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Receiver system for the Ooty synthesis radio telescope

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Abstract. This paper describes the receiver system of the 4 km Ooty synthesis radio telescope (OSRT), consisting of 13 elements operating at 327 MHz. Major subsystems of the receiver electronics are briefly discussed. A round-trip scheme for generating coherent local oscillator (LO) signals at the distant antennas with one-way path loss exceeding 80dB is discussed in detail.

Key words : radio astronomy—electronics instrumentation; phase-coherant local oscillators

1. Introduction

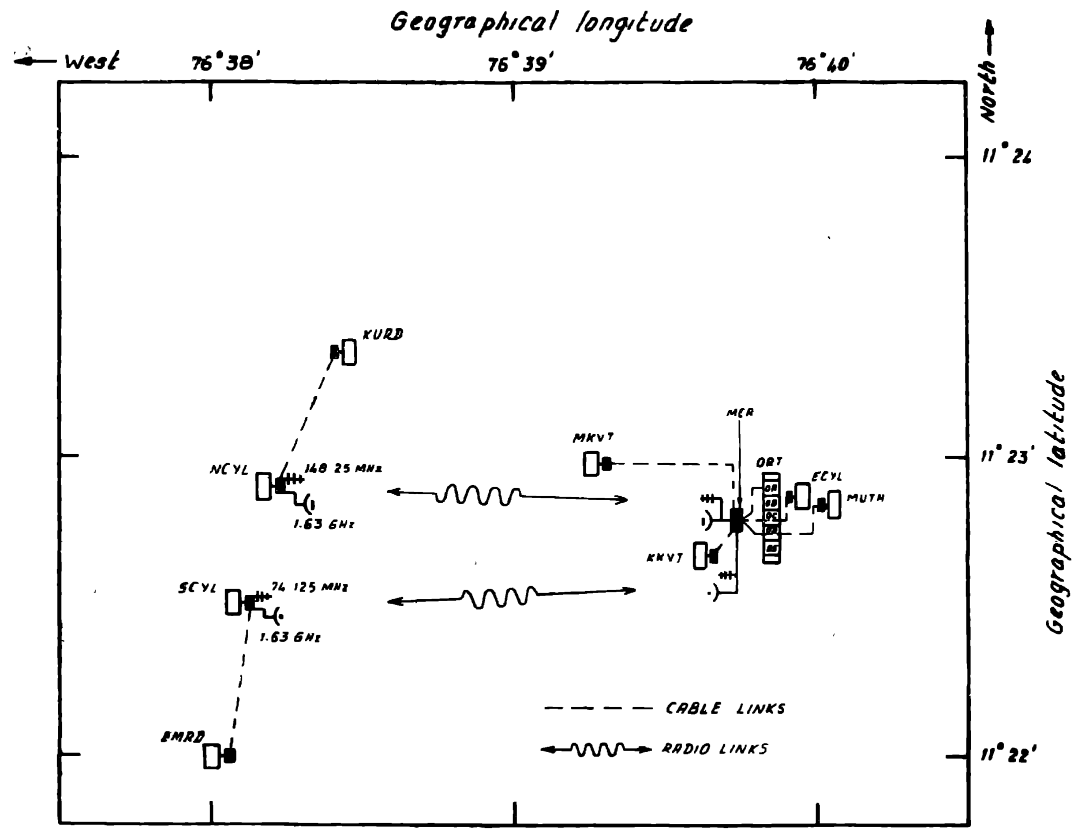
The requirements for the electronics system for a synthesis radio telescope are : (a) Low-noise front-ends; (b) generation of coherent local oscillator (LO) signals at each of the antennas for down-converting the received radio astronomical signal to an intermediate frequency (IF) signal; (c) transmission of the IF signal to a central location preserving the amplitude and phase, over a bandwidth of several MHz; (d) correlating the signals received from various antennas; and (e) recording of correlator outputs for further data processing.

The OSRT consists of : (1) The Ooty radio telescope (Swarup *et al.* 1971), which has been grouped into five sections each of size 92m × 30m, and (2) eight parabolic cylinders each of size 23m × 9m, distributed over an area of 2 km × 4 km as shown in Figure 1. The design and system performance of OSRT are described by Sukumar *et al.* (1988).

2. The receiver electronics

2.1. Block diagram

A simplified block diagram of the receiver system is shown in figure 2. At each station, the RF output of the dipole array at 326.5 MHz is amplified and converted



1 - CONFIGURATION OF THE 4 KM OSRT AND THE LO/IF LINKS

Figure 1. Configuration of the 4 km OSRT and the LO/IF links.

to a 30 MHz IF signal using a phase-coherent LO signal at 296.5 MHz available at the station. The IF signal with a bandwihth of 4 MHz is transmitted to the master control room (MCR). Each IF signal is converted to a video band of 1 to 5 MHz using a second LO at 32.96 MHz. The video signals are sampled and correlated in a digital delay correlator system (A. Mageswaran, personal communication).

2.2. *The receiver electronics at the Ooty radio telescope* (*ORT*)

The details of ORT feed system comprising of: (i) 1056 half-wave dipoles along the focal line of the cylinder, (ii) low-loss diode phase shifters for declination steering, and (iii) transmission line combiner to divide ORT into 22 modules has been described by Joshi *et al.* (1988). The RF output at 326.5 MHz of each module is amplified in a low-noise amplifier ($T = 100$ K) and converted to an IF signal at 30 MHz using a LO signal at 296.5 MHz. The LO signal is synthesized at the MCR from a 5 MHz rubedium source and distributed to each module by buried low-loss coaxial cables in a 'branching tree' scheme (Sarma *et al.* 1975). The IF signals from the 22 modules are brought to the MCR by buried underground cables. After introducing the required delays, the signals pass through phase and gain equalization circuits and amplifiers. Then they are combined into five groups of four modules each (the northernmost and southernmost

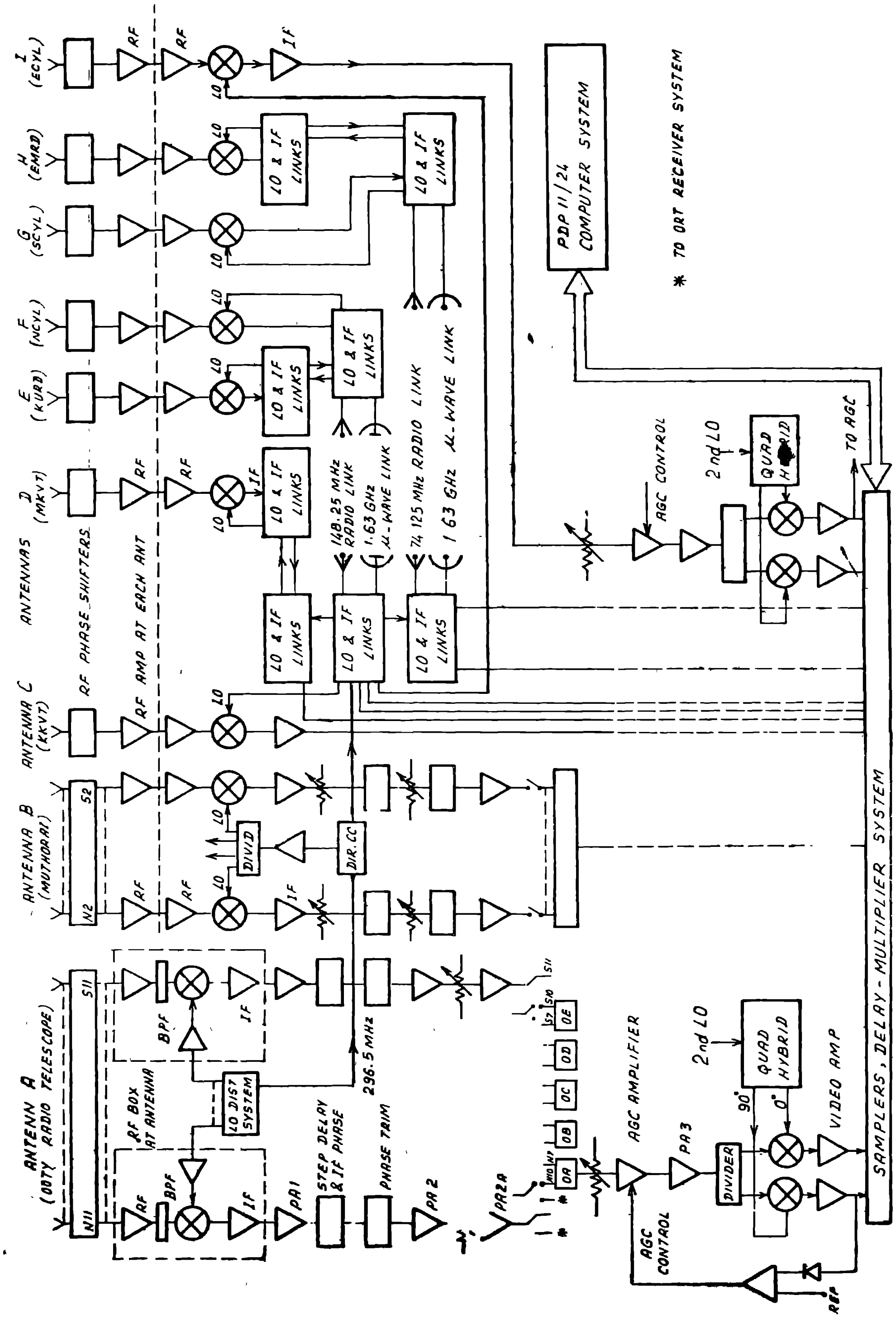


Figure 2. Block diagram of the receiver system of 4 km OSRT.

modules are not used). These five groups (designated OA, OB, OC, OD, and OE), treated as five independent antennas of OSRT for further processing, are shown in figures 2, together with the eight remote antennas of OSRT.

2.3. The receiver electronics at the remote antennas

The feed system at the remote stations consists of : (i) 48 half wave dipoles, (ii) low-loss diode phase shifters, and (iii) transmission line combiner. The scheme of RF amplification and conversion to IF is similar to that employed at the ORT.

3. Generation of coherent LO at remote antennas

For nearby antennas (MUTH, ECYL, and KKVT) located within 500m of ORT, the LO signal is transmitted at 296.5 MHz using coaxial cables buried at a depth of 1m underground. Since the lengths of cables are comparable to those used at ORT, the LO phase variations due to temperature changes are nearly the same as for ORT.

The IF signals are also brought to MCR using buried coaxial cables for further signal processing.

3.1. Phase coherent LO distribution for distant stations

Swarup & Yang (1960, 1961) proposed a modulated reflection technique for measuring phase of the round trip path over large distances with path losses exceeding 100 dB. A variant of the scheme, whereby signals differing by a small frequency are transmitted in opposite directions through the medium, with the phase of the difference frequency signal providing information about the round-trip path ('difference frequency method') has been adopted for generating the phase coherent LO at the remote stations of OSRT.

3.1.1. The principle of operation of the phase-coherent LO system

A schematic of the difference frequency method is given in figure 3.

The master oscillator at the central station transmits a signal at frequency f_1. The received signal at any of the remote antennas is used to generate a signal at

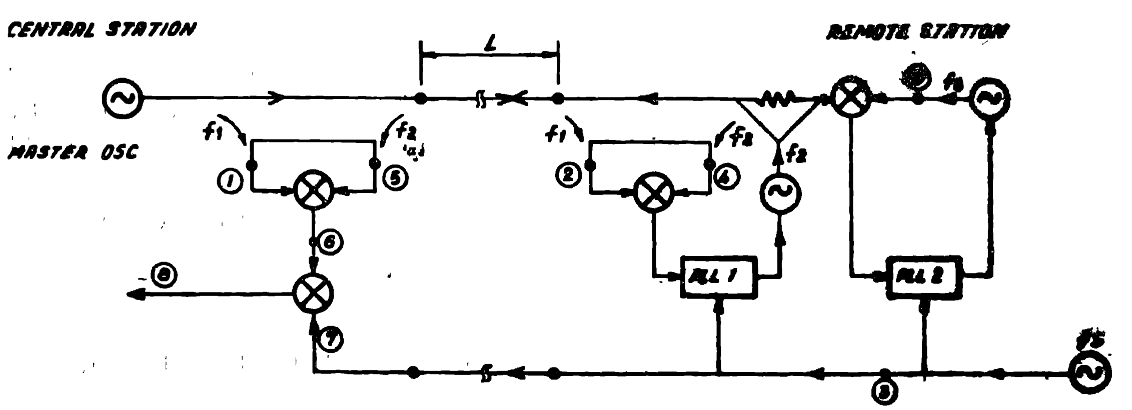


Figure 3. Schematic of the difference frequency method.

frequency $f_2 (= f_1 + f_3, f_3$ being a fixed, low-frequency offset), using phase locked loop PLL 1. The signal at frequency f_2 if retransmitted to the central station, where f_1 and f_2 are multiplied to generate a signal at f_3, whose phase corresponds to the two way propagation path at f_1. The signal f_3 is also independently transmitted by a separate link to the central station for deriving the phase information. The desired signal at frequency f_1 is regenerated at the remote station by phase locking another oscillator at $(f_2\text{-}f_3)$, using PLL2.

The signals at various locations are (*cf.* figure 3) :

(*i*)	Transmitted signal from the central station	ω_1	ϕ_1
(*ii*)	Received signal at the remote station (L = Propagation path length and c = velocity of electromagnetic waves in free space)	ω_1	$\phi_1 - \omega_1 L/c$
(*iii*)	Low frequency offset signal	ω_3	ϕ_3
(*iv*)	Intermediate oscillator signal under locked condition of PLL 1	ω_2 where $\omega_2 = \omega_1 + \omega_3$ and $\phi_2 = \phi_1 + \phi_3 - \omega_1 L/c$	ϕ_2
(*v*)	Received signal at the central station	ω_2	$\phi_2 - \omega_3 L/c - \omega_1 L/c$
(*vi*)	Low frequency regenerated signal	ω_3	$\phi_3 - \omega_3 L/c - 2\omega_1 L/c$
(*vii*)	Low frequency signal received by a separate link	ω_3	$\phi_3 - \omega_3 L/c$
(*viii*)	DC output proportional to $2\omega_1 L/c$		
(*ix*)	Final oscillator signal under locked condition of PLL 2	ω_4 where $\omega_4 = \omega_2 - \omega_3 = \omega_1$ and $\phi_4 = \phi_1 - \omega_1 L/c$	ϕ_4

Thus the signal at frequency f_1 is regenerated at the remote station, whose phase can be estimated with respect to the oscillator at (i) by the DC output at (viii).

The round trip phase measurement results is an ambiguity of half wavelength in the computed phase of the distant oscillator. This problem is overcome by choosing f_1 to be an even sub-harmonic of the desired LO frequency and later by frequency multiplication to get the required phase stable LO signal. It should be noted that the phase errors also get multiplied in the process.

The measured phase information is applied as a correction during offline data analysis.

3.1.2. Implementation of the scheme

A schematic showing the distribution of the phase stable local oscillator for the remaining five of the OSRT antennas is given in figure 4 and the salient features of the links are given in table 1.

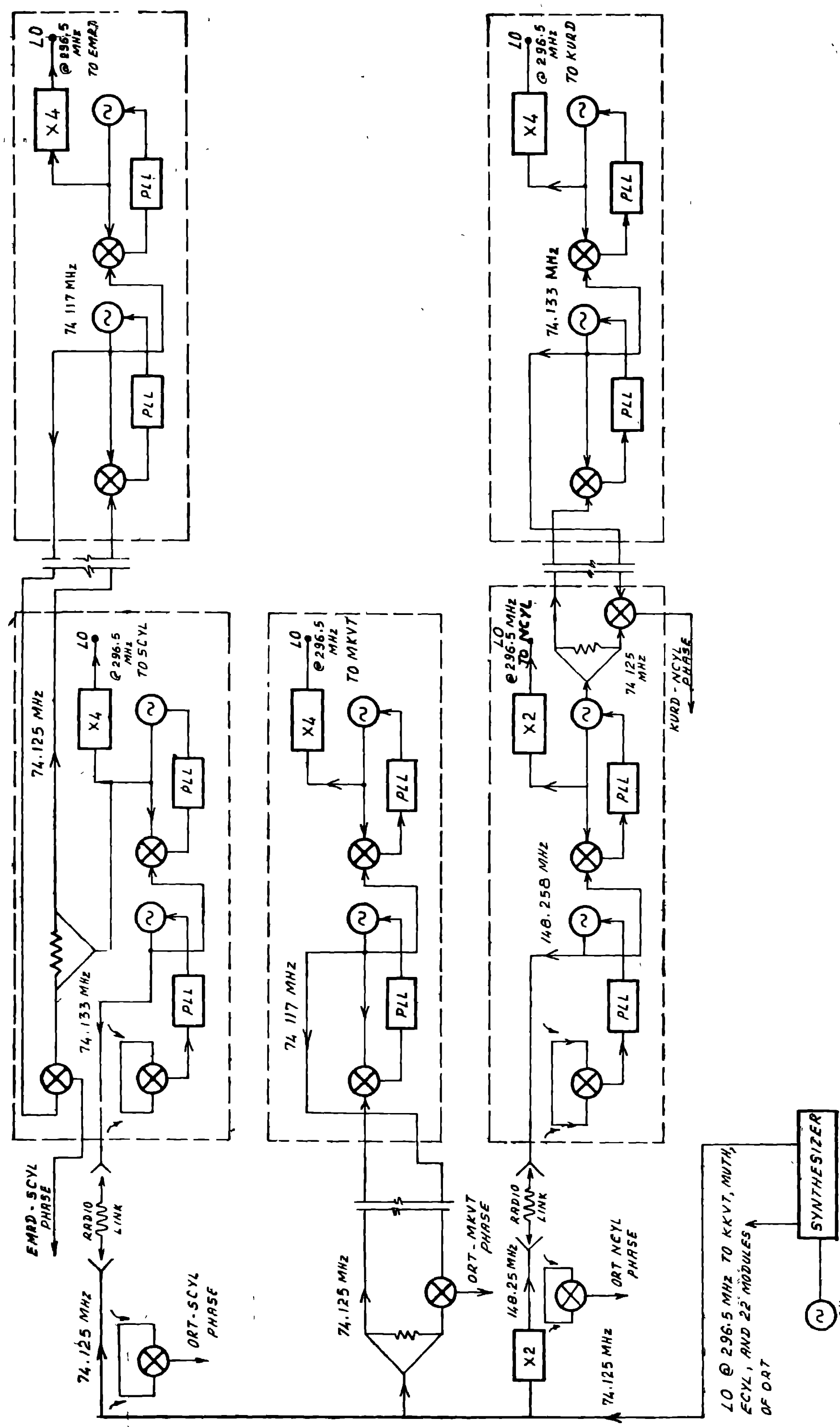


Figure 4. Schematic showing the distribution of phase stable LO using the difference frequency method.

Table 1. Salient features of the OSRT local oscillator links

Station	Central Station	f_1 Used (MHz)	f_3 Used (kHz)	Path loss (dB)	Medium for transmitting f_1 & f_2	f_3
MKVT	ORT	74.125	8.043	90	2 seperate cables**	cable
KURD	NCYL	,,	,,	55	,,	,,
EMRD	SCYL	,,	,,	60	,,	,,
SCYL	ORT	,,	,,	75	Bidirectional air-link	UHF link
NCYL	ORT	148.25	,,	75	,,	,,

**The return cable shares IF signal. Forward cable shares the low frequency offset signal f_3.

The KURD and EMRD stations are not directly linked to ORT, but through the electronics of NCYL and SCYL respectively. The phase information of NCYL-KURD and SCYL-EMRD links are transmitted to ORT through telemetry system (Sankararaman *et al.* 1982) for offline data correction.

4. The IF signal transmission scheme for the distant stations

The IF signal is brought from the KURD station to NCYL station by coaxial cable. The signal is transmitted to ORT as the upper side band of a 1.63 GHz signal through a one-way UHF link established between NCYL and ORT. The IF signal of NCYL is transmitted as the lower side band. At ORT, the IF signals are recovered coherently in a UHF receiver using phase locked loops.

A similar method is used for transmitting the IF signals from EMRD and SYCL stations to ORT.

The IF signal from the MKVT station is transmitted to ORT using a buried RC 8 cable.

5. Performance of the LO and UHF links

The performance of the LO and UHF links were studied in the laboratory, using a test set-up shown in figure 5. In the reference channel, a 326.5 MHz signal from a stable source is converted into 30 MHz signal using the master oscillator at 296.5 MHz. In the test branch, the phase stable LO signal generated by the LO link is used to convert the same 326.5 MHz signal to 30 MHz, which is applied to

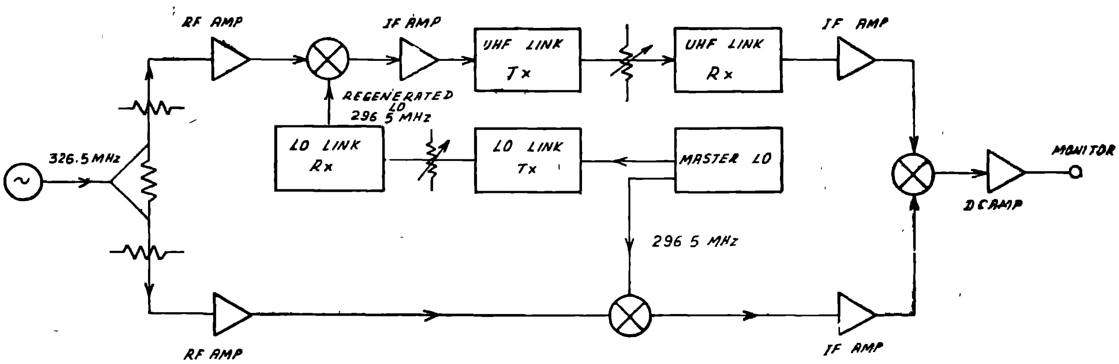


Figure 5. Test set-up for measuring the phase stability of LO and UHF links.

the UHF link electronics of the station under test. The recovered 30 MHz output from the UHF link receiver is compared with the 30 MHz output of the reference channel.

The following conclusions were drawn after continuous monitoring of the test setup output over a period of 10 to 15 hours:

(a) There are no sudden phase jumps.

(b) There are slow drifts in phase by about 15 degrees. This is not a problem as the system is frequently calibrated by astronomical observations of known point radio sources.

(c) The variation of path attenuation in both LO and UHF links by 75 $\pm$ 5 dB does not make it necessary to adjust gain of the system for achieving a phase lock.

(d) The entire system consisting of several interconnected phase locked loops achieves synchronization automatically when main power fails and comes back.

(e) The signal-to-noise ratio of the regenerated LO signal in a 300 Hz bandwidth is about 35 dB, corresponding to a phase jitter of about 1° RMS. There are no discrete frequency components to —70 dBc level, except at about 8 MHz away from the LO frequency of 296.5 MHz. These lines are produced as the system used 8.2361 MHz crystal sources as basic oscillator for all VCXOs. The level is about —30 dBc.

6. Conclusions

The typical phase variation of the regenerated local oscillator at NCYL is shown in figure 6. The effect is corrected off-line during data analysis.

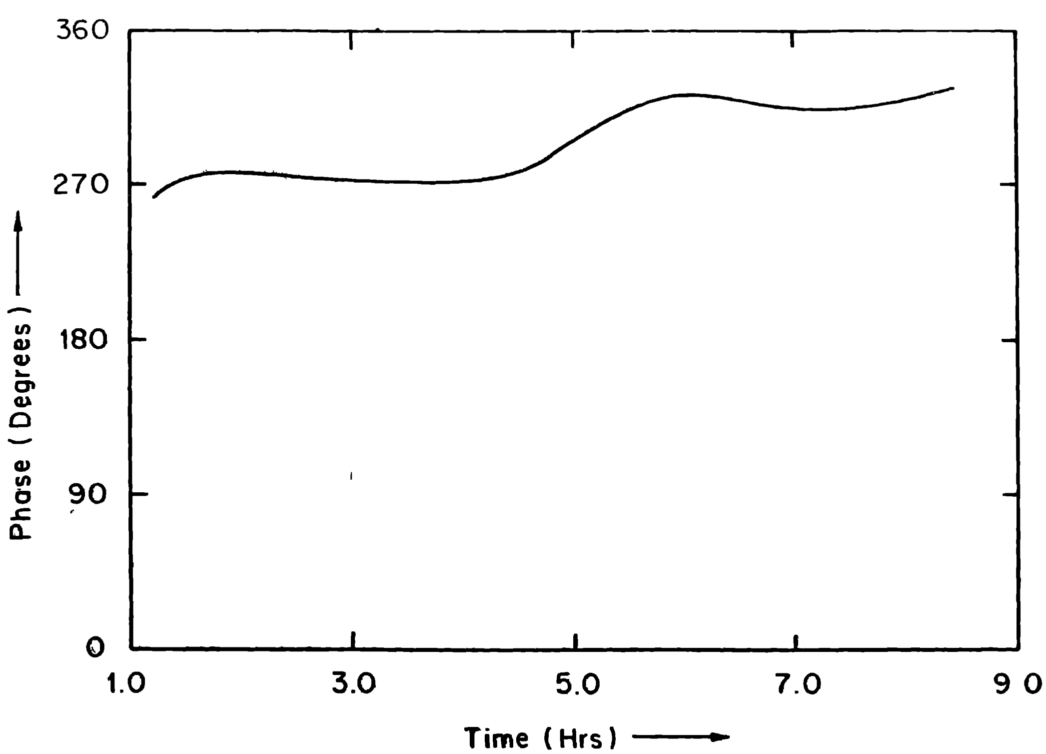


Figure 6. Typical phase variation of ORT-NCYL link.