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INFORMAL REPORT

ONE-FREQUENCY LASER INTERFEROMETER USING THE OPTIC FIBER AS A POLARIZATION-INDEPENDENT INTERFERENCE PHASE DETECTOR

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1. Introduction

A soft x-ray scanning microscope will be built on the NSLS x-ray ring's undulator beam line.(1-3) It is expected that the beam line will provide more powerful coherent soft x-ray flux to improve the resolution of scanning microscopy to the sub-1000Å range and form pictures in seconds rather than minutes.

A laser interferometer has been developed for encoding the coordinates of the scanning plane of the soft x-ray microscope with 300Å resolution. A pair of the optical fibers has been used as an interference fringe phase detector in the interferometer which can make the system phase adjustment simpler, more accurate, and polarization-independent.

The last character is important because if the fringe phase detector is polarization dependent the interferometer's optical design will be complicated when the optical path of the interferometer have to include additional windows or mirrors which usually change the polarization situation.

In the first section of this report we discuss the optical arrangement of the interferometer. In the following two sections we describe the schematic of the resolution extending unit and the interferometer's other possible applications.

2. Optical Design and Accuracy Analysis

The interferometer design, shown in Fig. 1, is based on the Michelson configuration.(4) The system is composed of a Helium-Neon laser, a laser beam expander, a prism, three cube beamsplitter, a retroreflector, a couple of optic fibers with analog receivers and various additional components for adjustment.

The collimated and expanded output one-frequency laser beam is split equally by a beamsplitter oriented at 45° to the wavefront to provide a second axis (y) of measurement. Then the x axis output beam is reflected by a right angle prism, meets another cube beamsplitter and is split equally again. After reflection from the retroreflector and beamsplitter, the separated plane wavefront beams are recombined by the third cube beamsplitter. The beams interfere when they are recombined. A couple of optic fibers with polished ends receive the interfere fringe signal.

As we all know, for a mutimode step index fiber, we have

$$\sin \theta_{max} = \frac{1}{n_o} (n_f^2 - n_c^2)^{1/2} \tag{1}$$

where n_f is the index of the core, n_c is the index of the clad layer, n_o is the index of the air.(5)

So, the optic fiber has a $2\theta_{max}$ receipt angle. If the angle of the two laser beams causing the interference pattern is smaller than the receipt angle as

$$\alpha \leq 2\theta_{max}, \tag{2}$$

we can get all of the intereference information at the location where the optic fiber is set on. If the interfere fringe's space interval is larger than 2d, we can adjust the phase difference between two optic fibers by changing the position of the fibers on the fringes.

For a frequency non-stabilized Helium-Neon laser, for instance, MG-LHP-121, the Doppler FWHM is about 1400 MHZ or 1.9×10^{-3} nm.(6) So, the frequency stability is

$$\frac{\Delta\nu_D}{\nu} = 1.4 \times 10^9 / 4.7 \times 10^{14} = 3 \times 10^{-6} \quad . \tag{3}$$

As we know, the formula for the two beam interferometer is

$$K = 2n(L + (L_m - L_c))/\lambda_o \tag{4}$$

where K is the total number of the interference fringes, L is the measured length, n is the index of refraction of the air, λ_o is the laser wavelength in vacuum, L_m is the measuring length at the start position and L_c is the reference length (Fig. 1) or

$$K = K_1 + K_2 \tag{5}$$

$$K_1 = 2n(L_m - L_c)/\lambda_o \tag{6}$$

$$K_2 = 2nL/\lambda_o \tag{7}$$

where K_1 is the number of the fringes when the interferometer is put at the start position and K_2 is at the end position.

For analysis, we make a differential

$$dK = dK_1 + dK_2 \tag{8}$$

$$dK_1 = \frac{\partial K_1}{\partial n} dn + \frac{\partial K_1}{\partial(L_m - L_c)} dc(L_m - L_c) - \frac{\partial K_1}{\partial \lambda_o} d\lambda_o$$

$$= \frac{2}{\lambda_o} \left[(L_m - L_c)dn + nd(L_m - L_c) - \frac{n}{\lambda_o}(L_m - L_c)d\lambda_o\right] \tag{9}$$

$$dK_2 = \frac{\partial K_2}{\partial n} dn + \frac{\partial K_2}{\partial L} dL - \frac{\partial K_2}{\partial \lambda_o} d\lambda_o$$

$$= \frac{2}{\lambda_o} \left[L dn + n dL - \frac{n}{\lambda_o} d\lambda_o\right] \tag{10}$$

Thus, the total error of the measuring is

$$\Delta K = \int dK = \int dK_1 + \int dK_2 = \Delta K_1 + \Delta K_2 \quad . \tag{11}$$

The measurement is done during a finite time interval (t_2-t_1). The environment of the start time t_1 may differ from the standard situation, then during the measuring time (t_2-t_1) it may change again. If we define that Δ_{i0} is the increment caused by the difference from the standard situation in the start time t_1, and the δ_i is the increment caused by the variation of the environment during t_2-t_1.

So,

$$\Delta K_1 = \Delta K_{10} + \delta K_1$$

$$\Delta K_2 = \Delta K_{20} + \delta K_2$$

and

$$\Delta K_{10} = \frac{2}{\lambda_o} \left[(L_m-L_c)\Delta n_o + n\Delta(L_m-L_c)_o - \frac{n}{\lambda_o} (L_m-L_c)\ \Delta\lambda_{oo} \right]$$

$$\Delta K_{20} = \frac{2}{\lambda_o} \left[L\Delta n_o + n\Delta L_o - \frac{n}{\lambda_o} L\Delta\lambda_{oo} \right]$$

$$\delta K_1 = \frac{2}{\lambda_o} \int \left[(L_m-L_c)\delta n + n\ \delta(L_m-L_c) - \frac{n}{\lambda_o} (L_m-L_c)\ \delta\lambda_o \right]$$

$$\delta K_2 = \frac{2}{\lambda_o} \int (L\delta n + n\delta L - \frac{n}{\lambda_o} L\delta\lambda_o)$$

In applications such as scanning microscopy, we usually designate a special point, for instance the start point, as the reference point. And we just are interested in the distance relative to the reference point, and never care about the real value related to an absolute coordinate system. It means that we can set the interferometer's counter to "zero" at the start point. So,

$$K_1 + \Delta K_{10} = 0 \quad .$$

I find that it is possible to limit the error caused by δK_1 by limiting the bandwidth of the interferometer's fringe receiver. When we set the interferometer on a NRC vibration isolated table with a common air conditioning environment, less than one additional error output pulse has been observed from a tenth resolution extending net during ten minutes observation using a NG LHP-121 frequency non-stabilization Helium-Neon laser, when the bandwidth of the receiver is in the range 10 HZ ~ 1 MHZ.

As a worst case for two scanning pictures with M x N points the maximum error from the first scanning point to the last point caused by $\Delta\lambda_{oo}$ and $\delta\lambda_o$ for a frequency non-stabilization Helium-Neon laser are Δx and Δy

$$\Delta x = M \cdot C_o \cdot \Delta\lambda_D \cdot N/2$$

$$\Delta y = N \cdot C_o \cdot \Delta\lambda_D$$

Where $\Delta\lambda_D$ is the laser's Doppler FWHM, C_o is defined as $C_o = D/\lambda_o$ and D is the distance between two nearest points of the scanning. So the maximum relative error is given by

$$\Delta x/x = (M \cdot N \cdot C_o \cdot \Delta\lambda_D)/(M \cdot C_o \cdot \lambda_o \cdot 2)$$

$$= (N/2)\frac{\Delta\lambda_D}{\lambda_o} = N \cdot 1.5 \times 10^{-6}$$

$$\Delta y/y = \frac{\Delta\lambda_D}{\lambda_o} = 3 \times 10^{-6} .$$

For instance if

$$M = N = 300,\ C_o = 1/20,\ D = 316.4\ \text{Å} ,$$

we have

$$\Delta x/x = 4.5 \times 10^{-4},\ x = 9.492\ \mu m,\ \Delta x = 42.71\text{Å}$$

$$\Delta y/y = 3 \times 10^{-6},\ y = 9.492\ \mu m,\ \Delta y = 0.285\text{Å}.$$

3. Resolution Extension Electronics

There are several different ways to extend the interferometer's resolution. For a scanning system with scanning speed slower than 100 μs per point, it is more convenient to use a microprocessor and an A/D converter. In this system the output voltage of the interference fringe receiver will be read out by the microprocessor which calculates or/and compares with a lookup table to find the interference phase. Then the microprocessor will produce resolution extended sub-pulses to drive the data acquisition system.

In our present system shown in Fig. 4 a resistance net has been designed to produce five sinusoidal signals. There is $\pi/5$ phase offset from one to another. Through Schmitt circuits these signals are converted to TTL level up-down signals and are combined into a logic circuit to produce tenth resolution extended sub-pulses. This system is expected to be compatible with the scanning speed up to 1 μs per point.

For addressing the interferometer's incremental signals a high speed microprocessor-based counter has been considered. It is also necessary to include a constant memory system in the counter to avoid loss of the addresses when the system power is shut down. Changing the interferometer's resolution extending scale will be easily done by software.

4. Conclusions and Applications

The interferometer described here is suitable for the fast scanning data acquisition system as a space position encoder. Its resolution is twentieth of the laser wavelength. The maximum scanning speed of 1 M data points per second is just limited by the optic fiber analog receiver and the resolution extending circuit. It is possible to improve the speed to 10 M points per second.

Because of the lower price and the easier adjustment the interferometer can also be used in another application range instead of grating or magnetic linear encoder, especially in those situations where the encoder has to work inside ultra high vacuum.

For applications where a long measuring time is necessary, a frequency stabilized laser will be suggested to reduce the error caused by $\delta\lambda_0$. Figure 5 shows the unit of the interferometer. Figure 6 shows the output sin and cos signal of the optic fiber analog receiver when the retrorefrector is scanning by a dc motor. Figure 7 shows the resolution extending circuit output pulses with sinusoid (test model).

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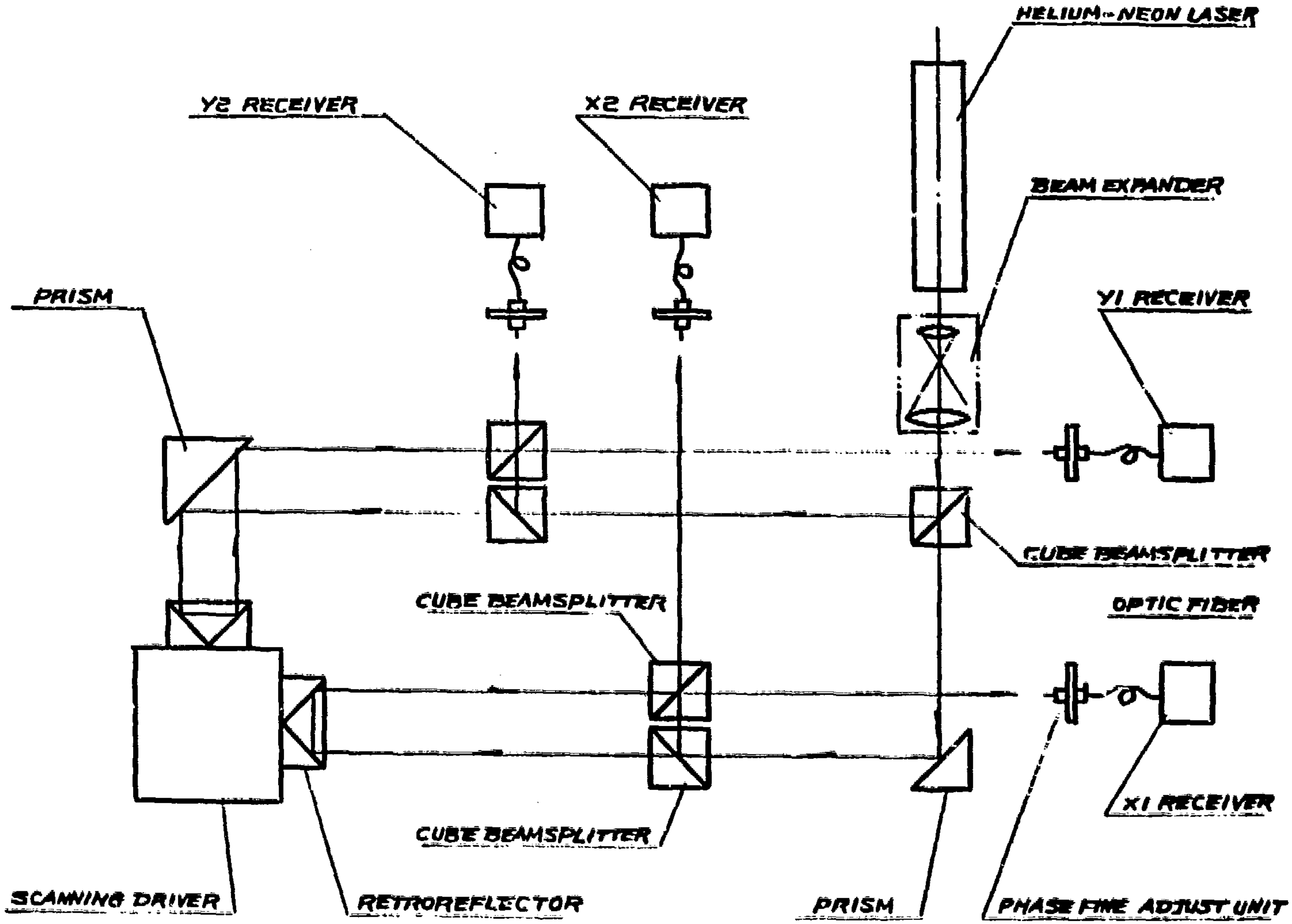


FIG. 1 TWO DIMENSION LASER INTERFEROMETER

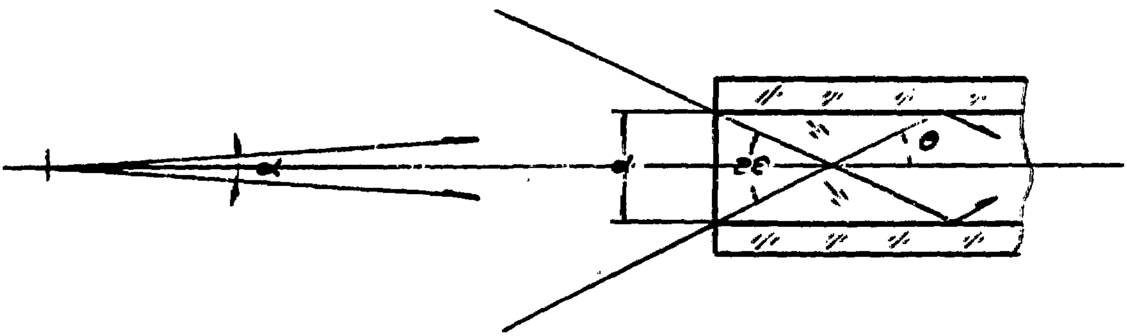


FIG. 2

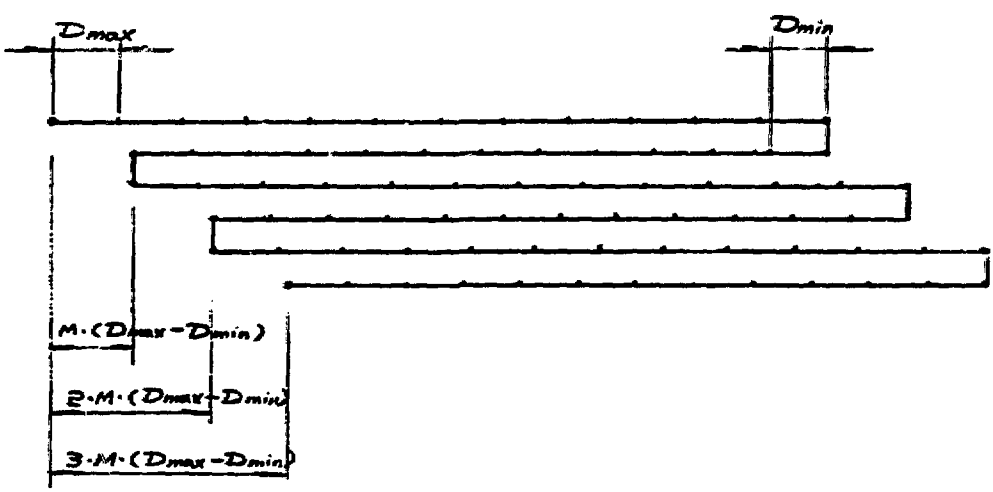


FIG. 3

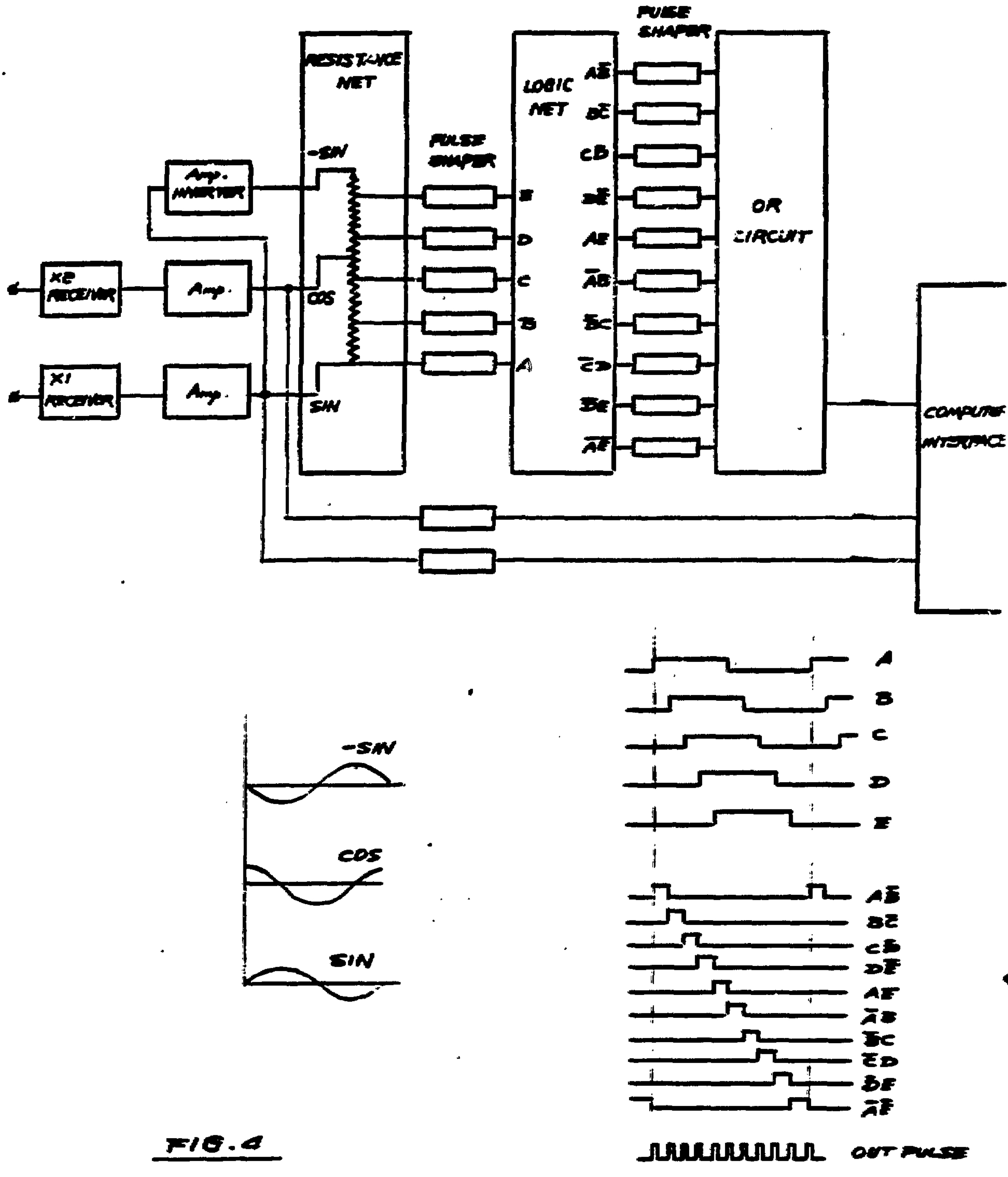
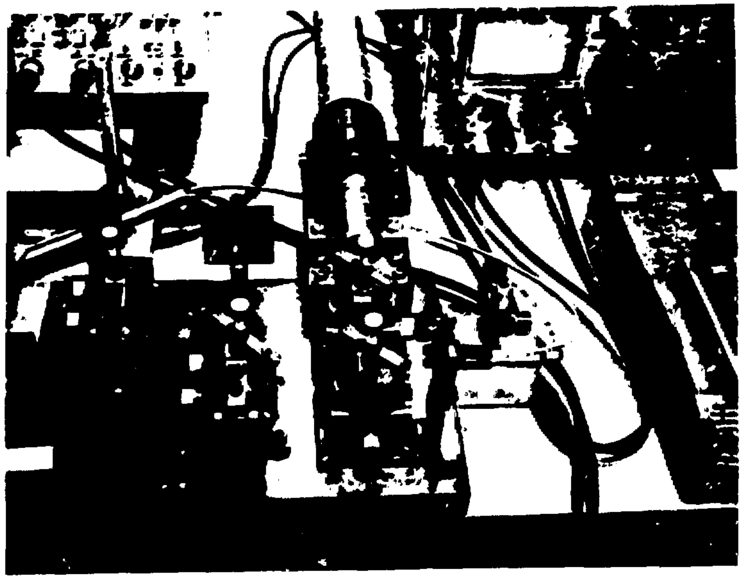

RESISTANCE NET
-SIN
COS
SIN
Amp. INVERTER
X2 RECEIVER
X1 RECEIVER
Amp.
Amp.
PULSE SHAPER
LOGIC NET
PULSE SHAPER
OR CIRCUIT
COMPUTER INTERFACE
-SIN
COS
SIN
A
B
C
D
E
OUT PULSE

FIG. 4

FIG.5



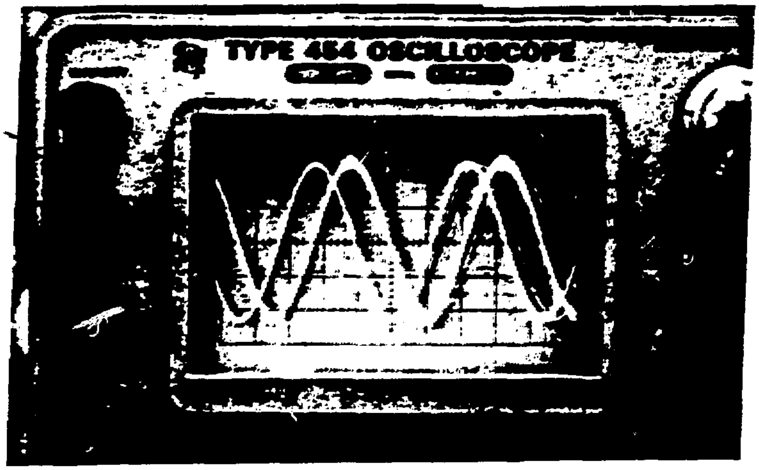


FIG.6

FIG.7