NATIONAL RADIO ASTRONOMY OBSERVATORY

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INTERIM REPORT ON PROTOTYPE LOCAL OSCILLATOR SYSTEM

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A single correction loop of the local oscillator distribution system as described in the VLA Proposal has been bread-boarded at the University of Virginia. The purpose of this effort has been to provide experimental proof of the adequacy of the "offset frequency" phase correction technique and to establish design and performance limits for the necessary system components.

I. System Description

A block diagram of the system is shown in Figure 1. The major units are outlined, and the signal flows, frequencies, and power levels are indicated. The basic reference frequency f_o = 449.166... MHz, and therefore the two line frequencies, $f_o/2 + f_r$ and $f_o/2 - f_r$, were chosen as a compromise between minimum line loss and higher multiplication to the final f_{LO} = 2695 MHz. The choice of f_r determines the maximum phase correction ratio, and for f_r = 50 kHz, the ratio is $(f_o/2)/(2f_r) \simeq 2,240$.

The Central Station consists of the Master Oscillator (MO), Difference Mixer (DM), Phase Locked Receiver (PLR), and Phase Locked Transmitter (PLT). The basic oscillator is a precision quartz unit in a proportional oven and is rated by the manufacturer at a stability of 2×10^{-9} per day at 4.678819 MHz. An output level of 9 dBm drives a times-16 transistor frequency multiplier and provides a +27 dBm level at 74.861111 MHz. At this point a narrow band (20 kHz bandwidth) crystal filter is used to reduce FM noise sidebands. An output level of +17 dBm drives a times-six transistor multiplier. This unit provides an output of +37 dBm for f_o = 449.166666 MHz. A 10 dB directional coupler and 20 dB pad provide a +7 dBm level to the master

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station difference-frequency mixer. The main line, through a 3 dB pad, provides +33 dBm output to a times-six varactor multiplier. This unit provides an output of +27 dBm at 2695 MHz. The PLT and the PLR are essentially identical units differing only in signal frequency and power level. They are basically IF phase-comparison, phase-locked receivers. A common local oscillator signal is provided by a 112.089166 MHz, 5th overtone, quartz oscillator in a proportional oven. This unit is rated at 1×10^{-7} per day stability by the manufacturer. A times-two multiplier provides a +16 dBm level at 224.178333 MHz. The 3 dB hybrids provide power levels of +10 dBm to the mixers and adequate isolation between units. The signal input to the PLR mixer is at 224.533333 MHz. The IF frequency is therefore 355 kHz. For the PLT the signal frequency is 224.63333 MHz and the IF is 455 kHz.

Except for the difference in the IF frequency, the two units are identical. Each channel (signal and VCO) consists of a balanced transistor mixer followed by a nine disc ceramic ladder filter at 355 kHz or 455 kHz. Gain is provided by an integrated circuit amplifier/limiter, RCA CA-3012. A second ceramic filter and CA-3012 provide further out-of-band attenuation and in-band gain. The net bandwidths are 31 and 40 kHz. The output of the second CA-3012 provides a square wave of 0.75 volts (p-p). The two output square waves (signal and VCO) are differentiated and drive the Set and Reset inputs of an AC toggled flip-flop. This unit uses an RCA CD-2150 dual-4-input gate. Complimentary outputs are averaged and differentially drive an RCA CA-3015 operational amplifier. The net result is a linear phase-voltage transfer function of 10 millivolts per degree phase difference. The output is bipolar about DC ground and extends to nearly ± 180°. Full phase difference sensitivity is maintained for signal level inputs between 0 dBm and -115 dBm. Less than 1 dB of gain reduction results from an out-of-band signal of 0 dBm (50 to 100 kHz separation).

The VCO for the PLR consists of a quartz unit in a proportional oven operating at 4.667777 MHz. A deviation sensitivity of 0.5×10^{-6} per volt is obtained and is nearly linear over ± 10 volts. This unit is rated at 2×10^{-9} per day stability. A times 48 transistor frequency multiplier provides an output level of +7 dBm at 224.533333 MHz. The VCO signal is coupled and attenuated to -53 dBm at the reference mixer input. An attenuated signal of +0 dBm drives the Master Station "difference frequency" mixer (DM) through a band-pass filter.

The output of the DM is passed through a band-pass filter which provides additional attenuation to the 449.166 MHz signal. A signal level of -10 dBm is delivered to the PLT input.

The VCO for the PLT is identical to the VCO for the PLR except for its frequency of 4.678961 MHz. The frequency multiplier chain is identical to the Master Oscillator except for the unit following the crystal filter. This unit is a times three multiplier and provides an output of 224.533333 MHz at +35 dBm. This signal is delivered to the Line Circulator and through a directional coupler and attenuator to the VCO reference input at a level of -43 dBm.

A double stub tuner on the line port of the circulator is adjusted to balance the PLT signal at the circulator signal port and the input to the PLR.

Phase lock for both units is established through an active filter. Second-order servo characteristics are established with a choice of loop bandwidth and damping factors. Equivalent RF noise bandwidths from 1.9 Hz to 320 Hz can be obtained.

The circulator line port connects to a "simulated long line." A "trombone line stretcher" and attenuators permit setting of the total line loss and division of loss on either side of the Line Station Unit (LSU). The line stretcher allows an equivalent of approximately 1500° of phase change at 2695 MHz to be introduced.

The termination oscillator unit provides the 224.533333 MHz line signal. Except for line frequency it is identical to the VCO chain in the PLT.

The Line Station Unit couples the two line signals, $f_o/2 + f_r$ and $f_o/2 - f_r$, through dual 10 dB directional couplers to the inputs of a balanced mixer. The sum frequency output is band-pass filtered and provides the "phase corrected" input signal, f_o, to the LSU phase locked receiver. Double stub tuners are provided on the main line terminals of the directional couplers to cancel the reverse coupled signal components.

The LSU receiver uses separate balanced mixers and IF pre-amplifiers instead of the balanced transistor mixers. The remaining IF (455 kHz) filtering, gain stages, and phase comparator are identical to the PLT. The VCO and multipliers are identical to the MO units, including the final 2695 MHz output. The local oscillator is identical to the Master Station local oscillator except for frequency and for times four multiplication to 448.611666 MHz. The phase lock filter is identical to the PLT and

PLR units. The loop gain in the line station filter is doubled, however, by the VCO, and therefore the line station equivalent noise bandwidths are increased by $\sqrt{2}$.

For overall system testing the 2695 MHz outputs of the Master Oscillator and the Line Station Unit are phase compared. This phase comparator consists of a 3 dB hybrid and Schottky diodes as detectors. The MO level of +17 dBm and a LSU level of +7 dBm provide good output sensitivity and phase linearity at balance.

II. System Testing

The major emphasis to date has been to establish the temperature induced effects over periods of eight hours minimum for the complete system subjected to the ambient temperature variations in the laboratory. A typical system record is shown in Figure 3.

Examination of the phase error indicates a peak-to-peak change of 3.1° corresponding to a change in ambient temperature of 4.7 °C. Although subjecting all of the system components to the same ambient temperature variation does not represent actual system conditions, it is at least indicative of the system capability.

Pertinent System Parameters and Recording Techniques for System Testing

1. Total line loss: 90 dB
2. Line Station Unit position: Mid-line (45 dB loss on each side)
3. PLR input signal level: Approximately -60 dBm
4. Line Station Receiver signal level (449.166 MHz): Approximately -70 dBm
5. Loop Time Constant (all units): 1.5 seconds
6. Loop Damping factor (all units): 5.0
7. PLR and PLT RF noise bandwidth: Approximately 80 Hz
   LSU RF noise bandwidth: Approximately 110 Hz

Loop time constants and damping coefficients were set on the basis of minimum noise bandwidth without excessive phase error noise. The system phase error was filtered by a 0.05 second low-pass RC filter and recorded using a Sanborn recorder.

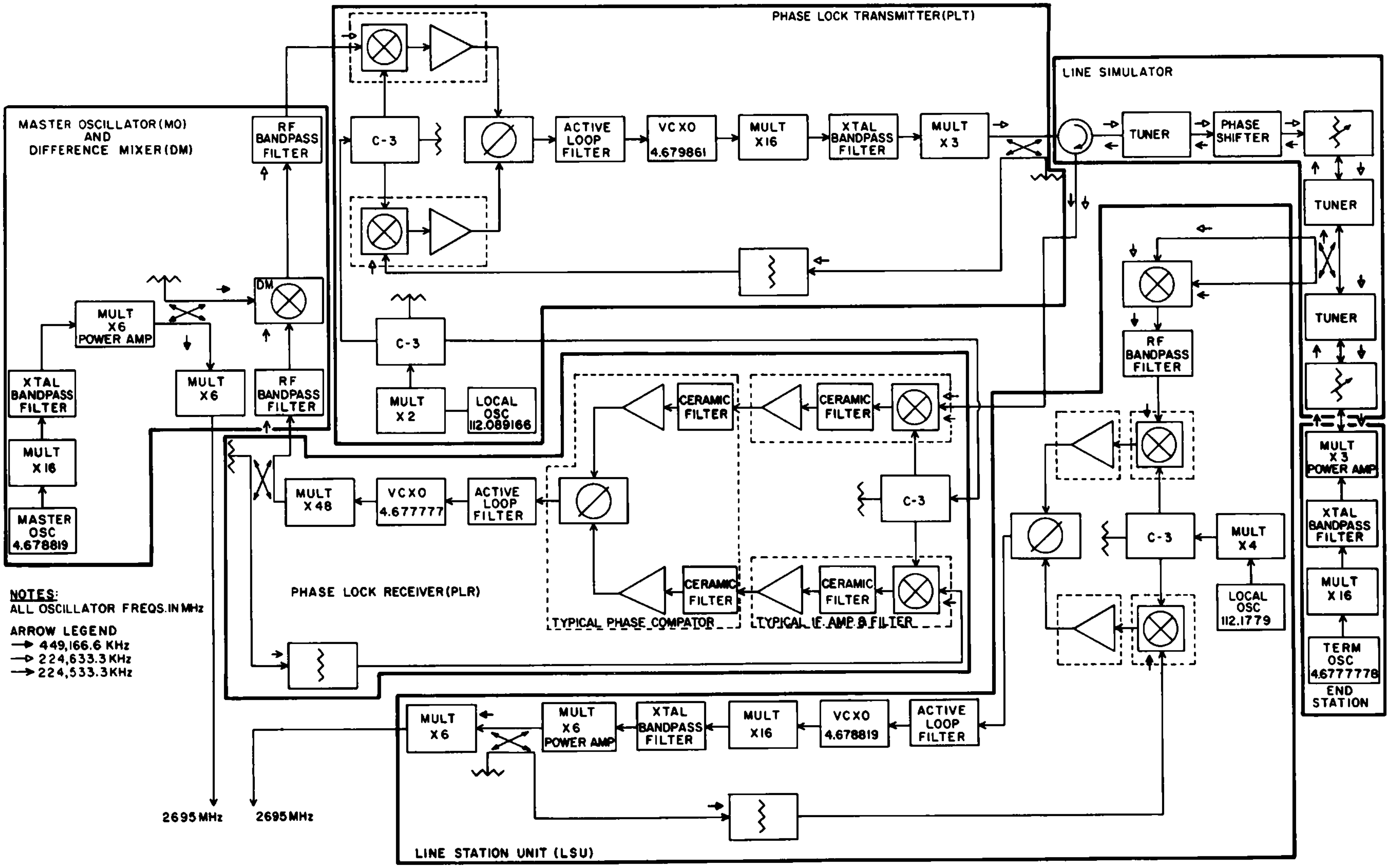

Figure 1 — Block Diagram of Prototype Local Oscillator

Component Temperature Study

A series of temperature studies were conducted on several critical elements of the oscillator distribution system to determine if a correlation existed between the resultant system phase error and the temperature of the component under consideration. For this investigation the following definitions will be used:

System Phase Error — the variation in phase between the 2695 MHz signal developed at the Master Oscillator and the 2695 MHz signal developed at the Line Station.

Temperature Coefficient (K_t) — degree change in phase error per degree Centigrade change in component temperature.

The temperature coefficient will provide a basis for comparison of the dependence of the system phase error on the element under consideration.

The testing procedure consisted of cycling the component temperature by means of a DC supplied power resistor regulated by an automatic timer for approximately half-hour, on-off cycles. The component temperature, as well as the temperatures of other critical locations were monitored by VECO 28D1 thermistors in the circuit of Figure 2. The thermistors were calibrated against an ASTM thermometer and were accurate to better than ± 0.7 °C over the region of interest, i.e., 20 °C to 40 °C.

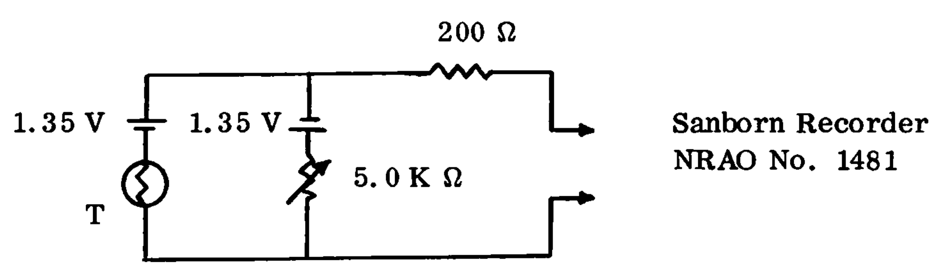

Figure 2 — Thermistor Circuit

The results of the study are given in Table 1. In addition to the temperature coefficient (K_t), the ambient temperature drift and the phase error drift are listed for the period under consideration. Although a correlation may exist in the phase error and temperature drift figures, it should be noted that secondary heating effects may also be a contributing factor to the system phase error drift. As a further check of the testing procedure, the component chassis temperature is tabulated to indicate possible large temperature gradients. The chassis temperature, component temperature, and system phase error were measured peak-to-peak and then averaged over the region of interest.

TABLE 1

TEMPERATURE COEFFICIENTS

Component	$K_t \frac{Deg.}{°C}$	Ambient Temp. Drift	Phase Error Drift	Chassis Temperature
Micromega Multiplier No. M6-2700	2.24	0.9 °C	1.8°	0.5 °C
Applied Research Multiplier No. 154-1	-0.76	-0.4 °C	0.4°	0.3 °C
10 dB Attenuator Serial No. 03005	*	0.2 °C	1.1°	0.1 °C
HP Variable Attenuator No. 218-11010	*	0.4 °C	2.4°	0.1 °C
Easy Match Tuner	*	1.0 °C	-1.5°	0.2 °C
Receiver No. 1 (PLT)	0.27	-1.7 °C	1.1°	0.6 °C
Receiver No. 2 (PLT)	-0.58	-0.2 °C	1.3°	0.4 °C
Receiver No. 3 (PLR)	-0.45	0.3 °C	0.6°	0.4 °C
Receiver No. 4 (PLR)	-0.21	0.2 °C	0.4°	0.5 °C
Receiver No. 5 (LSU)	*	0.2 °C	2.3°	0.1 °C
Receiver No. 6 (LSU)	*	1.0 °C	1.8°	0.1 °C
Circulator	0.53	0.4 °C	0.3°	0.5 °C
Phase Comparator No. 1 PLT	*	0.9 °C	1.5°	0.5 °C
Phase Comparator No. 2 PLR	*	1.0 °C	1.1°	0.6 °C
Phase Comparator No. 3 LSU	*	1.4 °C	2.4°	0.2 °C

* No detectable correlation.

In Figure 4 is the oscillograph recording for the PLR Receiver No. 4. The system phase error is registered on channel 1 calibrated for one degree per 5 mm. A sampling switch is used to step channel 2 through the seven thermistor circuits which are calibrated for one degree Centigrade per 5 mm. It is evident that a correlation does not exist between the receiver temperature (thermistor No. 2) and the system phase error. Note that the chassis (thermistor No. 4) and the adjacent receiver No. 3 (thermistor No. 3) also suffer temperature variations. It was very desirable to minimize these secondary heating effects for this study; however, they cannot be completely eliminated without actual removal of the component from the chassis, and therefore, must be considered when interpreting the data. An example of no apparent correlation is given in Figure 5, the oscillograph recording for the Easy Match tuner. It is necessary to comment that this study was intended only to establish a relative comparison of the correlation between the system phase error and a particular component's temperature, i.e., worst-case conditions. For example, it is evident from the data in Table 1 that the Micromega Multiplier will induce a larger system phase error per degree of temperature variation than the attenuators which show no apparent correlation.

III. System Operation

The entire system began operation on November 13, 1967. The first component failure was noted on February 8, 1968 when a zener diode regulating the power supply to the Bulova oscillator in the PLT failed. The diode had been in operation for 2,088 hours, and it is probably the cause for the discontinuities noted in the system phase error of Figure 3 since they have not appeared in subsequent records (Figures 4 and 5).

The first major component failure occurred February 15, 1968, after 2,256 hours, when the Micromega Multiplier in the Master Station Oscillator dropped from a rated output of 6.4 watts to 20 milliwatts. The multiplier had been in operation for 3.216 hours, and as yet, the cause of the failure has not been reported by the manufacturer.

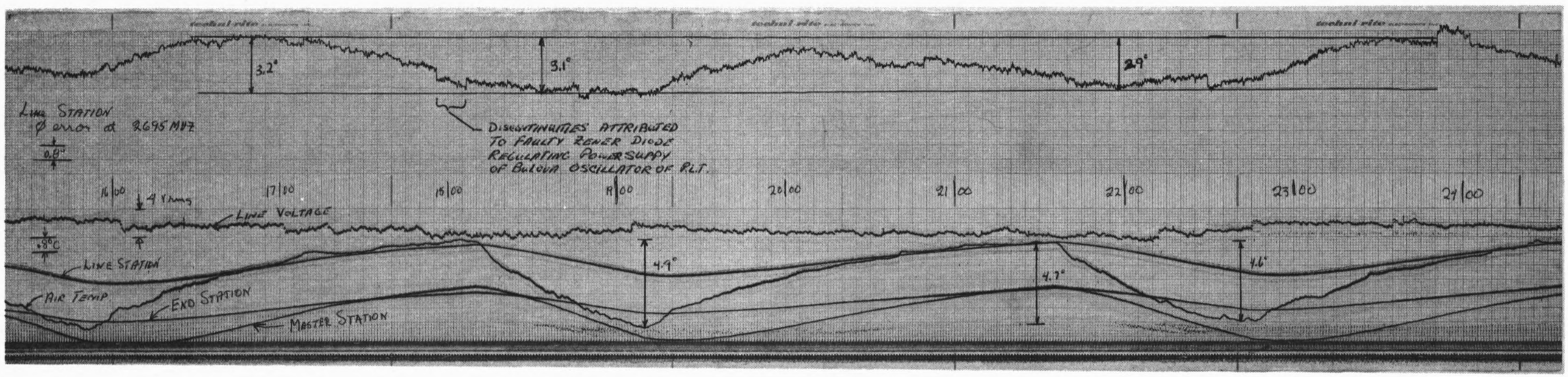

Figure 3 — Typical phase stability in room with ~ 5 °C temperature variations.

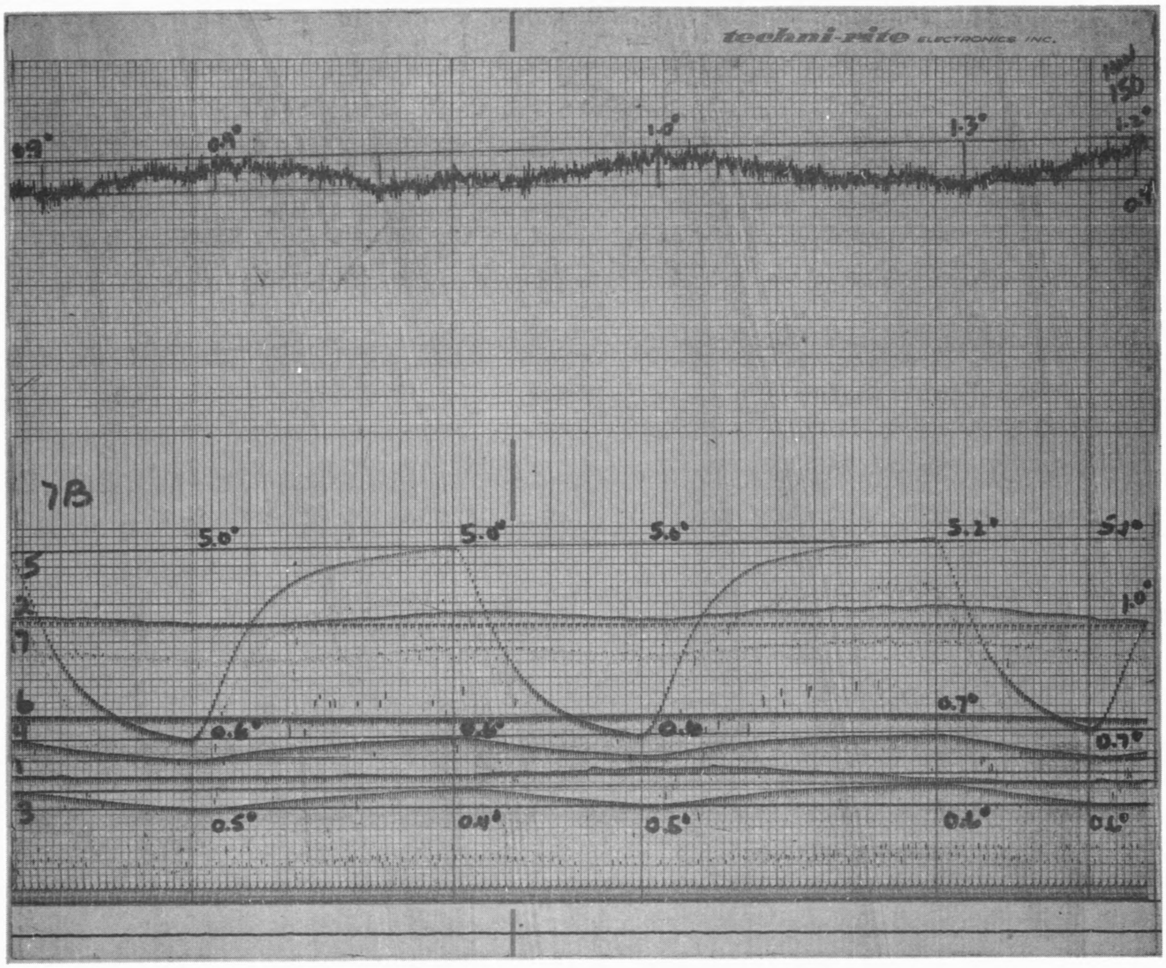

Figure 4 — Phase stability of system with periodic heating applied to receiver.

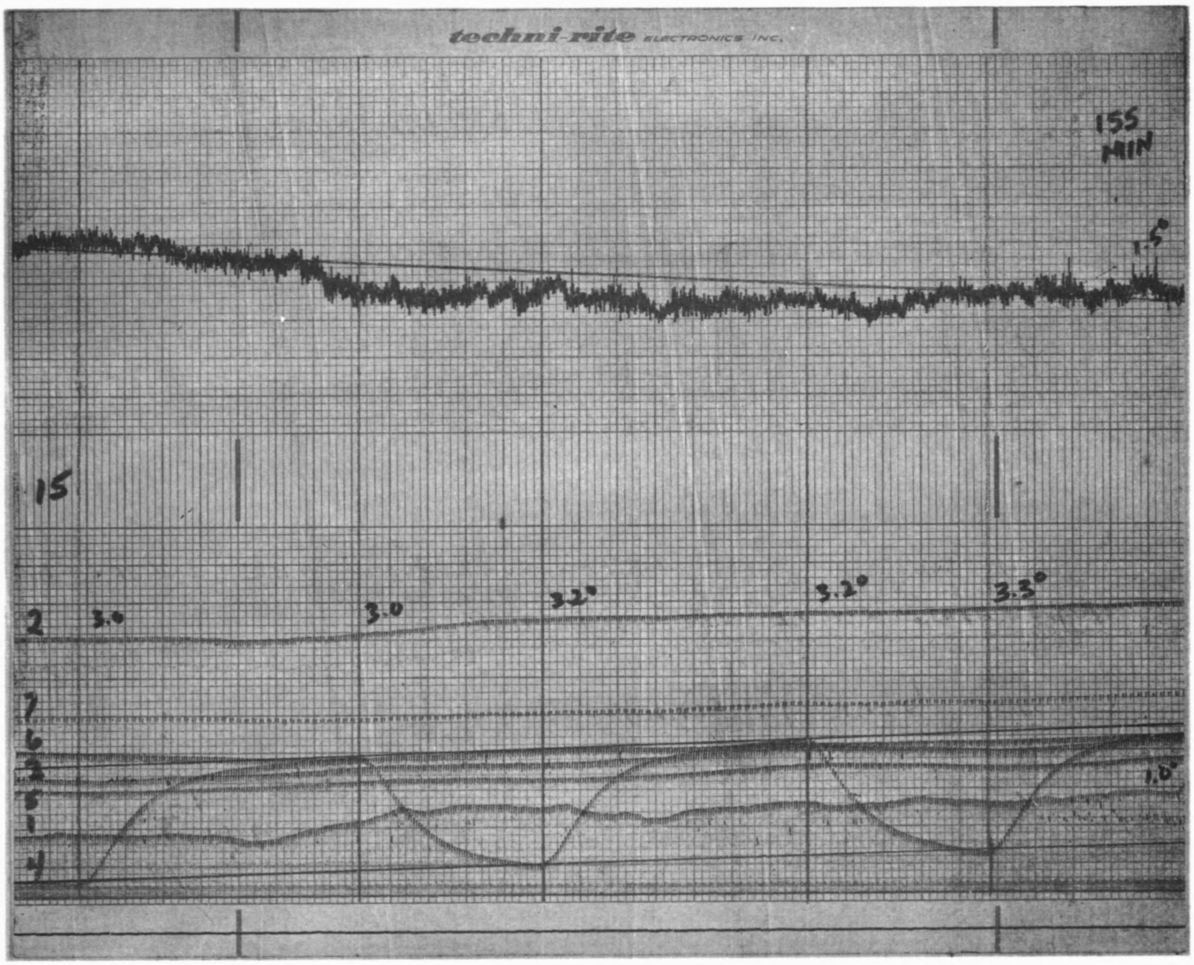

Figure 5 — Phase stability of system with periodic heating applied to tuner. No correlation is evident.