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NATIONAL RADIO ASTRONOMY OBSERVATORY

MEMORANDUM

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To: IG File

From: K. H. Wesseling

Subject: Interferometer Local Oscillator System Description

1. Introduction

The local oscillator system for the interferometer provides a phase and amplitude stable local oscillator signal at each of the telescopes. A synchronous and leveled pump signal for the parametric amplifiers is derived from the LO signal. For the 42-foot telescope a phase stable reference frequency is generated in the control building.

A computer monitors the entire system operation but does not provide corrective control in case of malfunction.

2. Overall System Description

The LO-system consists of the following units:

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a) A crystal stabilized Master Oscillator, located in the Control Building.

b) Four phase locked slave oscillators. One is provided for each of the three 85-foot telescopes. The fourth one, located in the Control Building, generates the 42-foot reference signal.

c) Four roundtrip Phase Controllers. Part of the output of each slave oscillator is sent back to the Control Building and phase compared with the transmitted signal.

II

Figure 1 gives a simplified block diagram.

The Master Oscillator is shown on the left. It has two groups of four outputs each, with stable relative phases within a group. The RF output is a frequency stable 1317.5 MHz. The IF output is used as an offset frequency in the phase comparators. This frequency is 30 MHz and stable. There are three reasons for using an offset frequency:

a) It separates the outgoing and the incoming signals at both ends of the transmission path.

b) It makes a higher sensitivity system possible, using mixer type receivers at both ends of the high attenuation transmission path.

c) The APC loop feedback can be designed without reference to the incoming RF signal level using an IF amplifier of the limiter type.

A slave oscillator is shown on the right in the diagram. The phase comparator output drives the voltage controlled oscillator (VCO) output phase towards zero phase difference with the incoming signals. The 1347.5 MHz from the VCO is multiplied in a frequency multiplier to the interferometer LO frequency of 2695 MHz. Another frequency multiplier delivers pump power for the synchronously pumped degenerate parametric amplifier front end at 5390 MHz. The paramp is very sensitive to pump level changes. For this reason the pump power is held constant with an ALC loop via the VCO.

The roundtrip phase controller is shown to the right of the master oscillator. A phase comparator measures the phase difference between the outgoing RF and IF signals and the return-signal from the telescope. A phase shifter is controlled by the phase comparator output, and maintains a constant roundtrip phase.

III

To summarize:

Stable frequencies are generated in the Master Oscillator and distributed over four independent channels. Three servo loops in each channel establish a phase and amplitude stable signal at each of the front ends. The APC-loop at the telescope keeps the VCO phase-locked to its inputs. The servo loop is an integrating loop for the phase and doubly integrating for the frequency, allowing no long-term phase errors, and consequently no frequency errors. The ALC-loop keeps the pump power at a constant level. The ARC-loop maintains a constant roundtrip phase. If the transmission path is the same in both directions, the one-way phase will therefore be constant also.

3. Detailed System Description

3.1 Master Oscillator and Associated Circuitry

A block diagram is presented in figure 2.

I

The heart of the Master Oscillator is a VCO in a phase locked loop. The VCO generates a spectrally pure 1317.5 MHz at a 2 W power level. Four outputs at 500 mW level are provided. The reference input to the phase locked loop is a harmonic mixer. The loop amplifiers, the phase comparator, the crystal oscillator and the harmonic mixer are located in a block named: Master Oscillator Crystal Control.

It is a Curry, McLaughlin and Len lockbox, with two modifications. The crystal oscillator is improved to give a better frequency stability. Further, an out-of-lock indicator is added, which can be monitored by the computer.

An automatic level control loop stabilizes the output power of the VCO. A crystal detector senses the VCO output level. It is compared with a stable DC reference voltage. The difference signal is amplified and modulates the output voltage of the VCO anode power supply. An integrating servo loop is used and thus ultimate stability is determined by the quality of the RF level detector.

II

Interferometer LO frequency is periodically monitored by the computer. A nominal 1347.5 MHz signal, generated in No. 4 slave oscillator, is measured in an HP-5245L counter with a type 5254A plug-in. The computer gives sample commands and reads the BCD counter output. A "Counter Select" panel is added, to manually monitor other system frequencies. When one of the other frequencies is being monitored a computer inhibit signal is given by the Counter Select circuitry. The computer sample command is thereby disabled.

III

An auxiliary 10 MHz output from the counter timebase generator is multiplied times three and amplified to a 1 W level to provide the 30 MHz offset frequency. Output level is held constant with an ALC-loop via a voltage variable attenuator at the frequency multiplier input.

The computer monitors the power level of both the 1317.5 MHz and 30 MHz signals. However, correct system operation is not critically dependent upon the power level of either of these signals.

3.2 The Slave Oscillators

A block diagram is shown in figure 3.

I

The slave oscillator is a voltage controlled oscillator of the triode cavity type in a phase-locked configuration. A varactor detunes the anode cavity over a ± 0.1% range. Points in favor of the chosen type oscillator are:

a) The very clean spectrum. Harmonics are down more than 60 dB from the fundamental. Short term stability is excellent, and therefore a narrow bandwidth APC loop is possible.

b) High output power.

c) Easy output power leveling by modulating the anode supply voltage. Such a leveling scheme is free from additional phase shifts.

Limited tube life is a disadvantage. Average tube life expectation is one-half year.

The tube oscillates at a nominal 1347.5 MHz. Output power is 2 W, and divided into four parts.

500 mW is sent back via the input circulator to the Control Building, to complete the roundtrip path. 20 mW can be used for monitoring purposes. 1 W is reserved for interferometer second frequency operation. The last 500 mW is frequency multiplied to 2695 MHz at 250 mW. 10% of the output at 2695 MHz is used as the interferometer LO signal. The other 90% is further multiplied to 5390 MHz, and pumps the front end parametric amplifier at a 50 mW level. Both frequency multipliers use a varactor as the non-linear element. Forward bias is applied for good efficiency. Three-cavity output filters with a 5% wide passband are used. As a result spurious outputs are below the desired output by more than 60 dB.

II

The VCO is enclosed within two servo loops. A phase control loop (APC) keeps the VCO output phase locked to the input phases. An automatic level control loop (ALC) keeps the pump level constant.

Operation of the APC-loop is as follows (see figure 3). An input circulator directs the incoming 1317.5 MHz signal through a bandpass filter with 1317.5 MHz center frequency to the signal port of a mixer. The mixer LO signal is 1 mW of the VCO output. The 30 MHz difference frequency is amplified to a constant level and phase compared in a balanced mixer (HP-10514A) with 30 MHz reference. The difference output voltage from the balanced mixer controls the VCO in frequency. Once locked, the VCO oscillates at exactly the sum of the two input frequencies. When the oscillator frequency starts to drift a correction voltage is applied to the voltage tune terminal of the VCO. This correction voltage is derived from a phase difference between the two inputs of the balanced mixer. This causes the VCO output phase at 1347.5 MHz to be different from the sum of the input phases at 1317.5 and 30 MHz, although the frequency is still correct. By increasing the gain of the DC amplifier, that follows the balanced mixer, this phase error can be reduced to negligible values. However, this very high DC gain prevents the loop from locking onto the inputs, when out of lock. A detector looks at the output of the balanced mixer. When this output differs from DC by more than a few kilohertz the loop is judged to be out of lock. The circuit following this detector gives an "oscillator-out-of-lock" signal to the computer. It simultaneously reduces the previously very high DC gain to a sufficiently low value to allow the loop to lock, if the VCO is still within the capture range. Capture range depends on the APC-loop bandwidth and is ± 200 kHz. Once locked, the loop will hold over the voltage tune range of the VCO of ± 1.5 MHz. This property is used as follows:

When the loop is out of lock, the out-of-lock detector circuit starts a search oscillator. It sweeps the VCO over its entire voltage tune range searching for the proper frequency. When the frequency comes within the capture range of the loop, it automatically relocks, the search oscillator is disconnected, and very high DC loop gain re-established. In this way the APC-loop acquisition range is extended from the capture range to the hold range.

The automatic level control loop operates as follows. A directional coupler samples the pump power flow in the direction of the parametric amplifier. An HP-423A crystal detector converts the RF voltage to DC. The detector is used in its voltage linear range. The DC detector output, after amplification, is compared with a DC reference voltage. The difference is amplified and modulates the VCO anode voltage power supply in the PLO-monitor. The servo loop is of the integrating type. The two frequency multipliers in the loop have an approximate one-to-one input to output power relationship, over the power range of interest.

Interaction at the VCO between the APC and ALC loops is small. Frequency modulation of the VCO causes a negligible amplitude modulation. Amplitude modulation causes some frequency modulation; however, amplitude modulation is small. It has to compensate only for changes in frequency multiplier conversion efficiencies. APC and ALC loop time constants are made different by several orders of magnitude. This prevents oscillations by interaction.

III

The arrangement used to separate the incoming 1317.5 MHz signal from the outgoing signal at 1347.5 MHz may need some further explanation.

The outgoing signal is separated from the incoming signal by the input circulator only to a first order. Isolation of the circulator is not perfect. Also the incomplete match between cable and circulator and small reflections inside the cable force part of the outgoing signal to reflect back into the input port. Reflected signal level and mixer local oscillator level can be of the same order of magnitude in practice. If no filter is present this reflected signal adds to the local oscillator signal with arbitrary phase. Changes in the phase or amplitude of the reflected signal thus cause the phase to change, which is undesirable. Two measures taken solve this problem. The insertion of a filter in the signal port tuned at the signal frequency, but with high loss at the local oscillator frequency reduces the unwanted signal. Using a balanced mixer reduces the sensitivity to LO power at the signal port. A balanced mixer to a first order is insensitive in its output phase to the presence of LO power at the signal terminal.

Poor mixer LO to signal port isolation also causes LO signal to be present in the input line. The isolator, after reflection against the filter, absorbes this leakage signal. The separation scheme as shown guarantees less than 1° phase error for 50% reflection of the outgoing signal. It also protects the mixer crystals from burnout would the input cable inadvertently be disconnected.

IV

All components in the block diagram, except the PLO-monitor unit, are mounted inside the front-end box at the telescopes. The PLO-monitor is located in an air-conditioned hut at ground level.

The PLO-monitor contains regulated DC power supplies for VCO anode, filament and bias voltages. Four monitor meters are mounted on the front panel. One pair of meters indicates all the systems supply voltages and currents and the mixer crystal currents, when selected with a monitor switch. The third meter displays the phase locked oscillator level as measured at the pump frequency. Upon operation of a push button it indicates the position of the level servo loop. The fourth meter displays the position of the APC-loop. An "out-of-lock" lamp lights up when the VCO is out of lock.

The critical monitor signals are again displayed on a "PLO Remote Monitor" panel in the Control Building. From the PLO Remote Monitor the signals are offered to the computer for supervision.

3.3 Roundtrip Phase Controller

Figure 4 shows a block diagram.

I

The circuitry is identical to that of the slave oscillator, except that a phase shifter is controlled in position instead of a VCO in frequency. Zero phase difference between the signal from the telescope and the outgoing signals is thus maintained.

The same phase comparator circuit and components are used, with the bandpass filter now centered at 1347.5 MHz. Step attenuators in the RF and IF channels compensate for changes in cable loss when the two movable telescopes are changed from station. Two phase comparator outputs are provided, one proportional to sin ϕ and the other to cos ϕ. Roundtrip phase is thus measured imambiguously. The necessary 90° phase shift at 30 MHz is obtained by inserting a $\lambda/4$ cable between the two directional couplers. Both sin ϕ and cos ϕ are displayed on zero center meters on the Phase Controller front panel. Both signals are also transmitted to the computer. The sin ϕ output is used in the control loop.

When the "auto-monitor" switch is in the auto position the ARC-loop is closed. The sin ϕ output will then read zero, and the cos ϕ output full scale.

II

The phase shifter used in this circuit is a motor driven GR trombone line stretcher. This precision phase shifter has the following favorable points:

a) No signal distortion or intermodulation.

b) Negligible variation of insertion loss with position, when used within the specified frequency range.

c) A low initial VSWR, and small VSWR changes with position.

d) Reciprocal operation.

The slowness of response, as with any mechanically variable component, is no disadvantage. Cable electrical length variations that have to be compensated for are slow.

The motor drive is designed by the engineering division and constructed in the NRAO workshop. A SloSyn stepping motor drives a lead screw ballnut arrangement. The ballnut is attached to the trombone line stretcher. The movable part of the line stretcher gets additional support from two shafts fitted with ballbushings.

Each step of the stepper motor corresponds to 0.05° phase shift.

III

The servo loop is non-linear. A decision circuit determines the direction of rotation of the stepper motor. Pulses from a fixed frequency oscillator then drive the motor via a translator. Maximum speed of the phase shifter is 1°/sec. A slew mode is provided at 30°/sec, but the servo loop is not stable in this mode. Deadzone of the decision circuit corresponds to 1.5 steps of the stepper motor, or less than 0.1° phase.

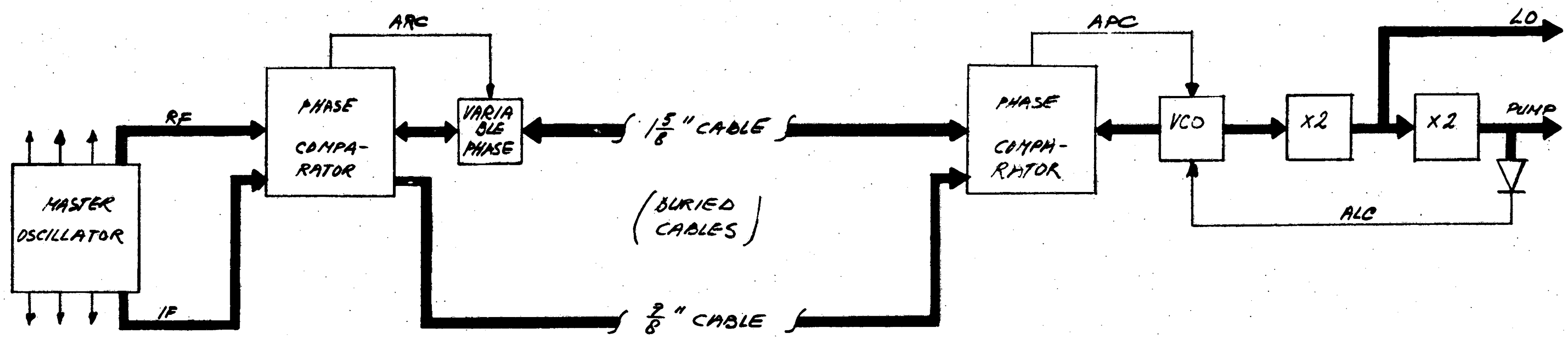
Limit switches detect the trombone's position as it reaches its end of travel and stop the drive motor. A warning signal is shown on the Phase Shifter Servo Control front panel, indicating upper or lower limit and number of phase shifter in question. Also a signal is given to the computer.

Decision circuits, oscillator, translators, and power supplies for all four channels are located in the "Phase Shifter Servo Control" unit.

All four motor driven trombones, together with their limit switches, are mounted behind the "Phase Shifter" front panel.

KHW/cjd

Distribution: IG File (3), J. Coe, L. Howell, W. Kuhlken, B. Pasternak, M. Balister, L. D. Gore, Jesse Davis, S. Weinreb, K. Wesseling, Scientific Staff, R. Ervine, W. Shank, J. Oliver, Interf. Telescope Operators



RF : 1317.5 MHz
IF : 30 MHz
VCO : 1347.5 MHz
LO : 2695 MHz
PUMP : 5390 MHz

ARC : AUTOMATIC ROUNDTRIP CORRECTION
APC : AUTOMATIC PHASE CONTROL
ALC : AUTOMATIC LEVEL CONTROL

FIG. 1: LO SYSTEM SIMPLIFIED BLOCK DIAGRAM

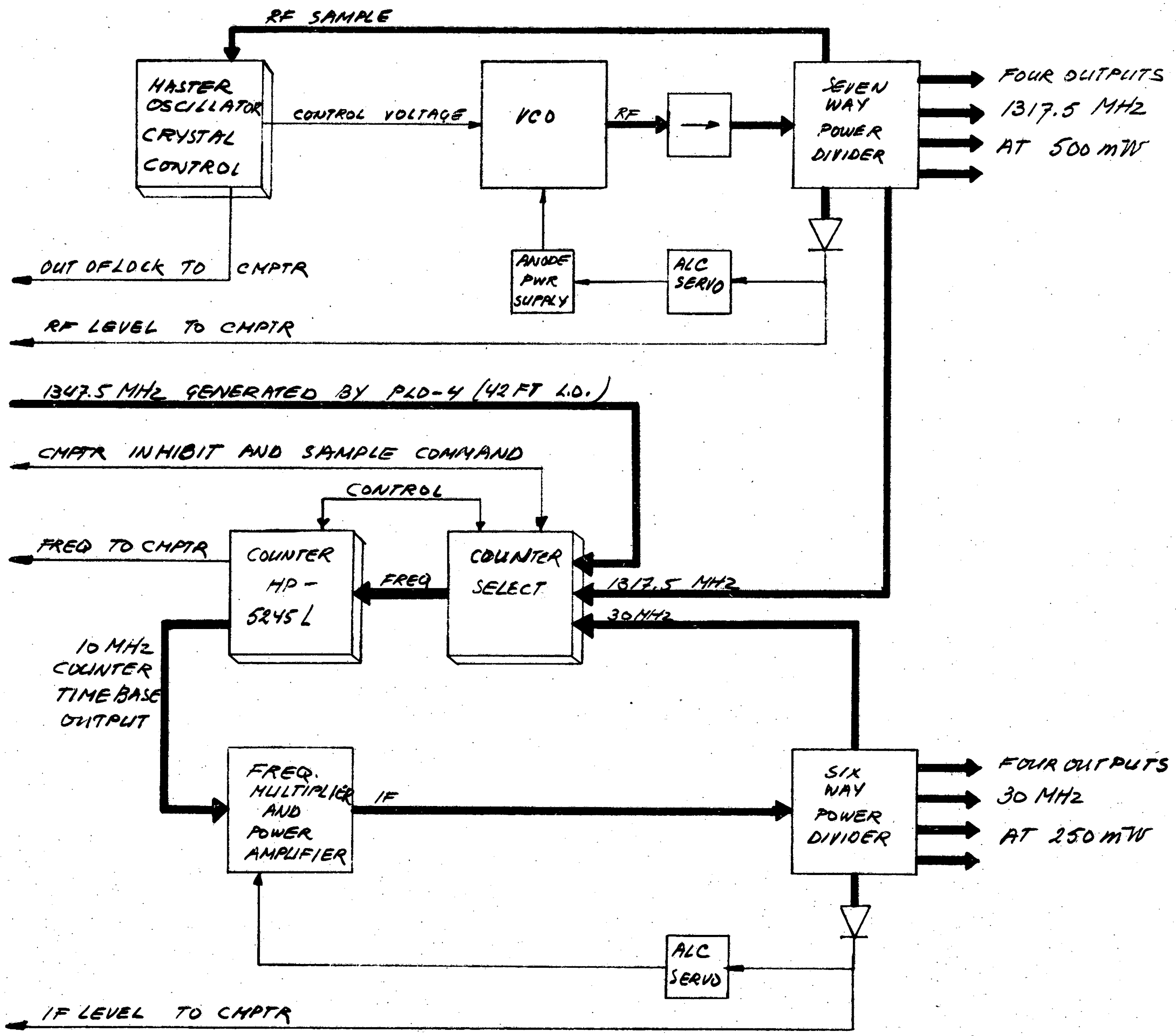
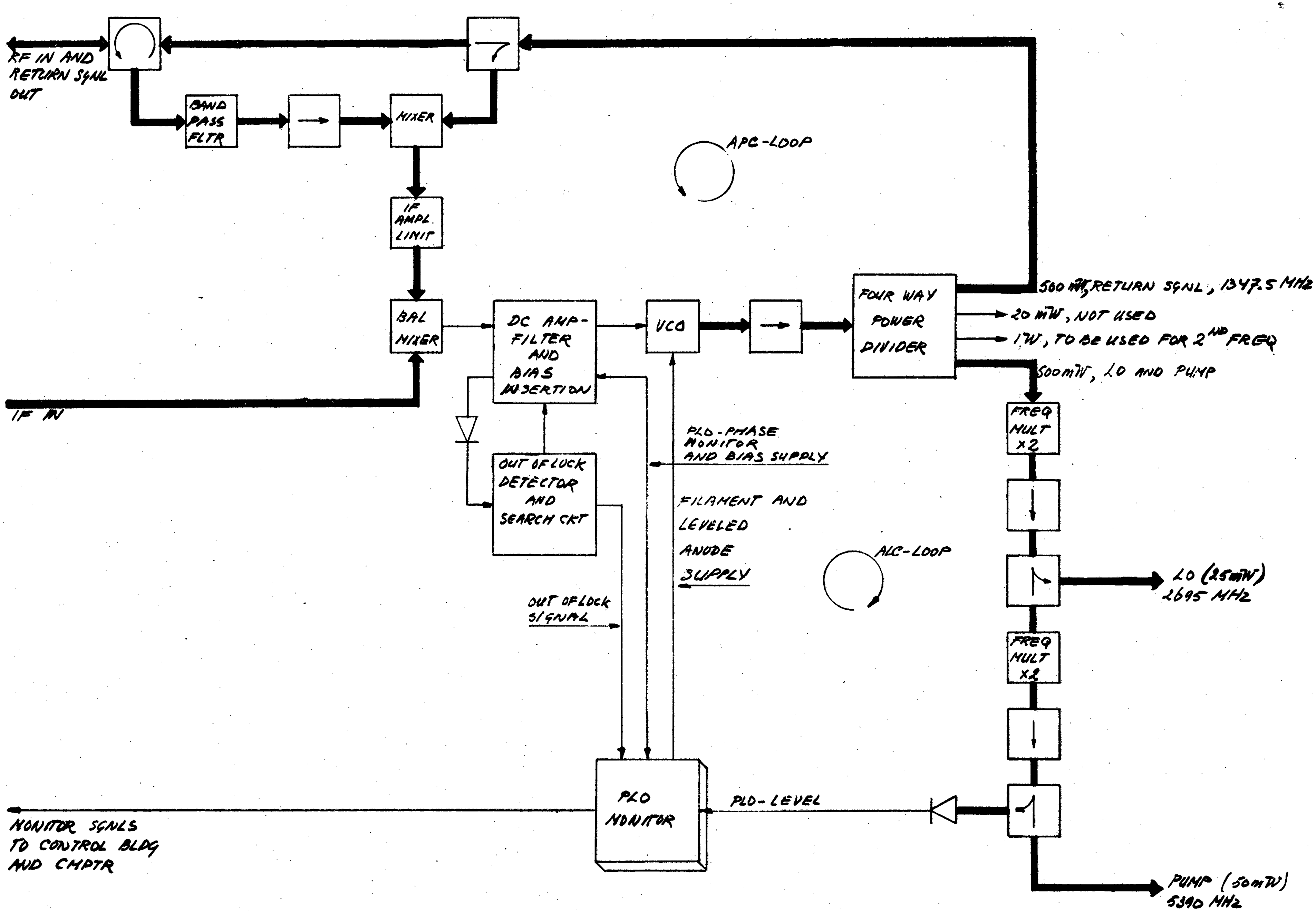


FIG. 2: THE MASTER OSCILLATOR AND ASSOCIATED CIRCUITRY


RF IN AND RETURN SGNL OUT
BAND PASS FLTR
MIXER
APC-LOOP
IF AMPL. LIMIT
BAL MIXER
DC AMP-FILTER AND BIAS INSERTION
VCO
FOUR WAY POWER DIVIDER
500 mW, RETURN SGNL, 1347.5 MHz
20 mW, NOT USED
1W, TO BE USED FOR 2ND FREQ
500mW, LO AND PUMP
IF IN
FREQ MULT x2
PLO-PHASE MONITOR AND BIAS SUPPLY
OUT OF LOCK DETECTOR AND SEARCH CKT
FILAMENT AND LEVELED ANODE SUPPLY
ALC-LOOP
LO (25mW) 2695 MHz
OUT OF LOCK SIGNAL
FREQ MULT x2
PLO MONITOR
PLO-LEVEL
MONITOR SGNLS TO CONTROL BLDG AND CMPTR
PUMP (50mW) 5390 MHz

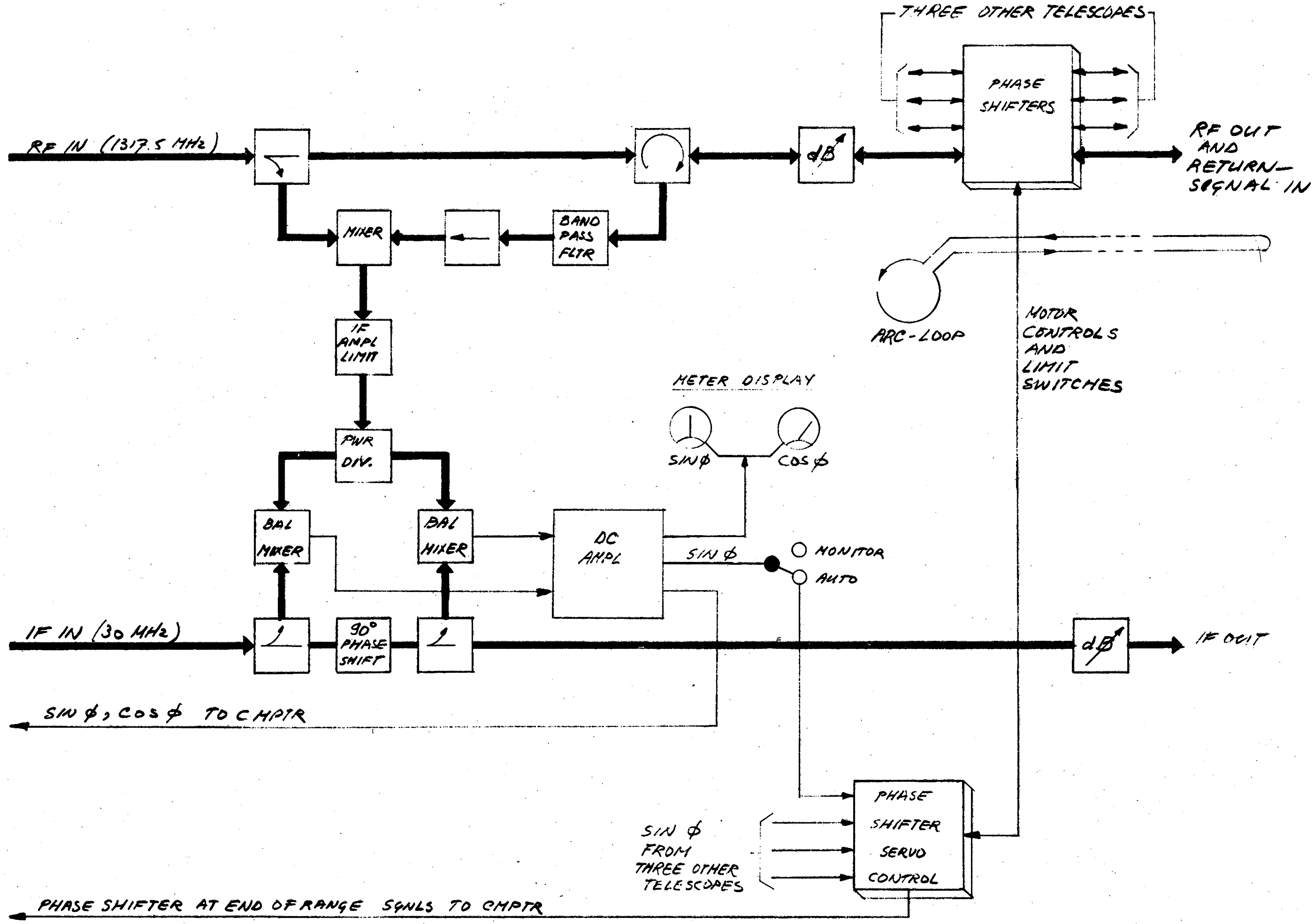


FIG. 4: A ROUNDTRIP PHASE CONTROLLER