A 500 MHz Mixer-Type Phase Detector with Wide Dynamic Range and Small Phase Error

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Abstract

Many modern applications require accurate phase detectors able to operate over a wide dynamic range.Such a phase detector has been developed at Daresbury and will handle a 55dB input signal range for less than 0.2 degree phase error at balance.Insensitivity to input signal variation to the detector considerably simplifies the design of RF equipment such as cavity phase control and the setting of station phase in multi-klystron accelerator systems.The paper describes the techniques used to acheive this excellent phase detector performance.

1. INTRODUCTION

The basic technique used in this equipment is to synchronously mix two input channels at 500MHz down to two channels at 2 MHz, at which frequency a phase comparison is made.The present phase detector is an improved version of equipment developed at Daresbury for use with the Pohang source in South Korea[1]. In multi -klystron systems there are two likely uses for such a phase detector ; to set the station phase relative to the master oscillator and to control cavity resonance phase angle. If a storage ring is to be ramped after injection two distinct performance parameters are required from the phase detectors.Firstly in the case of the cavity resonance control, cavity field strength increases proportionately to RF forward power.If there is no beam loading no differential change to the voltages between the two phase comparing inputs occur as the RF power is increased. The error from the phase detector for a given input total dynamic range could thus be quoted. However in the case of setting station phase the RF input to one comparison input - the master oscillator- would be constant whilst the amplitude of the other could change by 30dB as the RF output power from the Klystron increases. The differential dynamic range is therefore important and this can be measured by keeping one input contant and varying the amplitude on the other to obtain the phase detectors error to this situation.

2 DESIGN METHODS

2.1 Post Mixer Amplifier

It was felt that this amplifier was likely to be the most critical device in terms of phase shift with signal level.Initial experimental work centred on an Avantek AGC553 since it was desired to obtain an output signal level reading from the AGC control voltage. This device proved unsatisfactory the best performance was at 50MHz where an AGC change of 40dB gave a phase change of 0.8 degrees.
The Plessey SL532C low phase shift limiter was then tested at 2MHz with excellent results; a four stage limiter gave less than 0.2 degree change for a 50dB signal level change.

2.2 Mixer Selection

Initially a Minicircuits SRA 1H was chosen as the mixer and the assembly of Fig. 1 was constructed for tests. This set up gave a 35dB dynamic range but only a 12dB differential dynamic range for 0.5 degrees phase error. It was established that the reason for this poor differential dynamic range was leakage from the local oscillator port via the power splitter to the local oscillator port on the second channel. There was bound to be a limit to differential dynamic range if one channel carried a larger signal than the other before corruption of phase information on the second channel occured. This differential dynamic range was much less than estimated.
Manufacturers of mixers quote LO port to RF port isolation but not RF port to LO port isolation . Our experience showed they are deffinitely not the same, but there is a relationship. So good LO to RF isolation is important in selecting a device but it is better than RF to LO port isolation of that device.
The Minicircuits SBL-2LH was chosen for its good LO to RF port isolation and it improved differential dynamic range to 22dB.

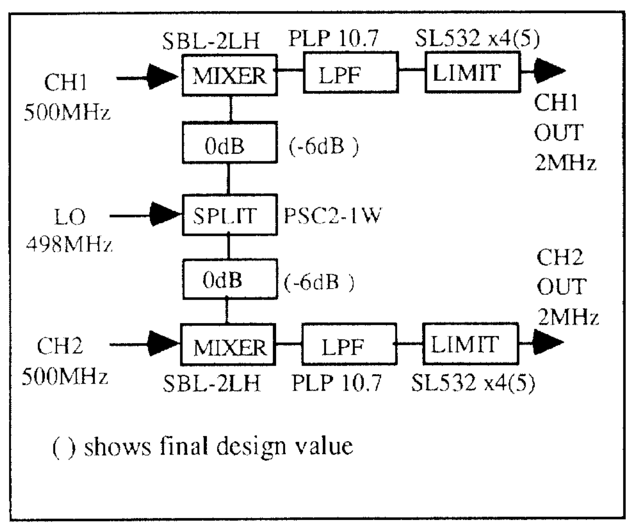

Fig. 1 Down Mix Test Circuit

Measurements were made of sensitivity of phase error to local oscillator drive level to the mixer. It proved to be important that the mixer drive was near to the manufacturers optimum level to acheive the best differential dynamic range performance. In addition the drive level needed to be stabilised within 0.5dB to keep phase error with LO amplitude change under 0.2 degrees.

2.2 TTL Discriminator

Each channel of the limiter is followed by a low pass filter to set the noise bandwidth and to select the fundamental frequency component to be used in the phase comparisson. An Analog Devices AD9696KN low jitter discriminator is used in a circuit with ac hysteresis applied Fig 2. This circuit together with a Five section limiter gives an input dynamic range of 55dB.

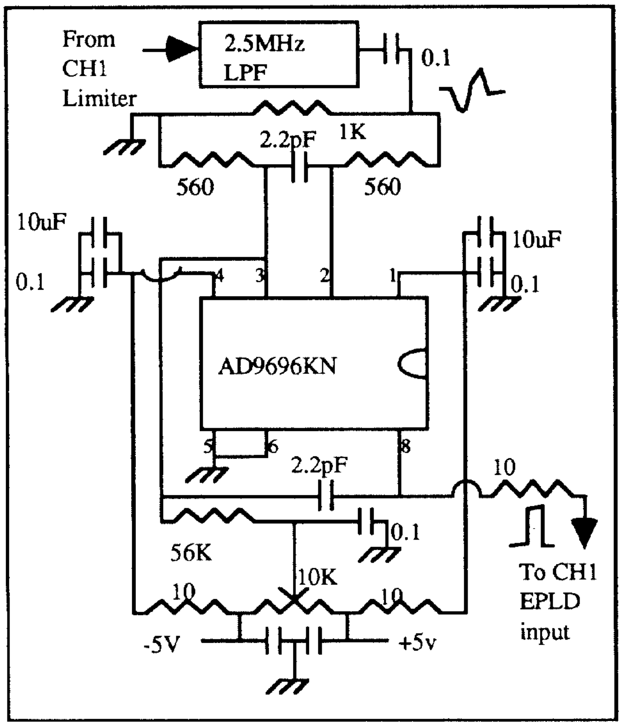

Fig. 2 Discriminator with AC Hysteresis

2.4 Phase Comparison EPLD

The two square waves from the comparators are time compared in an edge sensitive phase phase detector within an EPLD(Erasable Programable Logic Device). There are two versions of this EPLD for cavity resonace or station phase applications. One gives an output corresponding to + - 180 degrees and the other corresponding to + - 360 degrees.Unlike most edge sensitive phase detectors there is no uncertainty at balance essential for low phase error . This is acheived in the EPLD logic by allowing a minimum pulse of a few nanoseconds to be present at both the two phase detector output pins at balance. One output for leading phase has a positive pulse which increases in width with phase error, the second output for lagging phase has a low pulse which increases in width for lagging phase error. The average dc level is summed and offset in an operational amplifier to give a phase error either side of 0 volts.Two input pins on the EPLD are used to assist setup. One when selected joins both phase inputs together so zero phase difference can be adjusted on the dc amplifier. The second is used to reverse the sense of the output if needed in a closed control loop situation.

This phase detector reliably indicates differences of under 0.2 degrees at 2MHz giving a resolution of better than one picosecond at 500MHz.

2.5 Local Oscillator

A block diagram of the local oscillator is shown in Fig. 3 , there is nothing particularly special about the circuitry. A 7th overtone crystal oscillator at 124.55MHz is buffered and amplified to +13 dBm and drives a Minicircuits doubler used as a four times frequency multipler. The output from the multiplier is bandpass filtered at 498MHz and amplified to +7 dBm at which point it enters a gain control stage followed by additional amplifiers and filters to the output stage an Avantek UTO518. The output from this stage is low pass filtered to give a clean sine wave before going to the output connecter via a coupler. The coupled outut is attenuated by 15dB and level detected and used in an amplitude control loop to maintain an output level from the local oscillator of 20dBm.

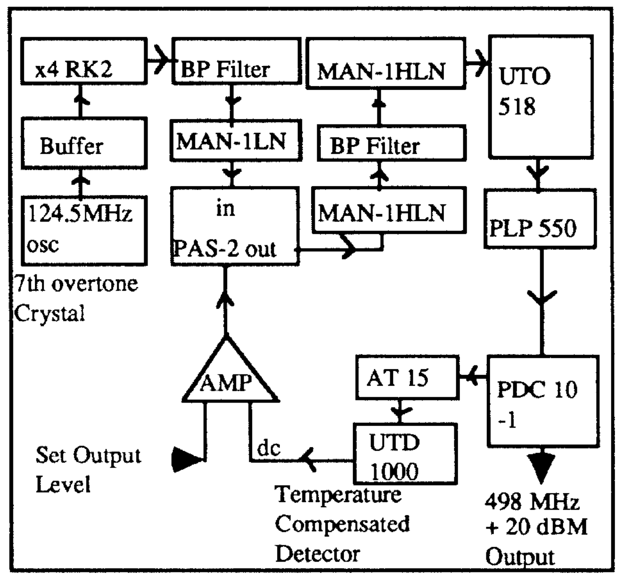

Fig 3 Local Oscillator Assembly

Local oscillator output amplitude is maintained within 0.2dB by the temperature compensated detector an Avantek UTD1000. On a practical note, experience has shown that the overtone crystals used age during the first 48 hours of operation.Final adjustments of the coil associated with the oscillator are made at this time to avoid switch on problems.

2.6 Construction

A special purpose aluminium box was manufactured having three identical screened inner compartments. One contains the local oscillator board, another the mixer and limiter assembly and the third the discriminators and EPLD phase detector board. Each printed circuit is of earth plane construction with the earthplane in physical contact with shoulders inside the aluminium screened box. The attention given to the equipment construction has resulted in this complex detector being very stable even when deliberately touching parts of the circuitry

3. TESTING

The set up for dynamic range testing is shown in Fig 4. To facilitate testing a high gain output amplifier is included within the internal phase detector circuitry to drive a meter test output connector. When the meter is in circuit the scaling is such that the small scale graduations on the meter when high gain is enabled are 0.2 electrical degrees at 500MHz. The signal generator amplitude can be switched through a 60dB range and the phase detector errors at balance seen immediately from the meter scale.
There is however a problem in measuring differential dynamic range because it involves the use of two attenuators in each input to the phase detector each set to a different value.The change in time delay through the attenuator as each switch is brought in is significantly greater than the phase detectors 1pS resolution. The solution adopted to get realistic results was to calibrate the attenuator switch settings using a network analyser. The error observed from the phase detector could be subtracted from the known switch error to obtain the phase detectors differential dynamic range performance.

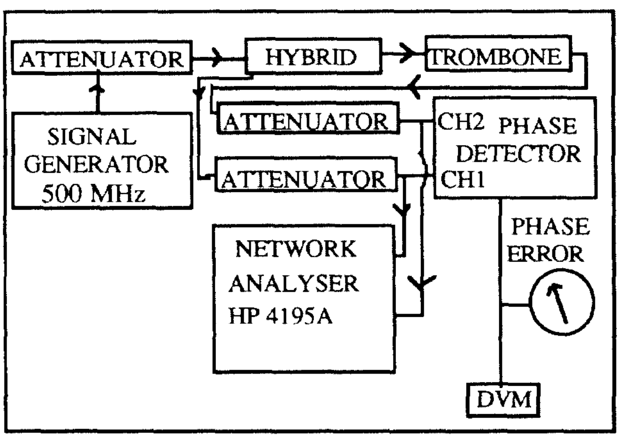

Fig 4 Performance Test System

Eight of these phase detectors have now been constructed and dynamic ranges of better than 50dB for 0.2 degree phase error are typical for them all with some exceeding 60dB.
In the case of differential dynamic range the best performance was recorded when the fixed amplitude on the reference chanel was set at -20dBm.The signal on the other channel could move between +20 and - 20 dB for less than 0.5 degree phase error. This is noticably superior to the original circuit developed for Pohang. It is thought that the reason for this is that the 6dB attenuator between mixer and local oscillator power splitter (see Fig 1) , has reduced leakage between the two channels for two reasons.It reduces dirrect local oscillator port leakage and it probably presents a more resistive termination to the mixer further improving its balance and thus signal leakage.

4. INSTALLATION ON THE SRS

Four units have been in use for a number of months on the storage ring at Daresbury and when used with new quadrature hybrid phase shifters show less than 0.5 degree phase error during an RF ramp on the storage ring cavities.

5. CONCLUSIONS

The method used and the equipment designed has been shown to offer excellent phase detector performance. The insensitivity of the equipment to input RF amplitude variations will considerably simplify the design of multi klystron RF systems. This excellent phase detector performance has only been acheived by identifying key fundamental areas of the basic design and ensuring that optimum performance was achieved in each .

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REFERENCES

1 D.M.Dykes et al A Low Power RF System for the PLS Cavity Test Facility