VLA ELECTRONICS MEMORANDUM NO. 142

Interoffice

National Radio Astronomy Observatory

Charlottesville, Virginia

September 24, 1973

To: S. Weinreb

From: R. Predmore

Subject: Transmit/Receive Changes in the VLA LO System

1. Introduction

The VLA primary local oscillator for each antenna is a 500 MHz frequency which is phase-locked to a 500 MHz oscillator in the control building. The antenna oscillator must be stabilized between observation of calibration sources which may be as long as 8 to 12 hours. Phase errors which are not corrected by the LO Loop can occur in the mm-transmission system or in the transmit/receive processing at the antenna and control room. The errors due to the mm-transmission system will be considered in this memo.

2. Phase Error in MM-Transmission

The main VLA electronics block diagram is duplicated in Figure 1 for reference. We are concerned with Blocks 3, 4, 6, 7, 8 and 9 in studying the 500 MHz phase-locked loop. Two tones at f_o + 1250 MHz and f_o + 1750 MHz are transmitted to and from the control room on a time-shared basis, to provide the phase-locked 500 MHz at the antenna. Mismatches at the mm-mixer and the antenna coupling system will cause second order variations in the resultant 500 MHz phase. The phase loop will not cancel these effects completely, if the mixer match changes between transmit and receive.

The second order effects due to mismatches at the source and load of a transmission line of length l are illustrated in Figure 2. These effects occur when a portion of a transmitted wave is reflected from the load and the source and added to the primary wave at the load. The primary phase change $\exp(jB_i l)$ is modified by a term of order $\rho_i \rho_{ci}$ whose phase, γ_i, depends on the length of the transmission line, and the phases of the reflections from the source and load.

This error occurs at both the transmitted frequencies. When received at the antenna and control room these tones are first mixed down to the 1-2 GHz band and then each tone is amplified separately before they are mixed to give 500 MHz (ω_3). Figure 3 shows the 500 MHz phasor at the antenna with errors due to mismatch. The reflections at the two millimeter frequencies (f_o + 1250 MHz) and (f_o + 1750 MHz) change the magnitude and phase of the resultant 500 MHz phasor by:

$$\Delta M \approx \rho_1 \rho_{c1} \cos \gamma_1 + \rho_2 \rho_{c2} \cos \gamma_2$$

$$\xi \approx \rho_2 \rho_{c2} \sin \gamma_2 - \rho_1 \rho_{c1} \sin \gamma_1$$

As γ_1, γ_2 are varied by a change in the length of transmission line, the peak to peak phase variation is:

$$\xi_{pp} = 2\ (\rho_1\rho_{c1} + \rho_2\rho_{c2})$$

and rms variation is:

$$\xi_{rms} = \frac{\rho_1\rho_{c1} + \rho_2\rho_{c2}}{2}$$

For the case where the mixer and coupler matches are the same at both frequencies:

$$\rho_1 = \rho_2;\ \rho_{c1} = \rho_{c2},$$

the variation of ξ with changes in length is given in Figure 3. The mismatch is assumed to occur where the antenna waveguide couples into the main circular waveguide trunk, approximately 30 meters from the mixer in the vertex room. The phase error is:

$$\xi = \rho_1 \cdot \rho_{c1} \cdot \sin\ ((\gamma_2 - \gamma_1)/2)\ \cdot\ \cos\ ((\gamma_1 + \gamma_2)/2),$$

where $\dfrac{\gamma_2 - \gamma_1}{2}\ \alpha\ (\omega_2 - \omega_1) \cdot \ell/c$

and $\dfrac{\gamma_2 + \gamma_1}{2}\ \alpha\ (\omega_2 + \omega_1) \cdot \ell/c$

As ℓ changes due to temperature and/or flexure in the antenna coupling system, ξ will change rapidly with ℓ due to the $(\omega_1 + \omega_2) \cdot \ell/c$ term, with an envelope which varies as $(\omega_2 - \omega_1) \cdot \ell/c$.

However, if the magnitudes (ρ_1, ρ_2) and phases (θ_1, θ_2) of the mixer match do not change significantly for transmission and reception, ξ will be almost the same and should be compensated for in the phase loop. The change in ξ due to changes in ρ_1, ρ_2, θ_1, and θ_2 are considered in Figure 4. Since variations in ρ_i are most important when γ_i is $(2n+1)\pi/2$ (error phasors normal to 500 MHz phasor), and changes in θ_i are significant when γ_i is $m\pi$ (error phasors along 500 MHz phasor), the two effects do not occur simultaneously and can be handled individually.

The maximum limits on $d\xi$ for changes in rho or theta are given by:

$$|d\xi(\rho)| \leq \rho_{c1} \cdot |d\rho_1| + \rho_{c2} \cdot |d\rho_2|$$

and

$$|d\xi(\theta)| \leq \rho_1\ \rho_{c_1} \cdot |d\theta_1| + \rho_2\ \rho_{c2} \cdot |d\theta_2|.$$

We are trying to limit $d\xi$ to 0.1° = 0.0017 rad.

Assuming that $\rho_1 = \rho_2 = \rho$,

$$\rho_{c1} = \rho_{c2} = \rho_c,$$

$$d\rho_1 = d\rho_2 = d\rho,$$

and $d\theta_1 = d\theta_2 = d\theta < 0.1$ radian*,

we can establish limits on the match for the mixer and antenna coupling system. These matches are determined by the variation in theta:

$$\rho\rho_c < \frac{|d\xi|}{2|d\theta|} \approx \frac{0.0017}{2\times 0.1} = 0.0085 \rightarrow -41 \text{ dB}$$

The variation in ρ is limited to

$$d\rho = |d\xi|/(2\rho_c), \text{ or}$$

$$\frac{d\rho}{\rho} = |d\xi|/(2\rho\rho_c) \approx 0.1$$

This change corresponds to 0.8 dB change in reflected power from the mixers, assuming the required ρ_c at both frequencies (f_o + 1250) and (f_o + 1750).

The value of $d\theta$=0.1 rad is the experimental limit of the mixer SWR measurements. If $d\theta$ is less than 0.1 the restraint on the product $\rho \cdot \rho_c$ can be relaxed. An upper limit to $\rho \cdot \rho_c$ is then given by the variation in rho:

$$\rho \cdot \rho_c < |d\xi|/(2d\rho/\rho).$$

Section 3 describes a test setup which will simulate the mismatch in the antenna coupling system.

3. Measurement of 500 MHz Phase Error as a Function of Millimeter Mismatch

The main VLA electronics block diagram was duplicated in Figure 1 for reference. Block 7 will be neglected for our one antenna analysis, while the circular waveguide trunk will be simulated in rectangular WG for tests. Figure 5 gives a test setup for creating a mismatch in the waveguide transmission system. With the 3 dB coupler, the variable attenuator and the movable short, the coupler match ρ_c can be varied as well as the length ℓ. This system will allow each mixer to be evaluated and will allow matching specifications for the antenna coupling system to be established.

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*From laboratory measurements using a slotted line.

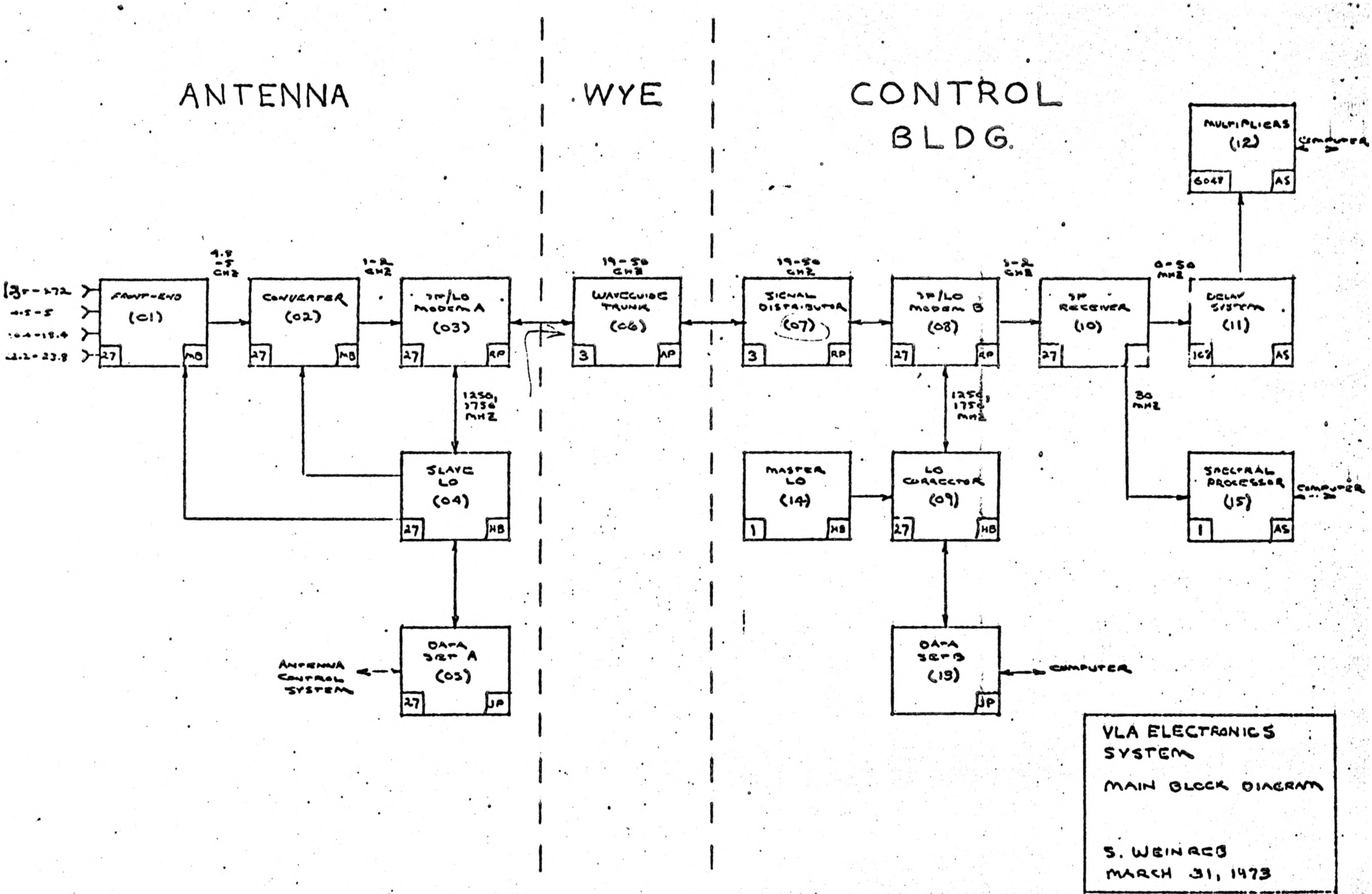
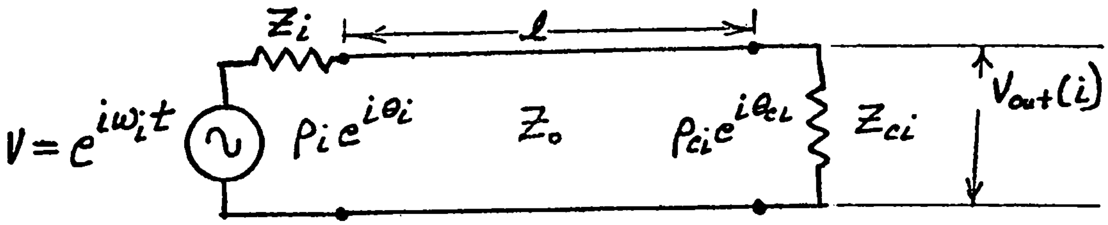

ANTENNA
WYE
CONTROL BLDG.
FRONT-END (01)
CONVERTER (02)
IF/LO MODEM A (03)
SLAVE LO (04)
DATA SET A (05)
ANTENNA CONTROL SYSTEM
WAVEGUIDE TRUNK (06)
SIGNAL DISTRIBUTOR (07)
IF/LO MODEM B (08)
LO CORRECTOR (09)
IF RECEIVER (10)
DELAY SYSTEM (11)
MULTIPLIERS (12)
DATA SET B (13)
MASTER LO (14)
SPECTRAL PROCESSOR (15)
COMPUTER
1-2 GHZ
19-50 GHZ
0-50 MHZ
1250, 1750 MHZ
30 MHZ
VLA ELECTRONICS SYSTEM
MAIN BLOCK DIAGRAM
S. WEINREB
MARCH 31, 1973

FIGURE 1.

FIGURE 2. Phase Errors Due to Source and Load Mismatches



$$\omega_1 = 2\pi \; (f_0 + 1.250 \text{ GHz})$$

$$\omega_2 = 2\pi \; (f_0 + 1.750 \text{ GHz})$$

$$\frac{V_{out(i)}}{V_{(i)}} = e^{j\beta_i \ell} \left[1 + \rho_i \rho_{ci} \; e^{j\gamma_i} \right]$$

where $\gamma_i = 2\beta_i \ell + \theta_i + \theta_{ci}$,

ρ_1, ρ_2, (θ_1, θ_2) are the magnitudes (phases) of the mixer reflection coefficient at frequencies ω_1, ω_2.

ρ_{c1}, ρ_{c2}, (θ_{c1}, θ_{c2}) are the same quantities for the load (antenna coupling system).

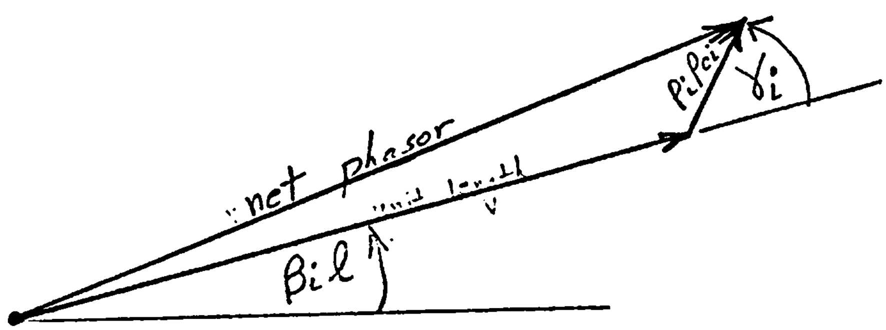


FIGURE 3 Phase Error as function of Line Length l.

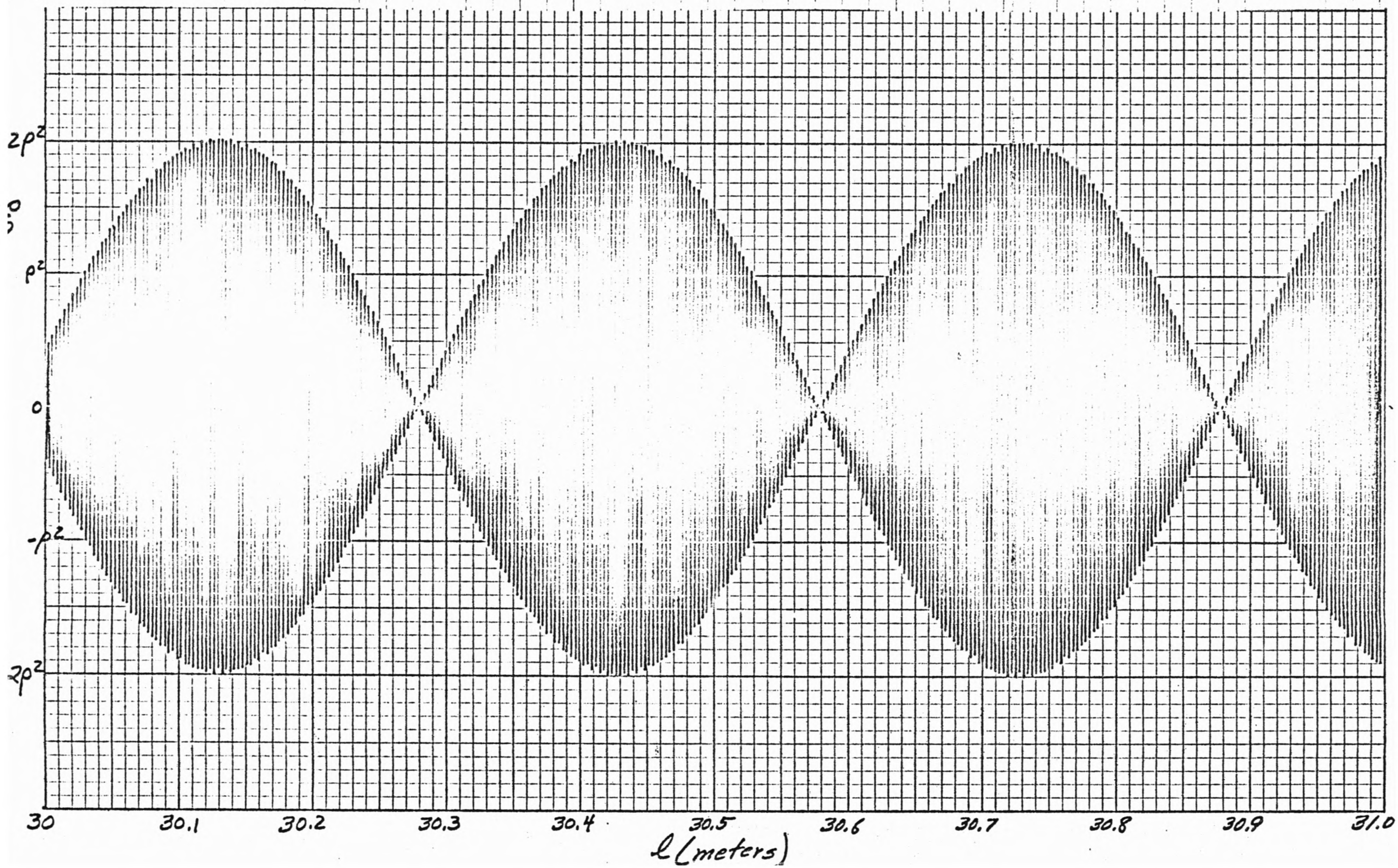
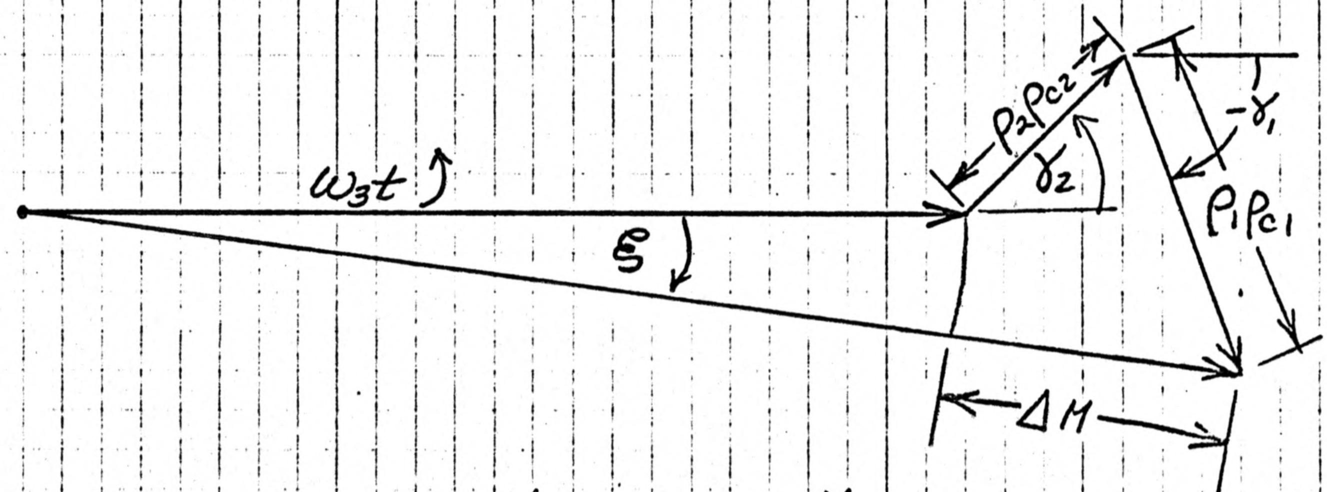


FIGURE 4 NET ERRORS IN 500 MHz PHASE.



$$\Delta M \approx \rho_1\rho_{c1}\cos\gamma_1 + \rho_2\rho_{c2}\cos\gamma_2 \,,$$

$$\xi \approx \rho_2\rho_{c2}\sin\gamma_2 - \rho_1\rho_{c1}\sin\gamma_1 .$$

FIGURE 5 SIMULATION OF COUPLER MISMATCH