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THE INTERFEROMETER MICROWAVE LINK

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INTRODUCTION

The design and construction of the microwave link was initiated in response to the Naval Observatory's requirement for an extended east-west interferometer baseline.

Section 1.0 of this report contains a general description of the link operation and the link equipment. The link path selection is covered in Section 2.0. Sections 3.0 and 4.0 contain details about the Local Oscillator Link Design and Section 5.0 covers the Intermediate Frequency Link Design.

1.0 GENERAL LINK DESCRIPTION

The purpose of the microwave link is to transfer the required information between the remote site and the interferometer control building. This information includes:

(1) The radiometer outputs from the remote site.

(2) The antenna position information.

(3) Antenna control data.

(4) The reference signals for the local oscillator.

Two separate links are used to transmit this information. The IF Link using the 17.5 GHz band is transmitted continuously from the remote site to the control building. It carries the two 30 MHz-wide radiometer outputs. The antenna azimuth and elevation positions and the environmental monitors are also sent over this link.

The LO Link at 17.0 GHz is transmitted from the control building to the remote site for 10 milliseconds. During the next 10 millisecond interval it is sent from the remote site to the control building. It carries the local oscillator reference signals. By using the same frequency for the transmission and switching directions at a 50 Hz rate, the same time delay in both directions is assured. The local oscillator phase stabilization system requires the identical delay in both directions. The antenna control and receiver control information is also sent over this link to the remote station.

1.1 17.5 GHz Link

Two radiometer outputs from the receiver are transmitted back to the interferometer control building. The two outputs are the right and left hand circularly polarized signals received by the antenna. These signals are amplified in the receiver and converted to the IF frequency band of 5 to 35 MHz. Then these bands amplitude modulate the 17.5 GHz carrier. The right hand channel modulates the carrier directly. The left hand channel is converted to 47 to 77 MHz to separate it from the right hand channel before it modulates the carrier. The 17.5 GHz carrier and its sidebands are amplified in the power amplifier and transmitted through the diplexer and waveguide to the feed of the 10-ft dish. The signals are radiated by the feed and reflected by the paraboloid to form the microwave beam.

At the control building the signals are received by the antenna. The 17.5 GHz signal band is separated from the 17.0 GHz signals in the diplexer. The signal level is amplified in the low noise amplifier and converted to the 5 to 200 MHz band by mixing with 17.4 GHz. The signals are then synchronously detected by mixing with a 100 MHz signal. This signal is generated by phase locking an oscillator to the incoming 100 MHz carrier. The right hand channel is recovered by passing the composite signal through a 35 MHz low pass filter. The left hand channel must be mixed with the 42 MHz subcarrier to translate it back to the 5 to 35 MHz band. These outputs are sent to the IF amplifier detector modules. Part of the signal is detected with a square law detector to generate the total power output. This monitors the power in the IF band for each channel. The 5 to 35 MHz IF signals derived from the right and left circularly polarized radiometer outputs are then sent to the Digital Delay Rack for further processing.

The digital data is also sent over this link to the control building. It contains the antenna azimuth and elevation positions along with the antenna drive monitors, receiver monitors, and environmental monitors. The Digital Link equipment processes this information and produces a serial bit stream. This bit stream modulates the frequency of an 87 MHz subcarrier. The 87 MHz signal then amplitude modulates the 17.5 GHz carrier.

At the control building the 87 MHz subcarrier is demodulated with a frequency discriminator. The serial bit stream is sent to the digital link equipment where it is decoded.

A video monitor is provided at the remote site, primarily for monitoring weather conditions. Its output amplitude modulates a 95 MHz subcarrier. Filters are used to remove the lower sidebands and pass only the 95 to 100 MHz band. This signal also modulates the 17.5 GHz carrier.

This video signal is demodulated at the control building by recovering the 95 MHz subcarrier and mixing it with the 95 to 100 MHz band. The output video is amplified and sent to the monitor.

1.2 17.0 GHz Link

The 17.0 GHz link transmits the local oscillator reference signal from the control building to the remote site. The reference signal is obtained from the master oscillator and used to amplitude modulate the 17.0 GHz carrier. The signals are amplified and transmitted through the waveguide to the 10-ft dish.

At the remote site the 17.0 GHz signal band is mixed with 17.5 GHz. The 400 to 600 MHz band is amplified and demodulated to recover the local oscillator reference signal. It is then sent to the front end through a coaxial cable. The reference signal stabilizes the phase of the local oscillator and pump signals than are used in the receiver front end.

When the oscillator in the front-end box is locked to the signal transmitted from the control building, the switching sequence is started. The control building 17.0 GHz oscillator and power amplifiers are gated off and on at the 50 Hz rate.

At the remote station the 17.0 GHz oscillator and amplifier are switched on when the trailing edge of the signal from the control building is detected. This oscillator is modulated by the reference signal originating in the receiver front end. This signal is sent down the same coaxial cable that carries the offset and reference frequencies up to the front end. This enables the system to correct for any phase changes that occur in the cable.

At the control building the 17.0 GHz signal band received from the remote site is mixed with 17.4 GHz. The 300 to 500 MHz band is amplified and applied to the detector-amplifier where the local oscillator reference signal from the remote site is recovered. An oscillator is phase locked to this signal and a locally generated 100 kHz offset oscillator. The phase locked oscillator output is mixed with the signal from the master oscillator as described in the first paragraph of this section. This completes the round trip phase correction system.

The 100 kHz offset frequency is also sent from the control building to the remote site by frequency modulating a 30 MHz subcarrier that is applied to the 17 GHz carrier.

The digital data containing the antenna and receiver control information is sent to the remote site by using a 45 MHz subcarrier to modulate the 17 GHz signal.

At the remote site the 100 kHz and digital data are recovered using frequency discriminators. The 100 kHz signal is sent to the receiver front end over the previously described coaxial cable.

The digital data is sent to the digital link equipment for decoding.

1.3 Link Equipment

Block diagrams of the link subsystems are shown in Figures 1 through 5. Figure 6 is a list of components used in the system. At the control building the link subsystems are mounted in the two bay rack in the equipment room shown in Figure 7. The equipment for the new link to Point Mountain and the revamped link to Huntersville is identical. The left hand bay houses the link components used in the Point Mountain link. The control building link assemblies, starting at the top of the rack, are as follows.

(1) Monitor Panel.

The monitor panel provides 5 BNC jacks for monitoring critical link signals on the oscilloscope.

The PLL amp jack samples the output of the control building 100 kHz phase detector amplifier. When the loop is not locked, this signal should be a slowly changing sweep signal from -10 to +10 volts nominally. This shows the automatic search circuitry is functioning. When the loop is locked, examining this signal gives information about the transient behavior of the sampled phase locked loop. The transients can be minimized by adjusting the DC offset potentiometer in the 100 kHz Phase Detector Box.

The 100 kHz Osc. and Rem. test points provide a convenient means of monitoring the LO reference signal received from the remote site. The Osc. signal triggers the oscilloscope. The Rem. signal is the difference between the 96.25 MHz signal from the remote site and the local 96.15 MHz oscillator. The signal to noise and the switching times can be easily checked.

The Total Power R. Ch. and L. Ch. test jacks provide a means of monitoring the detected right or left hand circularly polarized IF signals. These points provide a quick check of the radiometer performance. Receiver instabilities are easily detected.

(2) Waveguide Components Drawer.

The waveguide components drawer houses the diplexer and waveguide filters that separate the two frequency bands. It also has the Low Noise Amplifier used to amplify the 17.5 GHz band signals. The mixers used in the receivers and the mixer and power amplifier for the 17 GHz link transmitter are in this drawer too.

(3) LO Transmitter/Receiver Drawer.

There are six indicator lights on the front panel to show the local oscillator link status. The LO link is operating properly when all six indicators are ON.

The Transmit and Receive indicators show when the normal switching cycle is occurring.

The Local 1347.5 MHz Lock indicator is ON when the frequency translation components in the master oscillator rack are properly locked.

The Local 100 kHz indicator shows the control building phase lock loop is locked to the signal received from the remote station.

The Remote 100 kHz led is ON when the loop in the remote receiver front end is locked to the local oscillator reference signal sent from the control building.

The Remote 1347.5 MHz indicator shows that the frequency translation loop in the remote station front-end box is locked.

The two Remote indicators are driven by signals sent back to the control building through the digital data link.

The drawer contains the components used to generate the Local Oscillator reference signals. It has the 30 MHz and 45 MHz voltage controlled oscillators that are used by subcarriers for the 100 kHz offset frequency and the digital data. The components needed to amplify the local oscillator reference frequency received from the remote station are included in this drawer.

(4) Link Receiver.

The received link signals and the total power radiometer signals are monitored by two digital panel meters mounted on the front of this drawer. A selector switch provides for monitoring the LO (17 GHz) link or the IF (17.5 GHz) link received signal level. The levels shown on these meters usually only change when the link path attenuation varies. However, a continuous low reading when there is no rainfall along the path may indicate equipment problems.

The Total Power Meter has a selector switch to check the Left or Right channel levels. This provides a monitor of radiometer receivers and assures that adequate signal is available to supply the digital delay rack.

(5) Power Supplies.

The power supplies used have voltage and current meters that aid in locating malfunctioning components. Two +15 volt supplies are used. All the components that are switched on and off at a 50 Hz rate, such as the 17 GHz oscillator, are on one of the 15 V supplies. This helps isolate the switching transients. A +-15 V DC supply is used for operational amplifiers and a +5 V DC supply drives the digital circuitry. The voltage-controlled crystal oscillator operates from a +24 V DC supply.

(6) Receiver Control.

Control of the channel selection XR-XL, SR-SL, or XR-SL is implemented through the digital link. The switches on this panel provide for computer or manual control of these functions. These switches control opto-isolators in the digital link. At the remote site, an output from the digital equipment is received for each of the functions selected at the control building. These outputs control relay drivers.

Other functions that are remotely controlled are Paramps Off, Noise Modulation Off, S-Band Cal On, and X-Band Cal On.

The Paramps Off control turns off all four parametric amplifiers in the receiver front end. Uses include checking the gain of these amplifiers and occasionally stopping an oscillation in an amplifier.

The Noise Modulation Off control stops the 50 Hz noise modulation signal from switching the calibration signals on. It is switched off when the noise modulation is not required or when the full calibration signal is needed to measure antenna efficiency.

The S-Band and X-Band calibration switches control the noise calibration signals for the two frequency bands.

The control building part of the link to Huntersville is housed in the right-hand bay of the two-bay rack. The components are the same as described above for the Point Mountain link.

At the remote site most of the link components are mounted in the single rack in the equipment trailer.

(1) Waveguide Components Drawer.

Two FET power amplifiers, one for each of the frequency bands, are located in this drawer. The diplexer to combine the two bands and a circulator that separates the incoming and outgoing signals are located here. A mixer, used to convert the incoming 17 GHz signal to 500 MHz, is also in the drawer.

(2) Link Transmitter/Receiver Drawer.

This drawer contains the components needed to receive and transmit the Local Oscillator reference signals. It also has the parts required to modulate the 17.5 GHz carrier with the radiometer IF outputs, digital data, and the video monitor output.

Front panel meters with selector switches are provided to monitor the 17 GHz and the 17.5 GHz oscillator output power.

The received signal level is monitored. This monitor point is taken from the ALC amplifier and shows the level of the incoming 17 GHz band.

Other functions displayed on the meter are the PLL Amp output from the front-end box 100 kHz Phase Detector, the 192.5 MHz Phase Detector Output, and the 100 kHz Signal and Reference signals in the 100 kHz Phase Detector Box.

(3) Power Supplies.

Two +15 V DC supplies are used to power the 17 GHz and 17.5 GHz oscillators and associated power amplifiers. The +-15 V DC supply is used for operational amplifiers and the +5 V DC is used for the logic circuits.

The Phase Lock Loop Box is located in the Receiver Front End at the focal point of the antenna. It contains the components needed to generate the local oscillator signals from the reference signals transmitted over the link.

1.4 Link Antennas and Reflectors

The two frequency bands are transmitted between the control building and the remote sites using the microwave link antennas and reflectors. Since the terrain blocks direct transmission of the signal to the remote sites, passive reflectors are used to redirect the signals.

The link to Point Mountain has three 10' x 16' reflectors in the path. There is a single reflector located 3700 feet southeast of the control building. It reflects the signals from the control building toward the double passive reflector on Back Allegheny Mountain. The double passive is required there to redirect the signals toward the antenna at the Point Mountain site.

The 10-ft diameter paraboloids at each end of the link are used to transmit and receive the signals.

The link path to Huntersville has a single 10 x 16 reflector northwest of the control building. It reflects the signals transmitted from a 6-ft dish antenna at the control building. At the Huntersville site a 6-ft antenna is also used to receive and transmit the signals.

2.0 LINK PATH DESIGN

One of the first tasks in the design of the microwave link was to find a path with adequate clearance between the remote site and the control building. Back Allegheny Mountain blocks direct transmission of the signals between the Point Mountain site and Green Bank.

By examining topographic maps, several tentative paths were located. In trying to determine if a proposed path had adequate clearance, the general guideline of 1.0 Fresnel Zone clearance at 4/3 earth radius was used. During normal atmospheric conditions the microwave beam follows a path of 4/3 earth radius. This bending is caused by the denser atmosphere slowing the lower part of the microwave beam. The first Fresnel zone radius is defined as the radius of a reflecting surface that results in an indirect path 1/2 wave length longer than the direct path. At 17 GHz the Fresnel Zone radius is 34 feet at the midpoint of a 15 mile path. When plotting the path profiles, at least 60 feet of clearance was required at the middle of the path with decreasing clearance toward either end. A detailed description of the path selection criterion is given by Robert F. White of GTE Lenkurt, Incorporated, in reference [1].

From the plotted path profiles it was thought that the path from the Point Mountain site to Gaudineer Tower would be clear. Physical examination of the site showed 40 foot spruce trees surrounding the tower and attempts to flash this path using a mirror reflecting the sun were not successful. After further study of the maps, S. Smith thought it might be possible to locate a passive reflector on Back Allegheny Mountain that would have a clear path to Point Mountain and to a ridge near the control building. This area of Back Allegheny Mountain was explored with great difficulty. The spruce trees were so thick that no visual checks could be made of the path. After further field surveys on Back Allegheny, a site was found that had been logged recently. From this site part of the Observatory at Green Bank could be seen. Path profiles toward Point Mountain showed there should be adequate clearance. The path clearance was confirmed by flashing with a mirror.

The path from Back Allegheny to the control building was still blocked by Little Mountain. A second reflector site was located as close as possible to the control building. This was done by moving west along the ridge located to the east of the control building while still maintaining a clear path to the Back Allegheny reflector site.

The path losses were computed at 17.4 GHz with 10' x 16' passive reflectors. They are tabulated below starting at the Point Mountain end.

Path Losses

17-ft Waveguide Loss..................	-1.5 dB
10-ft Antenna Gain	52.3 dB
14.5 mile Path Loss	-144.7 dB
Double Reflector Gain	115.1 dB
5.3 mile Path Loss	-135.9 dB
10-ft Antenna Gain	52.3 dB
Near Field Correction	-3.0 dB
Atmospheric Loss 0.1 dB/km	-3.3 dB
8-ft Waveguide Loss	-1.0 dB
Total Path Loss	-69.7 dB

Note that the single passive repeater is within the near field of the 10-ft dish at the control building. The single passive gain and the 3700-ft path loss are not included and the -3 dB near field correction is applied.

Atmospheric absorption losses and rainfall attenuation rates over the frequency range of 3 to 24 GHz are shown on plots in reference [2].

Formulas and graphs for the path loss and passive repeater gain calculations are given in the Microflect Passive Repeater Handbook [3] and the GTE Lenkurt book cited above.

The 10-ft diameter parabolic antennas are needed to keep the loss to about 70 dB. This allows the use of lower powered FET amplifiers for the transmitters. These have much longer life than the Traveling Wave Tube amplifiers.

Measurements of the path loss after all reflectors were adjusted to maximize the received signal showed the nominal loss was 72 dB. During a 21-day test the received signal was measured at 1 second intervals. The measured levels were quantitized in 3 dB increments, and a count was made of the number of measurements within each of the three dB windows. The signals were within +-6 dB of the nominal level during 99% of the time. This test was started in January 1984. Weather conditions included some periods of light snow. Rainfall will increase the path loss substantially. A rainfall rate of 10 mm/hr would cause 0.6 dB/km extra path loss. When rain occurs at this rate over the full 33 km path, the extra attenuation would be 20 dB.

The location of the reflector site on Back Allegheny Mountain is such that a double reflector is required. The included angle between the incoming and outgoing ray is 176 degrees. So, with one reflector, the projected surface area would be proportional to the cosine 176/2 or 0.035. The closely spaced double reflectors are oriented nearly parallel to the incoming wave front. During adjustment of the double reflector it appeared that adjusting either reflector would maximize the received signal. R. Fisher confirmed that this was expected since the beam can be steered with either reflector.

Because the route from Point Mountain through the reflector site to the control building is nearly on line, the possibility exists that some signal from the remote site could reach the receiver at the control building without passing through the double reflector. If this overreaching signal is strong enough, it could cause interference with the primary signal. However, the calculated terrain obstruction loss and reflector and antenna discrimination loss are more than 80 dB extra for this interfering path.

We have operated a microwave link at 17.5 GHz from Huntersville to Green Bank since 1972. It has a single passive reflector that was originally an 8' x 8' flat plate. In 1982 we ordered a new 16' x 8' passive reflector from Microflect and installed it in place of the old reflector. The new reflector increased the signal level by 10 dB and showed no change in level when operated during the winter months. With this experience with the Microflect device we were confident that they would be satisfactory in the more stringent environment at the Back Mountain Allegheny site. The specifications for the passive reflector are given in Appendix A.

3.0 LOCAL OSCILLATOR LINK DESIGN

In designing the local oscillator link, the primary concern was to develop a system to provide the required phase stability under varying atmospheric and multipath conditions. The new link also had to interface with the existing interferometer oscillator system.

One of the first tasks was to determine the phase variations expected through a microwave link. The changes in the direct path delay and multipath phase fluctuations were considered.

3.1 Path Delay

The path delay will vary with the refractivity of the air. It is directly proportional to the barometric pressure and inversely proportional to temperature. Daily variations of the index of refraction are 20 to 40 parts per million have been measured by M. C. Thompson [4]. Over the 33 kilometer path this corresponds to 2 to 4 nanoseconds change in path delay. The phase stabilization system must correct for these path variations.

3.2 Multipath Phase Errors

If two separate frequency bands are used to transmit the local oscillator reference frequencies to and from the remote site, phase errors may occur because of multipath propagation. The signal arriving at the receiving antenna consists of a direct signal plus one or more signals reflected from the ground or atmospheric layers. These indirect signals have a longer path than the direct signals. The phase changes caused by the indirect path depend on the amplitude ratio and phase difference between the direct and indirect signals. To analyze the effect of many interfering signals is complex. Some insight can be gained by assuming only one reflection at the center of the path. For a single interfering signal reflecting from a surface at mid-path the phase difference is related to the extra length of the indirect path. This extra path length (L) is proportional to the angle off axis of the indirect path as well as the path length (D).

$$L = D\,(1/\cos(\theta) - 1) \qquad (1)$$

where (theta) is the angle between the direct and indirect paths.

The phase difference between the indirect and direct path is:

phi = 2 pi L/lambda + pi (2)

where lambda is the wavelength. The second pi term accounts for the 180 degree phase shift experienced by a signal reflecting from a surface at a low angle.

The expression relating the phase difference (phi) to frequency is:

phi = 2 pi L f/(3 x 10^8) + pi radians (3)

where (L) is in meters and (f) the frequency is in Hz. This phase difference and the amplitude ratio of the indirect to direct signal voltage (A) can be used to determine the resultant signal. The amplitude of the received signal (R) is:

R = (1 + A cos (phi)) / cos (psi) (4)

and its phase (psi) is

psi = arctan [A sin (phi)/(1 + A cos (phi)] (5)

The multipath induced phase changes were computed at 100 MHz frequency intervals for various values of theta and A for paths of 24 km and 35 km. These computations are shown in Appendix B. They show that generally multipath signals result in dispersion where the phase change with frequency is not constant. Only if the reflected signal amplitude is equal to the direct signal is the resultant phase change constant with frequency.

If A = 1, equation (5) can be reduced to

$$psi = \arctan [\tan phi/2] = phi/2 \qquad (6)$$

and the change in psi with frequency would be a constant.

A. R. Thompson has shown a method of calculating the maximum frequency separation for local oscillator phase correcting links implemented with coax cable or waveguide [5]. With a microwave link the multipath signals cause the same effect as double reflections in a coax or waveguide system. An estimate of the maximum frequency difference in the microwave link system was made. The reflector and antenna patterns reduce the signal amplitude of the off axis multipath signals. A single indirect signal reflected from a point in the middle of the path has a maximum amplitude of:

$$A = (lambda/(pi \times h \times \sin(theta))^2 \qquad (7)$$

where (h) is the reflector height. Using this equation to compute A for off axis angles (theta) of 0.1 to 2.0 degrees and then solving equation (5) gives a maximum frequency difference of 1.5 MHz for a 0.1 degree phase error.

3.3 Oscillator Phase Stabilization

The basic design uses the transmission of a single frequency in both directions. The transmitted and received signal frequencies are summed at each end. The phase of these summed signals is independent of the path length variations.

The scheme used is shown in Figure 8. A reference sigal is derived from the control building master oscillator. It is mixed with a tone from the remote station. The difference frequency is sent back to the remote station where it is summed with the original signal. The phase of this sum signal at the remote site is identical to the phase of the control building reference signal as long as the down and back time delays are equal.

In the practical implementation of this system it becomes apparent that there were some stringent component requirements. First, the mixer at the control building would have to have 50 dB isolation between the input and output. This high isolation is needed to prevent the leakage signal from causing significant phase changes. Secondly, a common coaxial cable carries these signals up and down the telescope at the remote station. Small mismatches in this cable would also cause large phase errors.

Both of these problems were overcome by introducing a frequency offset so that the incoming and outgoing signals at the mixer and the up and down signals at the telescope were at slightly different frequencies. The offset frequency of 100 kHz was used.

3.4 Local Oscillator Frequencies

To interface readily with the existing interferometer local oscillator system the reference frequency had to be a subharmonic of 1347.5 MHz. It was also desirable to make it as high as possible but still stay under 100 MHz for transmission as a sideband of the 17 GHz carrier. Therefore, 96.25 MHz was selected as the LO reference frequency. Four phase-lock loops are used to translate the frequencies and stabilize the phase of the remote local oscillator signal.

3.5 Signal- to-Noise Requirements

To keep the rms phase noise contribution from the link to less than 0.5 degree/GHz, the reference signal at 96.25 MHz must have a signal-to-noise ratio of at least 58 dB.

(20 log tan (0.05*1.4) = 58.2 dB

This high signal-to-noise ratio can be achieved with moderate transmitter power by using narrow-band phase-locked loops at each end of the link.

3.6 100 kHz Phase Lock Loops

These phase lock loops consist of a voltage-controlled crystal oscillator, a phase detector and loop amplifier. The oscillator at the control building operates at 96.15 MHz. The crystal oscillator is extremely stable and has a narrow tuning range of 30 Hz. This narrow tuning range was selected to prevent false locking. With the time multiplexed or switching system false locks can occur. The 50 Hz switching rate creates sidebands at 50 Hz intervals. By limiting the tuning range and the drift of the oscillator to less than 50 Hz, false locks are prevented. The phase detector operates with input signals of 100 kHz. The schematic is shown in Figure 9. The reference input to the phase detector is the 100 kHz offset oscillator. The 100 kHz signals are amplified and applied to a double balanced mixer that acts as the phase detector. An active loop filter is used after the phase detector output. Extensive use was made of Gardner's book on phase lock loops [6] and A. R. Thompson's paper [7] in the design of the active loop filters.

The response of the phase-lock loop to transients is determined by the loop natural frequency and the damping. These can be adjusted independently by changing the two time constants associated with the active loop filter.

At the control building the loop natural frequency is about 30 radians/second and the damping factor is 0.9. The remote loop active filter has a damping factor of 0.14 and a loop natural frequency of 3 radians per second. These low natural frequencies and damping factors were needed to suppress the transients introduced by the switching system. Both loops are operated as sampled loops. The control building loop has only the signal input 100 kHz switched on and off. The remote loop has both the signal and reference inputs switched on and off.

With these narrow-band loops the response to rapid changes in frequency and phase is slow. For the maximum frequency step change of 0.7 Hz, the phase error at 96.25 MHz is calculated to be less than 0.02 degrees within three seconds after the step occurred. The 0.7 Hz maximum step in frequency is derived from the maximum lobe rotation rate of 9.7 Hz at 1347.5 MHz. This large of a step would seldom occur in the normal operation of the interferometer and then only at the start of a scan.

The narrow-loop bandwidths also make the loops difficult to lock. The sweep rate must be slow to allow the loop time to acquire lock. The locking procedure has been automated with circuitry on the T/R Driver card at the control building. If the remote 100 kHz phase detector indicates that loop is not locked, then the control building signals are transmitted continuously and the remote station receives continuously. The 96.15 MHz oscillator is swept slowly by injecting a square wave with an 80 second period. When the remote 100 kHz loop locks, the transmit/receive cycle is started again. The local or control building 100 kHz loop then locks because it is receiving the signal from the remote station. When the local loop locks, the sweep signal is overridden. The change in tuning of the 96.15 MHz oscillator may be enough to pull the remote 100 kHz loop out of lock. If lock is lost, the transmit/receive cycle is continued for ten seconds. If the remote 100 kHz loop does not reacquire lock in this time, the switching is stopped and the sweep started again. The link may go through this sequence several times before lock is acquired.

4.0 LOCAL OSCILLATOR LINK TRANSMITTERS AND RECEIVERS

The local oscillator S/N requirements, the path loss, and the power output of FET amplifiers were considerations in the design of the transmitters and receivers. The signal-to-noise requirements for the various signals are tabulated below:

Signal	S/N Required	Receiver Bandwidth
96.35 MHz LO Ref	58 dB for .05° rms	30 Hz
30 MHz, 100 kHz Subcarrier	58 dB	30 Hz
45 MHz Digital Data Subcarrier	16 dB for 1 error/day	2 MHz

The noise figure of the mixer-preamps used for the LO link receivers is about 10 dB. The equivalent noise power at the input is -148 dBm in a 30 Hz bandwidth and -100 dBm for a 2 MHz band. The minimum received signal level for the LO signals would be -90 dBm.

With link path losses of 72 dB and an extra 20 dB needed for fading margin, the signal power for the LO ref and 30 MHz signals must be +2 dBm. Under the same conditions the 45 MHz subcarrier would have to be +8 dBm. Currently available FET medium power amplifiers can provide these output levels.

4.1 LO Link Signal Generation

The decision to use the same link frequency to transmit and receive the LO signals complicated the transmitter and receiver design. Filters cannot be used to isolate the receiver from the transmitted signals. Isolation of 110 dB, 40 dB more than the path loss, is needed. To keep the local carrier from interfering with the receiver it is switched off during the receive time period.

The 17 GHz carrier is generated with a Gunn diode oscillator. The oscillator has an internal regulator and is switched on and off with a TTL signal. The oscillator output is amplitude modulated by the local oscillator reference signal in a double balanced mixer. It is also modulated by the 30 MHz and 45 MHz subcarriers. These subcarriers are frequency modulated with the 100 kHz offset frequency and the digital data information. The output from the modulator is amplified with a FET amplifier with 23 dB gain and a maximum output of +22 dBm.

The effect of the power amplifier noise on the receiver sensitivity had to be considered. A circulator with 26 dB isolation separates the mixer from the power amplifier. Still, noise reflected from the feed or in the waveguide is directed back into the mixer. To overcome this problem the power amplifier is gated on and off at the 50 Hz rate.

4.2 LO Link Receiver

The local oscillator link receiver uses a double balanced mixer followed by a low noise amplifier. At the remote site a 17.5 GHz signal is mixed with the incoming 17 GHz frequency band. The 300 to 500 MHz band is amplified with a preamp with 56 dB gain. The next stage of the receiver is an ALC amplifier.

This amplifier has an output of +2 dBm with input levels from -47 to -20 dBm. A sample/hold circuit has been added to the ALC amplifier leveling loop so the ALC action only occurs during the receive part of the switching cycle. The power to the preamp is also gated on and off with the 50 Hz square wave to further improve isolation during the transmit part of the switching cycle.

Following the ALC amplifier, a detector-amplifier demodulates the amplitude modulated 400 MHz signal. With a 100% amplitude-modulated signal at +2 dBm applied to the detector-amp input, the output of the detector amplifier is +6 dBm.

The detector-amplifier output is split in a three-way power divider. One output drives the 30 MHz discriminator, the second output feeds the 45 MHz discriminator, and the third output supplies the 96.35 MHz LO reference signal to the amplifier. Output from the 30 MHz discriminator is the 100 kHz offset frequency at a level of 0 dBm. The discriminator design is similar to one used by N.V.G. Sarma [8].

The 45 MHz discriminator output is the biphase digital data stream at TTL levels. The digital data is transmitted at approximately a 20 kilobit rate.

The 96.35 MHz LO reference signal is amplified. Part of this signal is sent to the T/R Driver card where it triggers the transmit/receive circuitry. The received signal is detected, amplified, and applied to a threshold detector. When the level drops below a preset level, the transmit mode is triggered. Control signals from the T/R driver card turn off the preamp, the diode switch, and switch the ALC amplifier sample/hold to hold. Then the 17.0 GHz oscillator and power amplifier are switched on for 9.5 milliseconds to transmit back to the control building. At the end of this time the control signals switch to the receive mode until the trailing edge of the received signal is detected and the transmit cycle is started again. The LO reference signal is also sent to the Phase Lock Loop Box in the receiver front end.

4.3 Remote Station Phase Lock Loop Box

This box controls the phase of the 1347.5 MHz signal from the pump and LO power amplifier and generates the 96.25 MHz reference signal that is sent back to the control building. The 96.35 MHz signal is mixed with the locally generated 96.25 MHz to obtain 192.6 MHz. This signal is translated to 100 kHz by mixing with the 192.5 MHz signal from the comb generator. The 100 kHz signal phase is compared with the 100 kHz offset frequency received from the control building. The phase detector output controls the phase of the 96.25 MHz crystal oscillator. This signal is amplified and drives the comb generator.

The power amplifier in the Pump and LO package exhibits large phase changes with supply voltage variations. To stabilize the 1347.5 MHz signal phase, the comb generator 1155 MHz output is mixed with the power amplifier output. The difference frequency, 192.5 MHz, is compared with the 192.5 MHz output from the comb generator in a mixer used as a phase detector. An active loop filter, shown in Figure 10, amplifies the phase detector output and controls the phase of the 1347.5 MHz voltage-controlled oscillator. The loop natural frequency is 10 kHz with a damping factor of 0.7. The circuit board also contains a lock detector and sweep circuit. If the oscillator is out of lock, then the beat frequency is coupled into the detector. Comparison of the detector output with a preset level is performed with an operational amplifier. The op amp output is negative when the loop is not locked. This applies power to the 555 multivibrator that injects a 20 Hz square wave into the active loop filter amplifier to sweep the voltage controlled oscillator. When lock is obtained, the lock detector amplifier output goes positive, removes power from the multivibrator and turns on the 1347.5 MHz lock indicator.

4.4 Phase Stable Components

The design of the LO link was influenced by the required phase stability with time, temperature, signal levels, etc. Narrow-band filters were avoided. Mixers used as phase detectors are operated under saturated conditions. Other critical components are discussed below.

4.5 Comb Generator

The comb generator is a Hewlett Packard Model HP 33002A step recovery diode module. It is driven by a +26 dBm signal at 96.25 MHz. Although the phase of the output relative to the input is dependent on drive level and temperature, the relative phase of the comb outputs are stable. The design of the frequency translation circuitry in the Phase Lock Loop Box is such that only the comb outputs are used for critical phase comparisons.

4.6 Amplifier Phase Stability

The 96 MHz amplifiers used to amplify the LO reference signals are critical components. A phase stability specification of 0.01 degree phase per degree C at 100 MHz was set as the design goal. Bob Mauzy and Lewis Beale, after testing several different manufacturers' modular amplifiers, were able to select units that when assembled gave less than 0.002 degree phase change per degree C at 100 MHz with over 20 dB gain.

4.7 Phase Stable Phase Locked Oscillators

At the control building the master oscillator output signal had to be translated to 192.5 MHz. Instead of trying to use a digital type frequency divider, a phase-locked oscillator was used. The phase-locked oscillator input reference frequency is 192.5 MHz with an output of 1347.5 MHz. The specifications were for no more than one degree phase change at 1347.5 MHz for an input reference level change of one dB. None of the manufacturers contacted could meet this specification. Frequency West proposed a 3 degrees per dB input reference change, and the oscillators were ordered from them. When the units were tested they exhibited 30 to 40 degree phase changes for an input reference level of -1 dBm to +1 dBm. Several of the units were returned to Frequency West, but they had little success in reducing the phase sensitivity to input level changes. It was found that operating the units at inputs of +5 to +7 dBm reduced the phase errors to 2 to 3 degrees per dB of reference input change. In future designs, a comb generator would probably be used for this frequency translation. It would be driven at 96.25 MHz and phase stable 192.5 MHz and 1347.5 MHz outputs would be used.

4.8 LO Link Tests

After the link equipment was assembled it was set up in the control building for a final checkout. Waveguide with fixed and variable attenuators simulated the link path. The phase of the 1347.5 MHz signals from the receiver front end and the master LO were compared. Although the average phase was stable the peak-to-peak fluctuations were about 20 degrees. The frequency of this noisy sine wave was 10 to 20 Hz. After much trial and many errors it was reduced to 2 degrees rms by decreasing the bandwidth and damping of the remote 100 kHz loop. This attenuated the response of the loop at the higher frequencies and suppressed the switching transients.

The LO link operated with an extra 20 dB of attenuation in the waveguide. Phase measurements at 1347.5 MHz showed no detectable phase change as the path attenuation was increased in three dB steps up to 12 dB. At that level a 16 degree offset was apparent.

5.0 IF LINK DESIGN

The IF Link design is based on a system that has been used as part of the interferometer since 1973. This link was designed by Sarma [8].

In the new link FET Amplifiers are used in place of the TWT amplifier. Other components have been changed to make use of currently available amplifiers and integrated circuits.

Signal-to-Noise Requirements.

The IF Link carries the two radiometer outputs, the video monitor and the digital data. The signal to noise requirements and the receiver noise for a 10 dB Noise Figure receiver for these different signals are tabulated below.

Signal	S/N Required	Receiver Noise/ Bandwidth
Right Channel Radiometer Signal	17 dB for 2% noise	-89 dBm/30 MHz
Left Channel Radiometer Signal	17 dB	-89 dBm/30 MHz
42 MHz Left Channel Carrier	20 dB	-104 dBm/1 MHz
Video Monitor	40 dB	-97 dBm/5 MHz
87 MHz Digital Data Subcarrier	16 dB	-101 dBm/2 MHz
17.5 GHz Carrier	40 dB	-122 dBm/15 kHz

With the minimum path loss of 72 dB and a desired fade margin of 20 dB the transmitter power for this composite signal would be 3.5 watts. This greatly exceeds the output of the

0.5 watt FET amplifiers currently available. By reducing the fading margin, the lower power FET amplifiers can be used. The transmitted power and fading margin for each of these signals are shown below.

Signal	Transmitted Power	Fading Margin
R. Channel Radiometer Signal	+13 dBm	13 dB
L. Channel Radiometer Signal	+11 dBm	11 dB
42 MHz L. Channel Carrier	+3 dBm	18 dB
Video Monitor	+15 dBm	0 dB
87 MHz Digital Data	+6 dBm	19 dB
17.5 GHz Carrier	+10 dBm	20 dB

Since the microwave link path has proven to be stable, these signal levels are adequate for all of the functions except the video monitor. It may be possible to switch the radiometer outputs off when the video monitor is needed and increase the video signal.

5.1 IF Link Transmitter

A 17.5 GHz Gunn diode oscillator is modulated by two 30 MHz wide radiometer outputs, the 87 MHz digital data subcarrier and the 95 MHz video subcarrier. The output from the modulator is amplified in the FET power amplifier and combined with the LO link signals in the diplexer. One radiometer output is shifted up from the 5 to 35 MHz band to 47 to 77 MHz by mixing with 42 MHz. The mixer output is filtered to select the desired band. It is important to minimize the phase distortion over the 30 MHz band. Phase distortion will reduce the output from the interferometer. A phase equalizer section was added to the 47 MHz high pass filter to reduce the phase nonlinearity with frequency. The resultant rms phase nonlinearity was less than 14 degrees and the expected reduction in fringe amplitude would be 6% according to Thompson [9].

5.2 IF Link Receiver

At the control building the 17.5 GHz band is separated from the 17 GHz band in the diplexer. The 17.5 GHz signals are amplified in the low noise amplifier and mixed with 17.4 GHz. The 100 MHz output is amplified and then synchronously detected. The synchronous detection is done by phase locking a 100 MHz oscillator to the incoming 100 MHz signal.

The frequency stability of the 17.5 and 17 GHz oscillators is 250 kHz per degree C. So the tuning requirements for the 100 MHz oscillator should be less than 5 MHz. An active loop filter with automatic sweep is used to acquire and retain lock. The circuit is shown on Figure 11.

5.3 IF Link Tests

During the initial tests of the link the 100 MHz phase shifter had to be tweaked periodically to keep the detected signals at maximum. The delay of the 100 MHz band pass filter was so large that with only a small frequency offset changed the phase. Addition of the second 100 MHz bandpass filter in the other input to the phase detector overcame this problem.

This link operates satisfactorily with up to 19 dB extra path attenuation. At this level errors occur in the digital data.

Acknowledgement

A large number of NRAO people at Green Bank helped complete the microwave link. Without their support the project could not have been done.

I would like to acknowledge that Sidney Smith, Len Howell, and Bill Campbell located the reflector sites and assisted in checking the microwave paths. They, along with Fred Crews, Ron Gordon, Don Gordon, and Jim Oliver, erected and aligned the reflectors and antennas. Fred Bierer and his crew constructed the concrete foundations needed to support the reflectors.

Bill Shank and Jim Oliver constructed and checked out most of the electronics. They also helped with path loss measurements and system testing. Bob Mauzy designed and Lewis Beale constructed the phase stable 100 kHz phase detectors, the phase stable amplifiers and other components used in the system.

Discussions with Rick Fisher helped clarify my understanding of multipath propagation.

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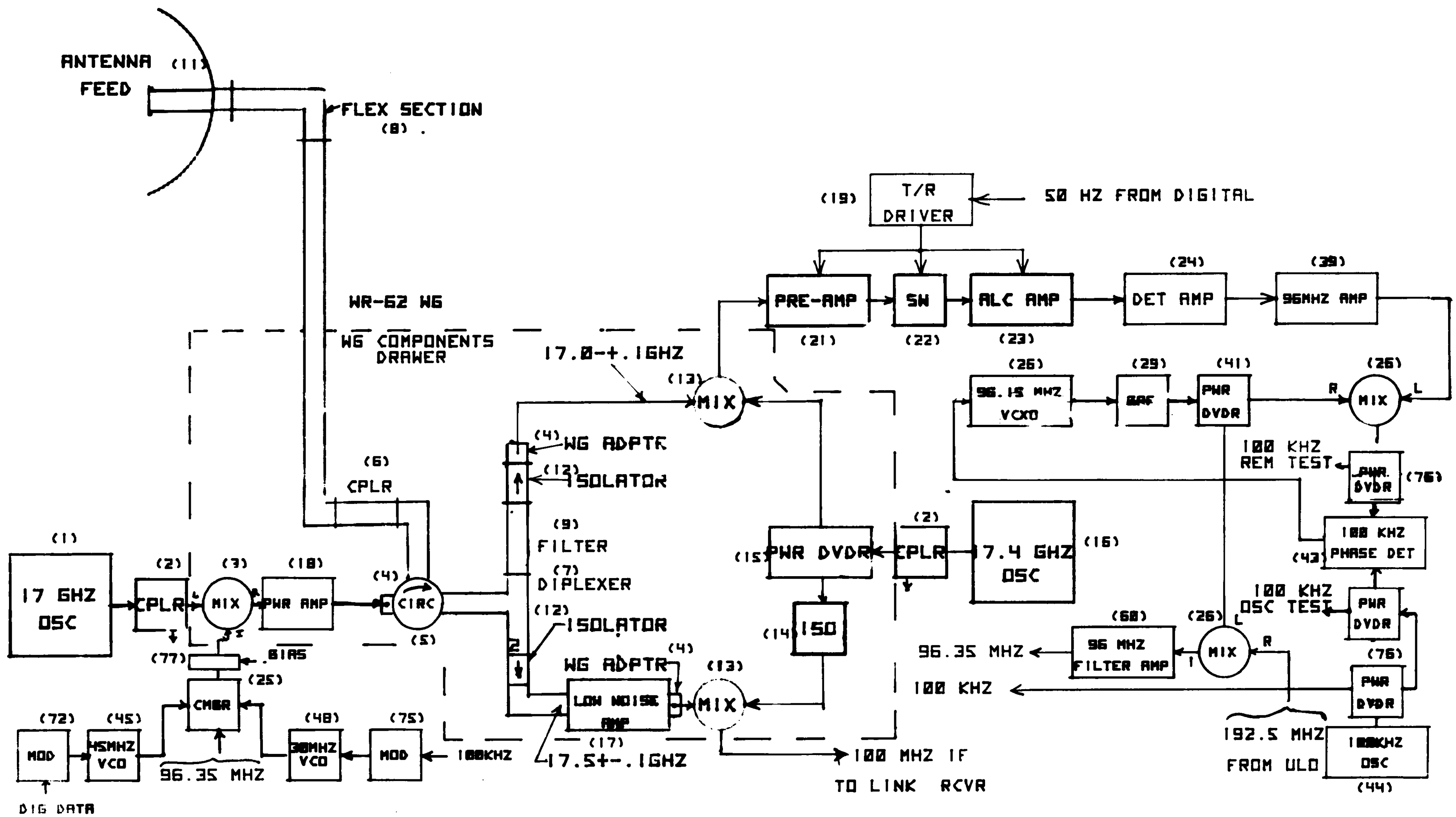

FIGURE 1

Control Building WG Components
and LO Trans/Receiver

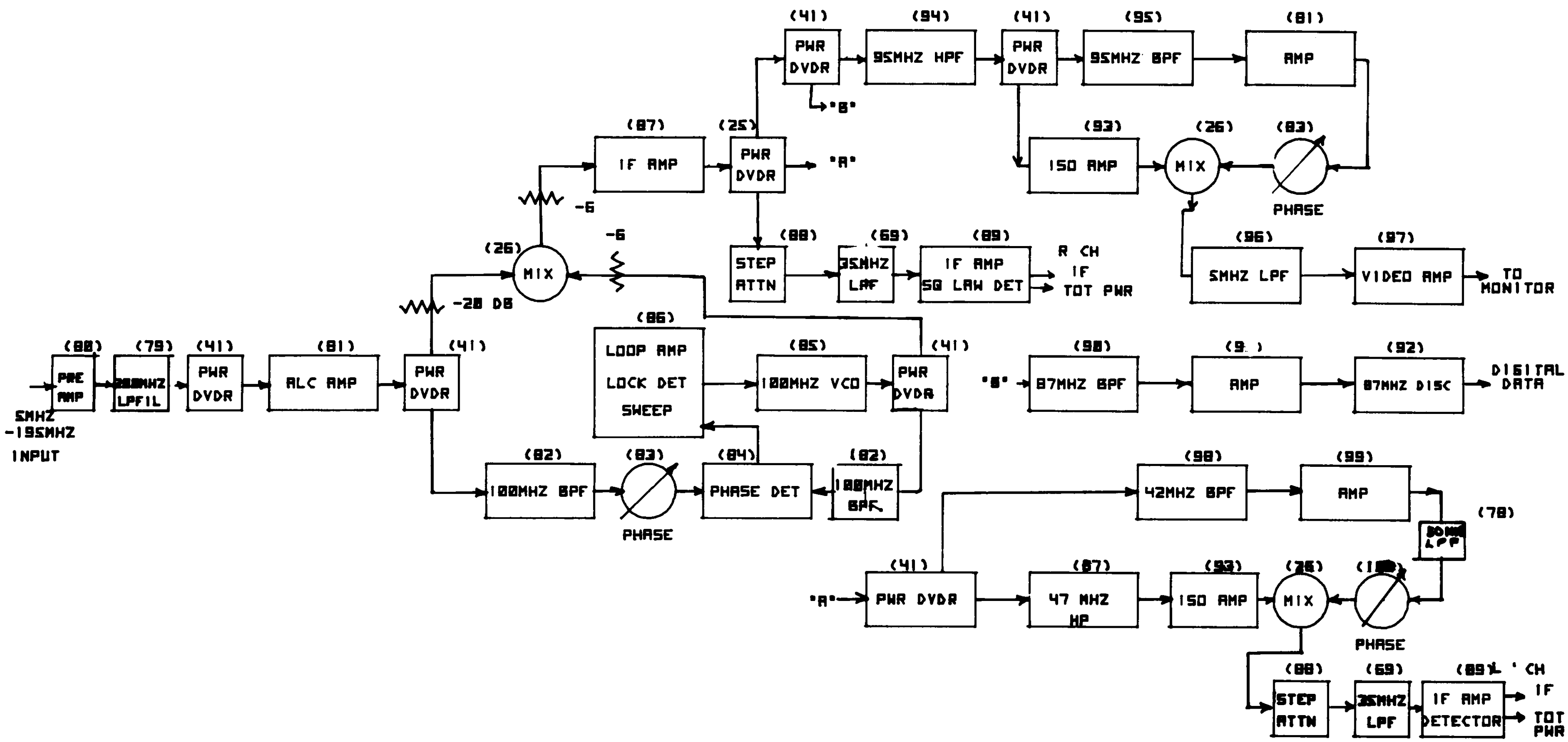

FIGURE 2

Block Diagram Link Receiver

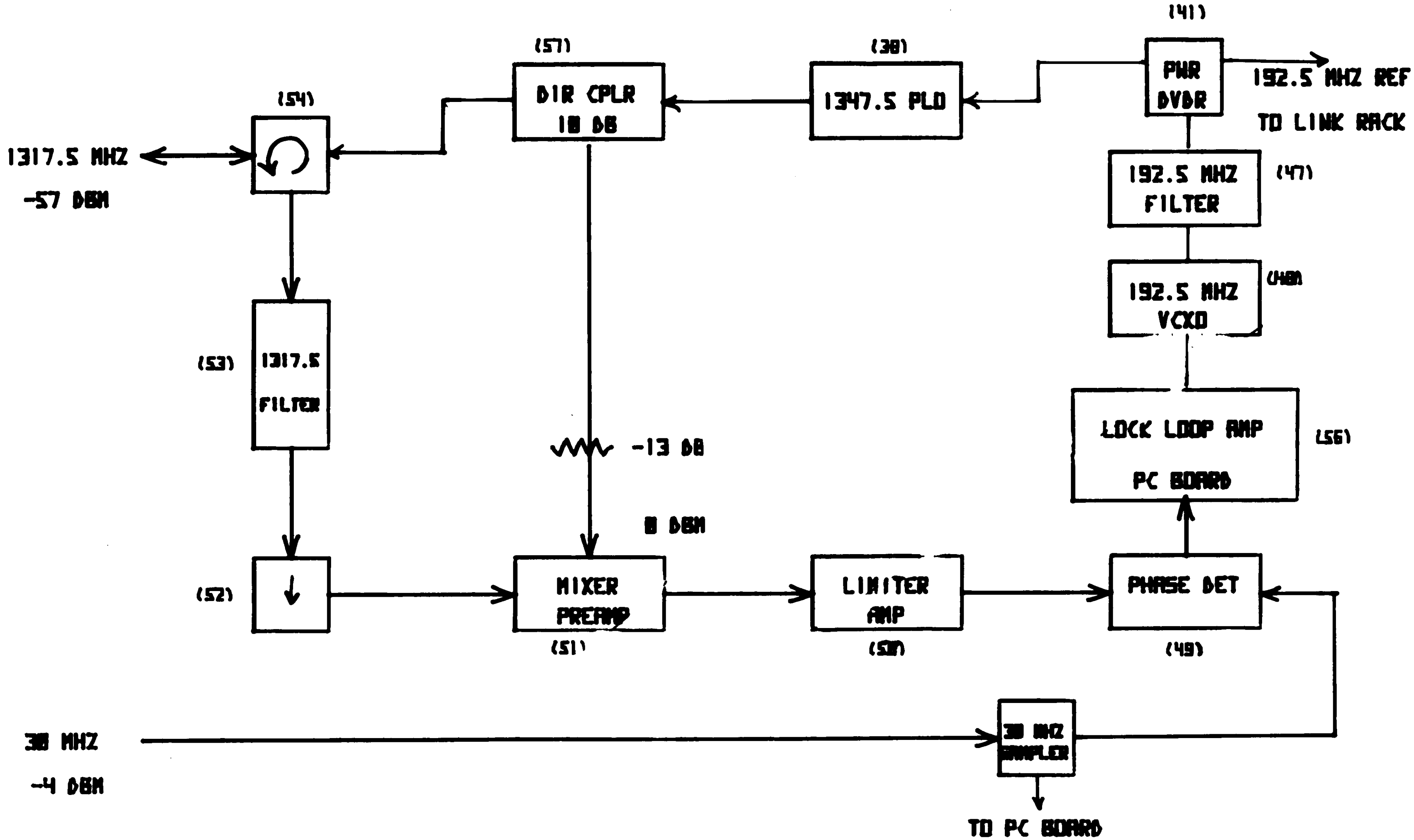

FIGURE 3

Control Building Reference Master LO Rack

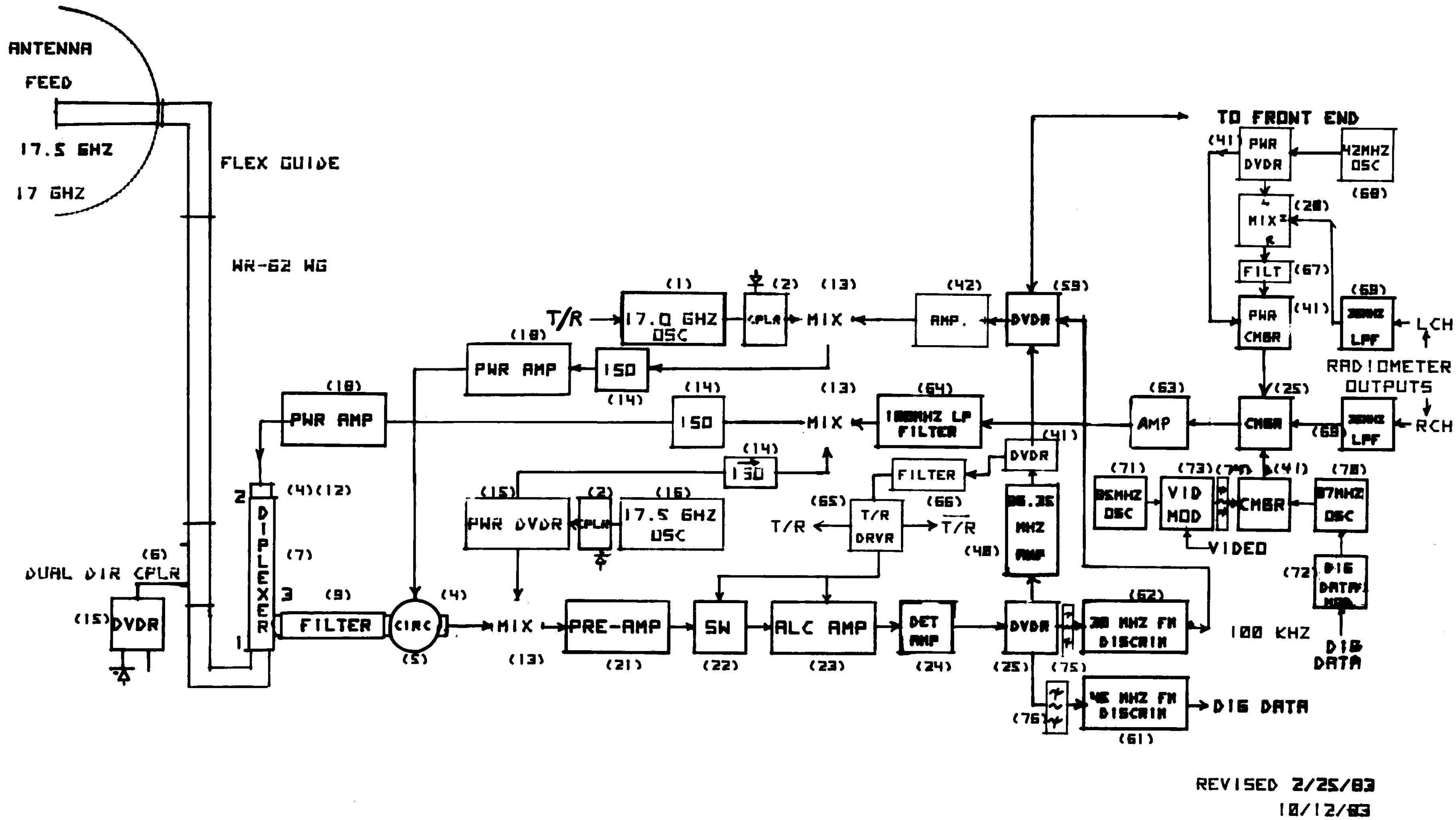

FIGURE 4

Remote Station Block Diagram

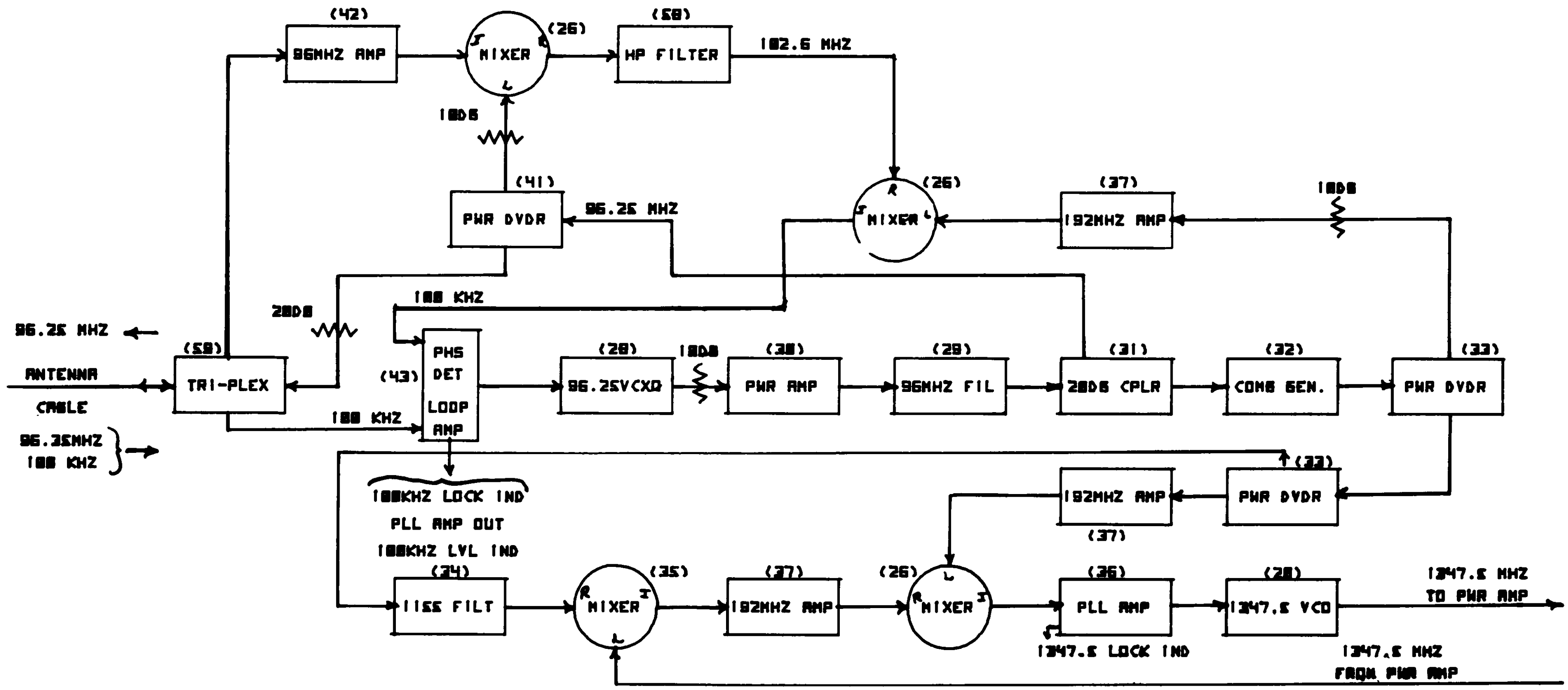

FIGURE 5

Remote Station Phase Lock Loop

ITEM	QUANTITY (C.B.)	(H.V.)	(M.V)	DESCRIPTION	MANUFACTURER/PART NO.	SPECIFICATIONS
1	2	1	1	17.0 Ghz Oscillator	Central Microwave CMF 520	100 mw min at 17 Ghz. Temp Coeff. < 500 Khz. 15 VDC @ 850 ma max.
2	4	2	2	Directional coupler	MAC Technology 3207-20	20 dB +- 1dB Coupling 12.4 to 18 Ghz. .55 dB Insertion loss. 1.3VSWR
3	2	0	0	High Level Mixer	Aertech MHX-18000	20 dB Isolation LO-IF LO-RF RF-IF Con.Loss 9.5dB max.LO PWR +20 dbm
4	6	3	3	Coax to WG Adapter	Astrolab 23004-J	VSWR 1.1 12.4 to 18 Ghz
5	2	1	1	Circulator	Microwave Assoc MA-8K219	26 dB Isol. 16 to 18 Ghz. .3 dB Insert. Loss. 1.1 VSWR
6	2	1	1	WG Directional Cplr	ARRA Model 1390	20 dB Coupling 16.9 to 17.6 Ghz, VSWR 1.1 to 1 max
7	2	1	1	Diplexer	Microwave Dev. Labs.	PORT 1-3,17.4 to 17.6 Ghz < 1dB Loss.;16.9 to 17.1,55 dB Loss
						PORT 1-2,16.9 to 17.1 Ghz < 1dB Loss.;17.4 to 17.6,40 dB Loss
9	4	1	1	Waveguide Filter	Microwave Dev. Labs.	16.9 to 17.1 Ghz Pass band; 17.4 to 17.6 Stop Band > 60 dB
10	4	2	2	Flexible Waveguide	Microtech MCKS62501N24B	
11	1	0	1	Antenna and Feed	Milliflect R-120	Surface RMS < .015"; Feed VSWR < 1.1:1
12	4	1	1	WG Isolator	MicrowaveAssoc.MA-8K288A	20 dB Isol. 17.0 to 17.6 Ghz. .3 dB Insert. Loss. 1.2 VSWR
13	4	3	3	Double Bal.Mixer	Aertech MX-18500	20 dB Iso.LO-RF LO-IF 9dB ISO RF-IF;Conv.Loss 7.0dB;LO PWR +10 dbm
14	2	2	2	Isolator Coaxial	Trak Microwave	18 dB min. Isol.12 to 18 Ghz. .5dBmax Insert. Loss 1.3 : 1 max VSWR
15	2	2	2	Power Divider	LARS LC-3318	7 to 18 Ghz
16	0	1	1	17.5 Ghz Oscillator	Central Microwave CMF 517	50 mw min 17.4 to 17.5 Ghz. Temp Coeff.<500Khz/C. 15 VDC @ 750ma
17	2	0	0	Low Noise Amp	Int MicrowaveAWP-17500-15	6 dB NF 17 to 18 Ghz;15 dB Gain; 28 VDC Bias
18	2	2	2	17GHZ Pwr Amp	Avantek SA82 -2761	25 db Gain 16.9 to 17.6 Ghz,+22dbm max outpput. 15 VDC @ 280 ma
19	2	0	0	T/R Driver (C.B.)	NRAO 8.112.19	50 Hz in, controls diode switch, preamp, pwr amp and 17ghz osc.
20	0	1	1	1347.5 Mhz VCO	Freq.Sources MO108F-XX	250 mw out 1300 to 1520 Mhz, 1.8 mhz tuning -4 to -14 V
21	2	1	1	Preamp	Avantek ASI 8221	57 dB Gain, 10 to 500 Mhz, 15 VDC 60 ma
22	2	1	1	Diode Switch	Triangle Microwave QL-36A	60 dB Isol., 1.0 dB loss from .1 to 2.0 Ghz
23	2	1	1	ALC Amplifier	Avantek ALC-1000	54 dB max. Gain 5 to 1000 Mhz, ALC-20 to -47 dbm,+15 V@.1A,-15,01A
24	2	1	1	AM Detector Amp	NRAO 8.112.24	6 dB Conversion Gain, 0 dbm input
25	4	2	2	Power Divider	MINI-CIRCUITS ZFSC3-13	3 way 0 deg, 1 to 200 Mhz, 30 dB Isol., 5.4 dB divison + loss
26	8	3	3	Mixer	MINI-CIRCUITS ZEM-2	20 dB Isolation LO-RF LO-IF 10 to 1000 Mhz, 7dB Conv. Loss

FIGURE 6

Microwave Link Parts

27	2	0	0	Volt.Cont.Xtal.Osc	Vectron 96.15Mhz	+13 dbm Output, 1x10-9/day aging,+-1x10-7 for +-10VAFC
28	0	1	1	Volt.Cont.Xtal.Osc	Vectron 96.25Mhz	+13 dbm Output, 1x10-9/day aging,+-1x10-7 for +-10VAFC
29	2	1	1	96 Mhz BP Filter	Reactel 6B2-96-6S11	92.5 to 99.7 Mhz 3dB BW,< 3dB Insert.Loss,40 dB Reject.86 & 106 Mhz
30	0	1	1	96 Mhz Power Amp	MINI-CIRCUITS ZHL-3A	24 dB Gain, +29.5 dbm Output, .4 to 150 Mhz, +24 VDC @ .6A
31	0	1	1	20 Db Coupler	MINI-CIRCUITS ZFDC-20-3	20 dB Coupling, .2 to 250 Mhz
32	0	1	1	Comb Generator	Hewlett-Packard HP33002A	100+-5Mhz Input at +26dBm, .2 to 4 Ghz out at -5 dBm
33	0	2	2	Pwr Divider	MINI-CIRCUITS ZFSC-2-5	2 way 0 degree 10 Mhz to 1500 Mhz, Isolation 25 dB, 1dB Insert Loss
34	0	1	1	1155Mhz BP Filter	Wavetek 50B4SS1155/40	1135to1175 3dB BW,3dB loss 1155,40 dB 1061&1243 Mhz,.1degPhase/degC
35	0	1	1	1-2Ghz Mixer	MINI-CIRCUITS ZLW-11	20 dB Isolation LO-RF LO-IF,5 to 2000 Mhz
36	0	1	1	192.5MHZ PLL AMP BD	NRAO 8.112.36	NRAO PLL Amp, lock detector, and sweep circuit on Douglas board
37	0	2	2	192 Mhz Amp.	NRAO 8.112.37	16 dB gain, 170 to 210 Mhz bandpass
38	2	0	0	1347.5Phase Lock Osc	Freq.Sources MO108XEL-XX	1347.5 Mhz, 260 milliwatts out, 192.5 Mhz 4 mw in
39	2	0	0	96 Mhz Amp	NRAO 8.112.39	10 dB gain, +7dBm power out, 300 to 500 Mhz 20 dB down
40	0	1	1	96Mhz Amp	NRAO 8.112.40	80 to 110 Mhz bandpass, 20 db gain
41	12	5	5	Pwr Divider	MINI-CIRCUITS ZFSC-2-1	5 to 500 Mhz, 20 db isolation, SMA connectors
42	0	2	2	96 Mhz Amp	NRAO 8.112.42	29 dB gain, +6 dBm output, input ret. loss 30dB min.
43	2	1	1	100Khz Phase Detect	NRAO 8.112.43	-20 dBm sig.input, -2 dBm ref., 100Khz amps, Loop amp and Lock Detect
44	2	0	0	100 Khz Xtal Oscill	Vectron 251-6038	+13 dBm out, 15 VDC .030A in, 5 x10e-7 aging per year
45	2	0	0	45 Mhz Volt.Cont.Osc	Vectron 371-6037	+13 dBm out, 15 VDC .030A in, +-1Mhz deviation for -+5v tuning
46	2	0	0	192.5Mhz VCXO	Vectron CO-226-5633	+7dBm out, 24VDC .13 to .26A,+-1x10e-5 tuning for +-10v
47	2	0	0	192.5Mhz BP Filter	Reactel 4B2-192-15-S11	184.4 to 201.5 Mhz bandpass, >30 dB rejection at 128.5 and 256.5 Mhz
48	2	0	0	30 Mhz VCO	Vectron 371-6037	+13dBm out, +15VDC .030A in, +-1Mhz deviation for -+ 5v tuning

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FIGURE 6 (continued)

Microwave Link Parts

ITEM	QUANTITY (C.B.)	(H.V.)	(M.V)	DESCRIPTION	MANUFACTURER/PART NO.	SPECIFICATIONS
49	2	0	0	Phase Detector	Hewlett-Packard HP10514A	Double balanced mixer used as phase detector
50	2	0	0	Limiter Amp.	LEL IF 6904	+16 dBm output, -30 to -40 dBm input, 3 Mhz bandwidth,-15VDC Supply
51	2	0	0	Mixer Preamp	LEL LAK-7-6904	RF to IF gain 30 dB, LO Pwr 0 dBm, IF band 24 to 36 Mhz
52	2	0	0	Isolator	Amlabs AMF 1902	26 dB Isolation at 1317 and 1347 Mhz
53	2	0	0	1317.5 Mhz Filter	Telonic TBA 1317.5-27-6SSI	3db BW 1304 to 1334 Mhz, 3.5 dB midband loss
54	2	0	0	Circulator	Amlabs AMF 1945	Insertion loss .4 dB at 1317 and 1347 Mhz
55	2	0	0	Limiter-Amp	NRAO 8.112.55	Output +11dBm with input varying from +4 to +8 dbm
56	2	0	0	100Mhz Loop Ckt.Bd.	NRAO 8.112.56	Phase lock loop amplifier and lock detecttor
57	2	0	0	Dir. Coupler	Anaren 10500-10	10 dB coupler 1-2 Ghz
58	0	1	1	High Pass Filter	NRAO 8.112.58	attenuates 100Khz by 35 db, passes 192.5 with min. phase/temp
59	0	2	2	Tri-plexer	NRAO 8.112.59	100Khz input>70db Iso. at 96 Mhz ports
60	2	0	0	96 Mhz Amp	NRAO 8.112.60	15 dB gain, +7dBm outout
61	0	1	1	45Mhz Discriminator	NRAO 8.112.61	-13 dbm input. TTL out
62	0	1	1	30Mhz Discriminator	NRAO 8.112.62	-13dBm input modulation index 5.5, 100khz 1.6 Vpp output
63	0	1	1	5-100Mhz Amp	TRM AD-112	30dB gain, .1 to 100 Mhz, +23dBm 1 dB pt.
64	0	1	1	100 Mhz LP Filter	Wavetek AL3SS111	111 Mhz low pass, 3dB pt. 118Mhz, <4 degrees from linear 5 to 80 Mhz
65	0	1	1	T/R Det.Driver	NRAO 8.112.65	Control signals for diode switch, ALC amp, 17 Ghz osc, pwr amp
66	0	1	1	96 Mhz BP Filter	Reactel 3B2-96-2-S11	3dB 94.8 and 96.7Mhz,3.5 dB insertion loss at 96 Mhz
67	2	1	1	47 Mhz HP Filter	NRAO 8.112.67	high pass 3dB 47 Mhz, phase linearity 14 degrees RMS 47 to 77 Mhz
68	0	1	1	42 Mhz Osc	Vectron 254-109-006	+13 dBm output,15 VDC .025 A, aging 2x10e-6/year
69	4	2	2	35 Mhz LP Filter	Wavetek AL7BB38	3dB 39 Mhz, 1.4 dB insertion loss, phase match all filters +-4 degrees
70	0	1	1	87Mhz Volt.Cont.Osc	Vectron 371-07-006A	+13 dBm output,+-1 Mhz with -+ 5V tuning,15 VDC .03 A
71	0	1	1	95 Mhz Osc.	Vectron 254-109-006	+13dBm output,+15VDC .025 A, aging 2x10e-6/year
72	2	1	1	Digital Data Mod.	NRAO 8.112.72	input TTL 20kbps, output +-5V,+-15VDC supply
73	0	1	1	Video Modulator	NRAO 8.112.73	inputs video and 95 Mhz, ouput AM
74	0	1	1	97.5Mhz BP Filter	Reactel 4B2-97.5-6-S11	3dB at 94.5 and 100.7 Mhz, 2db loss at 97.5
75	2	0	0	100 Khz Modulator	NRAO 8.112.75	100Khz 1 VRMS input, +-5 V out, -15 VDC supply
76	6	0	0	Power Divider	MINI-CIRCUITS ZFSC-2-6	2Khz to 60Mhz, 20 dB isolation

FIGURE 6 (continued)

77	2	0	0	Bias Tee	Triangle Microwave EP-18	.03 to 1.5 Ghz
78	2	0	0	50 Mhz LP Filter	NRAO 8.112.78	3 pole filter
79	2	0	0	200 Mhz LP Filter	NRAO 8.112.79	5 pole filter, SMA connectors
80	2	0	0	Preamp	ASI-8282M	20 dB gain, 5 to 500 Mhz, +15VDC .02A
81	2	0	0	ALC Amp	Avantek ALC-500	Output 2.5 dBm with input of -20 to -55 dBm,+-15VDC+.150A,-.01A
82	4	0	0	100 Mhz BP Filter	Reactel 6B2-100-18S11	3dB band 90.5 to 109.6, 1.6dB loss at 100Mhz
83	4	0	0	Phase Shifter 100Mhz	Merrimac PSM-3-100B	10% BW, 0-180 degree min., 1dB max loss
84	2	0	0	Phase Detector	Lorch CP411-100	100 Mhz in phase and quadrature detector, +13dBm LO, +3dBm RF
85	2	0	0	100 Mhz VCO	Vectron 371-6346	+13dBm output,+-2.5Mhz tuning for -+5V control, 15 VDC .03A
86	2	0	0	Loop Amp/Lock Det	NRAO 8.112.86	100Mhz PLL Amp, lock detector, and sweep on Douglas board
87	4	0	0	IF Amp-96 Mhz LO Amp	ASI 8283M	30 dB gain 5 to 500 Mhz, +15VDC .135A
88	4	0	0	Step Attenuator	Texscan MA-202	0 to 10 dB in 1 dB steps, DC to 2 Ghz
89	4	0	0	IF Amp-Detector	NRAO 8.112.89	-30 dBm input, IF output -5dBm, total power 1V
90	2	0	0	87 Mhz BP Filter	Reactel 3B2-87-2S11	3dB bandpass 86 to 88 Mhz, 3.7 dB loss at 87
91	2	0	0	Amplifier	ASI-8284M	31 dB gain 5 to 200 Mhz, +15VDC .05A
92	2	0	0	87 Mhz Discriminator	NRAO 8.112.92	-13dBm input, TTL output, +-15VDC,+5VDC
93	4	0	0	Isolating Amplifier	Merrimac IAM-01-200	isolation 40 db from 10 to 300Mhz, gain 0+-1dB
94	2	0	0	95Mhz HP Filter	Reactel 4B2-97.5-6S11	3dB band 94.5 to 100.7 Mhz, 2dB loss at 97.5 mhz
95	2	0	0	95 Mhz BP Filter	Reactel 3B3-95-0.95S11	3dB band from 94.48 to 95.51,5.5db loss at 95Mhz
96	2	0	0	5 Mhz LP Filter	NRAO 8.112.96	.5dB ripple 5 pole elliptic function filter, stop band 35 db at 1.2 fc
97	2	0	0	Video Amplifier	ASI-8286M	42 db gain 50 Hz to 400 Mhz, 43 dB gain, +15VDC .06A
98	2	0	0	42 Mhz BP Filter	Reactel 3B3-42-0.4-S11	3dB band 41.8 to 42.2 Mhz, 9db loss at 42 Mhz
99	2	0	0	42 Mhz Amplifier	ASI-8285M	38 dB gain 5 to 200 Mhz, +15VDC .06A
100	2	0	0	42 Mhz Phase Shifter	Merrimac PSM-3-42B	10% bandwidth, 0 to 180 degree min. phase adj., 1dB max loss

FIGURE 6 (continued)

Microwave Parts List

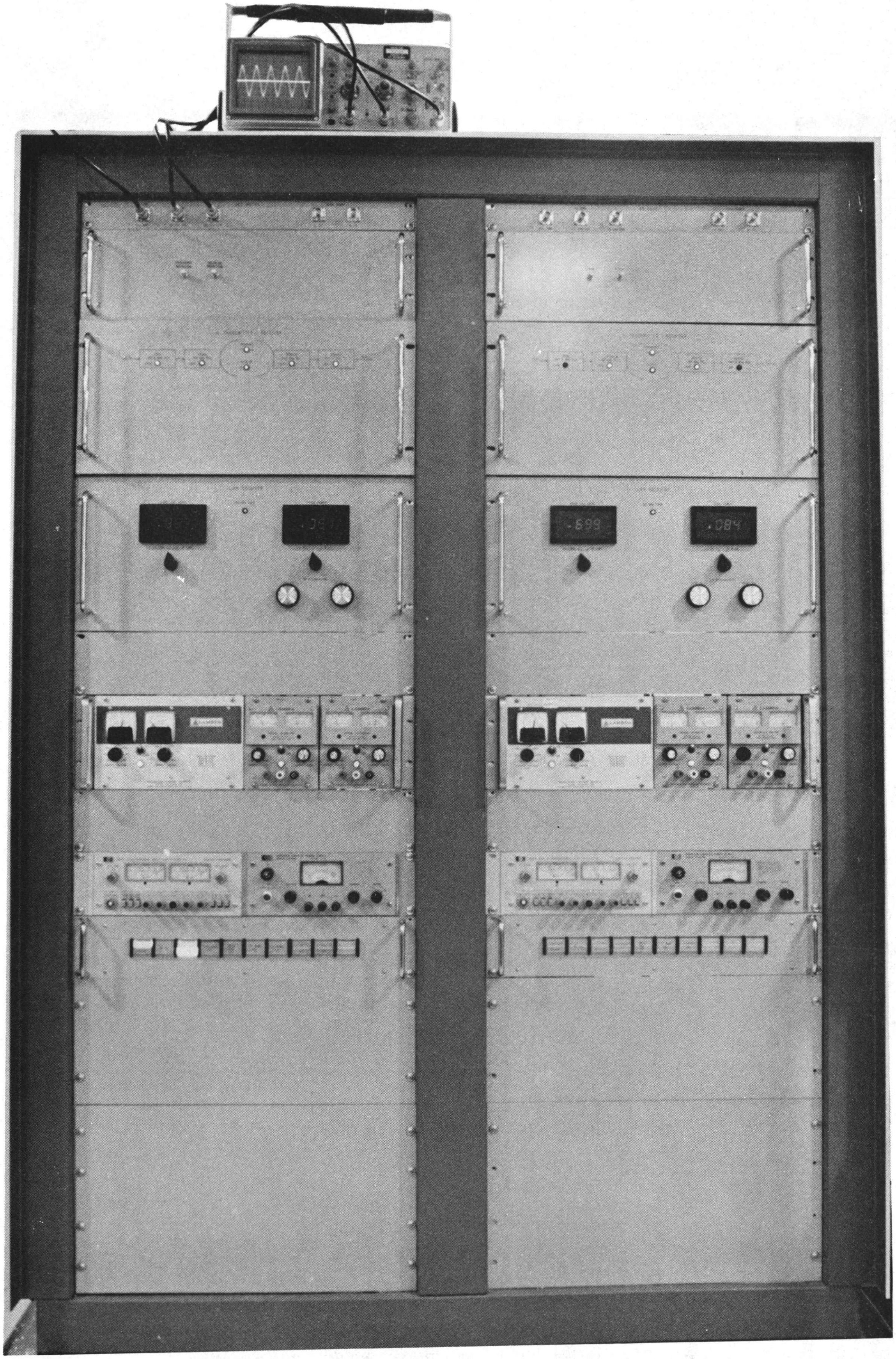

FIGURE 7

Two-Bay Rack at Control Building

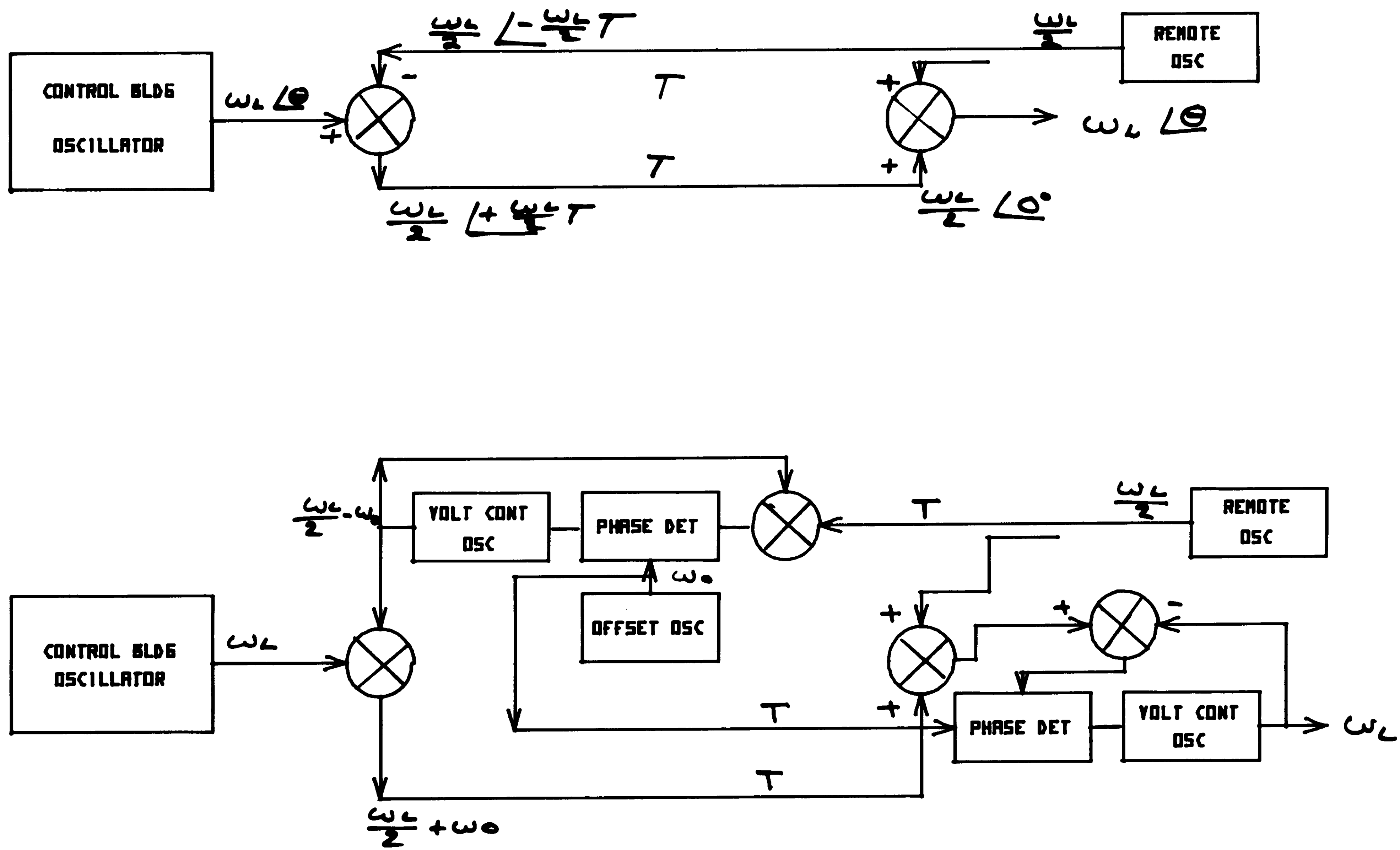

FIGURE 8

Basic Phase Control System

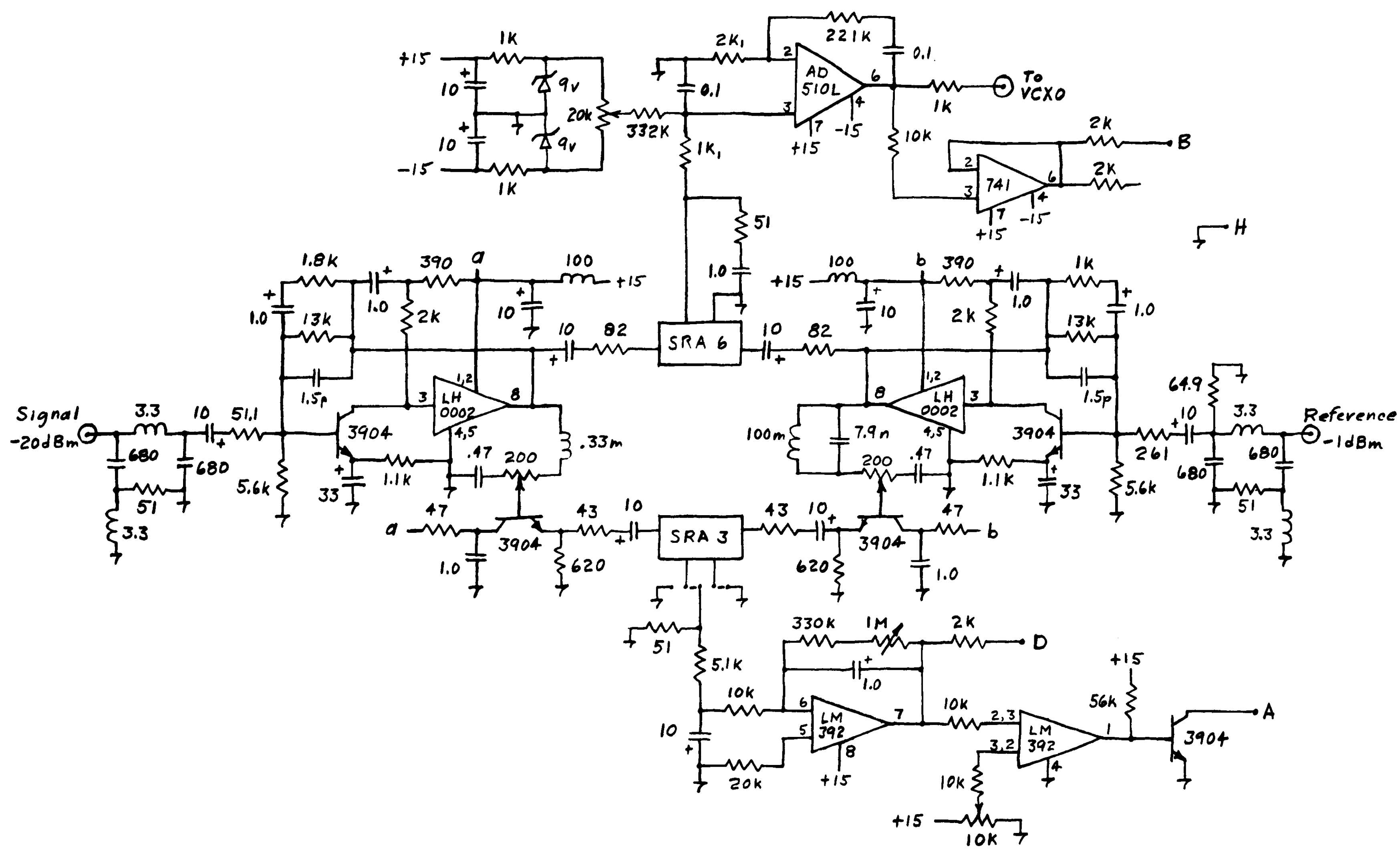

FIGURE 9

Phase Stable 100 kHz Phase Detector

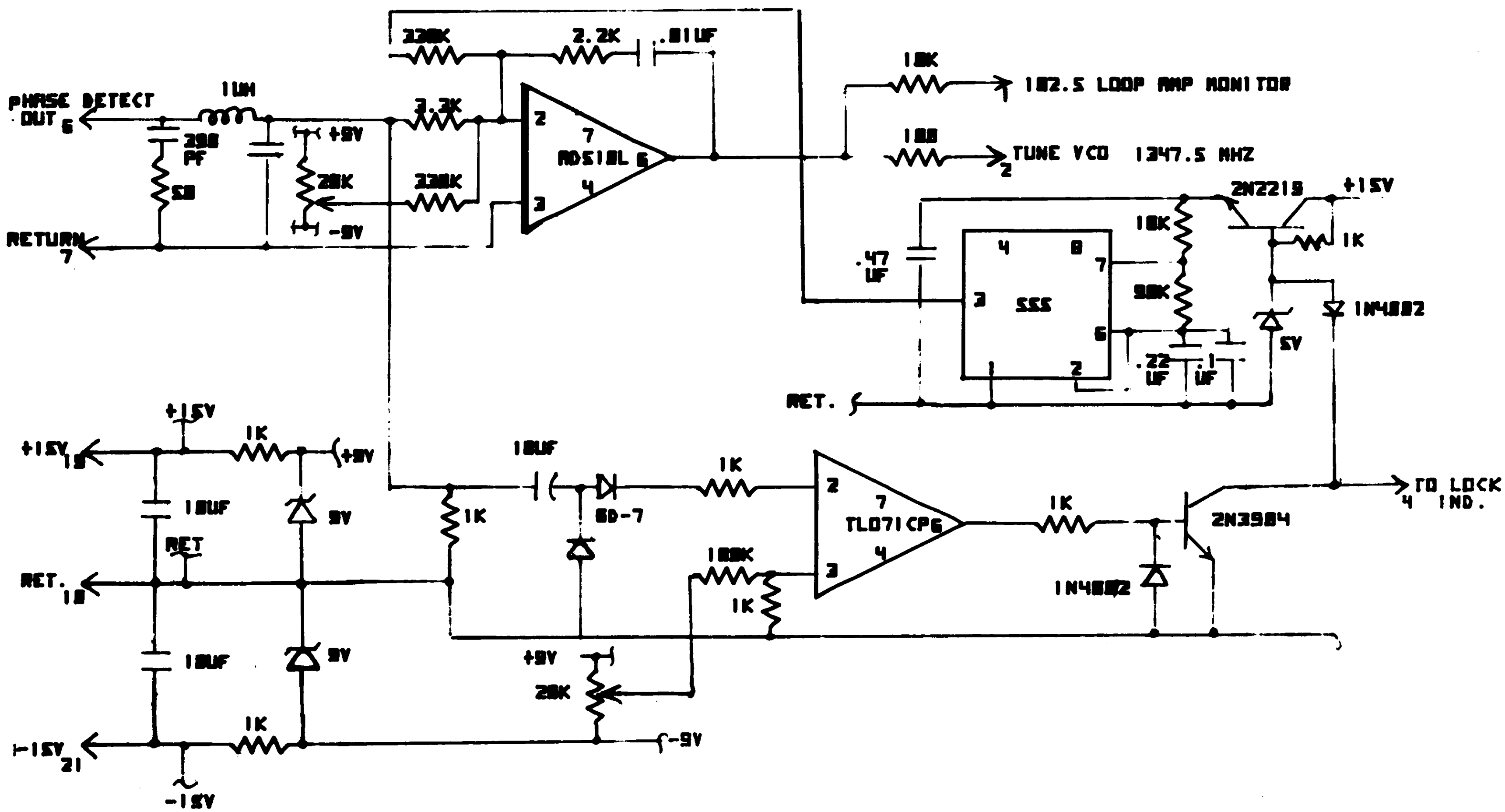

FIGURE 10

192.5 MHz Phase Lock Loop Amp

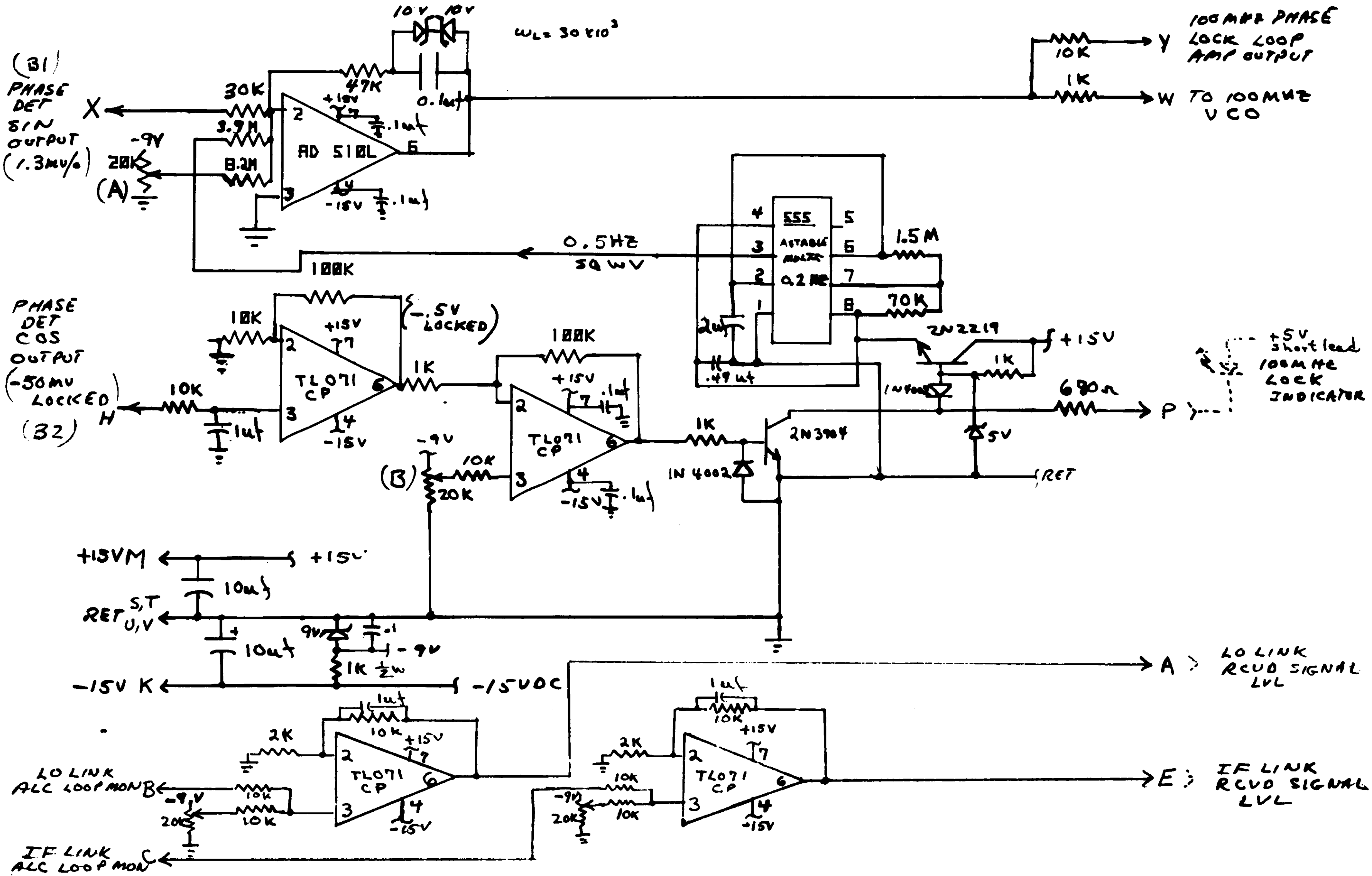

FIGURE 11

100 MHz Loop Amplifier and Lock Indicator

APPENDIX A

SPECIFICATIONS

(1) Microwave Link Reflector
(2) 16.9 to 17.6 GHz Amplifier
(3) Phase-Stable Phase-Locked Oscillator
(4) 96 MHz Voltage Controlled Crystal Oscillator
(5) 192.5 MHz Voltage Controlled Crystal Oscillator
(6) Voltage Controlled Oscillators
(7) Crystal Oscillators
(8) 300-600 MHz IF Amplifier

SPECIFICATIONS FOR MICROWAVE LINK REFLECTOR

General:

The microwave link reflector will be used to redirect microwave energy over obstructing terrain features. The reflectors must be designed to minimize degradation of signal levels with ambient temperatures ranging from -30°C to +35°C in winds up to 50 m.p.h. The highest operating frequency will be 17.5 GHz.

Reflector Face Size ...	10 foot x 16 foot or equivalent.
Face Flatness	With no wind load +0 to -0.080 inch where negative values indicate a concave surface.
Face Deflection	The face deflection must be less than ± 0.080 inch from the no-load position under the environmental conditions described above.
Supporting Framework ...	The supporting framework must provide a reflector ground clearance of 15 feet and be designed to prevent reflector face angle changes of more than ± 0.1° when subjected to the above environmental conditions.
Erection	The reflector and supporting framework should be designed so that erection can be accomplished using a vehicle power winch rather than a crane. Erection instructions must be provided.
Reflector Angle Adjustment	The reflector must be designed to provide for ± 2 degrees adjustment about both axes. Lead screws must be provided to smoothly adjust reflector angles
Corrosion Protection ...	All structural steel members and hardware will be galvanized after fabrication.

James R. Coe

James R. Coe, Electronics Engineer

Telephone:
304-456-2134

RFQ #GB-208

January 27, 1982

SPECIFICATIONS
FOR
16.9 to 17.6 GHz AMPLIFIER

Frequency Range	16.9 to 17.6 GHz
Small Signal Gain	23 to 26 dB
Gain Flatness over Frequency Range	± 0.5 dB
P_{out} at 1 dB Compression Point	25 dBm minimum
3rd Order Intermod Intercept Point	35 dBm minimum
Noise Figure	8 dB maximum
Operating Temperature	Must meet all specifications over 25°C ± 5°C. Must not be damaged by operating over 0°C to 40°C temperature ran
Input and Output VSWR	1.5:1 maximum
Input and Output Connectors	SMA female
Warranty	Minimum one year against defects.

James R. Coe

James R. Coe
Electronics Engineer

304-456-2011, extension 133

RFQ #GB-230

November 5, 1982

PHASE-STABLE PHASE-LOCKED OSCILLATOR

General:	We have a requirement for a quantity of five phase-locked oscillators which meet the following requirements:
Output Frequency:	1347.5 MHz
Output Power:	200 milliwatts minimum.
Input Reference Frequency:	192.5 MHz
Input Reference Power:	0 dBm ± 1 dB.
Phase Stability Sensitivity:	1° phase from 20° to 30 °C. ± 1° phase for ± 1 dB input reference. ± 1° phase for ± 1% supply voltage. The phase-locked oscillator output phase must be stable with respect to the input reference phase. Special testing will be required to determine the phase stability sensitivity to temperature, input reference level, and power supply variations. One method of making the test would be to connect two phase-locked oscillators to the input reference source; then measure the phase difference between the two oscillator outputs. Record any phase changes in the outputs when one of the oscillators is subject to temperature, input reference level, and power supply voltage variations. Test data must be supplied with each unit.
Oscillator Type:	Cavity-Stabilized Transistor.
Phase-Lock Oscillator Loop Bandwidth:	10 kHz minimum.
Lock Limit Alarm:	TTL Low = Limit exceeded.
Input Reference and Output Connector:	SMA Female
Power Supply Requirements:	-20 V DC at 0.5 amps maximum.

* * * * * * * *

SPECIFICATIONS

96 MHz VOLTAGE CONTROLLED CRYSTAL OSCILLATOR

General:	These crystal oscillators will be used in a 20 Hz rate-time multiplexed-clock synchronization system. To prevent false locking, the oscillators must not drift over 10 Hz in 100 days. They will be operated in a temperature controlle 25°C ± 5°C environment.
Aging Rate:	1×10^{-9}/day.
Frequency ... Unit A:	96.250 000 MHz
Unit B:	96.150 000 MHz
Output Power:	+13 dBm
Output Impedance:	50 ohms
Stability vs. Temperature:	$\pm 5 \times 10^{-8}$ over 0°C to +50°C
Stability vs. Supply:	1×10^{-8}/percent change in supply voltage.
Stability vs. Orientation:	1×10^{-8} maximum change any orientation.
Phase Noise:	-115 dB/Hz at 1 kHz from carrier.
Harmonics and Subharmonics:	> 20 dB below output.
Supply:	+24 V DC, 10 watts maximum.
RF Connector Output:	SMA female.
Mechanical Tuning:	Screwdrive adjust setable to 1×10^{-8}.
Electronic Tuning:	$\pm 1 \times 10^{-7}$ with ± 10 V control voltage.
Tuning Rate:	DC to 1 kHz.
Quantity:	Unit A (96.25 MHz) ... 3
	Unit B (96.15 MHz) ... 3

SPECIFICATIONS

192.5 MHz VOLTAGE CONTROLLED CRYSTAL OSCILLATOR

General:	These oscillators will be operated in a temperature controlled environment of 25°C ± 5°C at a fixed orientation.
Aging Rate:	1 x 10^{-7}/day
Frequency:	192.500 MHz
Output Power	> 0.5 V RMS into 50 ohm
Stability vs. Temperature:	± 5 x 10^{-8} over 0°C to +50°C.
Stability vs. Supply:	1 x 10^{-8}/percent change in supply.
Phase Noise:	-115 dB/Hz, 1 kHz from carrier.
Harmonics and Subharmonics:	> 20 dB below output.
Other Spurious:	> 80 dB below output.
Supply Voltage:	+24 V DC, 10 watts maximum.
Mechanical Tuning:	Screwdriver adjust setable to 1 x 10^{-8}
Electronic Tuning:	± 1 x 10^{-5} for ± 10 V control voltage.
Tuning Rate:	DC to 10 kHz.
RF Connector Output:	SMA female.
Quantity:	Three.

SPECIFICATIONS
FOR
VOLTAGE CONTROLLED OSCILLATORS

Center Frequency	A = 87 MHz B = 45 MHz C = 30 MHz
Tuning Range	± 1 MHz
Tuning Voltage	0 to +10 V or 0 to -10 V or -5 V to +5
Tuning Slope	Δf/ΔV positive.
Tuning Sensitivity	150 to 250 kHz/V over the full tuning range.
Modulation Rate	DC - 100 kHz.
Tuning Impedance	10 K ohm minimum
Frequency Pulling	± 2% with load VSWR of 1.5 to 1 any ph
Frequency Stability with Vibration ..	± .01% maximum
Frequency Pushing	± 0.1% for ± 1 V supply.
Frequency Stability with Temperature	20 to 30°C, 200 PPM/°C mV
DC Voltage	+15 V or -15 V or ± 15 V DC
Output Power	20 milliwatts minimum.
Load Impedance	50 ohms
Output Connector	SMA female
Harmonics	30 dB or more below output
Spurious	70 dB or more below output.
RFI	Oscillator must be enclosed in an RFI tight case with the power and tuning ports filtered.

SPECIFICATIONS FOR CRYSTAL OSCILLATORS

Oscillator Frequency	D = 100 kHz E = 42 MHz F = 95 MHz
Stability	1 part in 10^6 over 20 to 30°C
Aging Rate	1 part in 10^5/year
Harmonics	30 dB or more below output
Output Power	20 milliwatt minimum
Load Impedance	50 ohms
Output Connector	SMA Female
DC Supply	+15 V DC or -15 V DC
RFI	Oscillator must be enclosed in tight case with DC line filter

SPECIFICATIONS
FOR
300-600 MHz IF AMPLIFIER

Frequency Range	300 to 600 MHz
Gain over Frequency Range	50 dB minimum
Gain at 100 MHz and Lower Frequencies	20 dB maximum
Flatness over Frequency Range	± 0.5 dB
Noise Figure	2 dB maximum
1 dB Gain Compression Point	0 dBm minimum
Overload Recovery Time	500 microseconds maximum after being subjected to -20 dBm input level for 20 milliseconds.
Connectors	SMA female
Enclosure	RFI tight with filtered power feed-thru.
Quantity	5

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James R. Coe
Electronics Engineer

304-456-2011, extension 134

RFQ: GB-226

September 3, 1982

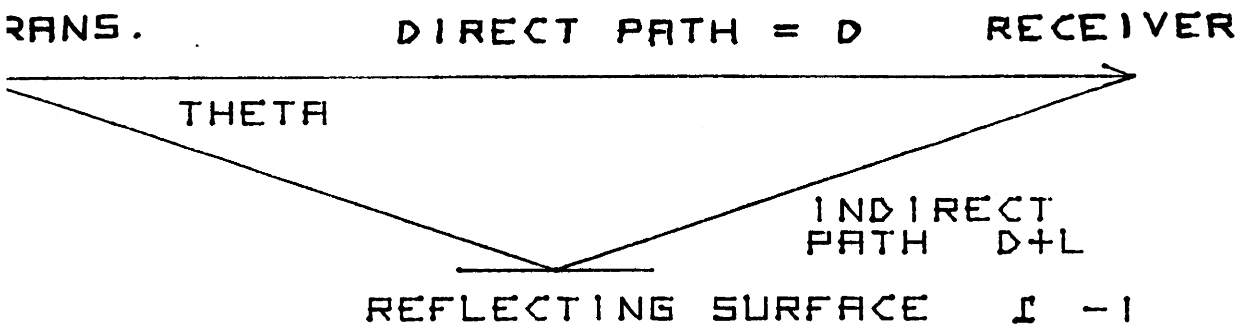
JRC/cjd

APPENDIX B

DIRECT AND INDIRECT PATH SIGNALS

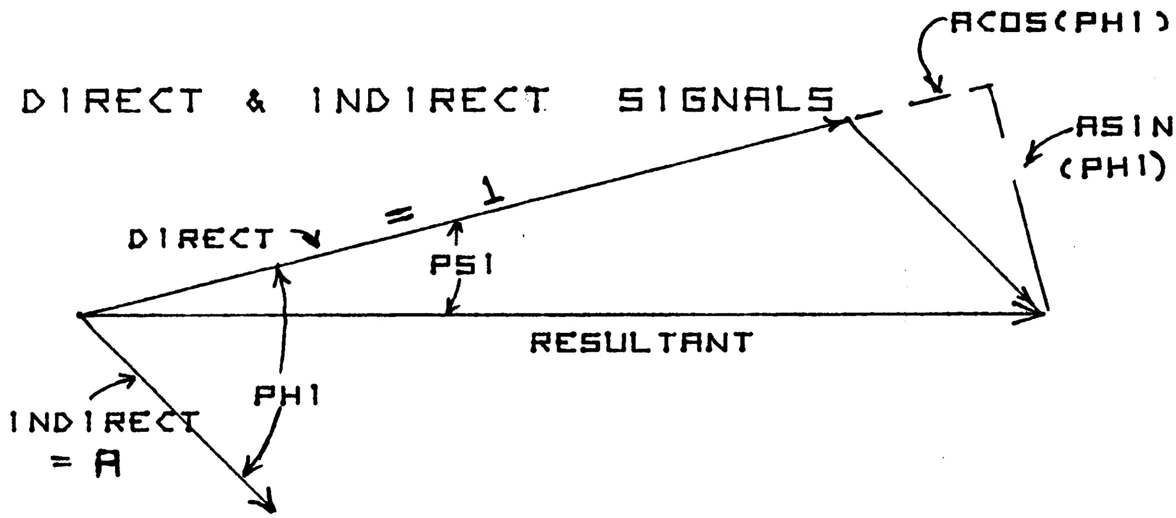
These tables display the resultant phase (psi) and amplitude (R) of an indirect signal combining with a direct signal for angles off axis of 0.1 to 1.2 degrees and with indirect/direct amplitude ratios of 0.1, 0.5, and 1.0 for a 24 000 meter path. The column headed "phase difference" shows the change in psi with frequency. It varies with frequency except where the indirect signal and the direct signal are equal in amplitude.

The results are also shown for a 35 000 meter path with a theta of 0.1 to 1.2 and A = 0.5.



$$L = D(1/COS(THETA) - 1)$$

$$PHI = 2PI\ L\ F/3 \times 10^{8} + PI$$



$$PSI = ARCTAN \left[\frac{A\ SIN(PHI)}{1+A\ COS(PHI)} \right]$$

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.037 METERS	.1	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	921.36	-2.3	0	.908
17000	925.75	-2.73	-.43	.911
17100	930.13	-3.15	-.41	.915
17200	934.52	-3.53	-.39	.919
17300	938.91	-3.9	-.36	.924
17400	943.29	-4.23	-.33	.93
17500	947.68	-4.53	-.3	.936
17600	952.07	-4.8	-.27	.942

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.146 METERS	.2	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	3145.44	-5.74	0	.997
17000	3162.99	-5.44	.29	1.027
17100	3180.54	-4.69	.76	1.054
17200	3198.08	-3.56	1.13	1.076
17300	3215.63	-2.17	1.39	1.092
17400	3233.18	-.62	1.55	1.099
17500	3250.73	.97	1.59	1.098
17600	3268.27	2.49	1.52	1.089

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.329 METERS	.3	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	6852.02	1.09	0	1.098
17000	6891.5	4.21	3.13	1.065
17100	6930.98	5.72	1.51	1.003
17200	6970.46	4.65	-1.07	.938
17300	7009.94	1.11	-3.54	.902
17400	7049.42	-3.08	-4.19	.914
17500	7088.9	-5.53	-2.45	.968
17600	7128.38	-5.26	.27	1.036

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.585 METERS	.4	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	12041.32	2.03	0	.906
17000	12111.51	-4.77	-6.8	.941
17100	12181.69	-4.62	.15	1.056
17200	12251.88	1.07	5.7	1.098
17300	12322.06	5.58	4.51	1.019
17400	12392.25	2.92	-2.65	.913
17500	12462.43	-4.17	-7.09	.929
17600	12532.62	-5.08	-.91	1.043

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.914 METERS	.5	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	18713.57	-.58	0	1.099
17000	18823.23	5.69	6.27	.982
17100	18932.9	-3.39	-9.08	.918
17200	19042.57	-3.22	.17	1.081
17300	19152.23	5.28	8.5	1.035
17400	19261.9	-.21	-5.49	.9
17500	19371.56	-5.13	-4.92	1.041
17600	19481.23	3.51	8.63	1.077

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	1.316 METERS	.6	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	26868.54	-4.59	0	.937
17000	27026.46	2.34	6.93	1.09
17100	27184.38	-.48	-2.83	.9
17200	27342.3	-1.59	-1.11	1.096
17300	27500.22	3.97	5.56	.925
17400	27658.14	-4.81	-8.78	1.051
17500	27816.06	5.74	10.55	.994
17600	27973.98	-5.64	-11.38	.977

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	1.791 METERS	.7	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	36506.68	3.43	0	.918
17000	36721.63	.15	-3.28	1.1
17100	36936.58	-3.71	-3.85	.922
17200	37151.53	5.25	8.96	1.036
17300	37366.49	-5.33	-10.58	1.033
17400	37581.44	3.87	9.2	.924
17500	37796.39	-.33	-4.2	1.1
17600	38011.34	-3.25	-2.92	.916

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	2.34 METERS	.8	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	47628	5.61	0	.974
17000	47908.76	2.53	-3.07	1.089
17100	48189.52	-4.15	-6.68	1.066
17200	48470.27	-4.7	-.55	.939
17300	48751.03	3.04	7.74	.914
17400	49031.79	5.26	2.22	1.036
17500	49312.55	-.68	-5.94	1.099
17600	49593.3	-5.67	-4.99	1.011

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	2.961 METERS	.9	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	60232.72	5.48	0	.966
17000	60588.07	5.6	.12	.974
17100	60943.41	5.69	.08	.982
17200	61298.75	5.73	.04	.99
17300	61654.09	5.74	.01	.998
17400	62009.43	5.7	-.03	1.006
17500	62364.77	5.64	-.07	1.014
17600	62720.11	5.53	-.1	1.022

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	3.656 METERS	1	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	74321.07	2.05	0	.906
17000	74759.78	-5.2	-7.25	.954
17100	75198.48	-3.53	1.67	1.077
17200	75637.19	3.2	6.73	1.081
17300	76075.89	5.37	2.17	.961
17400	76514.6	-1.6	-6.97	.904
17500	76953.3	-5.67	-4.07	1.011
17600	77392.01	-.73	4.94	1.099

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	4.424 METERS	1.1	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	89893.05	-5.63	0	.975
17000	90423.9	4.91	10.54	1.048
17100	90954.74	-4.95	-9.87	.946
17200	91485.59	3.82	8.77	1.072
17300	92016.44	-3.69	-7.51	.921
17400	92547.28	2.41	6.1	1.09
17500	93078.13	-1.97	-4.37	.905
17600	93608.98	.81	2.78	1.099

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	5.265 METERS	1.2	.1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	106949.11	2.56	0	1.088
17000	107580.88	-4.67	-7.23	1.055
17100	108212.65	-3.37	1.3	.917
17200	108844.42	5	8.37	.947
17300	109476.19	3.12	-1.87	1.082
17400	110107.96	-4.25	-7.37	1.064
17500	110739.73	-3.96	.29	.925
17600	111371.5	4.59	8.55	.937

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.037 METERS	.1	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	921.36	-18.82	0	.565
17000	925.75	-21.56	-2.74	.591
17100	930.13	-23.86	-2.3	.621
17200	934.52	-25.73	-1.87	.653
17300	938.91	-27.2	-1.48	.687
17400	943.29	-28.33	-1.12	.723
17500	947.68	-29.13	-.8	.759
17600	952.07	-29.66	-.52	.797

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.146 METERS	.2	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	3145.44	-27.43	0	1.082
17000	3162.99	-23.65	3.78	1.214
17100	3180.54	-18.95	4.7	1.326
17200	3198.08	-13.68	5.27	1.412
17300	3215.63	-8.07	5.61	1.47
17400	3233.18	-2.27	5.79	1.498
17500	3250.73	3.57	5.84	1.494
17600	3268.27	9.34	5.77	1.46

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.329 METERS	.3	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	6852.02	4	0	1.493
17000	6891.5	16.62	12.62	1.368
17100	6930.98	26.76	10.14	1.11
17200	6970.46	29.39	2.63	.775
17300	7009.94	9.76	-19.62	.515
17400	7049.42	-23.51	-33.28	.616
17500	7088.9	-29.63	-6.12	.943
17600	7128.38	-22.29	7.35	1.251

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.585 METERS	.4	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	12041.32	16.93	0	.55
17000	12111.51	-29.6	-46.53	.792
17100	12181.69	-18.62	10.98	1.332
17200	12251.88	3.95	22.57	1.493
17300	12322.06	24.85	20.9	1.178
17400	12392.25	22.67	-2.19	.604
17500	12462.43	-28.13	-50.8	.715
17600	12532.62	-21.16	6.97	1.278

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.914 METERS	.5	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	18713.57	-2.15	0	1.498
17000	18823.23	28.79	30.94	1.011
17100	18932.9	-25.08	-53.88	.641
17200	19042.57	-12.28	12.81	1.43
17300	19152.23	22.44	34.72	1.247
17400	19261.9	-1.89	-24.33	.501
17500	19371.56	-21.45	-19.56	1.272
17600	19481.23	13.47	34.91	1.415

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	1.316 METERS	.6	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	26868.54	-29.25	0	.767
17000	27026.46	8.75	38	1.465
17100	27184.38	-4.34	-13.09	.503
17200	27342.3	-5.88	-1.54	1.484
17300	27500.22	27.46	33.34	.694
17400	27658.14	-19.64	-47.1	1.312
17500	27816.06	27.69	47.33	1.07
17600	27973.98	-29.14	-56.84	.987

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	1.791 METERS	.7	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	36506.68	25.26	0	.644
17000	36721.63	.54	-24.72	1.5
17100	36936.58	-26.46	-27	.668
17200	37151.53	22.26	48.73	1.252
17300	37366.49	-22.78	-45.04	1.238
17400	37581.44	27.11	49.89	.684
17500	37796.39	-1.21	-28.31	1.499
17600	38011.34	-24.41	-23.2	.629

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	2.34 METERS	.8	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	47628	29.35	0	.97
17000	47908.76	9.49	-19.86	1.458
17100	48189.52	-16.32	-25.81	1.373
17200	48470.27	-29.47	-13.16	.781
17300	48751.03	23.3	52.77	.613
17400	49031.79	22.33	-.97	1.25
17500	49312.55	-2.49	-24.82	1.497
17600	49593.3	-25.89	-23.4	1.143

D PATH LENGTH	L EXTRA LENGTH	THETA OFF AXIS DEG.	A AMP RATIO
24000 METERS	2.961 METERS	.9	.5

FREQ MHZ	PHI ABS.PHASE DEG	PSI PHASE SHIFT DEG	PHASE DIFF DEG	R RESULT. AMP
16900	60232.72	29.75	0	.93
17000	60588.07	29.36	-.39	.97
17100	60943.41	28.81	-.54	1.009
17200	61298.75	28.14	-.68	1.048
17300	61654.09	27.34	-.79	1.086
17400	62009.43	26.45	-.9	1.123
17500	62364.77	25.46	-.99	1.158
17600	62720.11	24.4	-1.06	1.193

D PATH LENGTH	L EXTRA LENGTH	THETA OFF AXIS DEG.	A AMP RATIO
24000 METERS	3.656 METERS	1	.5

FREQ MHZ	PHI ABS.PHASE DEG	PSI PHASE SHIFT DEG	PHASE DIFF DEG	R RESULT. AMP
16900	74321.07	17.12	0	.552
17000	74759.78	-30	-47.12	.864
17100	75198.48	-13.57	16.43	1.414
17200	75637.19	12.19	25.75	1.431
17300	76075.89	29.92	17.73	.902
17400	76514.6	-13.7	-43.61	.531
17500	76953.3	-25.89	-12.19	1.143
17600	77392.01	-2.67	23.22	1.497

D PATH LENGTH	L EXTRA LENGTH	THETA OFF AXIS DEG.	A AMP RATIO
24000 METERS	4.424 METERS	1.1	.5

FREQ MHZ	PHI ABS.PHASE DEG	PSI PHASE SHIFT DEG	PHASE DIFF DEG	R RESULT. AMP
16900	89893.05	-29.25	0	.979
17000	90423.9	20.2	49.44	1.3
17100	90954.74	-29.85	-50.05	.82
17200	91485.59	14.81	44.66	1.396
17300	92016.44	-26.41	-41.22	.667
17400	92547.28	9.01	35.41	1.463
17500	93078.13	-16.49	-25.49	.547
17600	93608.98	2.98	19.47	1.496

D PATH LENGTH	L EXTRA LENGTH	THETA OFF AXIS DEG.	A AMP RATIO
24000 METERS	5.265 METERS	1.2	.5

FREQ MHZ	PHI ABS.PHASE DEG	PSI PHASE SHIFT DEG	PHASE DIFF DEG	R RESULT. AMP
16900	106949.11	9.6	0	1.457
17000	107580.88	-18.87	-28.46	1.328
17100	108212.65	-24.96	-6.1	.638
17200	108844.42	29.9	54.86	.828
17300	109476.19	11.87	-18.03	1.434
17400	110107.96	-16.79	-28.66	1.365
17500	110739.73	-27.43	-10.64	.693
17600	111371.5	29.26	56.68	.767

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.037 METERS	.1	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	921.36	-79.32	0	.371
17000	925.75	-77.13	2.19	.446
17100	930.13	-74.93	2.19	.52
17200	934.52	-72.74	2.19	.593
17300	938.91	-70.55	2.19	.666
17400	943.29	-68.35	2.19	.738
17500	947.68	-66.16	2.19	.808
17600	952.07	-63.97	2.19	.878

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.146 METERS	.2	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	3145.44	-47.28	0	1.357
17000	3162.99	-38.51	8.77	1.565
17100	3180.54	-29.73	8.77	1.737
17200	3198.08	-20.96	8.77	1.868
17300	3215.63	-12.18	8.77	1.955
17400	3233.18	-3.41	8.77	1.996
17500	3250.73	5.36	8.77	1.991
17600	3268.27	14.14	8.77	1.939

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.329 METERS	.3	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	6852.02	6.01	0	1.989
17000	6891.5	25.75	19.74	1.801
17100	6930.98	45.49	19.74	1.402
17200	6970.46	65.23	19.74	.838
17300	7009.94	84.97	19.74	.175
17400	7049.42	-75.29	-160.26	.508
17500	7088.9	-55.55	19.74	1.131
17600	7128.38	-35.81	19.74	1.622

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.585 METERS	.4	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	12041.32	80.66	0	.325
17000	12111.51	-64.25	-144.91	.869
17100	12181.69	-29.16	35.09	1.747
17200	12251.88	5.94	35.09	1.989
17300	12322.06	41.03	35.09	1.509
17400	12392.25	76.12	35.09	.48
17500	12462.43	-68.79	-144.91	.724
17600	12532.62	-33.69	35.09	1.664

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	.914 METERS	.5	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	18713.57	-3.22	0	1.997
17000	18823.23	51.61	54.83	1.242
17100	18932.9	-73.55	-125.17	.566
17200	19042.57	-18.72	54.83	1.894
17300	19152.23	36.11	54.83	1.616
17400	19261.9	-89.05	-125.17	.033
17500	19371.56	-34.22	54.83	1.654
17600	19481.23	20.61	54.83	1.872

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	1.316 METERS	.6	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	26868.54	-65.74	0	.822
17000	27026.46	13.22	78.96	1.947
17100	27184.38	-87.82	-101.04	.076
17200	27342.3	-8.86	78.96	1.976
17300	27500.22	70.1	78.96	.681
17400	27658.14	-30.94	-101.04	1.715
17500	27816.06	48.03	78.96	1.338
17600	27973.98	-53.01	-101.04	1.203

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	1.791 METERS	.7	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	36506.68	73.33	0	.574
17000	36721.63	.81	-72.52	2
17100	36936.58	-71.71	-72.52	.628
17200	37151.53	35.76	107.48	1.623
17300	37366.49	-36.76	-72.52	1.602
17400	37581.44	70.71	107.48	.661
17500	37796.39	-1.81	-72.52	1.999
17600	38011.34	-74.34	-72.52	.54

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	2.34 METERS	.8	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	47628	53.99	0	1.176
17000	47908.76	14.37	-39.62	1.937
17100	48189.52	-25.25	-39.62	1.809
17200	48470.27	-64.87	-39.62	.849
17300	48751.03	75.51	140.38	.501
17400	49031.79	35.89	-39.62	1.62
17500	49312.55	-3.74	-39.62	1.996
17600	49593.3	-43.36	-39.62	1.454

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	2.961 METERS	.9	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	60232.72	56.35	0	1.108
17000	60588.07	54.02	-2.33	1.175
17100	60943.41	51.69	-2.33	1.24
17200	61298.75	49.36	-2.33	1.303
17300	61654.09	47.03	-2.33	1.363
17400	62009.43	44.7	-2.33	1.421
17500	62364.77	42.38	-2.33	1.477
17600	62720.11	40.05	-2.33	1.531

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	3.656 METERS	1	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	74321.07	80.52	0	.329
17000	74759.78	-60.12	-140.65	.996
17100	75198.48	-20.77	39.35	1.87
17200	75637.19	18.58	39.35	1.896
17300	76075.89	57.93	39.35	1.062
17400	76514.6	-82.72	-140.65	.254
17500	76953.3	-43.36	39.35	1.454
17600	77392.01	-4.01	39.35	1.995

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	4.424 METERS	1.1	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	89893.05	-53.49	0	1.19
17000	90423.9	31.93	85.42	1.697
17100	90954.74	-62.64	-94.58	.919
17200	91485.59	22.78	85.42	1.844
17300	92016.44	-71.8	-94.58	.625
17400	92547.28	13.63	85.42	1.944
17500	93078.13	-80.95	-94.58	.315
17600	93608.98	4.47	85.42	1.994

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
24000 METERS	5.265 METERS	1.2	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	106949.11	14.54	0	1.936
17000	107580.88	-29.58	-44.12	1.739
17100	108212.65	-73.69	-44.12	.562
17200	108844.42	62.19	135.88	.933
17300	109476.19	18.08	-44.12	1.901
17400	110107.96	-26.04	-44.12	1.797
17500	110739.73	-70.15	-44.12	.679
17600	111371.5	65.73	135.88	.822

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	.053 METERS	.1	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	1261.15	-1.15	0	.5
17000	1267.55	-7.42	-6.27	.509
17100	1273.95	-13.18	-5.76	.529
17200	1280.34	-18.12	-4.94	.559
17300	1286.74	-22.12	-4	.597
17400	1293.14	-25.18	-3.06	.642
17500	1299.54	-27.39	-2.2	.692
17600	1305.93	-28.85	-1.46	.745

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	.213 METERS	.2	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	4504.6	-4.57	0	.503
17000	4530.19	-23.89	-19.31	.621
17100	4555.78	-29.91	-6.02	.829
17200	4581.37	-28.12	1.79	1.049
17300	4606.96	-22.65	5.47	1.242
17400	4632.55	-15.39	7.26	1.388
17500	4658.14	-7.25	8.14	1.476
17600	4683.73	1.24	8.49	1.499

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	.48 METERS	.3	1	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	9910.03	-84.99	0	.175
17000	9967.6	-56.2	28.79	1.113
17100	10025.18	-27.41	28.79	1.775
17200	10082.75	1.37	28.79	1.999
17300	10140.33	30.16	28.79	1.729
17400	10197.9	58.95	28.79	1.032
17500	10255.48	87.74	28.79	.079
17600	10313.05	-63.48	-151.21	.893

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	.853 METERS	.4	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	17477.76	-16.23	0	.546
17000	17580.11	-19.08	-2.85	1.323
17100	17682.47	13.85	32.93	1.41
17200	17784.82	25.98	12.12	.658
17300	17887.17	-29.76	-55.73	.928
17400	17989.53	-3.49	26.27	1.494
17500	18091.88	26.93	30.42	1.103
17600	18194.23	-13.41	-40.34	.53

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	1.333 METERS	.5	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	27208.12	-22.85	0	.607
17000	27368.05	2.68	25.53	1.497
17100	27527.98	11.53	8.85	.521
17200	27687.91	-10.57	-22.1	1.448
17300	27847.84	29.67	40.24	.798
17400	28007.77	-22.45	-52.11	1.247
17500	28167.7	26.09	48.54	1.136
17600	28327.63	-29.73	-55.82	.932

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	1.919 METERS	.6	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	39100.78	-27.72	0	.702
17000	39331.09	26.78	54.5	1.11
17100	39561.39	-12.65	-39.43	1.425
17200	39791.69	-11.21	1.44	.52
17300	40021.99	19.67	30.88	1.311
17400	40252.29	-21.26	-40.92	1.276
17500	40482.59	15.98	37.23	.544
17600	40712.89	10.82	-5.16	1.446

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	2.612 METERS	.7	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	53156.41	-29.93	0	.835
17000	53469.88	-9.58	20.35	.515
17100	53783.35	26.5	36.08	.669
17200	54096.82	27.82	1.32	1.064
17300	54410.29	16.25	-11.58	1.374
17400	54723.76	1.25	-15	1.499
17500	55037.23	-13.95	-15.2	1.408
17600	55350.7	-26.43	-12.47	1.123

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	3.412 METERS	.8	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AM
16900	69375	-29.02	0	.995
17000	69784.44	-17.83	11.19	1.347
17100	70193.88	-2.05	15.78	1.498
17200	70603.32	14.11	16.16	1.406
17300	71012.75	27.09	12.98	1.097
17400	71422.19	26.88	-.22	.678
17500	71831.63	-11.15	-38.03	.52
17600	72241.07	-29.99	-18.84	.875

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	4.318 METERS	.9	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	87756.89	-25.1	0	1.17
17000	88275.09	23.17	48.27	1.228
17100	88793.3	-29.76	-52.92	.807
17200	89311.51	10.37	40.13	1.45
17300	89829.71	-9.42	-19.79	.514
17400	90347.92	-4.03	5.38	1.493
17500	90866.13	25.49	29.52	.648
17600	91384.33	-17.86	-43.35	1.347

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	5.331 METERS	1	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	108302.4	-18.43	0	1.336
17000	108942.18	-28.06	-9.64	.713
17100	109581.95	26.96	55.02	.68
17200	110221.73	19.59	-7.37	1.313
17300	110861.51	-6.15	-25.74	1.483
17400	111501.29	-28.14	-21.99	1.048
17500	112141.06	-1.02	27.12	.5
17600	112780.84	28.45	29.48	1.031

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	6.451 METERS	1.1	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	131011.53	-9.42	0	1.459
17000	131785.68	8.48	17.9	1.467
17100	132559.84	24.32	15.84	1.195
17200	133333.99	28.87	4.55	.746
17300	134108.14	-7.93	-36.8	.51
17400	134882.29	-29.98	-22.04	.886
17500	135656.44	-20.13	9.85	1.302
17600	136430.59	-3.15	16.98	1.495

D	L	THETA	A	
PATH LENGTH	EXTRA LENGTH	OFF AXIS DEG.	AMP RATIO	
35000 METERS	7.678 METERS	1.2	.5	
	PHI	PSI		R
FREQ MHZ	ABS.PHASE DEG	PHASE SHIFT DEG	PHASE DIFF DEG	RESULT. AMP
16900	155884.95	1.63	0	1.499
17000	156806.28	-21.84	-23.47	.594
17100	157727.62	15.42	37.26	1.387
17200	158648.95	-29.64	-45.06	.943
17300	159570.28	26.61	56.24	1.116
17400	160491.61	-21.45	-48.06	1.272
17500	161412.94	29.04	50.49	.755
17600	162334.27	-8.53	-37.57	1.466