

PROGRAMMABLE MASKS FOR  
OPTICAL INFORMATION PROCESSING

J. H. Goebel, T. Matsumoto, C. Mina, and J. Welch  
NASA Ames Research Center  
Moffett Field, CA 94035

SUMMARY

Research in progress at NASA Ames Research Center on programmable masks is discussed in this paper. One type is a large area format liquid crystal mask intended for binary optical computation problems. To date, an on-off contrast ratio of  $>500:1$  has been achieved at a switching rate of  $<1$  Hz. With a  $32 \times 32$  format, a ratio of  $10^4:1$  is desirable. The switching contrast is entirely dependent on the polarized quality; therefore, we believe  $10^4:1$  in transmission is possible. Larger format masks are under development. An application to Hadamard transform polarized imagery at wavelengths of  $1.0$  to  $2.0 \mu\text{m}$ , which is competitive with the best monolithic infrared detector arrays, is discussed.

INTRODUCTION

The programmable mask for optical computer applications is currently the missing essential element. To date, matrix-matrix multipliers and systolic array processors have been made, but have been realized with fixed masks (Goodman, Dias, and Woody 1978; Psaltis and Cassasant 1979).

Variable fixed masks have been successfully used for Hadamard transform image encoding in astronomical applications (Singerland 1975, 1976; Davies 1975; and deBatz et al. 1977). Because Hadamard imagery can be performed with repetitive patterns, a truly programmable mask is not essential to realization of the technique.

A nematic liquid crystal cell has been used in a page composer for holographic memories where it acted as the spatial wave polarization modulator (Laburnie, Robert, and Borel 1974). They used a  $32 \times 32$  array format.

Here we report on work in progress, which synthesizes the three preceding concepts,

- 1) Programmable masks
- 2) Hadamard imagery
- 3) Liquid crystal arrays

into a single program. The program is aimed at demonstrating a truly programmable mask. The mask is understandably limited in capability and represents only the first step in our program to develop widely applicable programmable masks.

## THE MASK

We have chosen a large scale, binary mask format, suitable for Hadamard transform imagery. The mask consists of a 32 x 32 array of liquid crystal elements, the pixels of which are 1mm x 1mm. It is suitable for transmissive applications. The array was purchased as Model SX402 from Crystalliod Electronics. The reflective backing was removed and the polarizer replaced with a Model NPF-1008H polarizer manufactured by Nitto Electronics Co., Ltd.

The mask consists of two essential elements: the polarizer-analyzer and the liquid crystal array. Each element limits the performance in different manners.

The polarizer-analyzer standard with the display has a contrast ratio of 2:1 which is totally unsatisfactory in this application. We have investigated polarizer properties and found that 1000:1 contrast ratio for crossed polarizers can be achieved over limited wavelength ranges. The polarizer chosen has a ratio in the 1000:1 region near 600 nm. HR8 Polaroid infrared polarizer achieves 1000:1 between 1.2 and 2.0  $\mu\text{m}$ . The liquid crystal is transparent out to 2.5  $\mu\text{m}$ , and thus we expect to be able to achieve the desired performance in the astronomical I and J bandpasses (I = 1.25  $\mu\text{m}$ , J = 1.65  $\mu\text{m}$ ). A contrast ratio of 1000:1 is deemed necessary to fully block all pixels, so that when all are off there is no leakage greater than one equivalent pixel, i.e., all the signal is fully modulated for full efficiency. This is required to fully realize the Fellgett multiplex advantage.

The liquid crystal performance is limited by its addressing mode. The Model SX402 is addressed in column and row with no on-pixel storage. This requires the electronics to repetitively address the pixel during the observing period to make the pattern persist. The pattern stabilization time for this array is about 1 second. A 32 x 32 mask requires 1023 patterns for a complete transform cycle, or 1023 sec of dead time. This is a penalty which is application dependent. The astronomical penalty is significant but tolerable, being a 30-50% loss in observing time. Arrays with randomly addressable pixels and storage fet's will be forthcoming, and the 1023 sec dead time will shrink by 100 to 10 sec per cycle. For example, the Casio TV-10 liquid crystal pocket television is suitable for such an application, but was not available at the time when this work was initiated. It has fet storage and much faster response than the display which we are using. Examples of the patterns on the mask are shown in Figure 1. These have been photographed directly from the display when addressed with the row and column drivers. The driver board is also shown.

The exercising and data collection electronics are summarized in Figures 2 and 3. Control is through an HP 9816 computer, which starts the exercise sequence of the mask writing electronics and thereby impresses the sequence of

patterns on the liquid crystal mask. The mask logic control gates the shift register which stores the 1023 bit pattern which is impressed upon the mask and subsequently shifted one bit at a time, 1023 times. The adjustable setup time control allocates the mask rewrite rate. This rate is fast compared with the desired integration time at a setting of the mask, e.g., 17 Hz for 10 sec.

While the exercising electronics is sequencing, the computer is acquiring the detector output through a 12 bit A/D converter and storing the time averaged result in a 1023 array of data points which are subsequently transformed into an image. A flow chart of the entire sequence of exercising/acquiring is presented in Figure 4.

The Hadamard transform process itself is well studied and discussed in the book by Harwit and Sloane (1977). We have chosen a fast Hadamard transform, the logic of which is given in Figure 5. It is another example of the class of 2-dimensional  $n^2$  computational procedures which can be linearized to  $n \log n$  steps through a sorting and addition-subtraction algorithm.

## REFERENCES

- Batz, de, B., Bensammar, S., Delavaud, J., Gay, J., and Journet, A. 1977, Infrared Physics, 17, 305.
- Davies, D. W. 1975, J.O.S.A. 65, 707.
- Goodman, J. W., Dias, A. R., and Woody, L. M. 1978, Optics Letters 2, 1.
- Harwit, M. and Sloane, N. J. A. 1979, Hadamard Transform Optics, Academic Press.
- Labrunie, G., Robert, J., and Borel, J. 1974, Applied Optics 13, 1355.
- Psaltis, D. and Cassasant, D. 1979, Applied Optics 18, 163.
- Slingerland, J. 1975, Rev. Sci. Instrum. 46, 746.
- Slingerland, J. 1976, Rev. Sci. Instrum. 47, 1331.

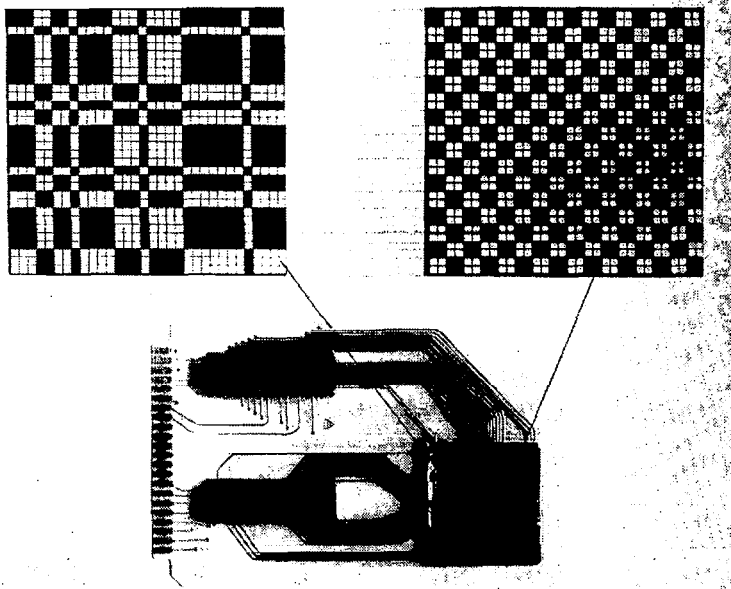


Figure 1.- Liquid crystal programmable mask for optical information processing.

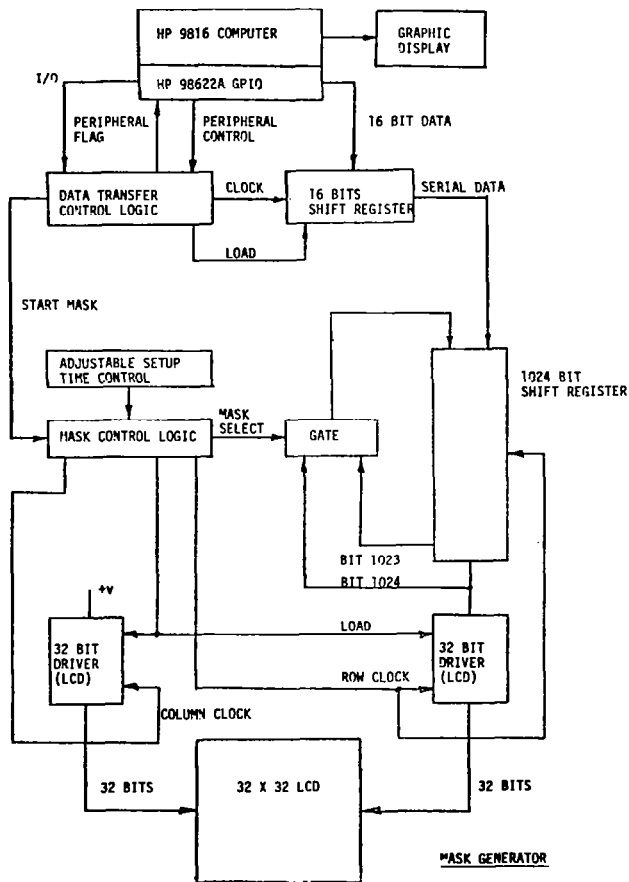


Figure 2.- Exercising and data collection electronics for mask generator.

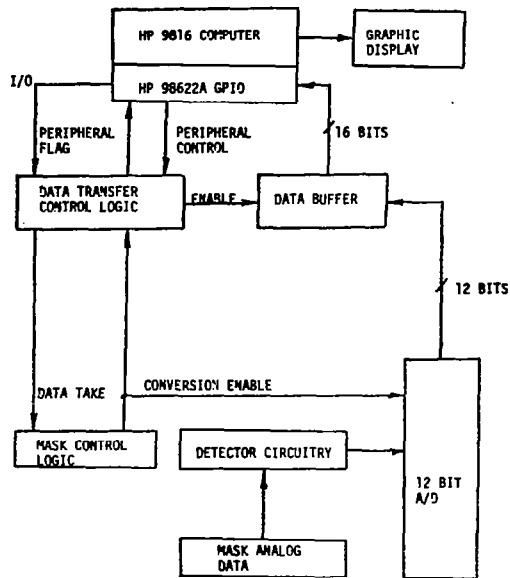


Figure 3.- Exercising and data collection electronics for mask reconstruction.

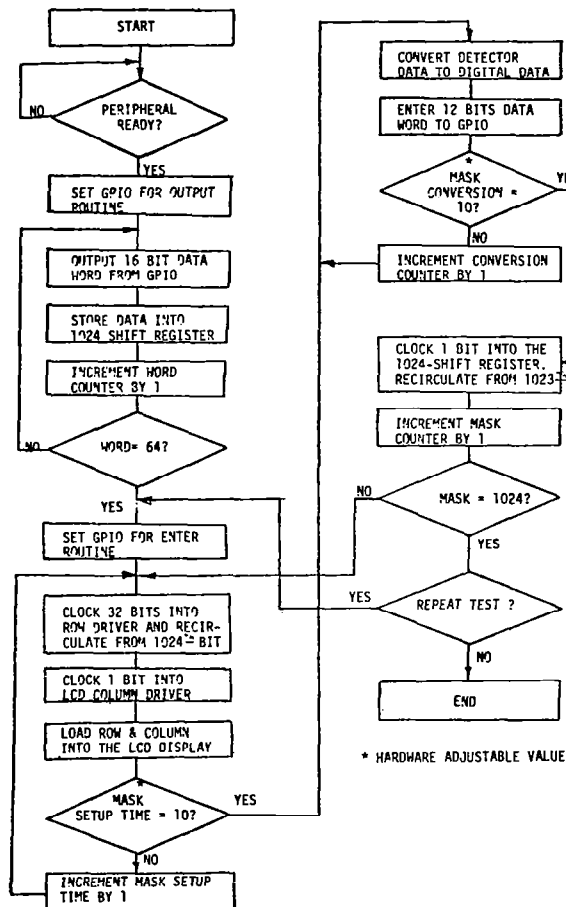
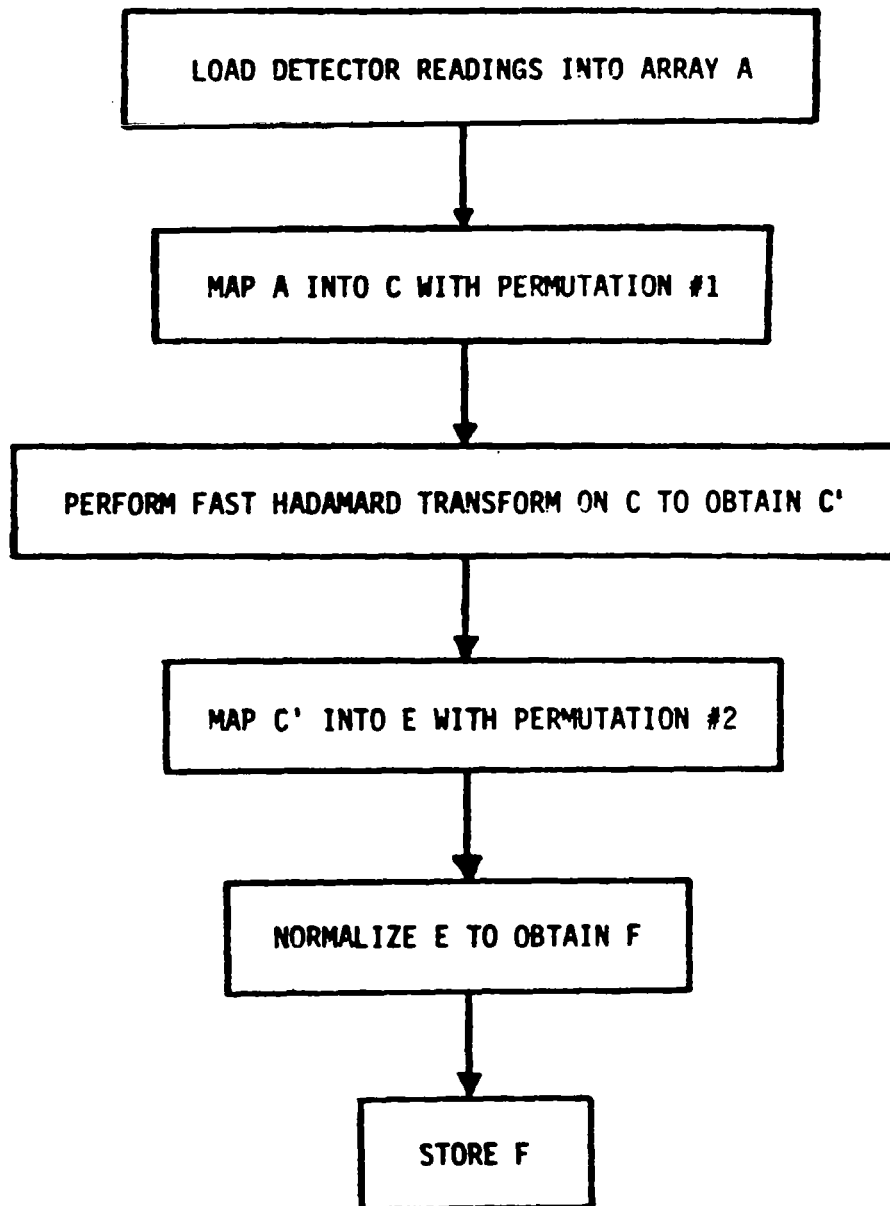


Figure 4.- Flow chart of entire sequence of exercising/acquiring.



ARRAY F IS THE FIELD IMAGE MAP  
ARRAY A IS THE DETECTOR TIME SEQUENCE  
ARRAY C IS THE FHT MA  
ARRAY C' IS ARRAY C AFTER THE FHT  
ARRAY E IS THE UNNORMALIZED FORM OF F

Figure 5.- Hadamard data processing flow chart.