyond a caution until the indicated conditions are fully understood and met.

1.1.3 This equipment must be earthed

An uninterruptible safety earth ground must be maintained from the mains power source to the product's ground circuitry.

WARNING
When measuring power line signals, be extremely careful and use a step down isolation transformer whose output is compatible with the input measurement capabilities of this product. The product's front and rear panels are typically at earth ground. Thus, never try to measure AC power line signals without an isolation transformer.

WARNING
Instructions for adjustments when covers are removed and for servicing are for use by service-trained personnel only. To avoid dangerous electrical shock, do not perform such adjustments or servicing unless qualified to do so.

WARNING
Any interruption of the protective grounding conductor (inside or outside the instrument) or disconnecting of the protective earth terminal will cause a potential shock hazard that could result in personal injury. Grounding one conductor of a two conductor out-let is not sufficient protection.

Whenever it is likely that the protection has been impaired, the instrument must be made inoperative and be secured against any unintended operation.

If the instrument is to be energised via an autotransformer (for voltage reduction), make sure the common terminal is connected to the earthed pole terminal (neutral) of the power source.

Instructions for adjustments while the covers are removed and for servicing are for use by service-trained personnel only. To avoid dangerous electrical shock, do not perform such adjustments or servicing unless qualified to do so.

For continued protections against fire, replace the line fuse(s) with fuses of the same current rating and type (for example, normal blow time delay). Do not use repaired fuses of short-circuited fuse holders.

1.2 Voltage, Frequency and Power Characteristics

Voltage 110-130V AC or 220-240V AC

Frequency 40-50Hz

Power characteristics 500mA Max

1.3 Environmental Conditions

1.3.1 Temperature

Operating (ambient)	0°C to +55°C
Storage	-40°C to +85°C

1.3.2 Magnetic Field

Sensitivity	$\leq 2x10^{-11}$/ Gauss
Atmospheric Pressure	-60m to 4000m
	$<1x10^{-13}$/ mbar

1.4 Replaceable Fusing Characteristics

800mA time lag HBC

1.5 Cleaning Instructions

To ensure long and trouble free operation, keep the unit free from dust and use care with liquids around the unit.

Be careful not to spill liquids onto the unit. If the unit does get wet, turn the power off immediately and let the unit dry completely before turning it on again.

Clean with a damp (with water) cloth.

Never spray cleaner directly onto the unit or let liquid run into any part of it. Never use harsh or caustic products to clean the unit.

Frequency, Phase and Phase Noise Measurement System A7-MX

2 Scope

This manual covers the installation, performance verification, and operation of model A7-MX with moving coil meter and internal phase meter. If an external counter is used aspects of the manual covering use of the model A7-MX with an external frequency counter will be relevant. If the rubidium frequency standard option or the 4 channel distribution amplifier option has been purchased, these will be covered by their own manuals. The same applies to the Stable-32 software.

3 Description

3.1 Overview

The A7-MX frequency and phase difference comparator is an improved version of the previous Quartzlock model A7-MXfor measuring a wide range of frequency standards, isolation amplifiers, frequency multipliers, dividers, and passive devices such as cables. The instrument is self contained with an internal phase meter and needs no external counter. A PC running most operating systems with one RS232 port provides a sophisticated user interface with immediate calculation and graphing of Allen variance. A digital display of phase or fractional frequency offset is provided. Tau values from 1ms to 2000 seconds may be used. A unique RS232 interface protocol has been designed which prevents Windows from losing data. The phase meter has a 32k buffer which provides complete protection to the data if the computer fails during a measurement run. Data blocks with up to 32k readings may be stored to disk for analysis with an external program such as Stable 32.

The instrument includes a moving coil meter for rapid, unambiguous display of fractional frequency difference or relative phase difference between two sources. Outputs are also provided for an external counter to connect to existing logging equipment if required. The instrument combines the production oriented capability of rapidly adjusting a source to within a certain tolerance using the panel meter, along with the metrology capability of a full time domain analysis of a source or passive component using data acquisition from the internal phase meter or external counter.

The A7-MX comparator has state of the art noise floor and drift characteristics. Its technique of frequency multiplication followed by down conversion provides lower noise floors than the simpler dual mix down convert system. The very low drift is achieved by providing identical multiplier/mixing chains for the reference and measurement channels. When the multiplied signals are finally mixed together (subtracted), any drift in the multiplier chains is cancelled.

The optional automatic battery backup facility enables very long measurement runs to be undertaken without concerns over line power failures. An external 24V car battery will power the instrument for at least 24 hours (without the rubidium frequency standard option)

A Rubidium frequency standard may be fitted internally along with a 4 output distribution amplifier with very low phase noise.

3.2 Outputs

Outputs are also provided for an external counter to provide higher resolution analysis of the time domain stability of a source or amplifier. The instrument combines the production oriented capability of rapidly adjusting a source to within a certain tolerance using the panel meter, along with the metrology capability of a full time domain analysis of a source or passive component using data acquisition from the frequency counter.

3.3 Making Measurements

Measurements are made in the time domain and consist of time difference measurements between a reference source and a measurement source. Measurements may be made on passive devices such as amplifiers by splitting a source output and comparing the time delay through the item under test with the direct path. In this way the time or phase stability of the amplifier may be measured. Unlike a general purpose time interval meter the inputs must be substantially sine wave and at either 5MHz or 10MHz. The resolution is much better than even the fastest counters, being around 50fs for a single measurement.

The A7-MX is a completely new design using phase locked multipliers as opposed to the harmonic multipliers used in previous Quartzlock phase and frequency comparators. Several new features have been added. The frequency input range is much wider, enabling measurements on VCXOs and OCXOs. Two resolutions are provided, with multiplication factors of 10^3 and 10^5. This optimises measurement on very stable sources such as Rubidium and Caesium oscillators and Hydrogen Masers, as well as lower stability sources. A variable band width IF filter has been added. This essentially sets the measuring bandwidth and allows sources with considerable phase noise to be filtered. This has particular advantages in frequency mode where the apparent jitter of a real time frequency readout can be reduced. A Rubidium frequency standard can be adjusted using 100ms sampling time to an accuracy of 1 in 10^{12}. The phase meter may be set to sample at the maximum rate of 1ms, with averaging to generate samples at the requested lower sampling rate. This digital averaging provides lower noise with some sources.

The comparator will operate at either 5MHz or 10MHz with automatic switching. The inputs are 50ohm impedance, and a level of between 0dBm and 13dBm is required at both inputs. The absolute accuracy of both reference and measurement inputs should be less than ±50 in 106. The maximum frequency difference should be less than ±10 in 10^6 in low resolution mode and less than ±100 in 10^9 in high resolution mode. The inputs are provided with level indicators.

3.4 Modes of Operation

The comparator has two modes of operation, frequency measurement mode and phase difference mode.

3.4.1 Frequency Mode

In frequency mode the moving coil meter indicates fractional frequency difference and the phase meter is configured as a frequency counter. Meter full scale ranges are selectable from the front panel in the range $\pm 10^{-7}$ to $\pm 10^{-12}$. The internal phase meter is configured as a frequency counter with gate times selected on the PC virtual panel as usual for a frequency measurement. The digital display shows fractional frequency with selectable number of digits displayed. The RMS resolution is typically better than 5 parts in 10^{14} for a 1 second gate. The Allen variance is calculated automatically and continuously as the samples are accumulated, and the graph is updated.

3.4.2 Phase Mode

In phase mode, the moving coil meter is configured to read phase difference between the reference and the measurement inputs. The full scale range is selectable between ±10us to ±100ps. An extended range phase detector is used so phase roll over will be between +10 and 0 on the meter if the frequency is increasing, and between -10 and 0 on the meter if the frequency is decreasing. The meter shows relative phase difference between the reference and measurement inputs. Because of the multiplication process in the comparator, the absolute phase difference is not available. A phase reset key is provided that zeros the indicated phase to within ±100ps.

The internal phase meter is configured as a time interval meter and measures the time difference between the measurement and reference channels. The sampling rate is set on the PC virtual panel. The phase may be reset to zero on the virtual panel. Allen variance is calculated continuously from the phase data. The single shot time resolution (measured as the standard deviation of 1024 readings accumulated over 1.024 seconds) is less than 50fs.

3.4.3 Data Storage

In both frequency and phase mode blocks of data may be accumulated and stored to disk. The block size may be up to 32k readings. The data is stored internally in the phase meter so that a failure of the computer or slow operation of the RS232 interface cannot lose any data. The computer may be used for other applications with the A7-MX application minimised without any concerns.

3.5 Software

A sophisticated software package is available for analysis of data. This is Stable Win 32 supplied by Hamilton Technical Services. It supports every possible type of time domain stability analysis, as well as conversion to the frequency domain for close in phase noise analysis.

4 Specification

INPUTS	
a) Reference	5 or 10MHz sine wave $\pm 50x10^{-6}$
b) Measurement	5 or 10MHz sine wave $\pm 50x10^{-6}$
c) Input levels:	+0dBm to +13dBm into 50Ohm
d) Max Freq difference (Filter off):	Low resolution $\pm 10x10^{-6}$
	High resolution $\pm 100x10^{-6}$
OUTPUTS	
a) Counter A channel	100 kHz square wave CMOS/TTL (frequency mode)
	10us pulse CMOS/TTL (phase difference mode)
b) Counter B channel	10us pulse CMOS/TTL (phase difference mode)
c) Counter external reference	10MHz CMOS/TTL
FILTER	Selectable bandwidth IF filter reduces measurement noise
Nominal 3dB Bandwidths	200Hz, 60Hz, 10Hz

FRACTIONAL FREQUENCY MULTIPLICATION

Selectable	High resolution 10^5
	Low resolution 10^3

MEASUREMENT RESOLUTION

Using external frequency/ time interval counter with 1ns or better time interval resolution

Frequency difference mode	High resolution $1x10^{-13}$/gate time
	Low resolution $1x10^{-12}$/gate time
	Gate times 1ms to 3200s
Phase difference mode	(High resolution: filter off)
RMS resolution (single measurement)	50fs (Measured as the standard deviation of 1000 phase difference measurements/ 1s)
Short-term stability (Allan variance)	$<5x10^{-11}$ 1ms

	$<5\times10^{-12}$ 10ms $<5\times10^{-13}$ 100ms $<5\times10^{-14}$ 1s $<1\times10^{-14}$ 10s $<2\times10^{-15}$ 100s $<5\times10^{-16}$ 1000s $<1\times10^{-16}$ 10000s
Sampling interval:	1ms to 1000s in decade steps
Drift:	<1ps per hour typical at constant ambient temperature <5ps per day typical at constant ambient temperature
Drift with temperature:	<2ps per °C

Using internal moving coil meter

Frequency difference mode	Full scale ranges $\pm1\times10^{-7}$ to $\pm1\times10^{-12}$ in decade steps Time constant 20ms to 10s linked to range Displayed noise $<2\times10^{-13}$ peak Zero drift $<2\times10^{-13}$/ hour
Phase difference mode	Full scale ranges ±10us to ±100ps in decade steps Displayed noise TBD Zero drift TBD
MECHANICAL	2U full rack unit
POWER SUPPLY	120/240V AC 50W max 24V DC battery back up with auto switching. Current consumption 1-4A max subject to options

5 Installation

5.1 A7-MX

The A7-MX unit can be used either bench mount or rack mount. The A7-MX unit should be connected to line power and 24V battery backup (Option) if required. If frequency difference measurements are to be made in the range 1 in 10^{13} to 1 in 10^{15}, an air-conditioned environment is recommended to minimize temperature drift of the A7-MX.

The RS232 9 pin connector should be connected to the computer RS232 connector using a female to female RS232 lead. This lead is identical to that used to connect 2 computers together.

If an external counter is to be used, the three BNC sockets on the rear panel of the A7-MX should be connected to the external counter inputs in order. i.e. top to bottom, channel A, channel B, external reference

The three BNC sockets on the rear panel of the A7-MX should be connected to the counter inputs in order. i.e. top to bottom, channel A, channel B, external reference.

The reference and measurement inputs on the front of the A7-MX are N jacks. For demanding measurements, it is highly recommended that only screw up connectors are used, preferably N or SMA. It can be easily shown that timing uncertainties of tens of picoseconds can result from using BNC connectors.

5.2 Software

The Frequency & Phase Comparator software should be installed according to the instructions on the installation CD.

The frequency analysis software STABLE-32 (Optional) should be installed according to the instructions supplied.

6 System Test and Verification

6.1 Frequency Measurement Low-Resolution

Turn on all units and start the A7-MX software. The software should immediately start showing readings on the virtual panel. If the interface is not working, the software will show an error message.

Connect a suitable frequency synthesiser to the A7-MX measurement input, and a suitable 5MHz or 10MHz reference source to the A7-MX reference input. The synthesiser must be locked to the reference source. Set the synthesiser to 10MHz. (see FIG 1.1)

Set the A7-MX controls as table 6.1

Mode	Multiplier	Tau	Filter	Δf/f
Freq	E3		200Hz	E-8

Table 6.1

Set the Virtual controls as table 6.2

Mode	Multiplier	Tau	Filter	Δf/f
		100ms		

Table 6.2

The level indicators on the A7-MX front panel should show green, indicating correct input levels, and all three phase lock LED's should be on.

The virtual display should show a fractional frequency near zero, the data plot should show noise about zero, and the Allen variance plot will be showing the Allen variance of the synthesiser. NOTE. If the synthesiser has spurii, the data plot may show a periodic waveform. This will be the spurii frequency aliased by the 100ms sampling rate. The meter should read near zero.

Now offset the synthesiser by 1Hz to 10.000001MHz.

The virtual display should now show a fractional frequency of about $+10^{-7}$ the meter should read +10, showing a fractional frequency difference of 10^{-7}. For a valid Allen variance plot the run should be restarted by using the on/off button on the virtual panel.

The above procedure has checked the A7-MX on the lower resolution multiplier setting (multiplier of 10^3). If the test synthesiser has low enough phase noise, the higher resolution setting may now be checked.

6.2 Frequency Measurement High-Resolution

Change the A7-MX resolution to 10^5. Note that the meter range scale changes to a range multiplier of 10^{-10}. The software will show an error message box that settings have been changed during acquisition of data.

Set the synthesiser to a frequency of 10.00000001MHz (10 mHz above 10MHz)

The meter should read +10, showing a fractional frequency difference of 10^{-9}.

The virtual display should show a fractional frequency of 10^{-9}.

6.3 Phase Measurement Low-Resolution

Set the A7-MX controls as Table 6.2

Mode	Multiplier	Tau	Filter	∅
Phase	E3		200Hz	1µS

Table 6.2

Set the synthesizer to a frequency of 10.000001MHz

Zero the phase on the virtual panel and start acquisition.

The data graph should show a ramp, and the display should show a phase value increasing at 1us every 10 seconds

The meter should be sweeping from left to right at a rate of 1us every 10 seconds.

6.4 Phase Measurement High-Resolution

Change the A7-MX resolution to 10^5. Note that the meter range scale changes to a range multiplier of 10ns.

Set the synthesiser to a frequency of 10.00000001MHz (10mHz above 10MHz)

Zero the phase on the virtual panel and start acquisition.

The data graph should show a ramp, and the display should show a phase value increasing at 10ns every 10 seconds

The meter should be sweeping from left to right at a rate of 10ns every 10 seconds.

NOTE
This completes the basic check out of the A7-MX system. However it is highly recommended that noise floor measurements be made before the system is used. These are described in the Performance Verification section.

7 Principles Of Operation

7.1 Overview

The principle behind the A7-MX is to increase the resolution of a frequency counter, which is essentially a time interval measurement device. 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 FIG 2.1, 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 either 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 manual, 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 FIG 2.1 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 FIG 2.1 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 more 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.

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, FIG 3.1. 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 very closely coupled thermally. 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.

The VCXO signals at 100MHz also drive high level 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 distribution chain that includes buffer amplifiers and passive power dividers. 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 IF's 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 IF's are used when a multiplication of 10^3 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 IF's 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 minimises 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 converters. They correspond to final multiplication factors of 10^3 and 10^5. 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 IF's could be divided down and measured directly by the phase meter, 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 when using an external counter. In addition bandwidth reduction would need 1MHz band pass filters on both IF outputs which would give problems with thermal tracking. For these reasons the IF's are compared before filtering and measurement. The IF's 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 900kHz using an LO of 100kHz derived from the un-multiplied reference. The 900kHz is then mixed with the 1MHz measurement channel IF to give a final IF of 100kHz. 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.

7.2 Detailed Process

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 400kHz. The 400kHz is then divided by 4 to give two quadrature signals at 100kHz. These signals are filtered using low pass filters to give 100kHz 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 100kHz quadrature sine waves as the linear inputs. The outputs are combined to form an image reject mixer, with the wanted sideband at 900kHz and the unwanted sideband at 1.1MHz. After amplitude and phase balancing the sideband suppression is about 60dB. The 900kHz sideband is filtered in an LC band pass filter to further remove the unwanted sideband (typically -80dBc) 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 100kHz. 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 100kHz with the drift and LO instabilities removed. This IF is now further processed to provide the inputs to the internal phase meter and external counter outputs as will be described in the next paragraphs.

7.3 Measurement Bandwidth Description

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 100kHz LC filter. The 3dB bandwidth is about 8kHz. This means that Fourier frequencies further displaced from the carrier of greater than 4kHz 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 1000sec). As with any sampling process, aliasing of higher frequency noise into the base band will occur. Thus further band limiting of the 100kHz IF is desirable before measurement takes place. It is important that the eventual calculation of the Allen variance is not in error due to excessive band limiting in the frequency domain. The effect of band limiting typical phase noise spectra on the calculation of Allen variance can be investigated by integrating the phase noise spectrum using the standard formula for phase spectral density to Allen variance conversion. This has been done for various types of noise band limited by a single pole filter. The general rule is that for a 3dB bandwidth of f Hz, the Allen variance calculation is accurate for tau’s greater than 1/f seconds. Thus if a 200Hz band pass filter is used to filter the IF, then a value of Tau less than 5ms should not be used. The A7-MX has a crystal filter following the LC filter with selectable bandwidths of nominally 10Hz, 60Hz, and 200Hz. It can be seen that for most Allen 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. It will also minimise aliasing of higher frequency periodic phase modulation of the source to lower frequencies.

7.4 Filtering

There is a further limitation to the use of the filters. When the difference between the measurement and reference inputs is too great, the 100kHz IF may fall outside the bandwidth of the filter. This is most important when the higher multiplication factor is being used. Table 8.1 summarizes the use of the filter. Provided the recommended limits are observed, the 100kHz IF will be within 10% of the filter 3dB bandwidth. When measuring passive devices by splitting the input signal (see operation section), the frequency at the measurement and reference inputs will be the same, so the limits in table 8.1 will not apply.

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

The internal phase meter uses the un-multiplied 100kHz reference and the multiplied 100kHz IF directly to make phase difference measurements between the two. The phase meter has a basic resolution of 12.5ps. Even with the 10^3 multiplier, this gives the A7-MX a resolution of 12.5fs. Of course the actual resolution is limited by noise. The phase meter makes fractional frequency measurements by subtraction of successive phase measurements, at a maximum rate of 1000/s. The sampling time is set from the virtual panel, and the instrument Tau control has no effect on the phase meter. The range of sampling times available is 1ms to 2000 seconds in 1, 2, 5 steps. For Allen variance measurements the phase meter makes single phase/frequency measurements at the selected sampling rate (Tau). However it may be used in an averaging mode, where it makes phase/frequency measurements at the maximum sampling rate of 1ms. Blocks of data are then averaged to report phase/frequency data at the requested sampling rate. Note that this is a block average rather than an exponential average, and therefore corresponds to the measurement of modified Allen variance.

7.5 References

The meter circuit also uses the 100kHz IF and 100kHz reference. The block diagram is given in FIG 4.1. The basis of the circuit is a differential frequency to voltage converter. However in order to increase the resolution of this circuit, a further stage of multiplication and mixing is employed. The 100kHz 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 100kHz 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 10^4 results. On the least sensitive meter range this 500Hz IF varies in frequency from 0Hz to 1kHz. The 500Hz measurement IF and the 500Hz reference both trigger digital mono-stables which produce very accurate fixed width pulses. These pulses are used to gate an accurate positive and negative current into a chopper stabilised 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}.

7.6 Meter time Constants

The meter time constants are linked to the meter range, however may be increased if desired using a switch mounted on the rear panel. The meter time constants are summarized in table 7.1

Meter Range FSD	Multiplication Factor	Meter Time Constant		
		x1	x3	x10
10^{-12}	10^{5}	10s	30s	100s
10^{-11}	10^{5}	1s	3s	10s
10^{-10}	10^{5}	100ms	300ms	1s
10^{-10}	10^{3}	10s	30s	100s
10^{-9}	10^{5}	20ms	60ms	200ms
10^{-9}	10^{3}	1s	3s	10s
10^{-8}	10^{3}	100ms	300ms	1s
10^{-7}	10^{3}	20ms	60ms	200ms

Table 6.2 Meter Time Constants

7.7 Noisy Sources

If a very noisy source is measured, the phase jitter on the 100kHz measurement IF may be so large that the phase lock loop in the meter circuit may slip cycles. This produces large and random movements of the meter. If a noisy source is being measured, the main comparator resolution should be set to 10^{3}. This reduces the jitter at the input to the meter circuit.

8 Operation

8.1 The A7-MX operation

The A7-MX operation is described for the following typical tasks:

Adjustment of the frequency of an unknown source

Measurement of offset frequency, time domain stability, and drift of an unknown source

Measurement of the time domain stability of a passive device.

The A7-MX will operate at either 5MHz or 10MHz with automatic switching. The inputs are 50ohm impedance, and a level of between 0dBm and 13dBm is required at both inputs. The absolute accuracy of both reference and measurement inputs should be less than ±50 in 10^6. The maximum frequency difference should be less than ±10 in 10^6 in low resolution mode and less than ±100 in 10^9 in high resolution mode. The inputs are provided with level indicators.

8.2 Frequency Adjustment

This can be done using either or both the meter and the frequency counter. The reference and unknown are connected to the A7-MX, making sure that the levels are within the recommended limits.

The mode should be set to frequency, the multiplication factor to 10^3, and the filter off. The rear panel time constant multiplier switch should be set to x1.

The meter range should be set to the minimum sensitivity (FSD 10^{-7}). A reading of offset frequency should now be obtained. The meter sensitivity can be increased if necessary.

> **NOTE**
> **The meter time constant increases as the meter sensitivity is increased. If the offset frequency is small enough, (see table 5.1) the filter may be used. This will generally have little effect on the meter readings as the effective bandwidth of the meter circuit is much less than even the 10Hz filter. However the amplitude of the phase jitter at the input to the meter circuit will be reduced, reducing the chance of cycle slips with a noisy source.**

The meter time constant may be increased if desired to provide a more stable but slower responding display.

The 10^3 multiplication factor should be adequate for adjusting OCXOs and even Rubidium oscillators. The 10^5 multiplication should be used for caesiums and masers.

NOTE
The meter zero adjustment is only necessary if using the most sensitive meter range. This is the 10^{-10} FSD range using 10^3 multiplication, and the 10^{-12} FSD range when using the 10^5 multiplication.

When zeroing the meter, set the time constant multiplier switch on the rear panel to x1. Press the zero button and adjust the zero set screwdriver adjustment to zero the meter reading.

8.3 Measurement of frequency offset, time domain stability & drift.

The A7-MX should be set to phase or frequency mode depending on the operators' preference. Frequency mode gives an immediate idea of the fractional frequency of the source; however phase mode is often preferred for very stable sources. The Allen variance calculation works equally well in frequency or phase mode.

The multiplication setting should be set according to the expected frequency offset between the reference and measured frequencies, and the time interval resolution required. The 10^3 setting is recommended for most sources except masers and caesium's. The filter should be set to 200Hz or less bandwidth, bearing in mind the restrictions discussed in section 7, and summarised in table 8.1. The Tau (sampling rate) should be set according to the length of the run to be performed and the total no of data points required. Finally in phase mode the phase difference should be set to the centre of the range using the phase zero push button. This is done to minimise the chance of a phase rollover. (Phase rollovers can only happen if an external counter is being used. The internal phase meter does not have any limit to its phase range).

The data block storage can now be set up on the A7-MX virtual panel. This is self explanatory and follows normal Windows file set up procedures. The title will appear in the header of the data file and is quite distinct from the file name. The "Sample new data block" button should be used to select a new data file name for the run. Once the file name has been selected, and the "Save" button pressed, the run will start automatically, and both graphs will be zeroed.

During the run, data is uploaded to the PC and saved in a file. It is also saved in the phase meter itself until the run finishes with the required no of data points having been collected, or the user terminates the run from the virtual panel. This gives automatic recovery if the A7-MX application is accidentally closed, or the computer is switched off.

When the application is restarted, it checks with the phase meter if a run is in progress, and if so uploads the lost data from the phase meter. The run then progresses as though there had been no interruption. When the run finishes, the data stays in the phase meter and may be uploaded to the PC by using the "Reload data block" button. A new file name is requested before this is done.

Provided that the supply to the A7-MX does not fail (by using the battery backup) a very long run may be set up with confidence that it will not be interrupted by line power failures.

8.4 Measurement of the time domain stability of a passive device.

The A7-MX should be set to phase mode. A reasonably stable source such as an OCXO should be split using an inductive type power splitter. The outputs of the splitter should be connected to the reference input of the A7-MX, and the input of the test device.

The output of the test device should be connected to the measurement input of the A7-MX. As passive devices generally have much lower phase noise than sources, the A7-MX multiplication factor should be set to 10^5.

As the nominal frequency of the signal at the test and measurement inputs will be the same, the narrowest filter bandwidth should be used, bearing in mind the effect on the Allen variance calculation for small taus. (See table 8.1). The accumulation of phase data should then follow the procedure described in the previous section.

8.5 Notes on operation.

In order to understand the results obtained with the A7-MX, it is important to understand its limitations, especially when noisy sources or sources with discrete spurii are measured. It is assumed that a high quality reference is used. This should have close in spurii of at least -100dBc.

8.6 Effect of sources with spurii

The A7-MX multiplies the absolute frequency difference (as opposed to the fractional frequency difference) by either 10 or 1000 depending on the multiplier selected. Phase noise and spurii on the source will be increased by either 20dB or 60dB depending on the multiplier. The noise and spurii will be transferred to the measurement IF at 100kHz. In order for the phase meter to make correct measurements, a signal to spurii ratio of at least 10dB will be required. Thus if the source is not clean enough, completely erroneous measurements may result. This usually happens when the 10^5 multiplier is used with inappropriate sources such as synthesisers, which often have high levels of close in spurii. The measurement IF is available at the rear panel output "counter A" when frequency mode is selected. This signal can be inspected with a high quality spectrum analyser with a 10Hz resolution bandwidth to ensure the spurii and noise is low enough.

NOTE
If the unknown source has discrete phase modulation, such as 50Hz line sidebands, these can be aliased to lower frequencies when taus of less than the Nyquist frequency are used. This can produce confusing results on the Allen variance plot. It is suggested that a run with a tau of 1ms is performed to check for the presence of discrete phase modulation.

8.7 Measurement of Allen variance

It is important to appreciate that the Allen variance statistics are not a unique measurement, but must be qualified by a statement of the measurement bandwidth. Allen variance is defined for single phase samples of the input signal at the selected sampling interval, or "tau". If any form of digital averaging or decimation from a faster phase sampling rate is used, then the statistic is not Allen variance. As single phase samples are used at the sampling rate "tau", noise from higher frequencies will be aliased into the measurement bandwidth. In fact if there is no band limiting at all, then the Allen variance becomes infinite for white phase noise. It is usual to restrict the bandwidth; in fact the A7-MX has a filter for this purpose. If a fast phase sampling rate is used, and the phase samples are averaged to give the required tau, then the statistic is "Modified Allen variance". The A7-MX can use this statistic by selection from the software. If the "Averaging on/off" box is ticked, the graph title changes to "modified Allen variance", and the phase meter runs at its maximum rate of 1000 s/s. Phase samples are block averaged to give the user selected tau for input to the Allen variance calculation. This averaging acts as a digital filter, and will give significantly lower values for modified Allen variance.

When comparing the results for the same sources from two different instruments, it is important to establish the measurement bandwidth, and also if digital averaging or filtering is being used.

8.8 Internal cross talk and mixer spurii

The standard test of the comparator is the zero drift and noise floor test. This is carried out by splitting a stable signal, and applying the same signal to the reference and measurement inputs of the comparator. This test is useful, and simple to carry out. It therefore forms the main method of verifying the performance of the instrument.

However the noise floor test only tests the comparator for two signals of a fixed phase relationship. The unit may show a different performance for two signals with a linearly varying phase relationship. This is equivalent to two perfectly stable signals of a slightly different frequency. The Allen variance measurement of short term stability ignores a fixed frequency variation, and so should give the same resulting noise floor for the case of a linear phase ramp as for the noise floor test. In practice, this is not so. The performance of the phase comparator is worse for two input signals of slightly different frequency, than for two input signals of the same frequency.

The origin of this degradation of comparator performance is the crosstalk between the channels and mixer spurii generated in the multipliers. When the zero drift test is used, the frequencies at the measurement and reference inputs are the same. The cross talk is only evident by a phase shift on the measurement output. This is caused by the vector sum of the wanted output, which is the multiplied frequency difference between the channels, in this case zero, plus 100kHz, and the unwanted signals caused by crosstalk. Similarly any mixer spurii add at a fixed phase relationship with the main signal. The result is to produce an incorrect phase value. This is not seen in the zero drift measurement as it is not varying. (If the comparator is warming up, the phase drift may show nonlinearities as if the input source was at a slightly different frequency). When two signals of different frequency are used, the phase of the wanted output (100kHz + the multiplied frequency difference) and the crosstalk components are continually varying in phase, sometimes adding to give a phase advance, and sometimes a phase retard. This produces an irregularity to the measured phase characteristic which should be a perfectly linear ramp. The pattern of the nonlinearities is scanned by the continuous phase advance due to the frequency difference (multiplied) at the inputs. When the phase is measured by the FXQ time interval meter, and converted to an

Allen variance, the noise floor will be worse than that measured by the zero drift test.

The periodic effect of certain crosstalk effects may be easily predicted. The most important relationship is that the period of the periodic phase variation will be related to the difference between the reference and measured frequencies. For example, if the frequency difference is 1Hz, then input crosstalk will cause a periodic phase variation at a 1Hz rate. The amplitude may be calculated from the cross talk measured in dBc. A symmetrical crosstalk of -100 dBc will cause a peak phase variation of 0.3ps.

As the frequency difference at the input of the A7 is multiplied first by 10, and then by 100, internal crosstalk and mixer spurii will cause phase variations at a rate of 10Hz and 1kHz for the above example where the frequency difference is 1Hz. Non linear effects also show crosstalk at harmonics of the above rates. The highest amplitude component in the current design occurs at a rate of 2000xdeltaF. This has amplitude referred to the input of typically -105 dBc, which corresponds to a peak phase variation of 0.18ps. Other crosstalk components are at an input referred level of -105 to -115 dBc.

Figure 6.0 is a normalised graph of the effect of a periodic phase variation caused by a spur at -105dBc on the Allen variance calculation. The x axis is (tau) x (frequency difference at comparator input) x (harmonic number). The y axis is (Allen variance) x (tau). It can be seen that the effect is worse for large frequency difference and large harmonic number. The effect always reduces with longer tau. An example:

Input =10MHz, fractional frequency =10^{-9}, tau = 1second, multiplier 10^3

deltaF	=	0.01Hz
n	=	10
Xaxis value	=	0.1
Yaxis value	=	$1.8x10^{-14}$ (max)
Error in Allen variance	=	$1.8x10^{-14}$

Input =10MHz, fractional frequency =10^{-12} tau=10 seconds, multiplier 10^5

deltaF	=	10-5Hz
n	=	1000
Xaxis value	=	0.1
Yaxis value	=	1.8x10-14
Error in Allen variance	=	$1.8x10^{-15}$

Although the specified spurious level is higher when the multiplier is 10^3, the highest harmonic number of the spurii will be typically 20 rather than 2000 when the 10^5 multiplier is in use. Therefore the effect of self generated spurii will be less when the lower multiplier is used. In addition the frequency separation of the sources should be minimised if at all possible.

9 Performance Verification

9.1 Overview

The primary performance verification method is to split a reasonably stable source such as an OCXO using an inductive type power splitter into two identical signals. These are then used as reference and measurement inputs to the A7-MX. Any noise or discrete spurii on the output is then a result of the instrument only. Noise floor measurements may be made in frequency or phase mode using the following procedures: -

9.2 Frequency Mode Verification

Connect the source as shown in FIG 5.1. Set the A7-MX to frequency mode, 10^5 multiplication, and filter off. Set the tau to 1s. Start a run. The frequency measurement resolution is specified as an RMS deviation from the exact frequency difference (in this case 0Hz). This value may be measured by setting the data graph to show 128 readings. The RMS standard deviation is then shown continuously for the data in the graph window.

The measurement should be repeated for gate times of 100ms and 10ms. The measurements can then be repeated with different filter bandwidths if required. The instrument is specified for frequency mode resolution with the 200Hz filter.

9.3 Phase Mode Verification

Connect the source as shown in FIG 5.1. Set the A7-MX to phase mode, 10^5 multiplication, and filter 200Hz. Set the tau on the A7-MX front panel. Zero the phase using the phase adjust push button. The single shot phase resolution may be verified by setting the tau to 1ms and starting a run. The data graph should be set to show 1024 readings. The standard deviation measurement is then the specified single shot phase resolution.

The Allen variance floor can be measured by setting up longer runs.

The following runs are recommended for complete Allan variance data from tau=1ms to tau=1000 seconds:

Run	Tau on A7-MX	Total Points	Run Time
1	1ms	32000	32 seconds
2	100ms	32000	53minutes
3	1 sec	32000	8.9 hours

NOTE
For long run times drift due to ambient temperature variations will distort the Allen variance graph. Drift rates should be measured directly from the phase plot. The drift rates that form part of the Instrument Specifications may be verified using the above procedure. However the requirements for constant ambient temperature and warm up time should be noted.

NOTE
When measuring zero drift or noise floor, the slightest disturbance of the cables or connectors may introduce phase discontinuities that will lead to incorrect Allen variances. The phase plot should be inspected for such problems.

10 A7-MX Software

10.1 Installation

The A7-MX comprises of two main parts the A7-MX instrument and the A7-MX Software.

Set up A7-MX as per the instruction in the Operating Manual supplied with the Instrument.

The only requirement for the PC is that it must have a RS232 serial port we cannot guarantee that this instrument or software will work through an USB to RS232 converter.

The software is installed simply by inserting the A7-MX Software CD in to the PC's CD ROM drive. If the set-up program fails to run automatically click on **Start** on the main tool bar and then click **Run** and type in **<*drive*>:\A7-Setup.exe** where **<*drive*>** is the letter corresponding to the CD ROM Drive being used.

Follow the on screen instructions.

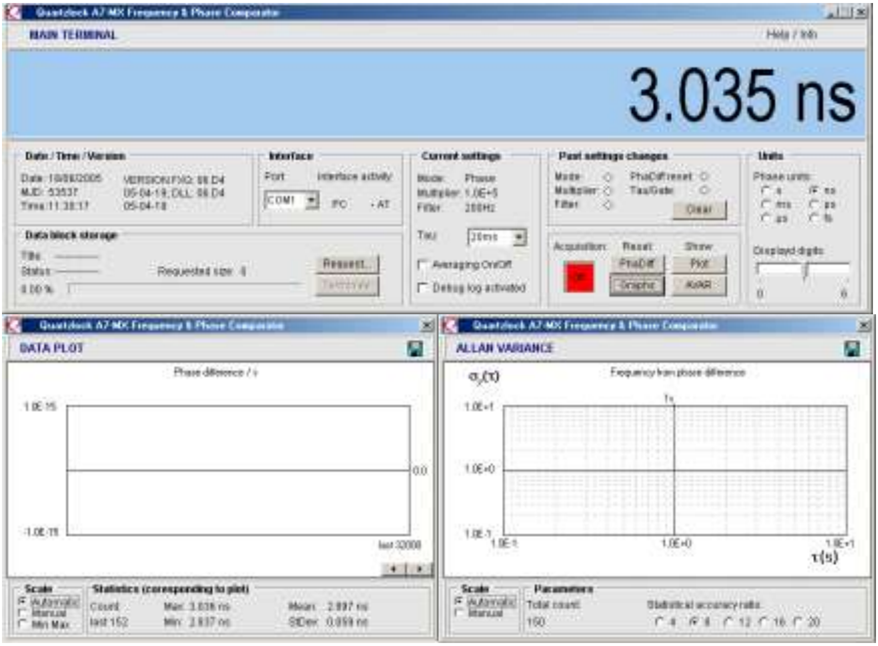
Once the software has been installed you must connect the A7-MX to the PC via the 9 Way RS232 Cable provided. Failure to connect the A7-MX to the PC will result in the following error message: -

Once the A7-MX is connected to the PC, run the A7-MX software (the short cut can be found on the desk top).

On initial run the following window may appear: -

Just click on OK and the program will load normally,

The following windows will be displayed: -



These are MAIN TERMINAL, DATA PLOT and ALLAN VARIANCE.

10.2 MAIN TERMINAL

There are several different sections: -

The main counter display that shows the instantaneous readings from the A7-MX

10.2.1 Date / Time / Version

This shows the PC's Date and Time, the A7-MX Firmware revision and the Software revision

10.2.2 Interface

The serial communications port that the A7-MX has been connected must be set using the drop down menu in order for the software to communicate; this is set to COM1 by default.

Interface activity is illustrated by a series of dots travelling between **PC** and **A7**

10.2.3 Current settings

This shows the settings on the A7-MX for Mode, Multiplier and Filter the Tau setting is independent of the A7-MX front panel (the front panel setting is only valid when using an external Time Interval Counter connected to the rear BNC connectors).

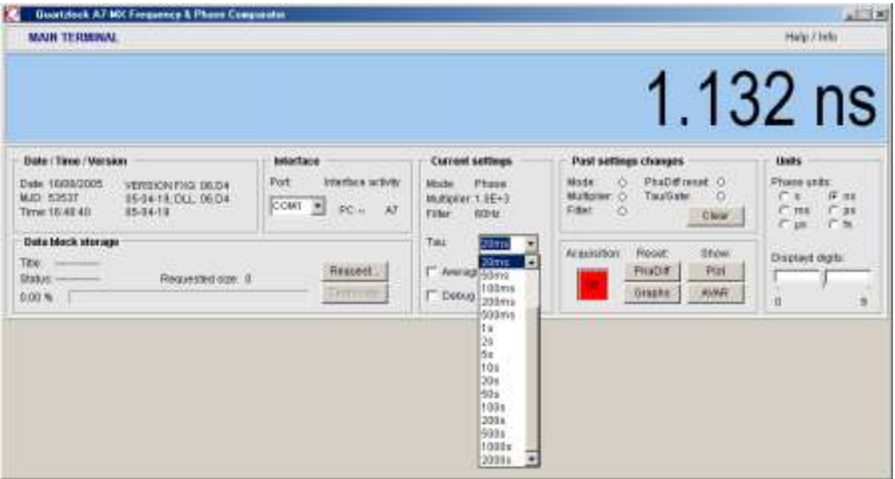
Mode: Phase or Freq

Multiplier: 1.0E-3 or 1.0E-5

Filter: Off, 200Hz, 60Hz or 10Hz

Tau

Displays the current Tau or Gate setting also you can change the current Tau or Gate by using the drop down menu.



Averaging On/Off

Ticking this box changes the displayed Allan Variance from Standard to Modified.

Debug log activated

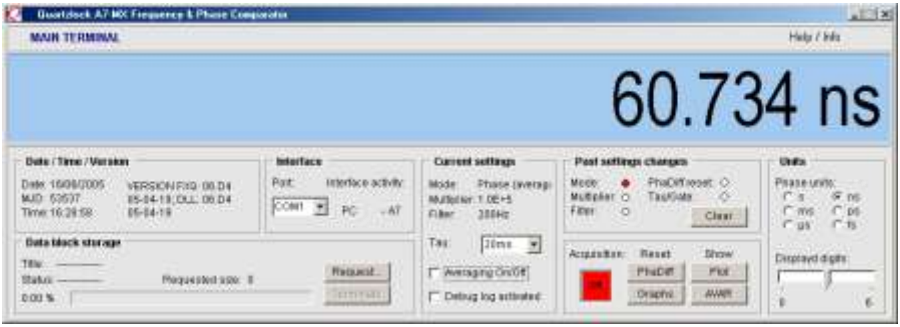
Ticking this box activates the activity log, for checking the operation of the system.

10.2.4 Past settings changes

The indicator will change from white to red when there has been a change by the operator on either the A7-MX Software or the A7-MX Instrument indicating that the data may in doubt or that the set-up has changed from the previous run. Pressing the CLEAR icon resets these.

Mode

Indicates red when the Mode switch is pressed on the A7-MX, Averaging On/Off is ticked in the current settings on the A7-MX software as shown below: -

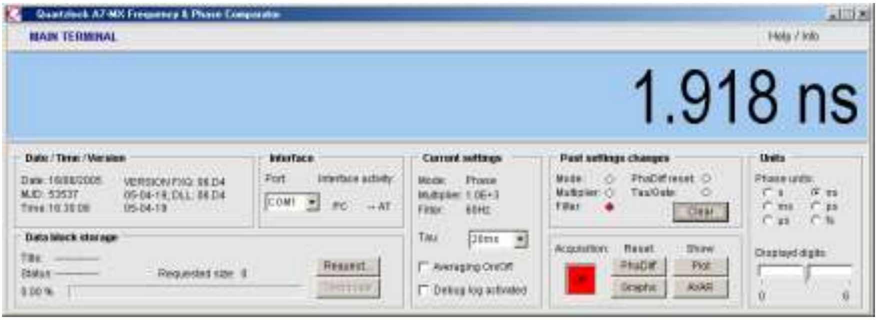


Multiplier

Indicates red when the multiplier switch is pressed on the A7-MX Instrument as shown below: -

Filter

Indicates red when the Filter switch is depressed on the A7-MX Instrument as shown below: -



PhaDiff reset

Indicates reds when the Phase Reset switch is pressed on the A7-MX Instrument or the PhaDiff icon is pressed on the A7-MX Software as shown below: -

Tau/Gate

Indicates red when the Tau is changed in the Current settings on the A7-MX software as shown below: -

When Mode, Multiplier, PhaDiff and Tau are changed the following warning will be displayed: -

and acquisition will be turned off.

10.2.5 Acquisition

Acquisition:

The Acquisition button indicates the current status, Red for OFF and Green for ON clicking this button will change its state.

Reset:

Clicking on the PhaDiff button has the same effect as pressing the Phase Reset button on the A7-MX it resets the Phase difference to zero.

Clicking on the Graphs button will clear the two graph windows and reset the data and statistics.

Show:

Clicking the Plot button will display the DATA PLOT window and clicking on the AVAR button will display the ALLAN VARIANCE window.

10.2.6 Units

Phase Units:

When the A7-MX is in Phase Mode the time period for the counter display can be select by clicking on one of the following: - s, ms, µs, ns, ps and fs.

These options are greyed out in Frequency mode and have no effect.

Displayed digits:

This is user selectable and only affects the counter display this is the number of digits displayed after the decimal point. This ranges from 0 – 15 in phase mode the maximum number of digits that can be displayed is dependent upon the Time Period selected: -

s = 15, ms = 12, µs = 9, ns = 6, ps =3 and fs = 0.

10.2.7 Data block storage

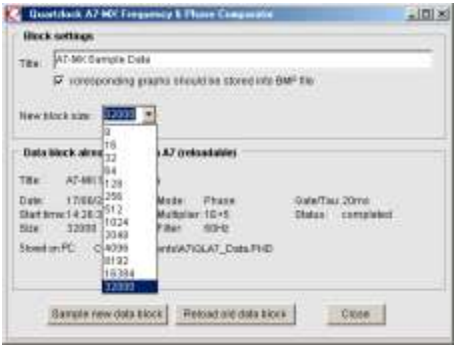
This is used to store the data for archiving and importing into other frequency and phase analysis programs, the number of data points that can be stored ranges from 8 to 32,000.

There are two types of file created depending upon the mode of the A7-MX these are Frequency data suffix FRD and Phase data suffix PHD.

To start data storage click on the Request button this will display the following window: -

Click in the title field and insert the required Graph title, this title appears in both the DATA PLOT and ALLAN VARIANCE Graphs.

Select the number of data points required from the drop down menu: -



Once the number of data points has been selected click on Sample new data block you will be asked to enter the file name for the data to be saved.

Once the A7-MX has started the data capture the MAIN TERMINAL window will display the progress, if at any time it is required to stop the data capture click on the Terminate button the data will still be stored to disk but no further data will be added.

Whilst the A7-|MX is capturing data if the PC is disconnected or there is a power failure then the A7-MX stores the data in its internal memory until the PC is reconnected (For Option 0 BBU is fitted and connect to a UPS).

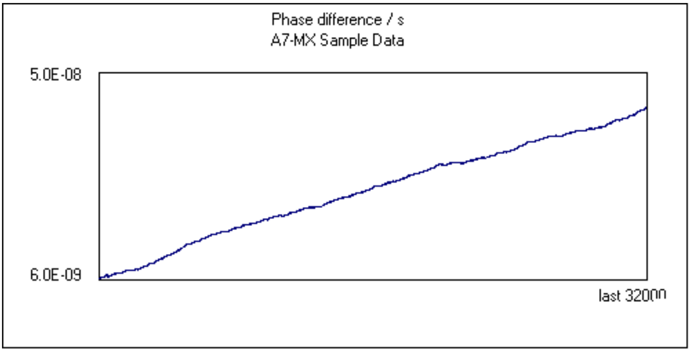
All the information about the data stored in the internal memory of the A7-MX is visible in the frame “Data block already stored on A7 (re-loadable)”. The data is kept in memory until a new block is requested, and can be reloaded at any time by pressing Reload old data block button.

There will be 2 files created a data file and a bitmap image. The data file will contain the following information,

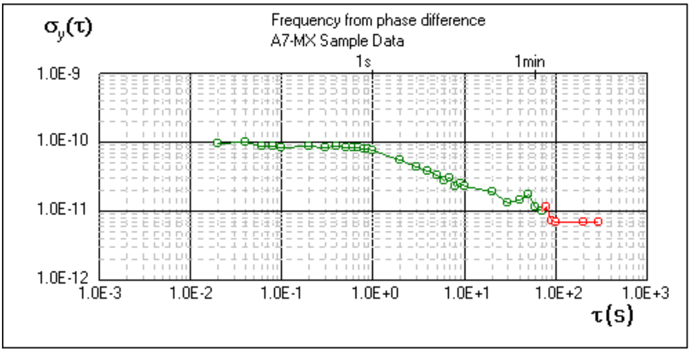
```
File: C:\My Documents\A7\QLA7_Data.PHD
Title: Quartzlock A7-MX Frequency & Phase Comparator   A7-MX
Sample Data
Date: 17/06/2005
Averaging: Off
Type: Phase
Points: 32000
Tau: 2.0E-2
 6.262409056300000E-09
 6.263581889800000E-09
 6.264719120200000E-09
 6.265904837800000E-09
 6.267623980700000E-09
```

the first seven lines are the header and then the remaining lines are the data for analysis.

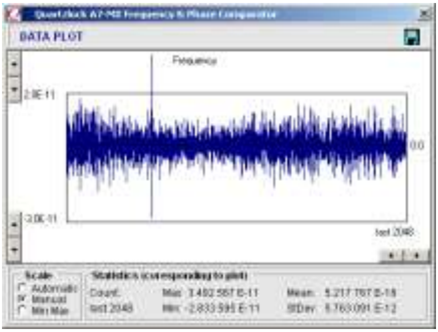
The bitmap file contains both the DATA PLOT and the ALLAN VARIANCE Graphs associated with the data as shown below: -



Statistics:
Max: 42.665 400 ns Mean: 25.020 183 ns
Min: 6.262 408 ns StDev: 10.152 271 ns



10.3 Data plot Window



The plot indicates the measured values in a logarithmic scale. The data of positive values (from range 1.0E-15 … 9.0 E3) are plotted on the upper part of the graph in logarithmic scale; the data of negative values (from range -9.0E3 …-1.0E-15) are plotted on the lower part of the graph by representing the logarithm of the absolute value of the data.

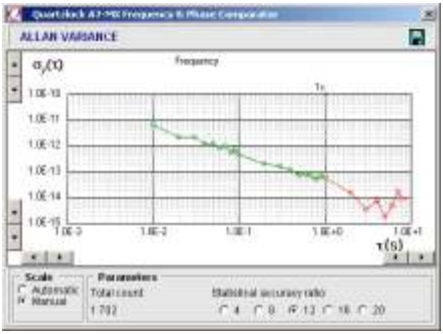
The scaling has three modes:

1. Automatic mode (with min and max borders automatically given by the program);
2. Manual mode (min and max borders can be selected by the user with the help of arrows on the left side of the graph)
3. Min Max (with min and max borders coinciding with the min and max values of the current record).

The plot shows a given number of the current last points. The number of the points being plotted (from 8 to 32000) can be selected by the arrows in the bottom right of the graph frame. The statistical data (Min, Max, Mean, and StDev) are calculated from these last points.

With the save icon (top right) the current plot image can be saved to a bitmap image (*.bmp file).

10.4 Allan Variance Window



The AVAR is plotted in a double-logarithmic scale, ranging:

Vertical for Sigma: from 1.0E-20 to 1.0 E 3,

Horizontal for Tau: from 1.0E-3 to 1.0 E 9

The scaling has two modes:

1. Automatic mode (with min and max borders automatically given by the program);
2. Manual mode (min and max borders for both Sigma and Tau can be selected by the user with the help of arrows.)

The Allan Variance is calculated from all data values since the last reset of graph (total count).

Allan Variance is always calculated by the formula:

$$\sigma_y^2(\tau) = \frac{1}{2(M-1)} \sum_{i=1}^{M-1} \left[y_{i+1} - y_i\right]^2$$

Where y_i are the i-th of M fractional frequency values averaged over the interval τ. By the mode “phase difference” the frequency values are calculated from the phase values.

When averaging is used, the Allan Variance calculated will become Modified Allan Variance, as the averaging process will have reduced the noise of the source. The exact details of the averaging are explained in the device Manual.

The colour of the points and the line connecting the points indicates the statistical accuracy of the corresponding points. The green points satisfy a selected statistical accuracy parameter, and points in red do not satisfy the parameter. The statistical accuracy parameter is the ratio of the total time record to the tau of the point, initially set to 8.

With the save icon (top right) the current plot image can be saved to a bitmap image (*.bmp file).

10.5 Warnings and Error Messages

1. 'No answer from A7 (FXQ)!! Interface terminated!'
   a) A7-MX is switched off.
   b) No or incorrect connection between PC and A7-MX. Reset of the program and/or the device.
2. 'FXQ and DLL versions: ………… are not compatible!'
   a) The revision of the software in the microprocessor of the device is not compatible with the DDL file Version. Please contact Quartzlock (UK) ltd.
3. 'FXQ overflow! Data lost!'
   a) The output buffer of the device is overflowed.
4. 'Can not open port COM1: 115200'
   a) The serial Port (it could also be COM2, COM3…COM9) is not available or busy.
5. 'Cannot find registry file. Load default'
   a) The file with the application settings is absent. This is normal the first time the program is run.
6. 'Cannot read registry file. Load default'
   a) The file with the application settings is damaged or the format is wrong.
7. 'Settings have been changed while sampling block data! Block terminated!'
   a) Mode, Multiplier, Gate, Phase reset has been changed (on the front panel of the device) while sampling block data.
8. 'Settings have been changed while acquiring data!'
   a) Mode, Multiplier, Gate, Phase reset has been changed (on the front panel of the device) while acquiring data.
9. ': % …*some part of the raw data*… %'
   a) Some data has been lost during transfer.

11 GLOSSARY

Terms, acronyms and unusual words as used in this handbook.

12 SERVICE GUIDE

12.1 Board 1 Multipliers

This board comprises 3 circuit blocks:

Input multipliers

Second multipliers

LO distribution

12.1.1.1 Input Multipliers

The input multipliers comprise two channels, very nearly identical. Each channel consists of:-

A 100MHz VCXO (VCXO1, VCXO2) with buffer (U5, U6) and power splitter (PS1, PS2).

An ECL divider chain (U1 U3, U2 U4) the division ratio can be switched between 1/10 and 1/20 by operating relays RL1, RL2.

A re-clocking D type (U16, U21). Note that these are thermally coupled.

A transformer which provides a sample of the input signals to board 3. (T5, T8)

An input phase detector which compares the phase of the input signal with the divided VCXO signal (D6, D7)

A loop filter (U10, U11)

A down convert mixer, which down converts the 100MHz VCXO signal to 1MHz (MIXER1, MIXER4)

An IF amplifier (U12, U13)

The B channel (reference channel) also has an additional divider U4C. This provides a 10MHz reference signal to board 2 irrespective of whether the divider chain is set to 1/10 or 1/20. It should also be noted that the 1MHz IF outputs to the second multipliers are taken from the outputs of the mixer diplexer filters, not from the outputs of the IF amplifiers. This is to avoid phase delay in the IF amplifiers. The outputs of the IF amplifiers provide the 1MHz-A and 1MHz-B outputs to board 2, connected to CONN9 and CONN10. When a multiplication factor of 10^5 is selected on the instrument, the measurement channel IF amplifier (U12) is disabled.

12.1.1.2 Second Multipliers

The second multipliers are similar to the Input multipliers, with the exception of the divider chains. These consist of a programmable divider which divides by 50 (U24, U26), a fixed divider which divides by 2 (U27, U7) and re-clock D types (U28, U17).

When a multiplication of 10^3 is selected on the instrument, the second multipliers are not used. The VCXOs and buffers are switched off using the power switch TR3, TR2, TR1. The IF amplifiers (U29, U22) are also disabled.

12.1.1.3 LO distribution

The LO distribution comprises power dividers PS3, 5, 6 and buffers U18, 23.

12.1.2 Board 1 Test Procedure

NOTE **Board 1 should always be tested while mounted on the chassis plate.**

12.1.2.1 Initial Connection and Power Supply Check.

Remove test links from JP5, JP6, JP7, and JP8.

Using a 10 way IDC test cable, connect +5V, +12V, and -12V power to JP2. Regulated power supplies with current limit should be used. The +12V and -12V should preferably come from a tracking type supply. The 12V supplies should be switched on before the 5V supply, and switched off after the 5V supply is switched off.

With no other signal inputs to the board, the supply currents should be: -

+5v	<820mA
+12V	<130mA
-12V	<70mA

Check the local +5V supply at C71 (limits 5V ± 100mV)

Check the local -5V supply at C140 (limits -5V ± 100mV)

Replace each test link one at a time. The 12V current should rise by 60 to 70mA.

Replace links on JP5 and JP6.

12.1.2.2 100MHz VCXO Output Levels

Set multiplier to 1000 on DIP switch adapter.

Using the spectrum analyser with the 500ohm probe, measure the 100MHz signal levels at U5, U6 output. A convenient connection is to C4 and C5. A spanner type ground must be used on the probe, and grounded to the nearest ground point. Signal level should be +14dBm ± 1dB. Note readings on test sheet

12.1.2.3 Input Multiplier Phase Lock Check

Connect function generator 1 to reference input (CONN2). Connect function generator 2 to measurement input (CONN1). Set both function generators to 10MHz, 0dBm into 50ohms, sine wave. The Input multiplier PLLs should be locked. Using the frequency counter with a $^{1}/_{10}$ probe; check that the frequencies at U5 and U6 outputs are 100.000000MHz. (The frequency counter and function generators should use the external reference, OCXO or rubidium).

Check tuning voltages at D2 and D3 to ground using the digital meter. The readings should be 2.6V ± 200mV.

Check the tuning range by varying the frequency of the function generators by ± 400Hz. The tuning voltages should remain in the range 1.5V to 4.0V. Note the readings on the test sheet. Return the frequencies of the function generators to 10MHz.

12.1.2.4 Down Converter Check, Input Multipliers.

Connect the RF signal generator to CONN5. Set frequency to 99.000MHz ± 1Hz (If necessary the signal generator should use an external reference with an accuracy of 10^{-8}), and level to 10dBm.

Connect the spectrum analyser to 1MHz-B (CONN10). Check for a 1MHz signal, amplitude 12dBm ± 1dB. Repeat the check at 1MHz-A (CONN9). Note the readings on the test sheet.

12.1.2.5 Cross talk Check, Input Multipliers

For this check it is essential that the input to the channel to be measured is essentially free from phase modulation spurs. For this reason the signal from an OCXO is used.

Connect an OCXO at 10MHz to CONN2 (reference input). Set function generator 2 frequency to 10.0003MHz (measurement input). Connect the spectrum analyser to 1MHz -B (CONN10). Centre the main signal at 1MHz. Spurious signals 300Hz and 3kHz away from the main signal represent crosstalk. The level of all spurii should be < -75dBc.

Connect the OCXO to CONN1 (measurement), and the function generator to CONN2 (reference) Transfer the spectrum analyser to 1MHz-A (CONN9) and repeat the checks made above. Record the spurii levels on the test sheet.

Note that all screens must be present on the board for the above test. The cover should be temporarily placed in position.

12.1.2.6 Reference check

Using the oscilloscope with 50ohm input, check for a 10MHz square wave at CONN7 Amplitude should be ± 200mV peak about 0V.

12.1.2.7 Level outputs check.

Reconnect the function generators, set to 10MHz, 0dBm into 50 ohms, to measurement and reference inputs

Transfer the spectrum analyser to CONN4 and check the signal level at 10MHz. Level should be -16dBm ± 0.5dB. Repeat for CONN3.

12.1.2.8 Second multiplier tests

For all the second multiplier tests, the RF signal generator providing the 99MHz LO signal should be locked to the same reference as the function generators.

12.1.2.9 100MHz VCXO output levels

Set multiplier to 10^5 on DIP switch adapter. Replace links on JP7 and JP8

Using the spectrum analyser with the 500ohm probe, measure the 100MHz signal levels at U8, U9 output. A convenient connection is to C25 and C33. A spanner type ground must be used on the probe, and grounded to the nearest ground point. Signal level should be +14dBm ± 1dB. Note readings on test sheet

12.1.2.10 Second multiplier phase lock check

Connect function generator 1 to reference and function generator 2 to measurement inputs, set to 10MHz, 0dBm. Select 10^5 multiplier on DIP switch adapter.

The second multiplier VCXOs should now be phase locked. Measure the tuning voltages at D4 and D5. The readings should be 2.6V ± 200mV.

Check the tuning range by varying the frequency of the function generators by ± 4Hz. The tuning voltages should remain in the range 1.5V to 4.0V. Note the readings on the test sheet. Return the frequencies of the function generators to 10MHz.

12.1.2.11 Down converter check, second multipliers.

Connect the spectrum analyser to 1MHz-BB (CONN8). Check for a 1MHz signal, amplitude 12dBm ± 1dB. Repeat the check at 1MHz-AA (CONN6). Note the readings on the test sheet. Note there may be a large number of high level spurs which are multiplied spurs from the function generators.

12.1.2.12 Second multiplier crosstalk and mixer spurs

For this check it is essential that the input to the channel to be measured is essentially free from phase modulation spurs. For this reason the signal from an OCXO is used.

The initial checks are for mixer spurs on each channel at a time. The unused channel is disabled by removing the test links.

Connect an OCXO at 10MHz to CONN2 (reference). Remove links JP7 and JP5. Connect the spectrum analyser to 1MHz -BB (CONN8). Centre the main signal at 1MHz by tuning the OCXO to 10MHz. Now adjust the IF signal to 1.0002MHz either by tuning the OCXO or the RF signal generator. The frequency multiplication is 1000, so a 0.2Hz detuning of the OCXO will produce the frequency offset required (a 2Hz detuning of the RF signal generator will have the same effect). Set the spectrum analyser span to 5 kHz, and record the spurii levels. The level of all spurii should ideally be < -40dBc. Isolated pairs of spurii at -35dBc are permitted.

Connect the OCXO to CONN1 (measurement). Replace the links at JP7and JP5, and remove the links at JP6 and JP8 Transfer the spectrum analyser to 1MHz-AA (CONN6) and repeat the checks made above. Record the spurii levels on the test sheet.

NOTE **That all screens must be present on the board for the above test. The cover should be temporarily placed in position.**

This completes the board 1 test procedure.

12.1.3 Equipment Required

2 off Agilent 33120A function generator with option 001 phase lock

Variable power supply +12V and -12V 0.5A with current limit

Variable power supply +5V 1A with current limit

Digital meter 0.3% accuracy

10MHz OCXO accurate to 10^{-8}, output level 7dBm

Passive power splitter

Spectrum analyser, HP 70000 series or equivalent modern synthesised analyser with 10Hz resolution.

Oscilloscope 200MHz or greater bandwidth, with 1/10 probe

500ohm, 1/10 probe for 50ohm input, 1GHz bandwidth

Synthesised RF signal generator, low spurii, accuracy 10^-8

100MHz frequency counter with external reference input

12.1.4 Special Equipment Required (See FIG 2.3)

10 way IDC to DIP switch adapter (JP3)

4 off MCX to BNC test cables, length 1m

10 way IDC test cable

12.2 Board 2 IF Processing

This board comprises 5 circuit blocks:

IF input zero crossing detectors

Frequency section

Crystal filter

Phase section

99MHz LO and phase lock

12.2.1.1 IF input zero crossing detectors

There are four 1MHz IF's routed to this board from the multiplier board, board 1. There are two pairs, one from the output of the first stage of multiplication, called 1MHz-A (CONN 9) and 1MHz-B(CONN 6), and one from the output of the second multiplier, called 1MHz-AA (CONN 10) and 1MHz-BB (CONN 7). The B and BB suffixes denote the B (reference) channel. The four linear IF signals are buffered by U35, 37, 38, 40, and 41. The selection of the pair appropriate to the multiplier that is selected on the instrument front panel is carried out by analogue switches U42 and U43. The sine signals are converted to square waves in comparators U5 and U32. The output of buffer U35 feeds the LO phase lock circuit.

12.2.1.2 Frequency section

The frequency section combines the two 1MHz IF's from the multiplied reference and measurement channels into a single 100 kHz IF.

A 10MHz un-multiplied reference signal is routed to CONN1 from board 1. This is limited by U4 and divided down to 1MHz and 400 kHz by U1. The 400 kHz signal is routed to the frequency section.

The signal is then divided down to 100 kHz using the quadrature divider U12. Two pairs of anti phase 100kHz sine waves are obtained by filtering. The two pairs are in quadrature.

The 1MHz -B IF from the multipliers is delayed by 250ns by U45 in order to generate quadrature outputs. In addition the 1MHz-B reference IF is initially passed through a differential programmable delay line U44. This enables the quadrature outputs to be trimmed in order to obtain optimum image rejection. U28 is a dual change over switch that is used as two mixers. When the outputs of the two mixers are summed at the input to T1, one sideband is suppressed. VR1 provides amplitude balancing. The desired output is 900 kHz, with the unwanted sideband at 1.1MHz. The sideband suppression is optimised by adjustment of VR1, SW1 and SW2.

The band pass filter T1 and T2 is tuned to 900 kHz. The anti phase outputs are input to U10A, a further switching mixer. The 1MHz-A IF is the other input.

The output of U10A comprises two sidebands, at 100 kHz and 1.9 MHz. The wanted sideband at 100 kHz is filtered in band pass filter T3 and T4. This filter sets the measurement bandwidth of the instrument when the crystal filter is not being used.

12.2.1.3 Crystal filter

The output of the band pass filter is routed to unity gain buffer U14A. The crystal filter is a single 100 kHz crystal operated at series resonance. The bandwidth is varied by changing the load resistance. T5 and C34 cancel the parallel capacitance of the crystal to give a symmetrical response. U14B is a gyrator circuit which terminates the crystal with a simulated inductance. The inductance cancels parallel capacitance which ensures that the crystal load is purely resistive. The bandwidth is varied by switching in loads R22 and R 32 under control of U47.

U33 and U36 are zero crossing detectors which limit the analogue signals prior to and following the crystal filter. U39 selects the crystal filter output or the bypass under control of U47.

12.2.1.4 Phase section

The square wave 100 kHz final IF is routed to:

> The output selector U29 which switches the mode between frequency and phase

The expansion port JP5 which connects to the meter board

The phase section.

In the phase section the 100kHz final IF is divided down to 1mHz in the divider string U17, 18, 19, and 20. The 100 kHz reference signal, which was obtained from the un-multiplied reference channel, is similarly divided by U21, 22, 23, and 24. U11 and U27 select one output from each divider chain under control of the 3 bit bus from the front panel "tau" setting. The identical circuits U15, U16 and U25, U26 select one cycle of the 100 kHz inputs after each divide cycle. This gives 10us positive going pulses on the PHASE-A and PHASE-B outputs.

The PHASE-B signal is connected directly to the external counter/timer B output. The PHASE-A signal goes to the output selector U29. In frequency mode the 100 kHz final IF is connected to the external counter A output, and in phase mode the PHASE-A signal.

12.2.1.5 99MHz LO and phase lock

The 99MHz signal originates in VCXO1, a voltage controlled crystal oscillator. The signal is amplified to a level of about 10dBm by buffer U2 and the attenuator pad R45, 53, and 54. The phase lock operates by comparing the un-multiplied 10MHz reference signal from board 1, divided down to 1MHz, with the 1MHz-B IF from the first multiplier. U46 provides an anti-phase copy of the 1MHz-B IF. When the frequencies of these two signals are the same, the 99MHz LO will be 1MHz lower in frequency than the reference input to the multiplier board multiplied by 10. For further clarification of the frequency plan, see the block diagram in the operator’s manual.

U8 is the phase comparator, and U6 the loop filter. The loop locks by natural acquisition. An anti parallel diode pair across R3 increases the loop bandwidth when unlocked.

12.2.2 Board 2 Test Procedure

12.2.2.1 Initial Connection and Power Supply Check.

Using a dummy cable, connect +5V, +12V, and -12V power to JP2. Regulated power supplies with current limit should be used. The +12V and -12V should preferably come from a tracking type supply. The 12V supplies should be switched on before the 5V supply, and switched off after the 5V supply is switched off.

With no other signal inputs to the board, the supply currents should be: -

+5v	<50mA
+12V	<110mA

-12V	<30mA

Check the local +5V supply at C25 (limits 5V ± 100mV)

Check the local -5V supply at D2 (limits -5.1V ± 250mV)

12.2.2.2 Reference Divider Chain Check

Connect a function generator to CONN1, set to 10MHz sine wave, 0dBm into 50 ohm.

Check the output at CONN3 using the oscilloscope set to 50ohm input impedance. There should be a clean, fast rise time square wave, amplitude 2.5V

Using the oscilloscope with a 1/10 10Mohm probe, check for a 1MHz, 5V square wave at U8 pin 1. Check for 100 kHz 5V square waves at R34, R35, R36 and R37 (Junctions with U34 and U13).

12.2.2.3 Input Zero Crossing Detectors Check

Connect the board as Fig 2.1. The JP1 to BNC adapter is required, also the JP3 DIL switch adapter (see list of special equipment).

Connect function generator 1 to JP1 pin 1 (1MHz-A). Set to 1MHz, sine wave and 0dBm. Select 10^3 multiplier using DIL switch adapter connected to JP3. Using the oscilloscope with 1/10 probe, check for a clean 1MHz square wave at TP13. Transfer the function generator to JP1 pin3 (1MHz-B). Check for a 1MHz square wave at TP12.

Select 10^5 multiplier. Transfer the function generator to JP1 pin 6 (1MHz-AA). Check for a 1MHz square wave at TP13. Transfer the function generator to JP1 pin 8 (1MHz-BB). Check for a 1MHz square wave at TP12.

12.2.2.4 Image Reject Mixer Check

Set multiplier to 10^3 and transfer function generator to JP1 pin 3 (1MHz-B)

Using the spectrum analyser with a 1/10, 500ohm probe; check the signal at the junction of R7 and R8. (It is assumed that unless instructed otherwise, the spectrum analyser will be set to suitable values of input attenuation, reference level, resolution bandwidth, span and sweep speed). Two signals should be present, at 900 kHz and 1.1 MHz. The 900 kHz signal is the wanted sideband, and should be at a level of +8dBm ±2dBm. The unwanted sideband at 1.1MHz should be suppressed <-30dBc.

12.2.2.5 L/C Filter Alignment

Connect the board as Fig 2.2. The extra mixer enables the tracking generator to operate at 1MHz, when the IF output from the board is at 100 kHz. The mixer converts the 100 kHz IF back to 1MHz for input to the spectrum analyser.

Set function generator 1 to 1MHz 0dBm sine wave, and connect to JP1 pin 1 (1MHz-A). Set the tracking generator to 0dBm output and connect to JP1 pin 3 (1MHz-B). (A 1kohm resistor must be connected to ground to provide a DC return path. This resistor is included in the JP1 to BNC adapter). Set function generator 2 to 1.1MHz +7dBm sine wave and connect to the LO input of the mixer. Connect the RF port of the mixer to the spectrum analyser input. Connect the 500ohm probe to the mixer IF port. Connect the 500ohm probe to TP15. Set the spectrum analyser to 1MHz centre frequency (shown on tracking generator counter), 2 kHz/div span, input attenuation 10dB, and reference level -10dBm. Set the vertical scale factor to 2dB/div.

The filter band pass response should now be shown on the screen.

Adjust T1 and T2 for maximum amplitude, T3 and T4 for optimum flat top band pass centred on 1MHz. T1 and T2 tuning is quite broad. The 3dB bandwidth should be 8 kHz ± 1 kHz. Check that the tuning is exactly centred about 1 MHz.

If possible the cores should be sealed with bees wax. Recheck the shape after sealing.

12.2.2.6 Crystal Filter Alignment

Apply a logic "0" to pins 13 and 14 of JP3 using the DIP switch adapter. This sets the crystal filter bandwidth to 200Hz. Using the same set up as step 5/-, transfer the 500ohm probe to TP14. Set the spectrum analyser vertical scale factor to 10dB/div, and the span to 200Hz/div. Slow the sweep speed so the filter response is not distorted.

Adjust C34 for a symmetrical stop band. The 3dB bandwidth should be 200Hz ±20Hz.

Remove mixer and connect function generator 2 to JP1 pin 3 (1MHz-B). Set function generator to 1MHz, 0dBm sine wave. Connect 500ohm probe to spectrum analyser and to TP14. Apply a logic "1" to pins 13 and 14 of JP1 using the DIP switch adapter. This sets the crystal filter bandwidth to 10Hz. Readjust spectrum analyser to display 100 kHz signal at TP14.

Adjust C37 for a maximum signal on the spectrum analyser. Function generator 1 frequency should be varied in 1Hz steps to check symmetry and bandwidth of crystal filter. Now apply logic "0" to pin 13 and logic "1" to pin 14 of JP1. This sets the crystal filter bandwidth to 60Hz. Check the bandwidth of the 60Hz setting.

Note that both function generators must be phase locked to the OCXO for this test.

12.2.2.7 Phase Section Test

Switch off crystal filter by applying logic "0" to pins 13 and 14 of JP3. Switch to frequency mode by applying logic "1" to pin 2 JP3. Using the oscilloscope with 50ohm input, check for a clean 100 kHz square wave at CONN2.

Switch to phase mode by applying logic "0" to pin 2 JP3. Set the tau to 1ms by applying logic "0" to pin 9 JP3, and logic "1" to pins 5 and 7 JP3. Check for a clean 10us pulse at a repetition rate of 1 kHz at CONN2. Amplitude should be 0 to 2.5V. Transfer the oscilloscope to CONN5 and check for an identical pulse.

The other available tau values should be checked by varying the logic word applied to pins 9 (LSB), 7, and 5 (MSB) of JP3. "0" should give a tau value of 1000s and "6" a tau value of 1ms. A timer counter should be used to check the longer tau values. Both CONN2 and CONN5 should be checked.

12.2.2.8 99MHz LO Check

Connect the spectrum analyser with a direct lead to CONN4. A 99MHz signal should be observed, with a level of +14dBm (-0.5 dBm + 2dBm)

Set function generator 2 (1MHz-B) to 1.0001MHz, 0dBm sine wave. The 99MHz signal should now be sweeping approximately ±10kHz centred on 99MHz. Connect the oscilloscope with 1/10 probe to U6 pin 6. A distorted sine wave at 100Hz rate should be observed. The amplitude limits should be approx 0V to 9V. If the signal is not symmetrical about these limits, a select on test resistor should be added in parallel with either R18 or R27 to correct the symmetry. Typical value will be 33k to 220k.

12.2.2.9 Residual Phase Modulation Check

The residual phase modulation due to the residual 1.1MHz sideband from the image reject mixer is checked.

Set function generator 2 (1MHz-B) to 1MHz. Set function generator 1 (1MHz-A) to 1.001MHz. Set frequency mode on DIP switch adapter. Connect the spectrum analyser directly to CONN2 with 30dB input attenuation. Set centre frequency to 100 kHz, span to 500Hz/div, resolution bandwidth to 100Hz, other settings as appropriate. The sidebands 2 kHz away from the 100 kHz signal represent the residual phase modulation from the image. The level should be < -45dBc.

12.2.3 Equipment Required

2 off Agilent 33120A function generator with option 001

Variable power supply +12V and -12V 0.5A with current limit

Variable power supply +5V 1A with current limit

Digital meter 0.3% accuracy

10MHz OCXO accurate to 10^{-8}, output level 10dBm

Passive power splitter

Spectrum analyser with tracking generator, HP141T /8553B /8552B /8443A or equivalent.

Oscilloscope 200MHz or greater bandwidth, with 1/10 probe

500ohm, 1/10 probe for 50ohm input, 1GHz bandwidth

Mixer, Minicircuits ZP-3 or equivalent.

12.2.4 Special Equipment Required (See FIG 2.3)

10 pin IDC socket to BNC adapter (JP1)

14 way IDC to DIP switch adapter (JP3)

12.3 BOARD 3 Power Supply And Monitoring

This board comprises 4 circuit blocks:

Power supply

Input level monitor

Input frequency detect and switching

Tuning voltage monitor.

12.3.1.1 Power Supply

The main power supplies are +5V (Vdd), +12V and -12V. These are all generated from 3 switch mode converters, and distributed to each board. Local supplies of +5V and -5V are used on some of the boards, and are obtained by regulation of the +12V and -12V supplies. The input circuits of the converters are isolated from the board ground. Power should only be applied to the board using both pins of the input connector HD1.

12.3.1.2 Input Level Monitor

A sample of the input reference and measurement signals is obtained on board 1 using transformers and resistive dividers, and is routed to board 3. These signals are amplified by U3A and U3B and rectified by D1 and D2. U4 is configured as a dual window comparator which directly drives out of limits LEDs on the front panel board. TR2, TR3 and associated components provide drive to within limits LEDs.

12.3.1.3 Input Frequency Detect And Switching

The amplified input signals are limited by U2A and U2B, and are used as inputs to phase/frequency comparators U7 and U5. The other inputs come from a 6MHz oscillator, U6B. The outputs of the frequency comparators are smoothed and applied to comparators U1A and U1B. The outputs of these drive transistor switches TR1 and TR4, which operate the relays on board 1. These relays switch the function of board 1 between 10MHz (relays NO) and 5MHz (relays NC).

12.3.1.4 Tuning Voltage Monitor

The tuning voltages of the 5 phase lock loops used on boards 1 and 2 are routed to JP4. U9, U10, U11, and U12 are configured as 5 window comparators. The output logic signals from these are routed to the front panel board via JP1.

12.3.2 Board 3 Test Procedure

Connect a variable PSU to HD1. Supply should have adjustable current limit. Connect LED adapter to JP1. Connect dummy cable to JP4. (See later section for details of special test equipment). Connect function generator to CONN1

Increase input voltage slowly to 24V. Maximum current should be <100mA.

Check DC supplies as follows:

Supply	test point	Value	Tolerance
+5V (Vdd)	C15	+5V	± 50mV
+12V	C13	+12V	± 100mV
-12V	C17	-12V	±100mV
-5V	D7	-5.1V	± 260mV

Set function generator to 10MHz, level in dBm calibrated into 50ohm, sine wave. Vary the level between -15dBm and -3dBm. Check that the green LED connected to pin 21 of JP1 lights between these limits, and the red LEDs connected to pins 19 and 23 light outside these limits. The levels may be adjusted collectively using VR1. Accuracy of level limits should be ± 1.0 dB.

Set function generator level to -15dBm. Connect digital meter to TP1. Decrease frequency setting of function generator in 1MHz steps. At frequencies greater than

6MHz, voltage should be 0V ± 200mV. At frequencies < 6MHz voltage should be 5V ± 100mV.

Connect function generator to CONN2. Repeat step 3 using LEDS connected to pins 13, 15, and 17 of JP1, and TP2.

Connect the second PSU to 10 way ribbon cable connected to JP4. The negative connection is pin 2, and the positive connection is pins 1, 3, 5 Connect the second PSU to 10 way ribbon cable connected to JP4. The negative connection is pin 2, and the positive connection is pins 1, 3,5,7,9. Monitor the voltage using the digital meter. Vary the voltage between 0V and 5V, observing the state of the LEDs connected to pins 25,27,29,31, and 33 of JP1. The LEDs should be off between 0.7V ± 100mV and 4.4V ± 200mV, 7, and 9. Monitor the voltage using the digital meter. Vary the voltage between 0V and 5V, observing the state of the LEDs connected to pins 25,27,29,31, and 33 of JP1. The LEDs should be off between 0.7V ± 100mV and 4.4V ± 200mV.

12.3.3 Equipment Required

Agilent 33120A function generator with option 001

Variable power supply 0 to 30V 1A with current limit

Variable power supply 0 to 15V 100mA

Digital meter 0.3% accuracy

12.3.4 Special Equipment Required

34 pin IDC socket with LEDs fitted

10 way ribbon cable with IDC socket

12.4 Board 4 Analogue Meter

This board comprises 6 circuit blocks:

Reference IF multiplier

Measurement IF multiplier

Mixer

Differential frequency to voltage converter

Phase detector

Switches and Indicators

12.4.1.1 Reference IF Multiplier

The reference IF at 100 kHz comes from board 2 via HD1 pin1. It is multiplied to 4.9995MHz in a phase lock loop circuit. VCXO2 is the VCXO at 4.9995MHz. This frequency is divided by 9999 in U4, 5, 6 and 7. The 100 kHz reference is divided by 200 in U8 and U17A. These signals at 500Hz are compared in frequency and phase by U2 and U42 connected as a phase /frequency comparator. The output phase locks VCXO2 via loop filter U31.

12.4.1.2 Measurement IF Multiplier

The measurement IF at 100 kHz comes from board 2 via HD1 pin 3. It is multiplied to 5MHz in a phase lock loop circuit. VCXO1 is the VCXO at 5MHz. This frequency is divided by 50 in U3A and U3B. This signal at 100 kHz is compared with the 100 kHz measurement IF by U1 and U40. The output phase locks VCXO1 via loop filter U41.

12.4.1.3 Mixer

The output of VCXO1 is buffered and used to generate two anti phase sine waves by filtering. These are applied to the NO and NC terminals of analogue switch, U34. The switch terminal is driven by the 4.9995MHz square wave from VCXO2. The output of the switching mixer is low pass filtered and limited by U13 (An op amp and comparator combination).

12.4.1.4 Differential Frequency to Voltage Converter.

The heart of the meter circuit is a low drift frequency to voltage converter. The frequencies of the reference 500Hz from U17A and the measurement 500Hz from the mixer are compared and converted into a voltage. The measurement 500Hz has a total FSD range of 0Hz to 1 kHz on the least sensitive meter range.

The principle behind the converter is that digital mono stables are triggered by the 500Hz signals. These generate a pulse of very accurate width based on a number of cycles of an asynchronous clock. The clock is generated by U29 and is at a frequency of 4.88281 kHz nominal (± 1.5%). Each cycle of the nominally 500Hz signal generates a pulse of length 1.6384ms nominal (± 1.5%) by counting 8 cycles of the asynchronous clock. The digital mono stable is made up of U9, U11 and U15C (other channel U10, U12, U15B).

The pulses from the digital mono stables are used to gate charge into the summing amplifier U19. Precision analogue switches, U18, are used to connect reference voltages of +5V and -5V to the summing amplifier for the duration of the pulses. The gain of the summing amplifier sets the meter sensitivity. An averaging time constant is provided by C7. On the lowest sensitivity range the width of the pulses is reduced to 0.8192ms nominal. This is to avoid missing pulses when the measurement 500Hz IF reaches 1 kHz. The range resistor, R19, is therefore twice the expected value.

Most sources of drift cancel in this circuit. U19 is a chopper-stabilised op amp. The only remaining source of drift is the temperature drift of the offset voltage of U14. This is very small. VR3 is the coarse zero set and the multi turn trimmer connected to TP3, TP4 and TP5 is the front panel zero set. The set zero switch SW3 holds both pulse outputs at logic high. This enables the summing amp to be zeroed. VR1 provides full-scale adjustment of the meter. U39 switches between frequency mode and phase mode.

12.4.1.5 Phase Detector

In phase mode the frequency to voltage converter is not used. The reference and measurement IF's at 100 kHz are divided in decade steps down to 100Hz. The reference IF dividers are U8, and U36B. The measurement IF dividers are U35 and U36A. The decade output appropriate to the meter phase range is selected by U28, and applied to the extended range phase detector, U37 and U32. The pulse outputs of the phase detector are averaged by U38. The phase range of the meter is 0 to 2Pi for increasing phase and 0 to -2Pi for decreasing phase. The meter is actually calibrated in time units taking into account the multiplication in the main comparator.

12.4.1.6 Switches and Indicators.

SW1 and SW2 increment and decrement the meter range. U21 and U22 de bounce the switches and provide pulse outputs to the up/down counter, U23. U27A and U27C prevent over/under flow of the counter. U24 adds the offset needed when the multiplier is switched on the main comparator. U25 provides decoding for the 6 range LEDs. U26 provides decoding for the frequency and phase range selection.

12.4.2 Board 4 Test Procedure

12.4.2.1 Connections

The board should be connected to +5V, +12V, -12V power at HD1. A dummy cable should be made up to connect to the IDC socket on the ribbon cable pre attached to the board. The two function generators should be connected to the reference and measurement inputs on HD1. They should both be set to 100 kHz, square wave, 4V peak to peak into HiZ, offset on and set to 2V. (This should result in a 0 to 4V square wave). The multiplier input should be connected via a 100kohm resistor to ground. (See Fig 4.1)

The 12V rails should be switched on before the 5V rail. The current consumption with the function generators on should be:

+5V	<50mA
+12V	<10mA
-12V	<10mA

12.4.2.2 Phase Lock Check

Check the frequency at TP15 using the frequency counter with 1/10 probe. The frequency should be 4.9995MHz with no jitter. Check the frequency at TP16. The frequency should be 5MHz with no jitter.

Using the digital meter check the tuning voltage at C2. The voltage should be 2.5V ± 200mV. Check the tuning voltage at C34. The voltage should be 2.5V ± 200mV. Now vary the frequency of the measurement input by +/10Hz from 100 kHz. The tuning voltage should remain in the range 1.5V to 4.5V. Return the function generator to 100 kHz.

12.4.2.3 Mixer Check

Connect the oscilloscope via a 1/10 probe to TP8. A 500Hz clipped sine wave should be observed of amplitude 0V to 5V. Now vary the frequency of the measurement input by ±10Hz about 100kHz. The sine wave should vary in frequency from 0Hz to 1 kHz. The amplitude should be approx constant. Transfer the oscilloscope to TP7 and repeat. A clean square wave of frequency 0Hz to 1 kHz should be observed. Transfer the oscilloscope to TP 6. A 500Hz square wave should be observed. Return the function generator to 100 kHz.

12.4.2.4 Digital Mono Stable Check.

Set multiplier to 10^3. Set the meter scale so LED 6 is lit. Check using the oscilloscope for pulses of width 1.6384ms ± 1.5% at TP9 and TP10. Set the meter scale so that LED7 is lit. The pulses should now be 0.8192ms ±1.5% wide.

12.4.2.5 Frequency To Voltage Converter Check.

Connect a 50 – 0 – 50-uA meter to HD2.

Connect 5V to TP12 to switch to frequency mode. Centre the front panel zero set control and check that adjusting VR3 can zero the meter. Select the least sensitive meter range and vary the measurement frequency ± 10Hz about 100kHz. The meter should deflect to full scale. Select the second range and set the frequency to 100.001 kHz. Adjust VR1 for full-scale deflection. Check the remaining 2 ranges with frequency deviations of □ 0.1 Hz, and ± 0.01Hz. The meter accuracy should be ±5% of full-scale deflection, i.e. ± 0.5 divisions.

12.4.2.6 Phase Detector Check

Connect 0V to TP12 to switch to phase mode. Select the least sensitive meter range. Set the measurement frequency to 100.100 kHz. The meter should be sweeping from 0 to +10 and back to 0, taking 10 seconds for a sweep. Set the measurement frequency to 99.900 kHz. The meter should now be sweeping from 0 to -10 at the same rate. Check the remaining 3 ranges in the same way, reducing the frequency offset from 100 kHz by a factor of 10 for each range.

12.4.3 Equipment Required

2 off Agilent 33120A function generator with option 001

Variable power supply +12V and -12V 0.1A with current limit

Variable power supply +5V 0.1A with current limit

Digital meter 0.3% accuracy

Frequency counter with ext reference

Oscilloscope 200MHz or greater bandwidth, with 1/10 probe

12.4.4 Special Equipment Required

HD1 adapter (see Fig 4.1)

12.5 Complete Comparator Test

The completed comparator module should be tested before installation in the instrument. This will test aspects of the comparator performance that are not covered by the final instrument test.

The standard test of the comparator is the zero drift and noise floor test. This is carried out by splitting a stable signal, and applying the same signal to the reference and measurement inputs of the comparator. This test is useful, and simple to carry out. It therefore forms the main method of verifying the performance of the instrument, and is included in the operators' manual as the verification method.

However the noise floor test only tests the comparator for two signals of a fixed phase relationship. The unit may show a different performance for two signals with a linearly varying phase relationship. This is equivalent to two perfectly stable signals of a slightly different frequency. The Allen variance measurement of short-term stability ignores a fixed frequency variation, and so should give the same resulting noise floor for the case of a linear phase ramp as for the noise floor test. In practice, this is not so. The performance of the phase comparator is worse for two input signals of slightly different frequency, than for two input signals of the same frequency.

The origin of this degradation of comparator performance is the cross talk between the channels. When the zero drift test is used, the frequencies at the measurement and reference inputs are the same. The cross talk is only evident by a phase shift on the measurement output. This is caused by the vector sum of the wanted output, which is the multiplied frequency difference between the channels, in this case, zero, plus 100 kHz, and the unwanted signals caused by cross talk. The result is to produce an incorrect phase value. This is not seen in the zero drift measurement, as it is not varying. When two signals of different frequency are used, the phase of the wanted output (100 kHz + the multiplied frequency difference) and the cross talk components are continually varying in phase, sometimes adding to give a phase advance, and sometimes a phase retard. This produces an irregularity, similar to noise, to the measured phase characteristic, which should be a perfectly linear ramp. When the phase is measured by the GT200 time interval meter, and converted to an Allen variance, the noise floor will be worse than that measured by the zero drift test.

This effect is difficult to see and measure, for if two frequency sources are used, their own noise will be multiplied by the comparator and will obscure the effect.

In order to overcome this problem, a unique measurement method has been devised. The set up is as for the zero drift test, however a delay line is inserted in the measurement path. The delay is electrically variable over about 1ns. By applying a voltage ramp to the delay line, a phase ramp may be generated. This is equivalent to a slight frequency separation between the measurement and reference inputs. The noise of the frequency source is still cancelled as it is applied to both inputs. The voltage ramp must eventually return to its starting point, so the frequency-offset condition only applies during the linear portion of the ramp. Phase measurements must be accumulated during the ramp period.

If two VCXOs of good quality are used for the reference and measurement inputs, then they may be separated in frequency sufficiently for a spectrum analyser to be used to measure the cross talk. The procedure is described in the next section.

12.5.1 Test Procedure

12.5.1.1 LO phase lock test.

The top board (power supply and monitoring, board 3) should be demounted from the comparator and reconnected using extension cables.

A function generator should be connected to the reference input. A spare front panel board should be connected to JP1 on board 3. A 24V, 1A power supply should be connected to HD1. The function generator should be set to 10MHz out, 0dBm into 50 ohms. The oscilloscope should be connected to HD1 on board 2. The unit should be switched on, and set to 10^3 multiplier. The reference and LO phase lock indicators on the front panel board should light. Vary the frequency of the function generator by ± 500Hz, and ensure that the LO remains locked. Disconnect the cable from CONN1 on board 2 (10MHz in). The LO should unlock and the voltage on the oscilloscope should go to about -8V. Set the function generator to 10.0005MHz. Reconnect the cable to CONN1. The LO should relock within 10ms.

Disconnect the cable to CONN6 (IF-B in). The LO should unlock, with the tuning voltage at about 8V. Set the function generator to 9.9995MHz. Reconnect the cable to CONN6. The LO should lock within 10ms. This tests the LO acquisition over all possible ranges of the input reference frequency.

12.5.1.2 Crosstalk and spurii test

Connect the comparator as shown in FIG 5.1

Set the comparator to frequency mode, 10^5 multiplier, and filter off. Connect a MCX test lead to CONN2 (counter A) on board 2. Connect the lead to a frequency counter. Adjust one of the VCXOs fine trim to give a frequency of 101 kHz. This has adjusted the input frequency difference to 1Hz.

Transfer the counter A lead to the spectrum analyser, so the spectrum analyser is now connected to CONN2 on board 2. Set the spectrum analyser to 40dB input attenuation, reference level +14dBm, resolution bandwidth 100Hz, video bandwidth 10Hz, span 1kHz per division, and sweep time 5s per div. Tune in the wanted signal at 101kHz and acquire a sweep. The sidebands at ±1 kHz, ±2 kHz etc are caused by the crosstalk. These should be less than 45dBc. Make a note of the levels on the test sheet.

12.5.1.3 Noise floor test, frequency mode.

Connect the comparator as FIG 5.2

Set Comparator to frequency mode, 10^5 multiplier, and filter off. Connect the FXQ board to JP5. Connect the FXQ clock to CONN8. Connect the FXQ to the computer RS232 port. Turn on the unit and set to frequency mode, 10^5 multiplier, and filter 200Hz. Set the FXQ control panel to a tau of 10ms. Start run.

For the instrument to meet its specification, the standard deviation should be less than 10^{-13} divided by gate time (tau). For a tau of 10ms, this is 10^{-11}. The data graph on the FXQ virtual panel should be set to display the last 1024 readings. The standard deviation figure that is continuously calculated gives the required value. This should be less than 10^{-11} the value will vary slightly as the phase relationship of the input signals drifts.

12.5.1.4 Noise floor test, phase mode

Set comparator to phase mode, 10^5 multiplier, and filter 200Hz. Reset phase to centre of range. On the FXQ panel set tau to 1ms.

Start a run. Set the data graph to show the last 1024 readings. The standard deviation figure will show the standard deviation of 1024 phase measurements over 1 second. For the instrument to meet its specification, the standard deviation should be less than 50fs.

12.5.2 Equipment Required

2 off low noise OCXOs at 10MHz, with frequency trim.

Power supply +24V 1A

FXQ board, connections, and computer

Spectrum analyser

Passive power splitter, SMA connectors

2 off short SMA to SMA cables

Function generator

Frequency counter

12.5.3 Special Equipment Required

Voltage dependent delay line.

Lead extender kit

13 APPENDIX

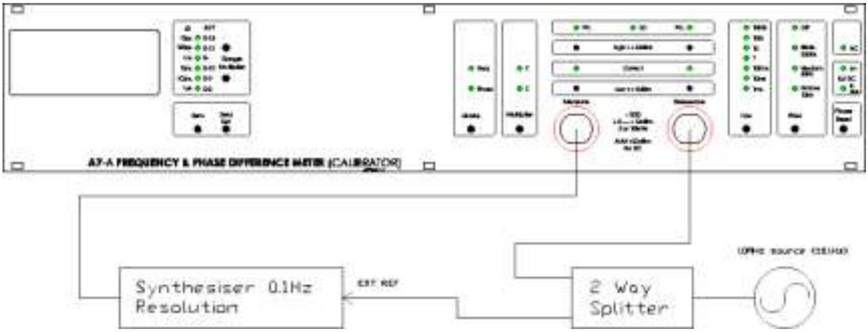
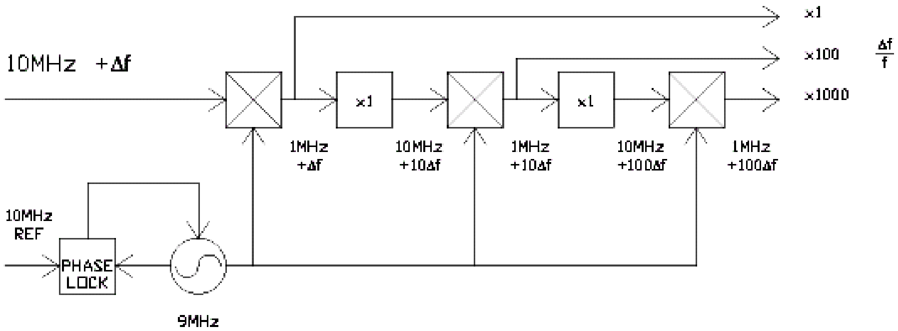
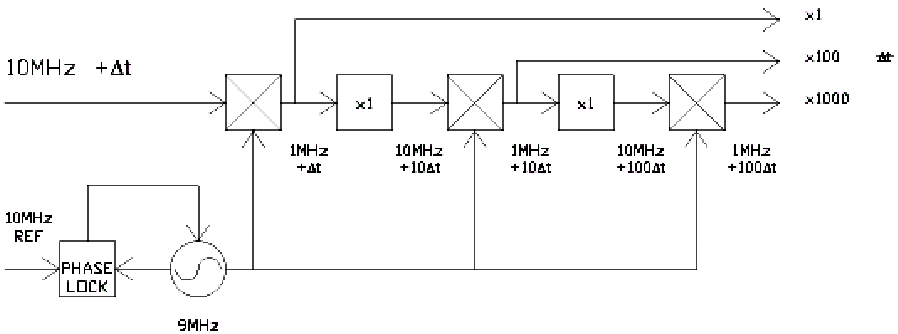


Figure 1.1 A7-MX System Test



Typical Mix/Multiply Chain Showing Frequency Relationships



Typical Mix/Multiply Chain Showing Phase Relationships

Figure 2.1 Mix/Multiply Chain Showing Frequency/Phase Relationships

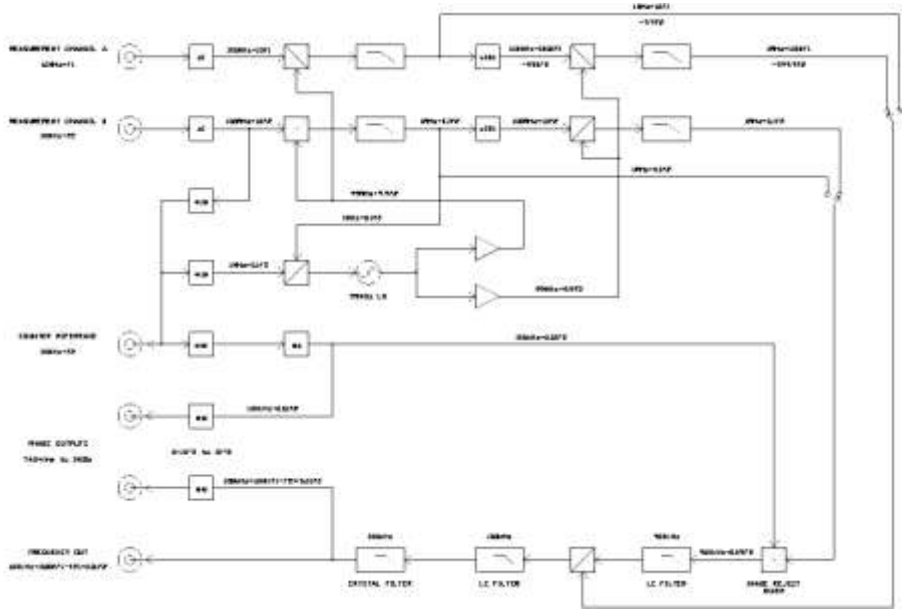


Figure 3.1 Block Diagram

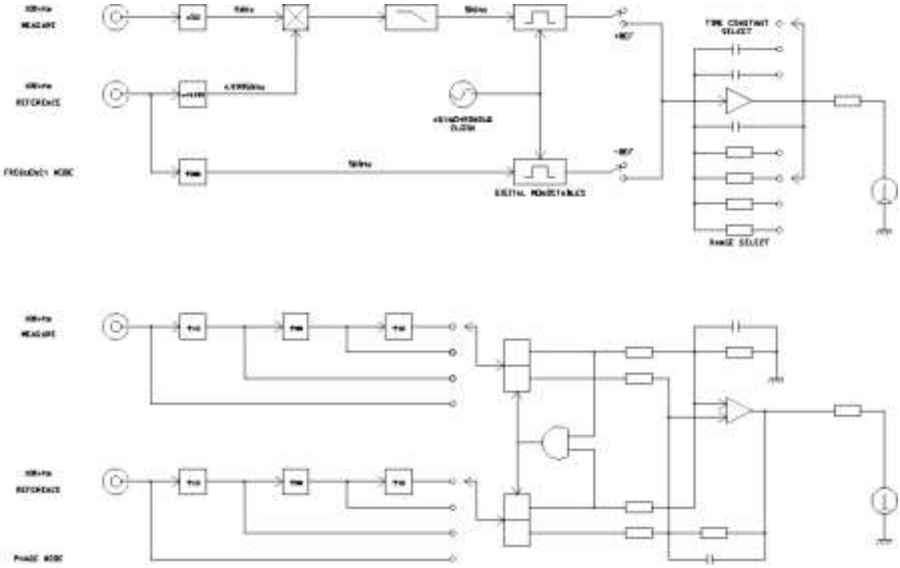


Figure 4.1 Meter Circuit Frequency And Phase Mode Block Diagram

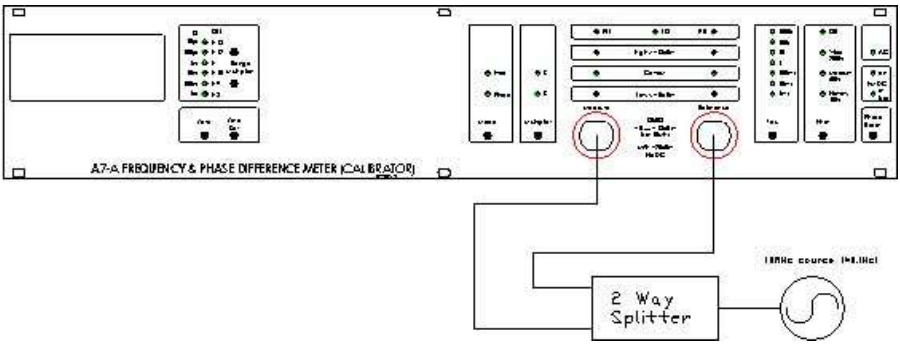


Figure 5.1 Frequency Mode, Phase Mode and Noise Floor Verification.