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UNIVERSITY SCHOLARS PROGRAM

DEPARTMENT OF ELECTRICAL ENGINEERING

# THE DEVELOPMENT OF A LARGE BEAM DEFECT SCANNER

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with honors in Electrical Engineering

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# The Development of a Large Beam Defect Scanner

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# ABSTRACT

This paper describes an alternative to defect scanning erasable magneto-optic (MO) disks. Magneto-optic disks require that their writing surface be totally reflective, like a mirror. The information is read from the disk by detecting a change in the polarization of the light, rather than by a phase change such as that used by the popular compact disc. Therefore, a good way of checking for defects would be to shine light on the disk's surface and to detect where the light does not reflect uniformly off the disk. At these points we would expect to find reflectivity defects. Alternatively, one could look for very small holes in the disk's magnetic coating, by shining light on the disk and placing a detector behind the disk. Where too much light shines through to the detector, these points would be locations of transmission defects. Equipment is now available that will focus a 1 µm laser on the disk's surface and scan each track for reflectivity defects. Since there are eighteen thousand tracks per disk, one scan takes approximately twelve minutes.

This paper discusses the use of a large laser beam scanner (about 10 X 30 µm). This type of scanner does not follow each track and will therefore scan an entire disk's surface in about 30 seconds, rather then 12 minutes. Because this type of tester does not follow each individual track, no focusing or tracking servo will be required. In an industrial environment this tester's simplicity as well as rapid scan time would provide an excellent alternative to the current method of sorting out defective disks.

# INTRODUCTION

Since the invention of the computer, people have been looking for ways to store ever increasing amounts of information. First there was paper, then microfilm, magnetic tape, floppy disks, CD-Rom, write-once-read-many (WORM) optical disks, and finally magneto-optic (MO) disks. The last three -- CD-Rom, WORM, and Magneto-optic -- all utilize the fairly new laser optic technology, making large information storage capacities possible. Optical data storage was a by product of video data, due to the high bandwidth of video signals, requiring large amounts of memory. These video disks have developed markets for both home entertainment and educational purposes. Laser technology has developed the digital compact disc, perfect for storing digital data, which has been commercially developed for music. On the compact disc, information is stored in a spiral, just like the phonograph, and the information is read with a laser, so there was no physical contact with the media. This media provided perfect reproduction every time it was played, but expense limited commercial recorders for the medium. The last type of optical storage is the CD-ROM, which is similar to the compact disc but is used for storage of information other than music. These digital optical storage devices have one thing in common, they are generally read-only, and cannot be recorded by the user. Figure 1 shows the different types of optical media. In order for laser optics to be a big success on the

# Types of Optical Disks

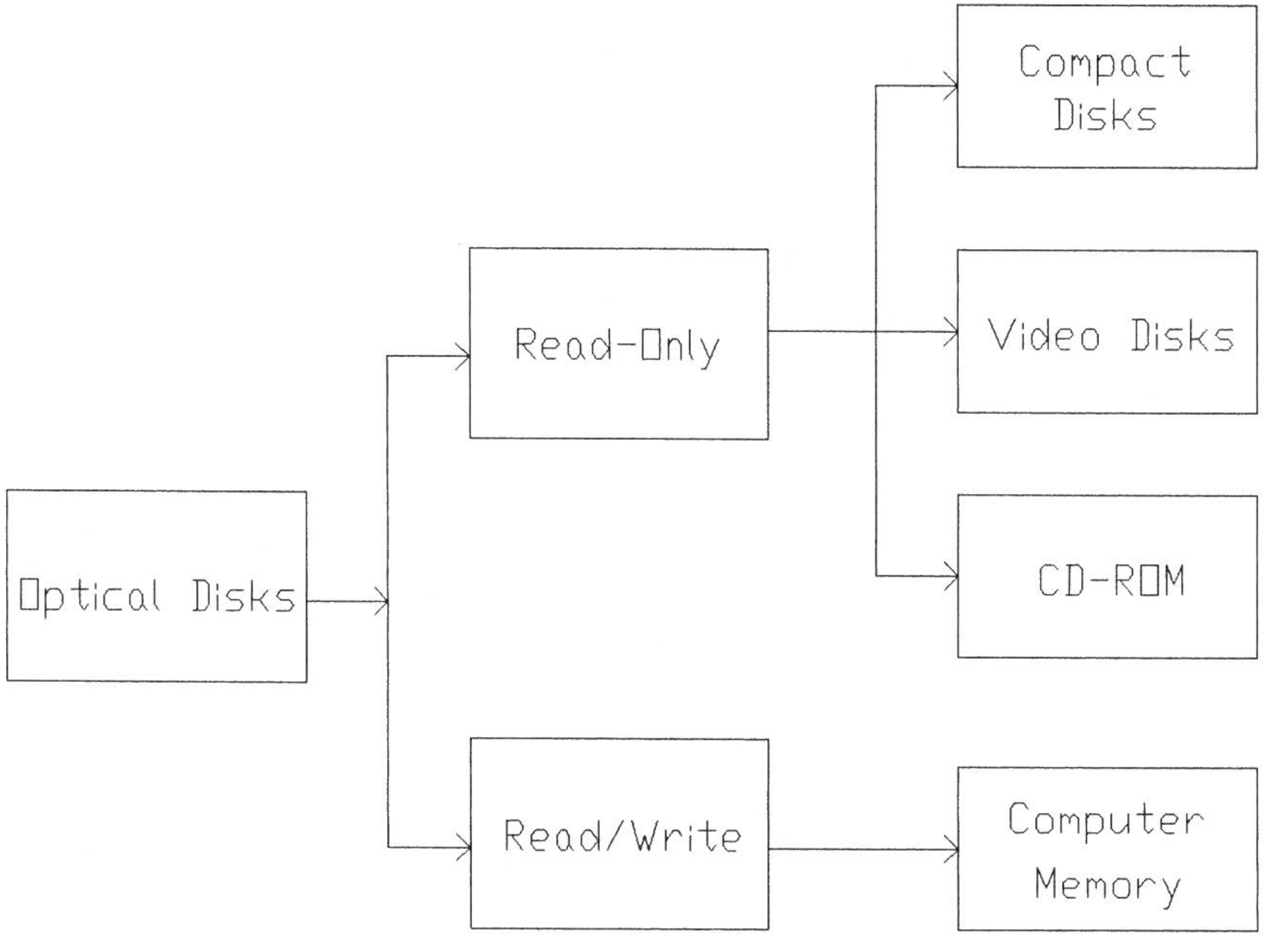


Figure 1

these disks must be erasable (Read/Write). Because of this, most of the optical disk research efforts have been focused towards magneto-optic (MO) disks.

Magneto-optic disk recording is based on the polar magneto-optic (MO) Kerr effect. Data is stored on the surface of the disk in a magnetic film. The film is magnetized either up or down, corresponding to a written "1" or "0". The magnetic field on the disk's surface induces a dipole moment which in turn causes the polarization of the incident light to rotate. (More information is provided in Appendix A). Each double sided disk is capable of an access time of 1 Mbyte/sec and storing up to one gigabyte. These disks are also removable and not permanently stored in the computer as are most other high density media.

Magneto-optic disks have many good features but are very difficult to manufacture. Each disk requires many long tests to decide if the manufacturing process is error free. One test the disks would go through is a defect test which looks for holes and reflectivity defects on the media. The currently used procedure requires almost 12 minutes to complete. This paper describes a tester which can scan a disk in 30 seconds and give valuable information about the sputtering process. Disks could be sorted out before the final manufacturing processes, thus saving manufacturing time and valuable testing time.

## NOTE

At this point the reader is asked if he or she is familiar with magneto-optic disks. If not, a review of appendices A and B before continuing any further with the reading of this paper is recommended.

# BACKGROUND

The development of magneto-optic disks require that many tests be conducted in order to find out both how to make better disks and how to improve the manufacturing process. Drive manufacturers require strict specifications in the following areas: acceleration, S/N, Read-Write capabilities, M.O. defects, reflectivity defects, birefringence and transmission defects. All disks must be tested for these specifications until the process is under control. Although all of these specifications are important, two of them are of major improtance, these are reflectivity and transmission defects.

The standard method for detection of reflectivity defects is accomplished by scanning the entire disk with a one micrometer diameter laser. This laser has a very small depth of field and must be continually focused with a focusing servo. The laser scans each of the 18,750 tracks individually, requiring a complicated tracking servo. The disk spins at 30 Hz; therefore, a total scan takes approximately 12 minutes. Overall, the 1um diameter laser tester is very complicated, very expensive, and very slow.

The large beam scanner was developed to scan disks rapidly and at a low cost. It uses a much larger laser than the small beam scanner, approximately 10 um x 30 um instead of the standard 1 um size. Because the laser is larger, the depth of field is larger, therefore, no focusing or tracking servo is required. This makes the electronics at the front end much simpler and a lot less expensive. While the small beam laser scans only one track at a time, the large beam laser scans 18 tracks simultaneously, making it possible to scan a disk in as little as thirty seconds.

# SYSTEM OPERATION

The large beam scanner consists of four major sections: the computer and storage, the motors and controllers, the optics, and the electronics. A simplified block diagram of the system is shown in Figure 2. The computer controls the beginning and the end of the system sequence. The computer begins the system's test sequence by telling the motor controllers to start. The motor spins the disk and moves it linearly past the stationary optics. The optical signal is converted to an electrical signal and analyzed by the electronics. The electronics sends the information back to the computer and storage block to be stored in R.A.M. Finally the computer outputs the data to the user.

A more detailed block diagram is shown in Figure 3. Figure 3 shows a block diagram of a system for measuring size and location of reflectivity defects as well as transmission defects on magneto-optic disks. There are two motors that control the positioning of the disk, a linear motor that controls the radial position and a rotational motor to controlling the angular position. The computer controls the motion of both motors to position the disk in front of the laser and the optics. The optics process the laser to a 10 x 30 um beam and focuses it on the surface of the disk. The disk reflects and transmits light from the laser. This laser light is then processed through more optics and converted to

# OVERVIEW
# SYSTEM BLOCK DIAGRAM

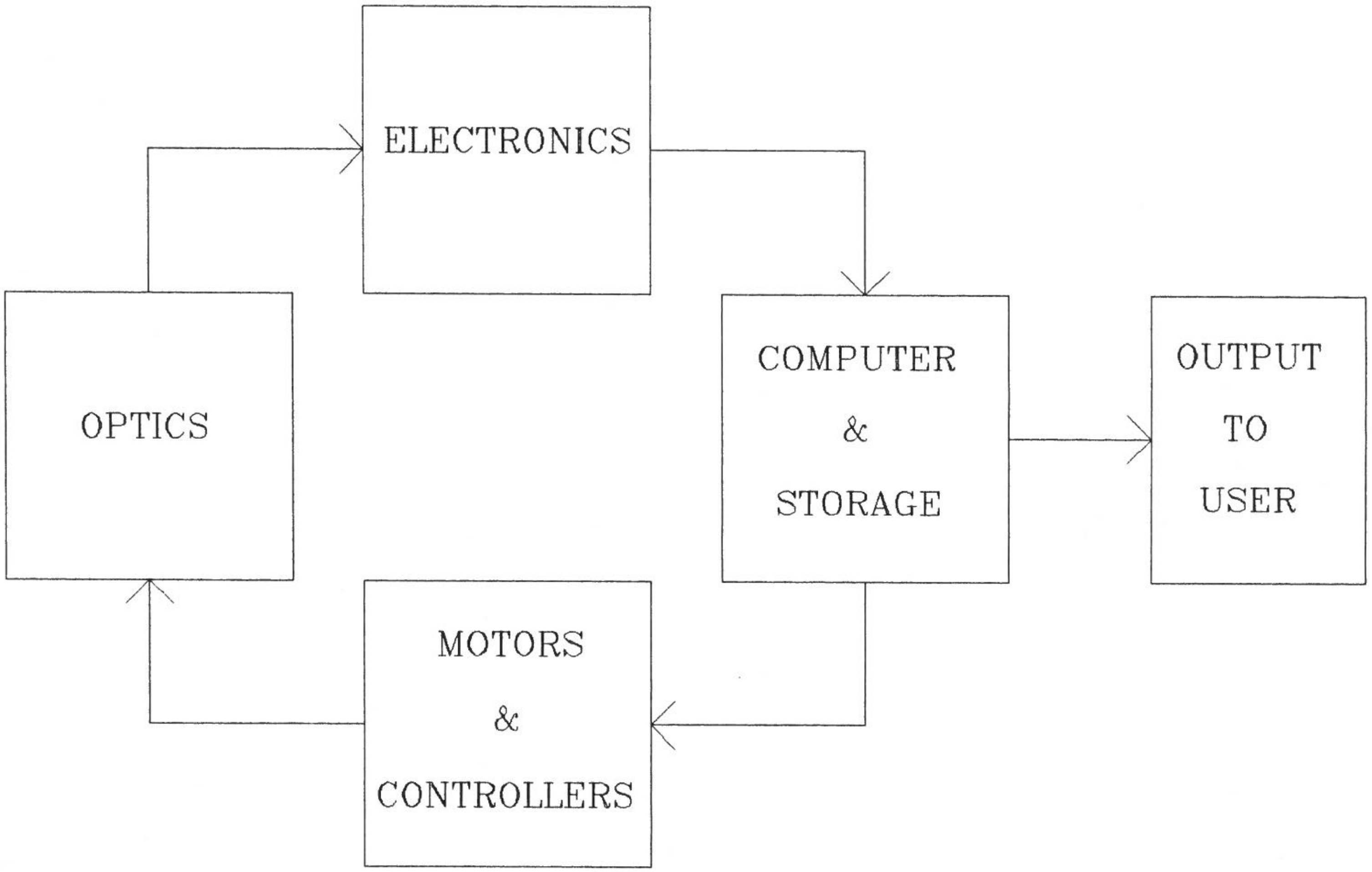


Figure 2

# SYSTEM BLOCK DIAGRAM

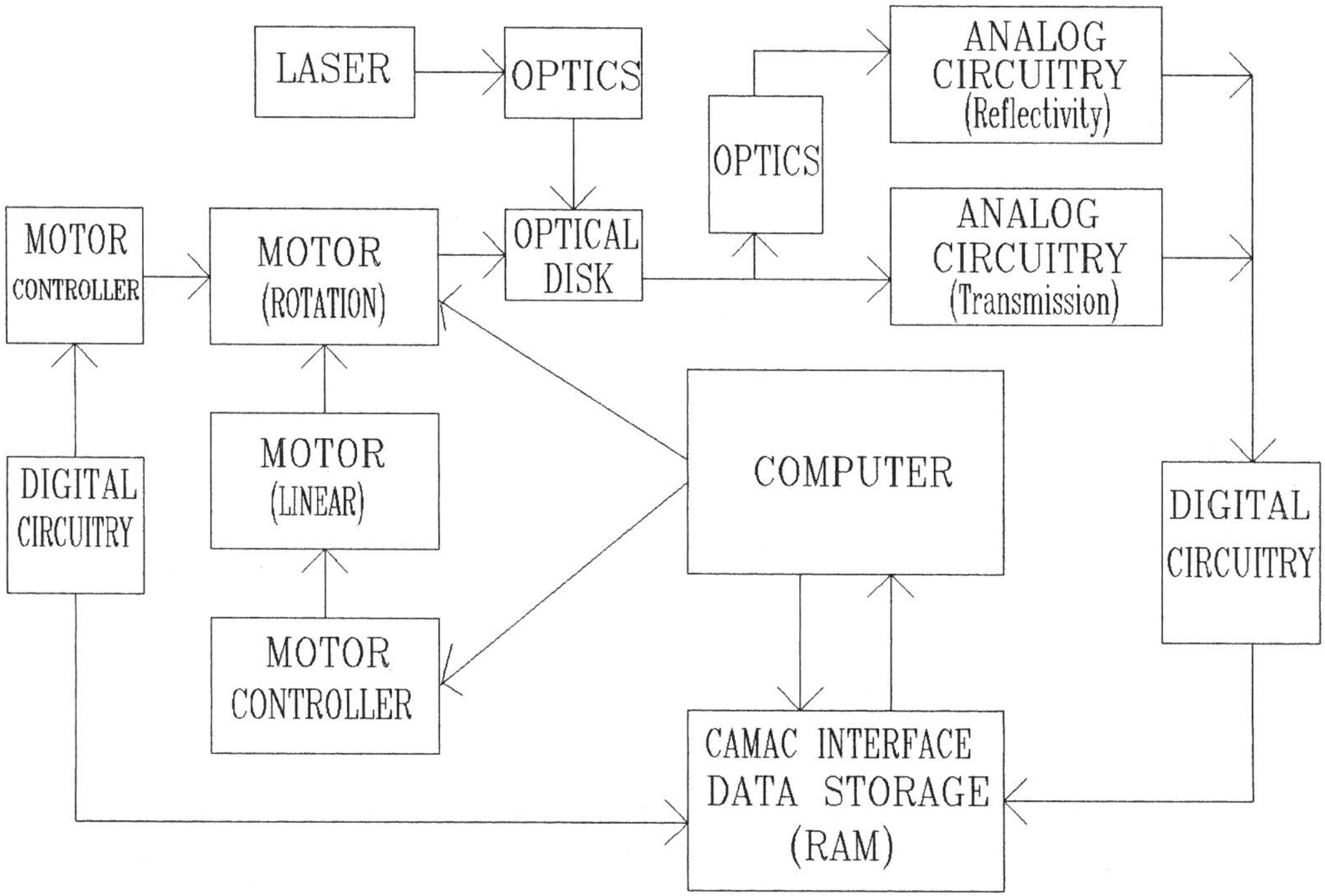


Figure 3

an electrical signal. The electrical signal is analyzed and converted to a digital signal from which the actual measurments of the defects are made. The data on defect size and position is sent to the CAMAC interface to be stored until the end of the scan. Once the scan is complete, the computer reads the data and displays the results.

The above system is broken down into two physical sections: the optic table and the electronics rack. All analog measurements are made on the optic table, both optically and electrically. All digital computations are made in the electronics rack. Figure 6 shows the drawing of the optic table and Figure 4 shows a drawing of the electronics rack.

## Electronic Rack Drawing

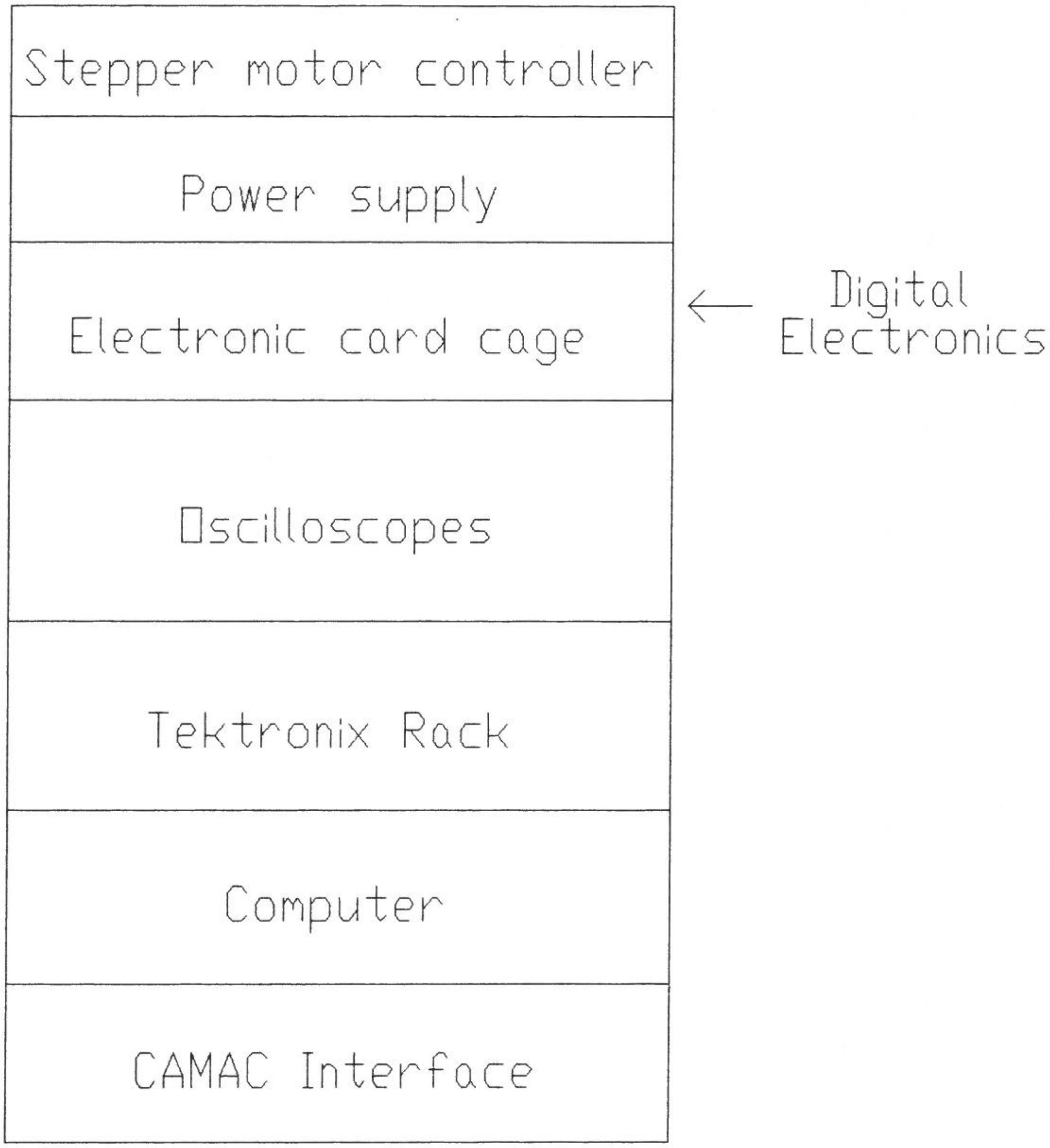


Figure 4

# OPTICS

A simplified block diagram of the large beam scanner's optics is shown in Figure 5. The system is initiated by a diode laser emitting 15 mW of radiation at 820 nm. This light source is positioned at the focal point of a convex lens so the laser is spread out over a large area. The light then travels through a polarizer beam splitter, which collects only the light linearly polarized in one direction.(The original design of the tester included a third channel to look for birefringence, for which a polarizer was necessary.) The polarized light passes through a 9 x 3 mm aperture to trim the laser beam into a small rectangle. The laser beam is then passed through a pellicle beam splitter and focused by a lens on the surface of the disk. At the disk's surface, the light can take one of two paths. It can be transmitted through the disk, possibly by pin holes, or it can be reflected. If the light is transmitted through the disk a detector will detect the light and analyze the signal for transmission defects. If the light is reflected, it will pass back through the focusing lens and be reflected by the pellicle beam splitter into a second pelicle beam splitter. The desired light beam is reflected by the beam splitter and focused by a lens onto a laser detector. This detector processes the light for reflectivity defects.

# OPTICS BLOCK DIAGRAM

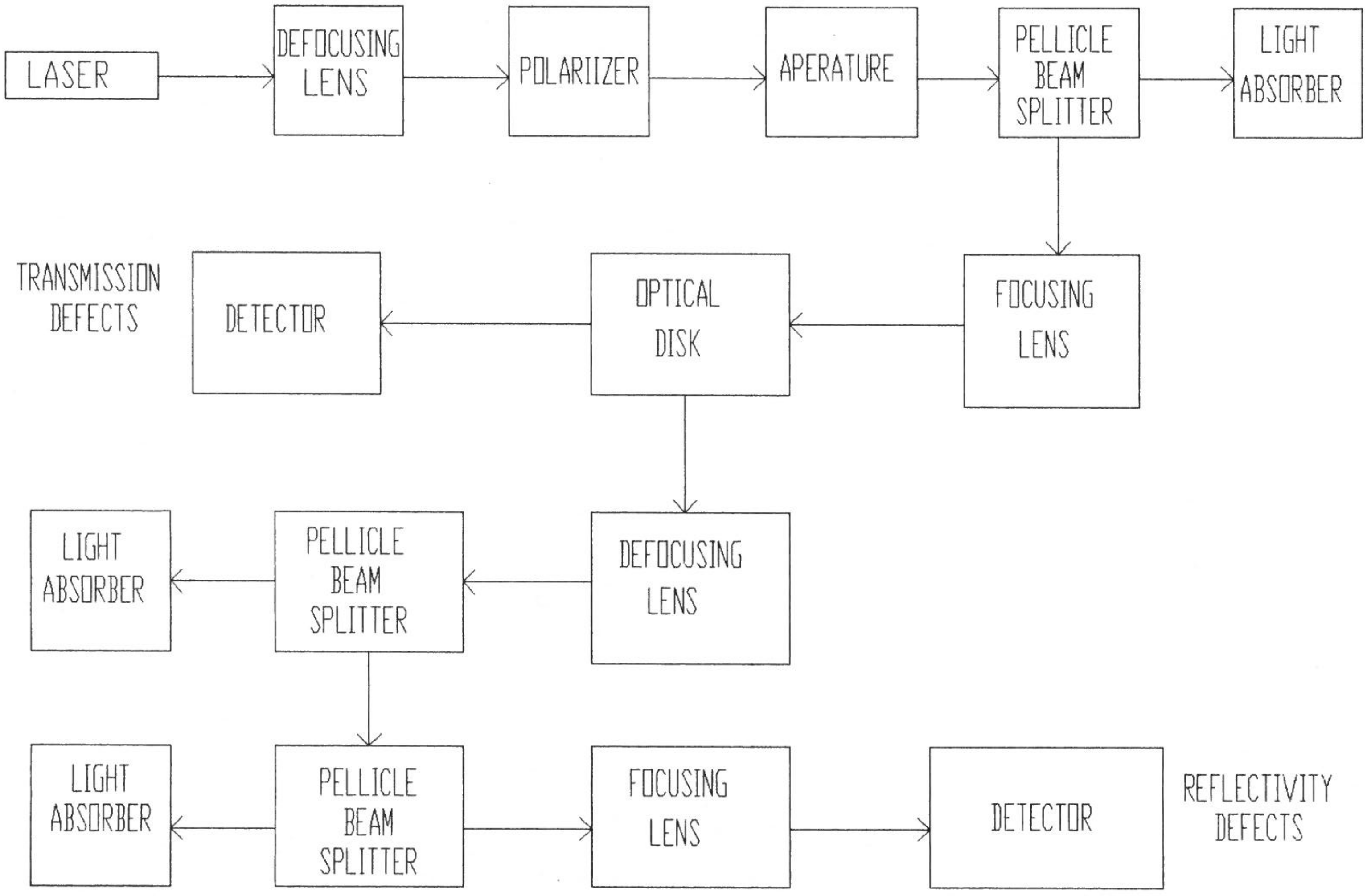


Figure 5

Specific optics:

To better understand the optics a ray tracing diagram is needed. In Figure 6 the path of the light rays are traced through the entire system. In this more detailed diagram, one can see how the rays are positioned with respect to the first pellicle beam splitter. The light ray is directed through the lower half of the beam splitter and the lens and reflected back through the upper half of the lens and beam splitter. This prevents feedback to the laser and keeps the incoming beam free of distortion from the reflected beam.

The derivation of the spot size is also of critical importance. Each disk has a diameter of 5 1/4 inches, and uses a 3 cm radius on the disk for information storage. The test was designed to run for 30 seconds, so the linear motion would have to travel 1 mm/sec. The rotational motion will be 30 rotations per second (30 Hz), which seems to be the standard, and the electronics occupy only a bandwith measuring a few megahertz. The disk moves linearly 1 mm and rotates 30 times per second. When we divide 1 mm by 30 rotations we get 33.33 um, which is the length the beam must measure to cover the entire disk in 30 seconds. To derive the height of the beam, three things must be taken into consideration: 1) smallest size of defect to be detected, 2) bandwidth of the circuitry, and 3) depth of field. The smallest defect that was to be detected was a 1 usec defect (disk spinning). We did not want to exceed more than a few megahertz in the

# OPTIC TABLE DIAGRAM

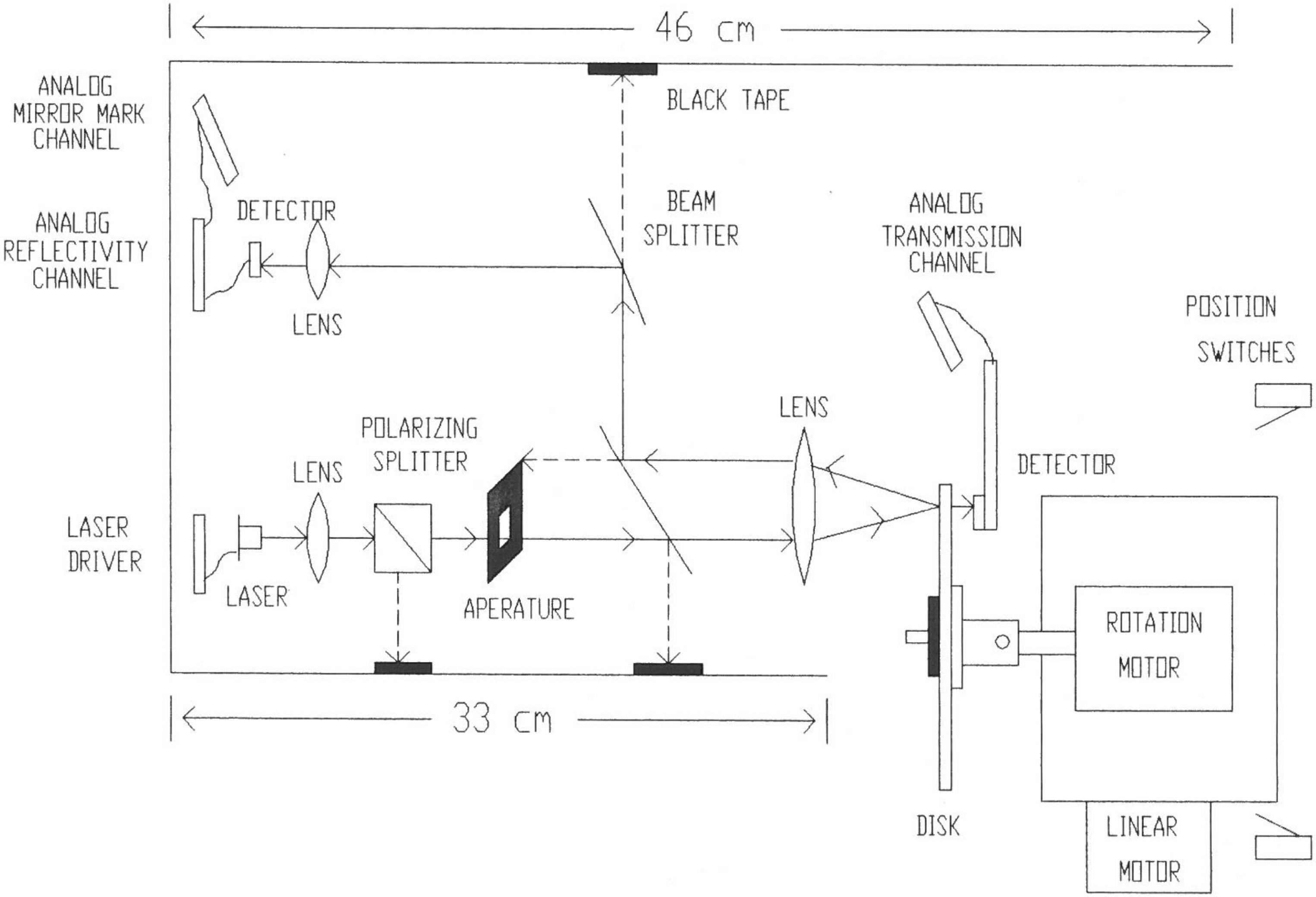
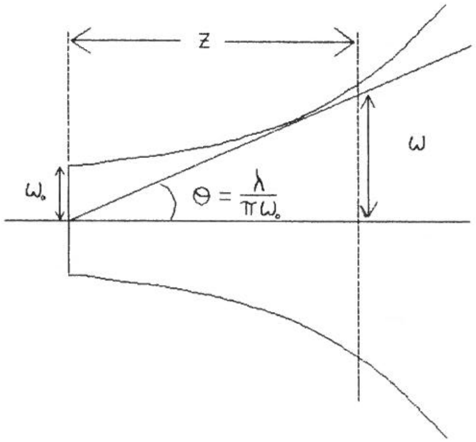
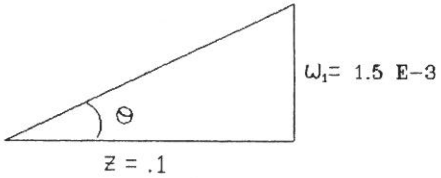


Figure 6

electronics. Finally, the depth of field had to be large enough that no focusing servo would be needed. Taking these three points into consideration, a spot height of 10 um was derived. Starting with a spot size of roughly 30 um X 10 um, an aperture size can be determined assuming a Gaussian beam. The aperture turns out to be roughly 9 mm X 3 mm. The derivation of this aperture is shown in Figure 7. The focal length of the lens is 0.1 meter, therefore z = 0.1. Using the aperture measurement of 3 mm X 9 mm we can calculate the beam waist as shown in Figure 7 and the spot size is calculated as shown in Figure 8.

# Beam Size Derivation





$\tan \Theta = \frac{\omega_1}{Z}$

$\Theta = \text{atan} \frac{1.5 \text{ E-}3}{.1}$

$\Theta = 15$ E-3

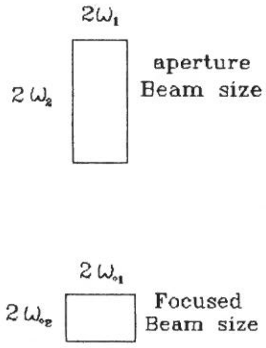
$\Theta = \frac{\lambda}{\pi \omega_o}$

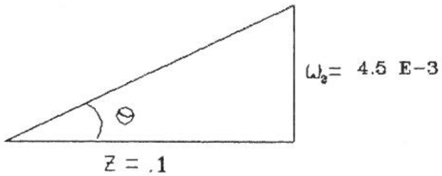
$\lambda = 820$ E-9

$15 \text{ E-}3 = \frac{820 \text{ E-}9}{\pi \omega_o}$

$\omega_{o1} = 17.4$ E-6

$2\omega_{o1} = 34.8$ um





$\tan \Theta = \frac{\omega_2}{Z}$

$\Theta = \text{atan} \frac{4.5 \text{ E-}3}{.1}$

$\Theta = 44.97$ E-3

$\Theta = \frac{\lambda}{\pi \omega_o}$

$\lambda = 820$ E-9

$44.97 \text{ E-}3 = \frac{820 \text{ E-}9}{\pi \omega_o}$

$\omega_{o2} = 5.8$ E-6

$2\omega_{o2} = 11.61$ um

Figure 7

# Beam Size Derivation

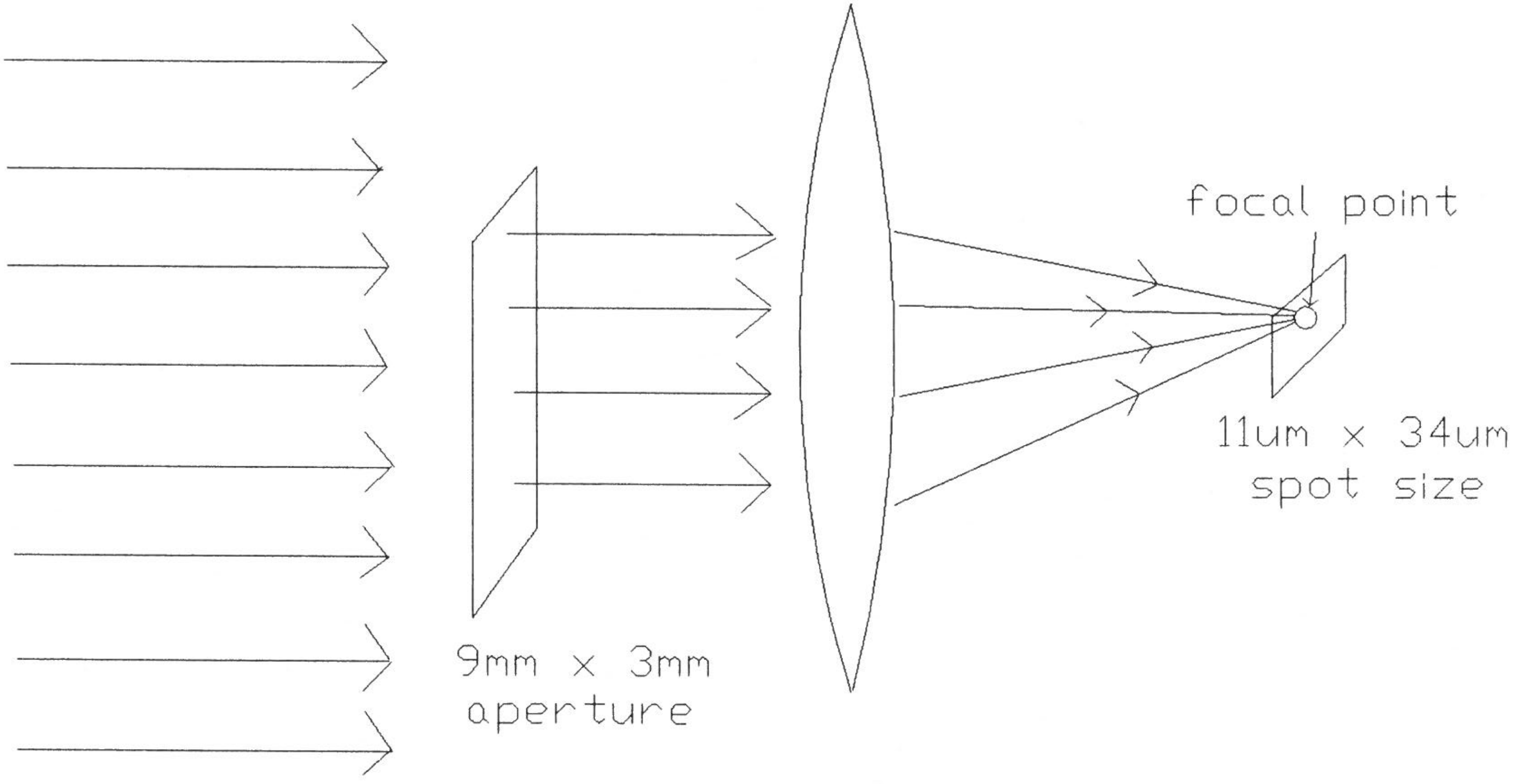


Figure 8

# ANALOG ELECTRONICS

## Analog Signal Processing:

The heart of the large beam scanner is in the analog circuitry on the optics table. The analog electronics are made up of three parts, the reflectivity channel, the transmission channel, and the mirror mark channel. A general block diagram of the analog section is shown in Figure 9. All signals originate from one of two diode lasers detectors. One diode detector is for transmission defects and the other is for reflectivity defects. The reflectivity channel processes the signal from its respective diode laser detector and sends some of the information to be analyzed by the digital circuitry and some of the information to be further processed by the mirror mark channel. The mirror mark channel's main purpose is for header detection, known as "header cutting". The mirror mark channel sends its signal to be processed by the digital circuitry. The transmission channel has its own transmission diode laser detector. After the transmission channel processes the signal from the diode detector, it sends the information to the digital circuitry.

# ELETRONICS BLOCK DIAGRAM

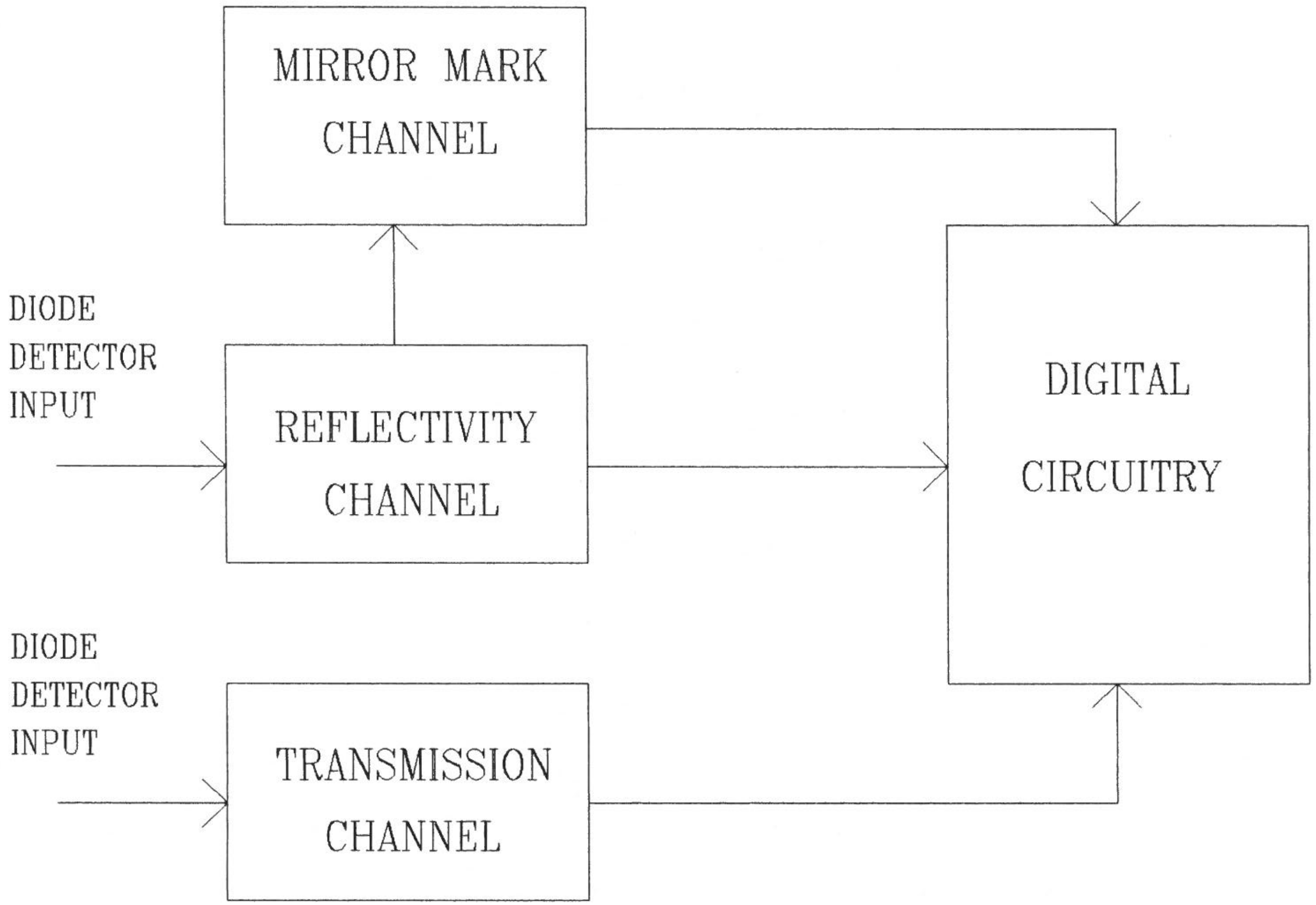


Figure 9

## Analog Reflectivity Channel:

First, we will look at the reflectivity channel, the channel responsible for manipulating signals received as reflectivity defects. As shown in Figure 10, the first function that must be performed on the signal from the diode laser detector is to transform the current signal to a voltage signal. A typical output at this stage is shown in curve 1 of Figure 11. Figure 11 shows an example waveform for each element of Figure 10. In this signal there are two headers (as explained in Appendix B ) and two reflectivity defects of differing sizes. In the next stage, this signal is then amplified approximately eighteen times and split three different ways, with separate buffers to ensure that no load is placed on the amplifier. In one path (element 3), the signal is low pass filtered at about 6.5 kHz, a value decided on using trial and error. A signal was needed that followed the base line very well, but did not follow the faster varying defects. In another path (element 4), the signal is also low pass filtered at a very low frequency, about 0.16 kHz. This part of the circuit calculates the average reflectivity of the disk over a few revolutions. The signal is inverted (see curve 5, Figure 11) and a percentage of it is added to the signal from element 3. This summed signal is inverted at element 7. Now, we have a duplicate signal of element 2, except the defects have been averaged out, and the signal is biased a few volts above the base line so only defects of a

# ANALOG CIRCUIT BLOCK DIAGRAM

## REFLECTIVITY CHANNEL

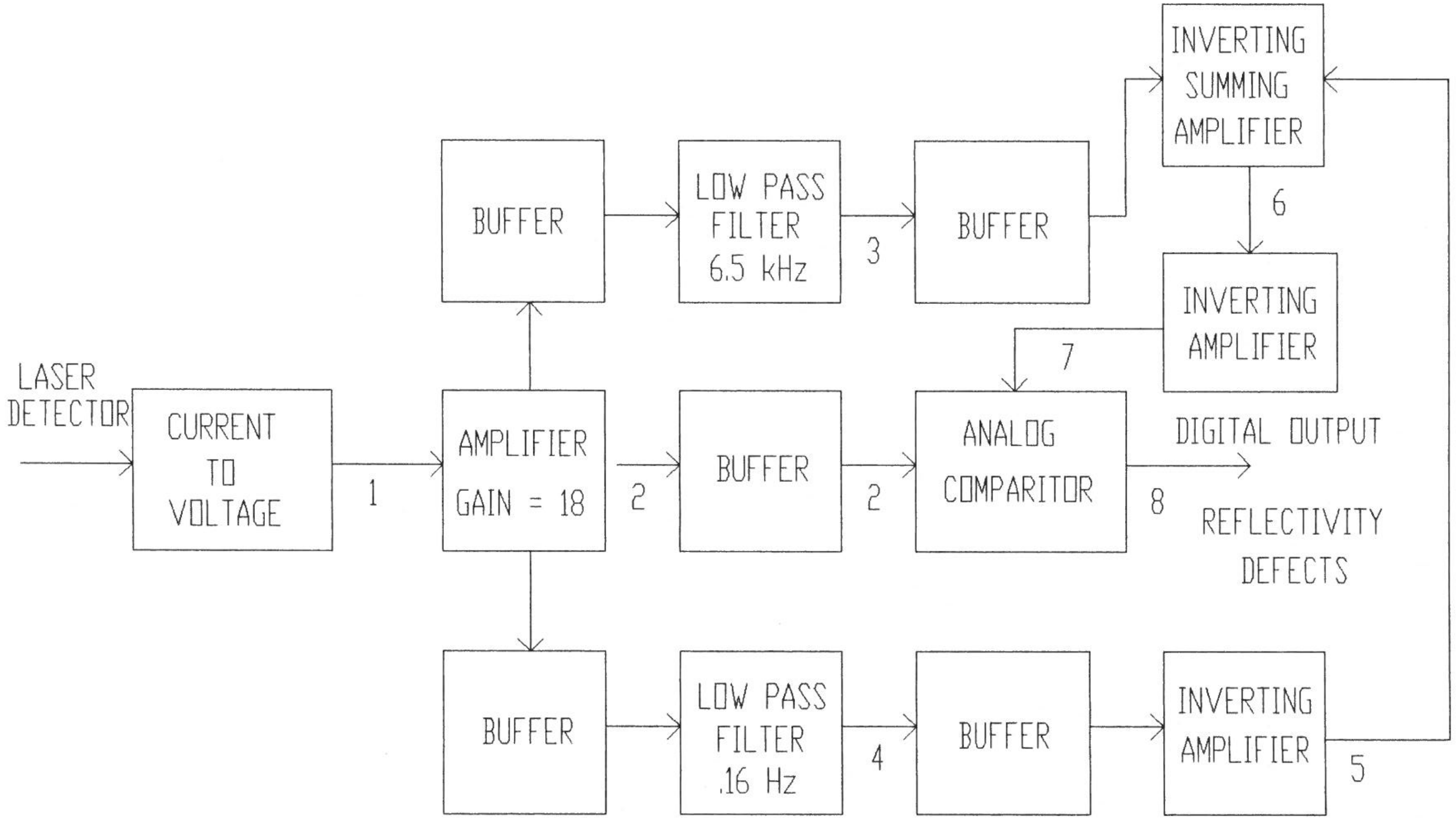


Figure 10

# Analog timing diagrams

reflectivity channel

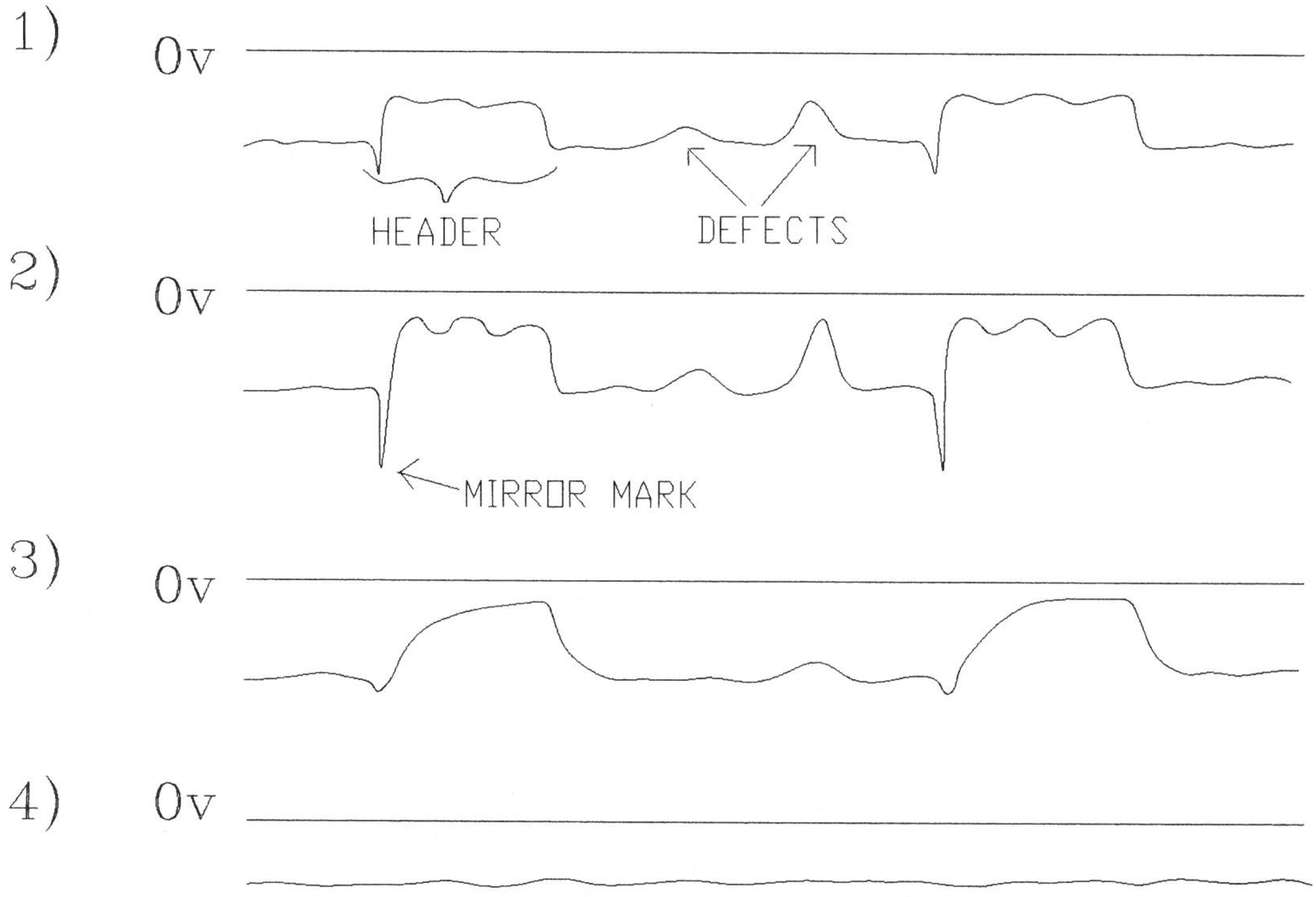


Figure 11

# Analog timing diagrams

## reflectivity channel

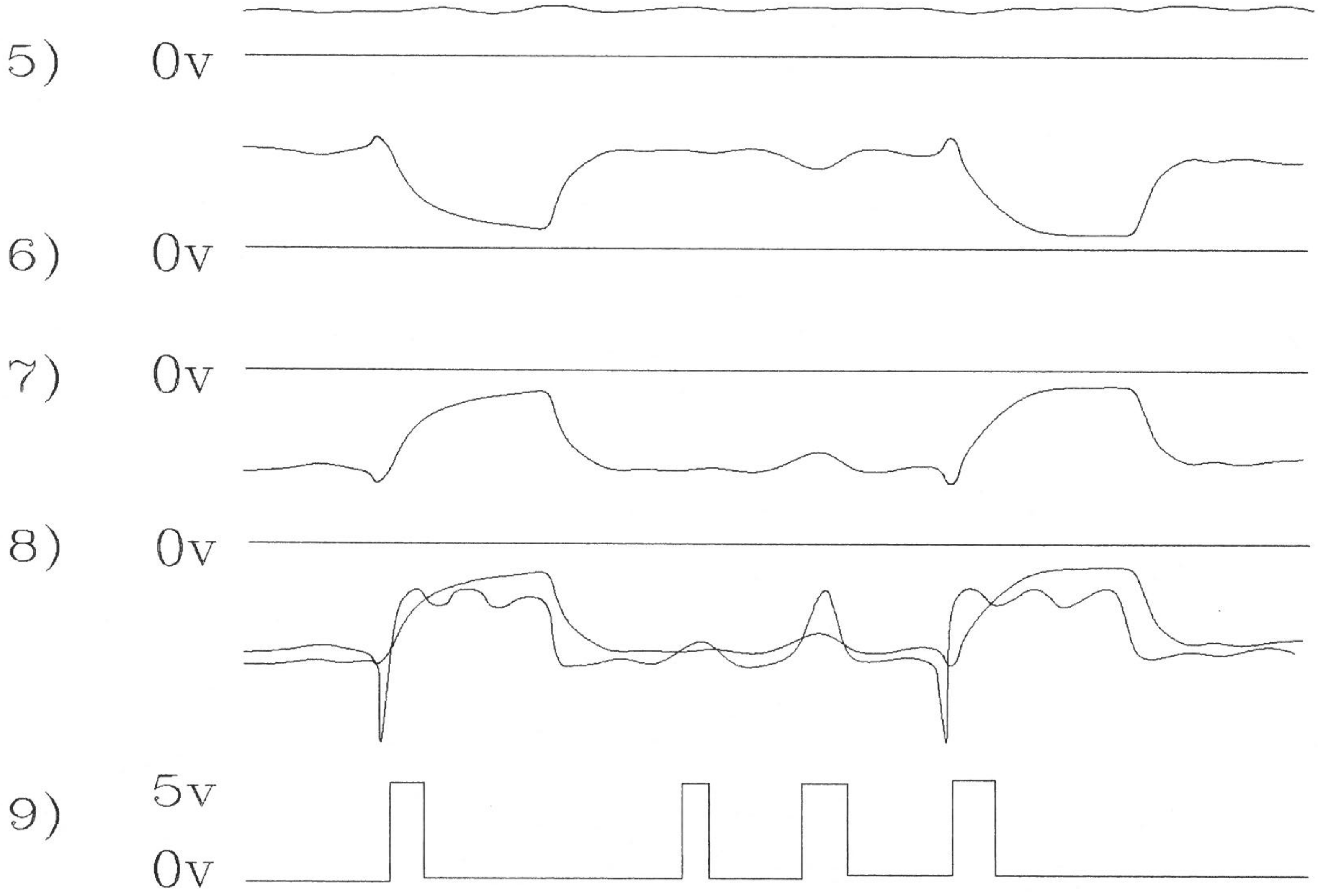


Figure 11

certain size are evaluated. The signal from element 7 is then fed to a comparitor along with the original signal from element 2. The comparitor reads these two signals in real time (element 8), and when the signal at element 2 is larger than the signal at element 7 the comparitor will output a digital five volt signal indicating a reflectivity defect. A typical signal is shown, curve 9 in Figure 11. This signal is now ready to be processed by the digital circuitry.

## Analog Mirror Mark channel:

The reflectivity channel detects reflectivity defects and provides an identifying signal for the digital circuitry, however, it can not differentiate between headers and defects ( see curves 8 and 9 in Figure 11). Each header is associated with a mirror mark which points downward, indicating a highly reflective point on the disk. These mirror marks need to be detected and the information sent to the digital circuitry. Using this information, along with information from the reflectivity channel we can decide if we have a reflectivity defect or a header. Figure 12 shows a block diagram of the mirror mark channel. Once again, a laser diode is used to convert optical information to electrical information in the form of current that is converted to a voltage and amplified 10 fold. These signals are shown as curves 1 and 2 in Figure 13. The signal is buffered and split in two paths. One signal goes to a negative peak detector and hold circuitry, curve 3 of Figure 13. The signal level is adjusted with a buffer trimpot circuit, at element 4 in Figure 12, and along with the original signal from point 2 is compared using an analog comparitor. If the signal at point 2 goes below the threshold set at point 5, then the output goes high to + 5v as shown at point 6. The digital signal is now ready to be sent to the digital circuitry.

# ANALOG CIRCUIT BLOCK DIAGRAM

## Mirror mark channel

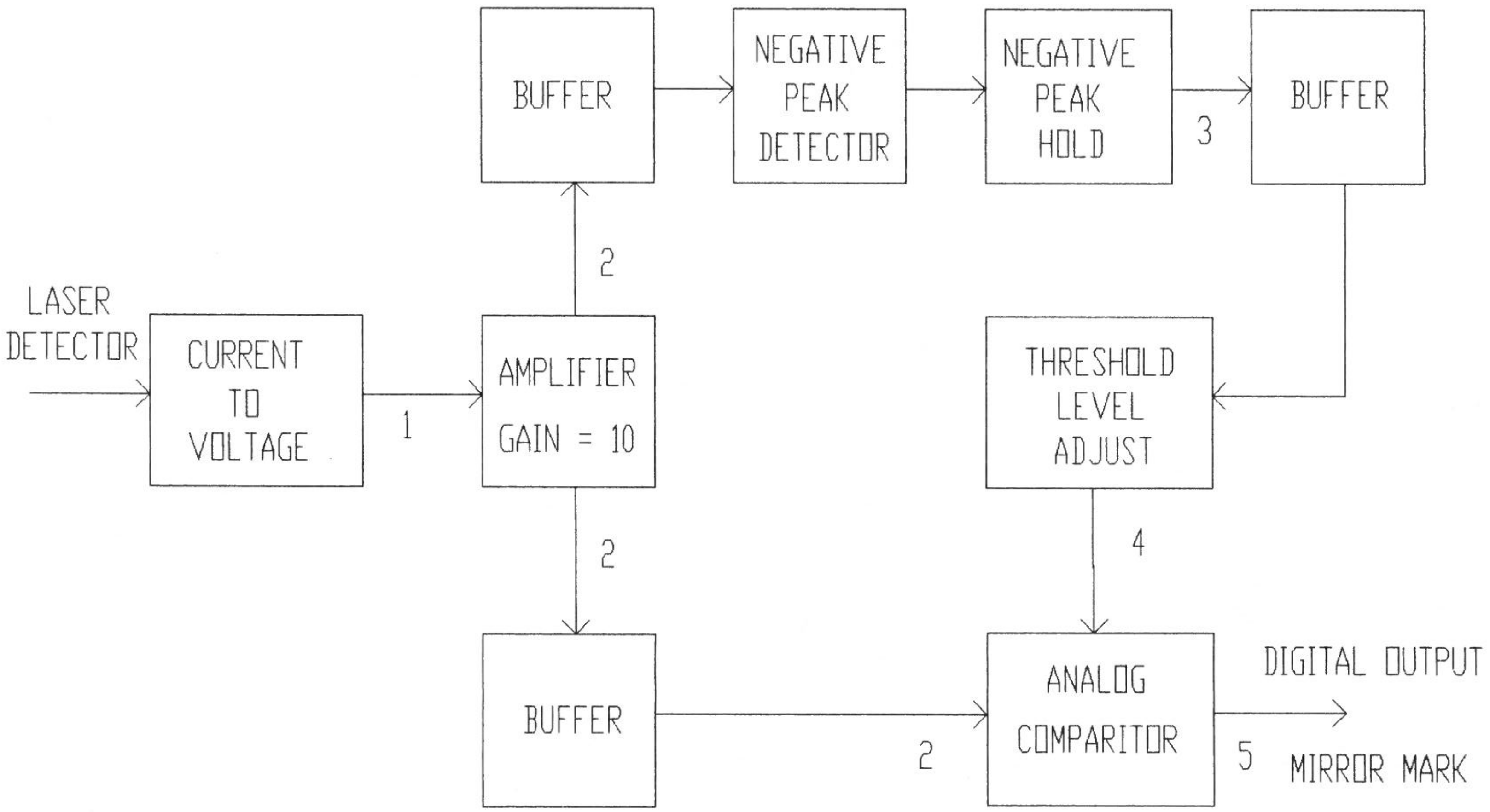


Figure 12

# Analog timing diagrams

## mirror mark channel

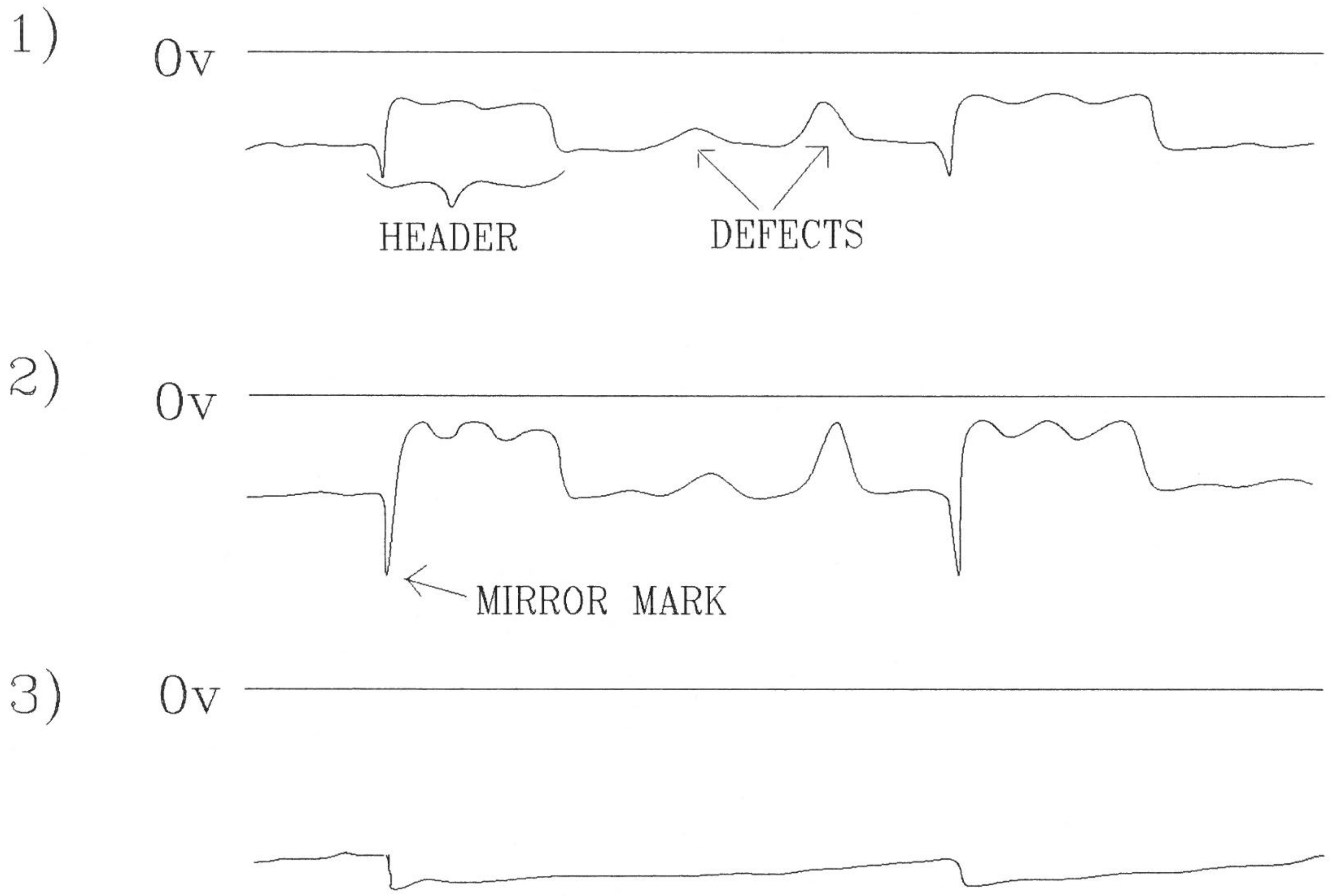


Figure 13

# Analog timing diagrams

mirror mark channel

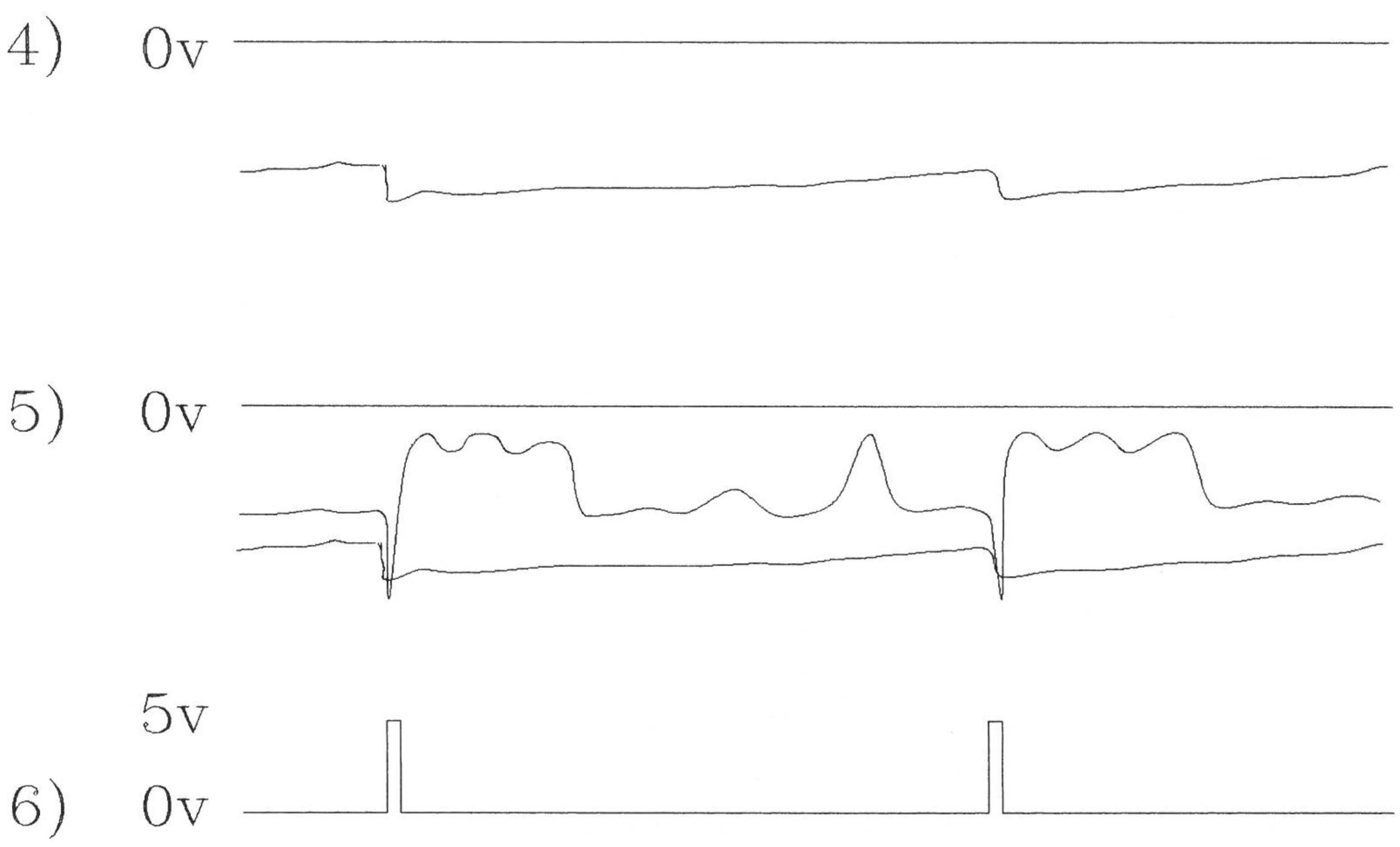


Figure 13

## Analog Transmission Channel:

The third analog signal that must be processed is the transmission signal. Figure 14 shows a block diagram of the analog transmission channel. The transmission channel signal depends on a diode detector which is placed behind the disk to measure the light transmitted by the disk. If laser light is transmitted, a transmission defect in the magnetic coating is indicated. The laser detector converts light information into current and in turn converted to a voltage, which is amplified approximately 18 times. Values for the analog transmission channel are not as critical as values for the other channels. Light either passes through the disk or it doesn't, so whenever there is a transmission defect the detector will be saturated. Following the amplifier, the signal is split and buffered. One component is low pass filtered at about 40 kHz, creating a signal of average level and without defects. The signals corresponding to points in Figure 14 are shown in Figure 15. At element 4, the signal's level is adjusted using a simple trimpot and buffer circuit. The low pass filtered signal and the signal from point 2 are compared using an analog comparitor. The comparitor outputs a digital +5v signal when the signal at point 2 drops below the signal level at point 4. This output is then sent to the digital circuitry for further analysis.

## Analog timing diagram
### transmission channel

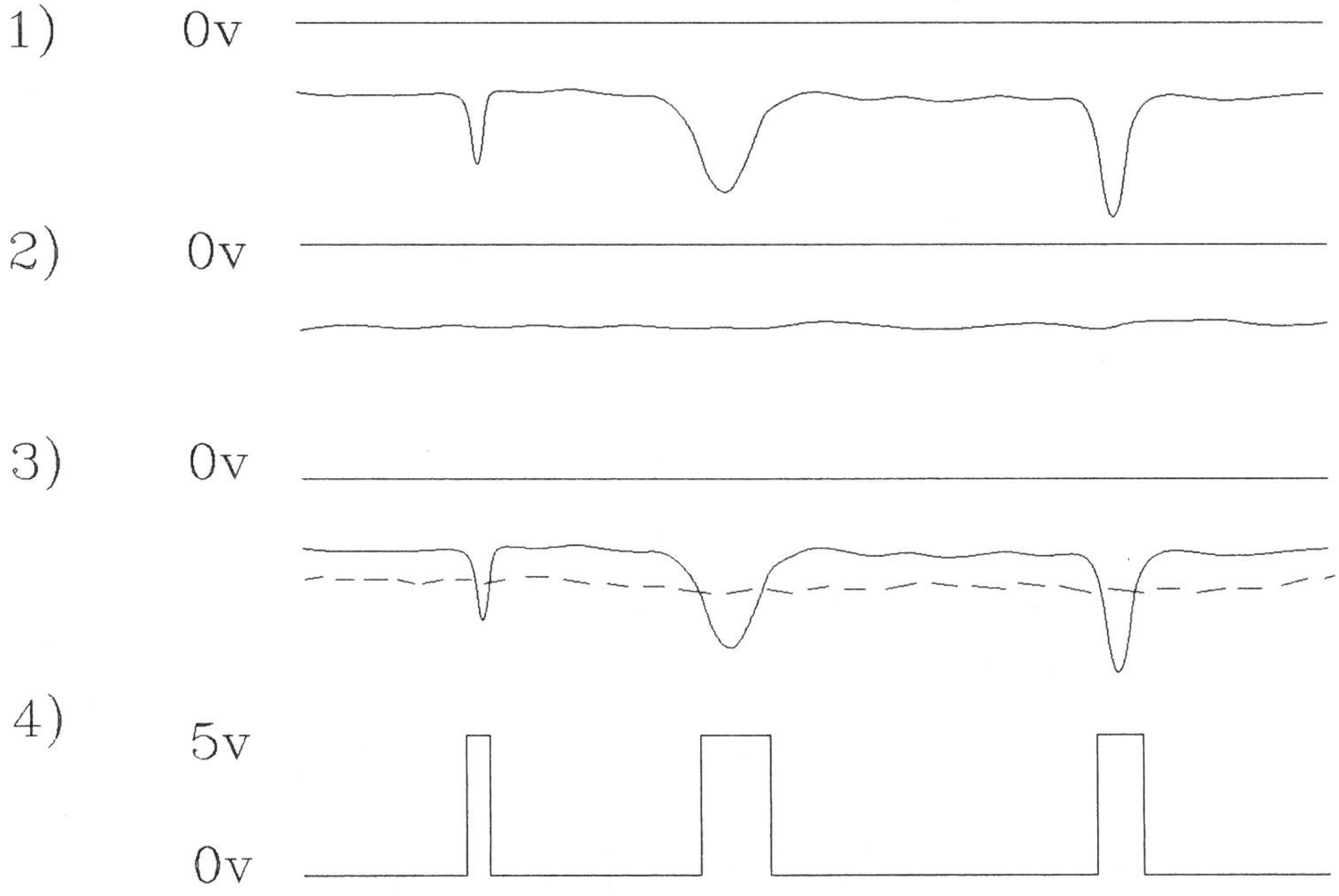


Figure 15

# DIGITAL ELECTRONICS

## Digital Signal Processing:

The digital electronics has three main sections. A block diagram of the main digital sections is shown in Figure 16. The digital circuitry for the reflectivity and transmission channels measure the width of the defects in microseconds and send the data to the CAMAC interface, which in turn sends it to the computer for human interface. The third section is the header cutting circuitry. This circuitry ensures that headers are not counted as reflectivity defects.

# Electronics Block Diagram

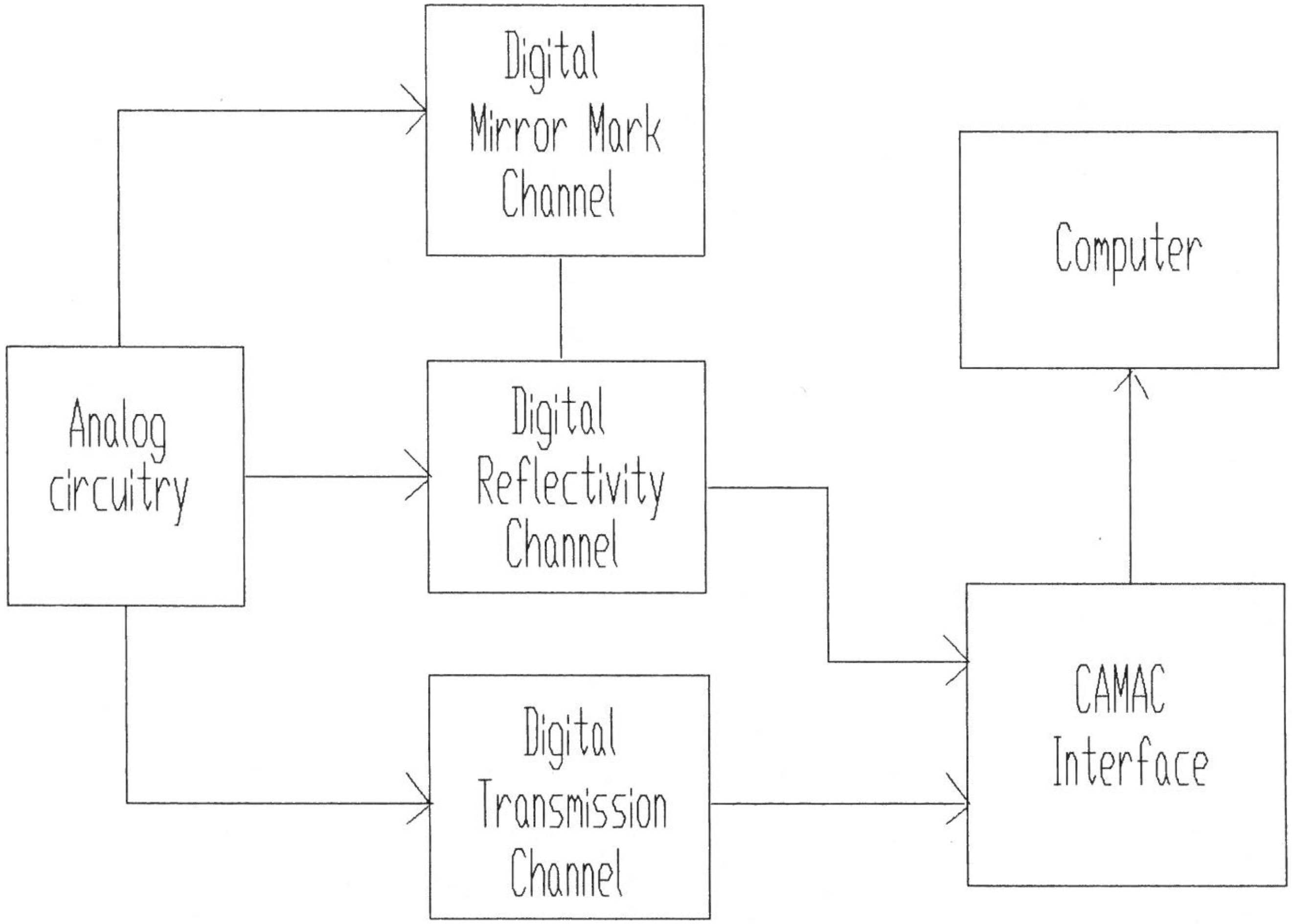


Figure 16

## Digital Reflectivity Channel:

Figure 17 shows a block diagram of the digital reflectivity channel. Curve 1 in the digital timing diagram of Figure 18, shows a typical input signal for the reflectivity channel, input at point 1 on Figure 17. First any noise and very short pulses must be filtered out of the signal. Any signal less than 50 nsec will be filtered out as shown in curve 2. All curves of Figure 18 correspond to their respective points shown in Figure 17. The filtered signal is fed into a clock that will count at 5 MHz for the time that the defect is present (see curve 3). The clock signal is counted using a digital counter, which provides a representation of the defect size. The signal is sent to the CAMAC interface for potential storage into RAM. The delay between point 2 and the digital counter is present so that two defects which are close together will not confuse the circuitry. The delay disables the digital counter for a few nanoseconds after detection of a defect, so the circuitry can record the defect size and reset to prepare for more defects. There are two digital comparitors in the circuitry; one to check for an overflow and another to ensure that recorded defects are at least 1 usec in size. The digital counter can only count so high, so a check must be put in to disable the clock if a defect is too large. A check must also be included to make sure the defect is at least 1 usec in size, so that noise does not get counted as defects. Defects less than 1 usec have been determined to be harmless. The signal from the

# DIGITAL CIRCUIT BLOCK DIAGRAM
## REFLECTIVITY CHANNEL

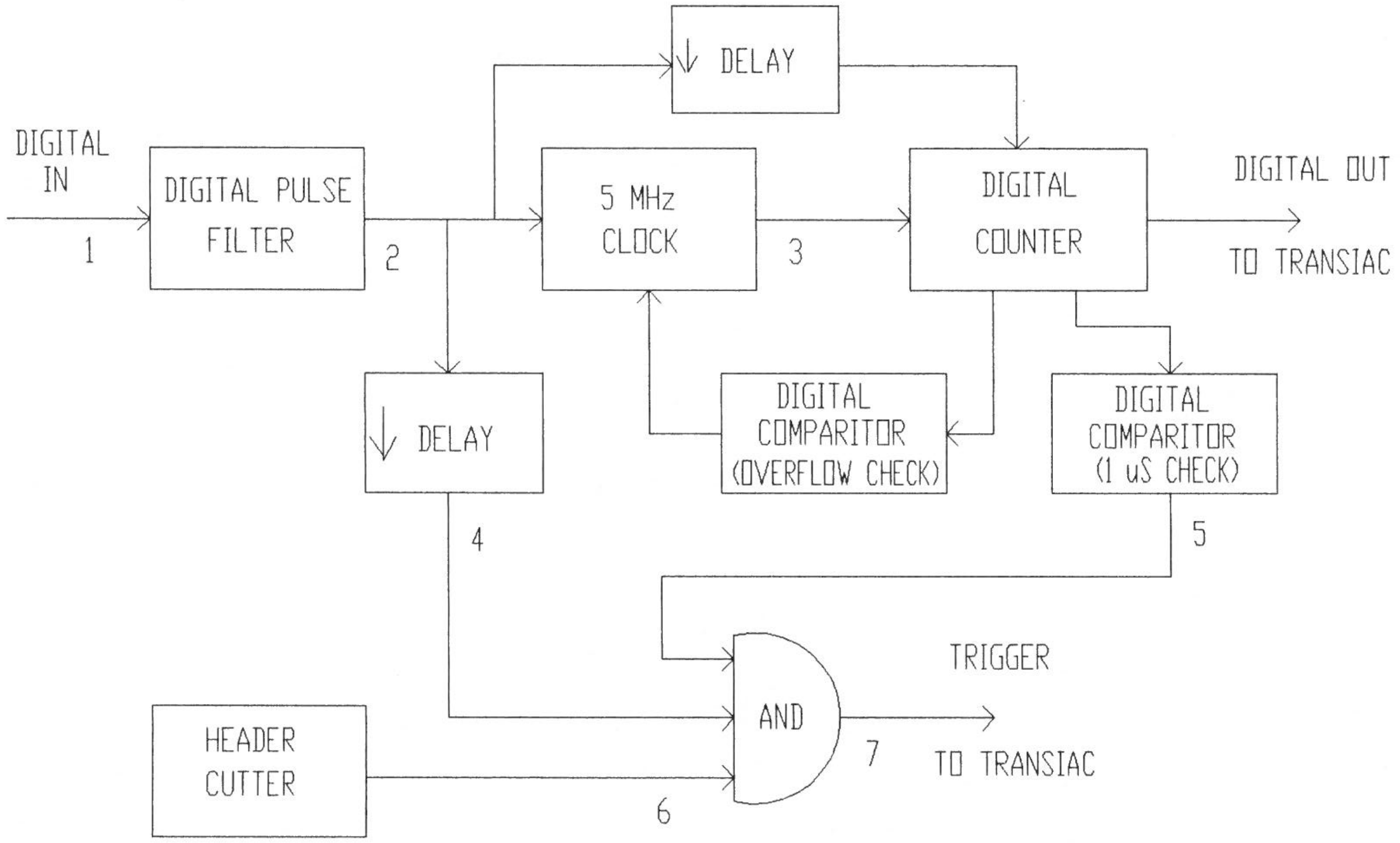


Figure 17

# Digital Timing Diagrams

## Reflectivity channel

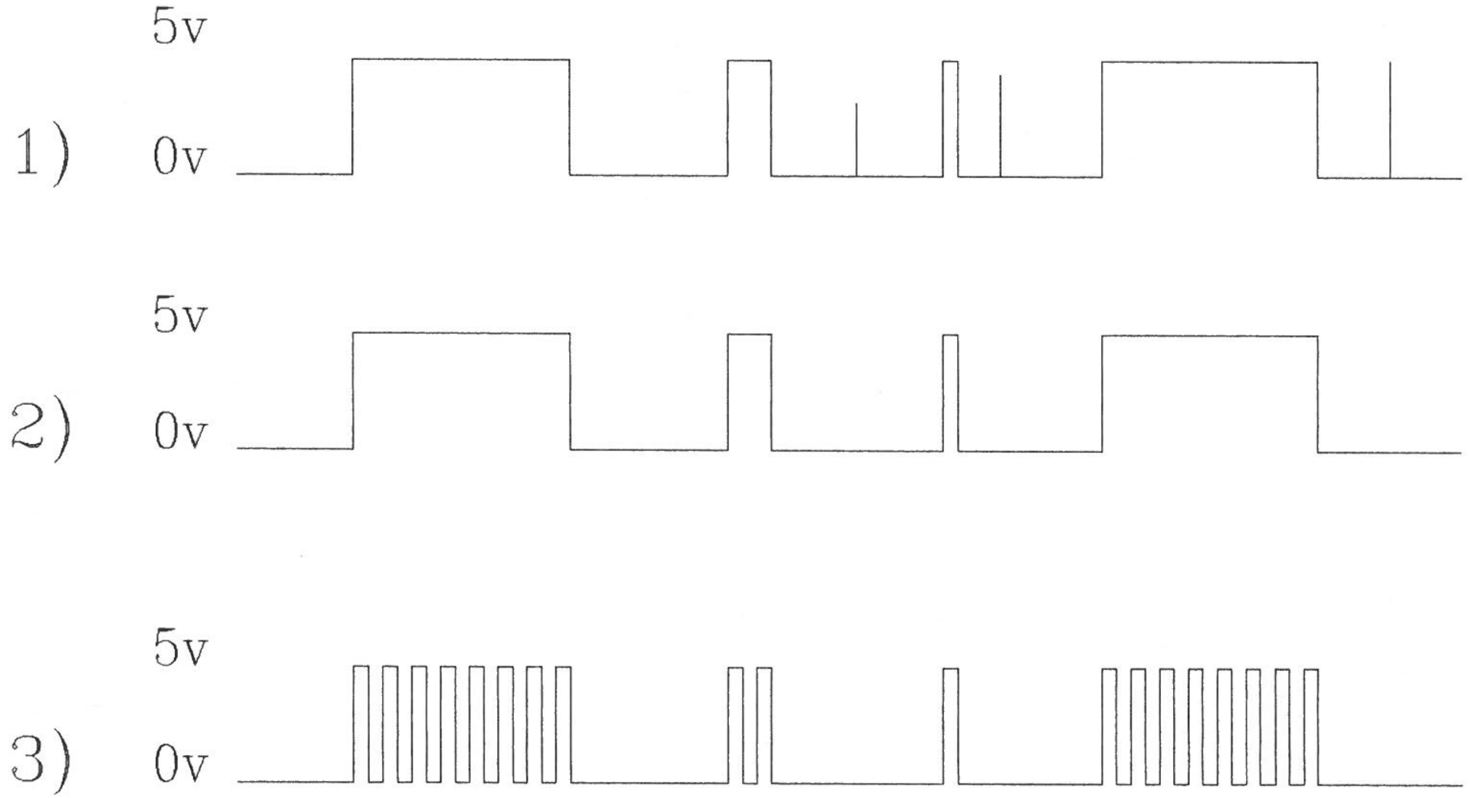


Figure 18

## Digital Timing Diagrams

### Reflectivity channel

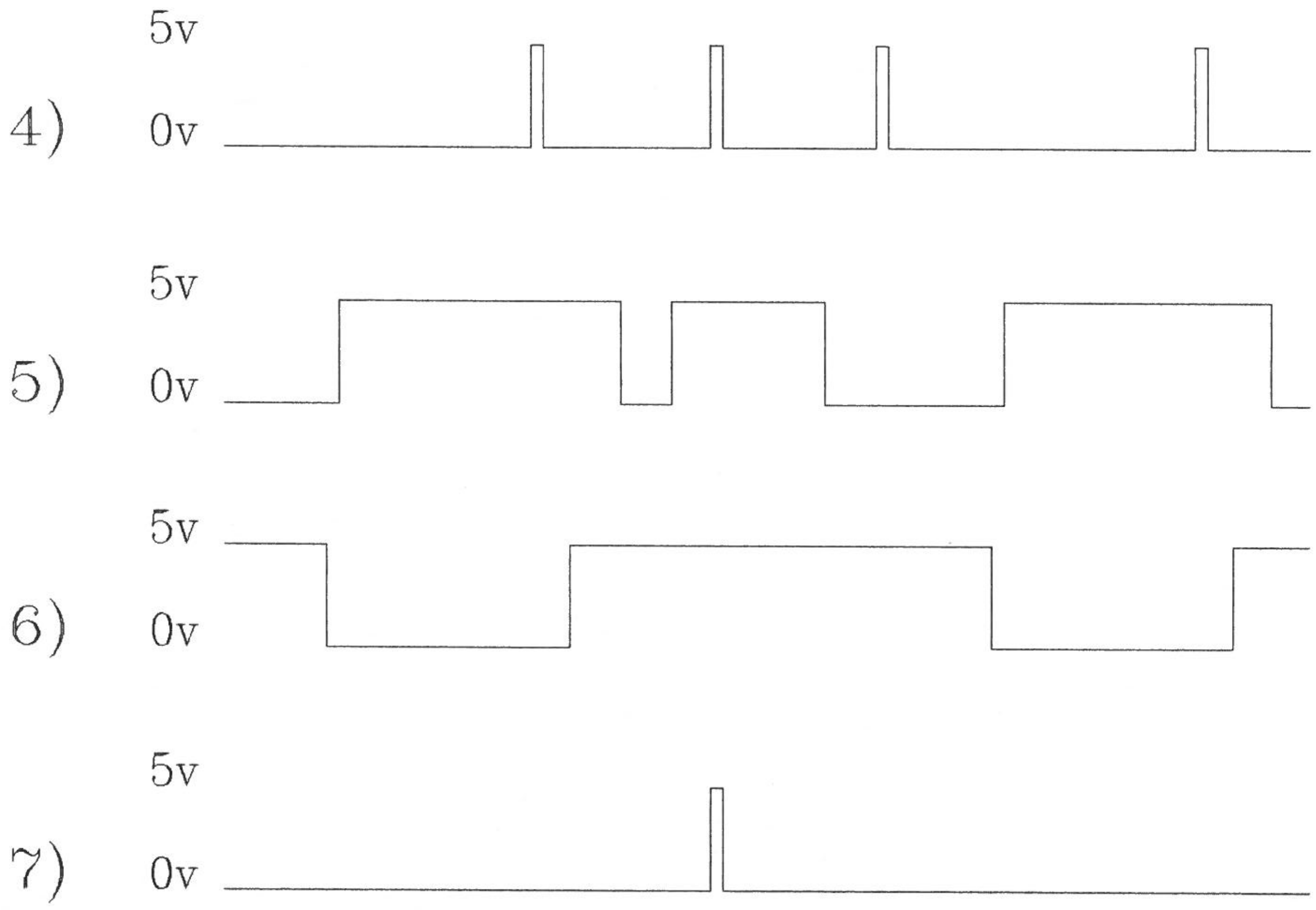


Figure 18

1 usec digital comparitor check is shown in curve 5. This signal goes high once the defect has reached 1 usec, staying high until the circuit is reset for that defect. It is then sent to an "AND" gate to be "ANDED" with the two other signals. A signal from point 2 is sent at the end of each defect to the "AND" gate (see curve 4). The header cutter signal from the mirror mark channel is also sent to the "AND" gate. This signal goes low when a header is encountered so that it is not recorded as a defect. A typical header signal is shown in curve 6. After "ANDING" signals 4, 5, and 6, a final output signal, signifying a defect, is sent to the CAMAC interface to trigger the memory to store the defect size from the digital counter. It can be seen from curves 4, 5, and 6 that the headers are not counted, nor are defects of less then 1 usec.

## Digital Mirror Mark Channel:

The next channel of importance is the digital mirror mark channel. A block diagram of this channel is shown in Figure 19. The digital mirror mark channel accepts the digital signal from the analog mirror mark channel and looks for pulses signifying mirror marks. A typical input to this channel is shown in Figure 20 (curve 1). The first step requires filtering the signal using a digital pulse descriminator. Pulses of less then 50 nsec will be filtered out (curve 2, Figure 20). This filtered signal is then sent through a pulse detector circuit, which looks for pulses and then sends out a signal triggering a one-shot to go low for a preset amount of time (Figure 20, curve 3). The signal from the one-shot is sent to the "AND" gate of Figure 17, causing the output of the "AND" gate to go low everytime a mirror mark is encountered. Triggers caused by a header will not trigger the transiac, therefore headers are ignored. Figure 20 also shows header cutters for ZCAV 1024 and ZCAV 512. ZCAV 1024 and ZCAV 512 are two additonal disk format types. The headers of these disks are not as easy to cut out and require more complex circuitry. To keep the length of this paper within reason, the calculations and discussions on ZCAV formats have been omitted.

# Digital Circuit Block Diagram
## Mirror Mark Channel

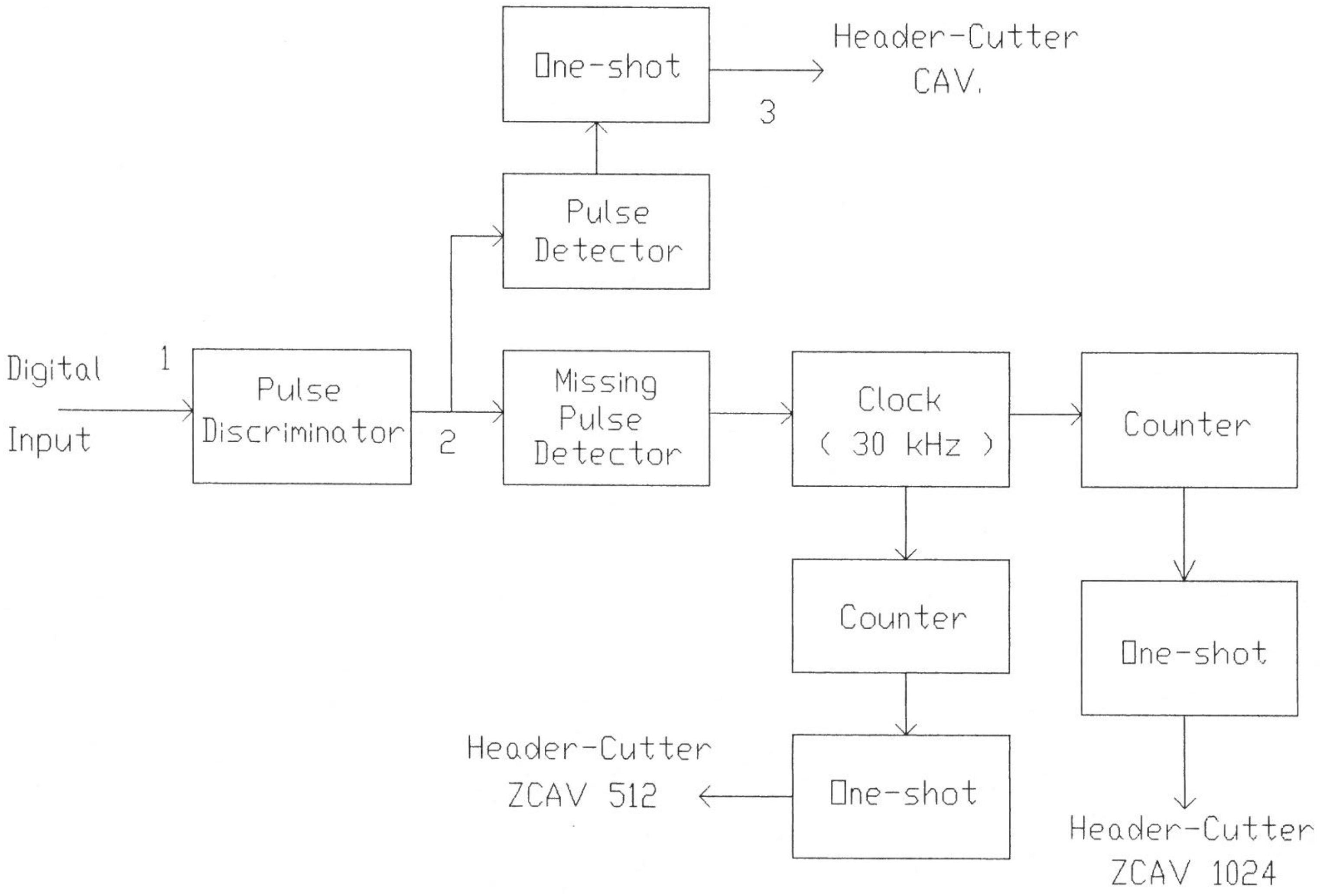


Figure 19

# Digital Timing Diagrams

## Mirror Mark Channel

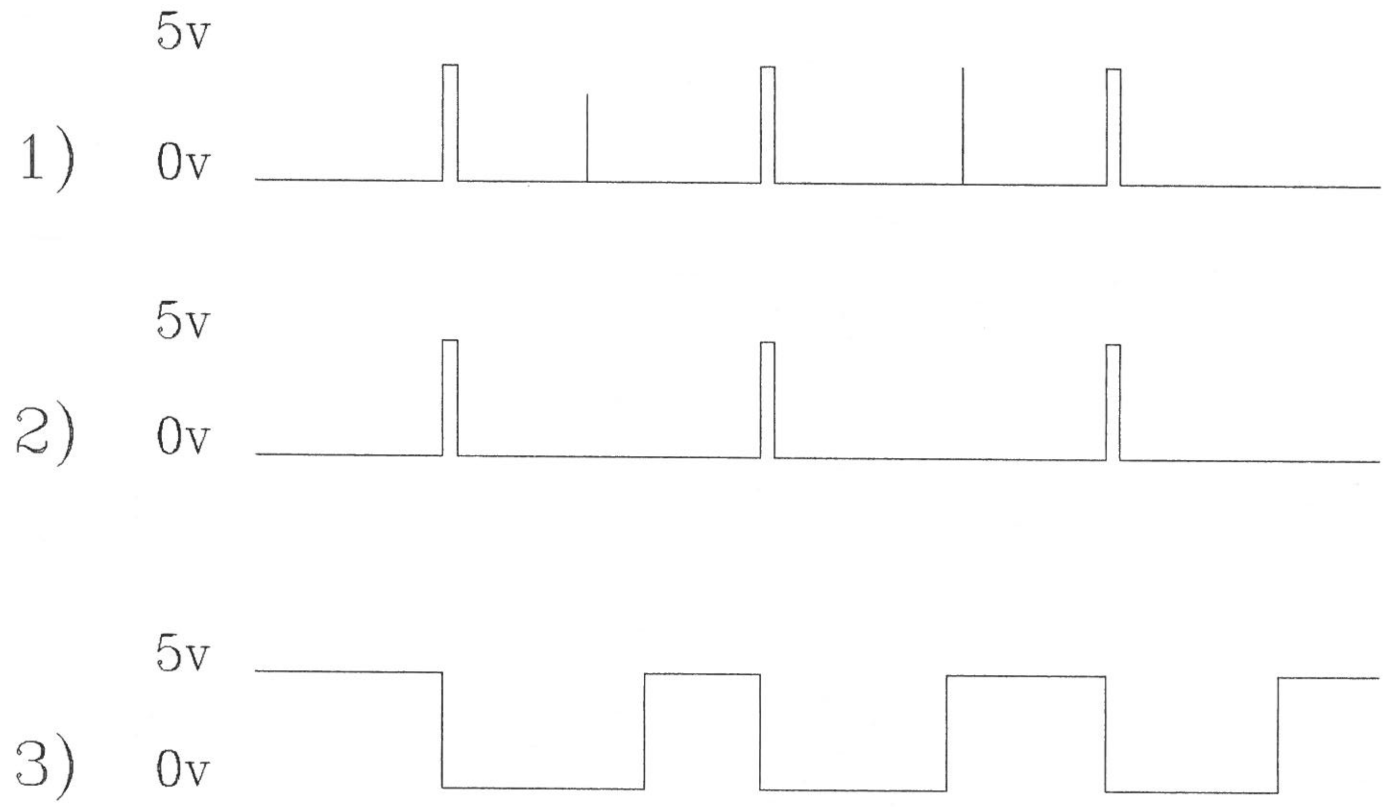


Figure 20

## Digital Transmission Channel:

The digital transmission channel is quite similar to the digital reflectivity channel. A block diagram of the digital transmission channel is shown in Figure 21. The main difference between the two channels is the input signal from the analog transmission channel. The input signal does not have headers in it, since only light that is passed through the disk is analyzed, and light gets through only when there is a hole in the magnetic coating of the disk. A typical input is shown in Figure 22, curve 1. This signal is filtered by a digital pulse discriminator. Any pulse less than 50 nsec is filtered out to eliminate noise. Curve 2 of Figure 22, shows an example of this signal after filtering. The filtered signal is fed to a 5 MHz clock, enabling the clock during defects. A digital counter counts the number of pulses and sends it to the CAMAC interface for possible storage to RAM. This number is a representation of the defect size recorded in microseconds. There is a delay between point 2 and the digital counter to allow the electronics time to reset between defects and to store the size of the defect to RAM. There are two digital comparitors: one for an overflow check and one to ensure that each defect is at least 1 usec in length. The overflow check disables the clock immediately before the digital counter wraps around, the 1 usec check makes sure the defect is at least 1 usec long. If a defect reaches 1 usec the digital comparator outputs a high signal (Figure 22 , curve 5). Defects of size less than 1 usec do not cause

# DIGITAL CIRCUIT BLOCK DIAGRAM
## TRANSMISSION CHANNEL

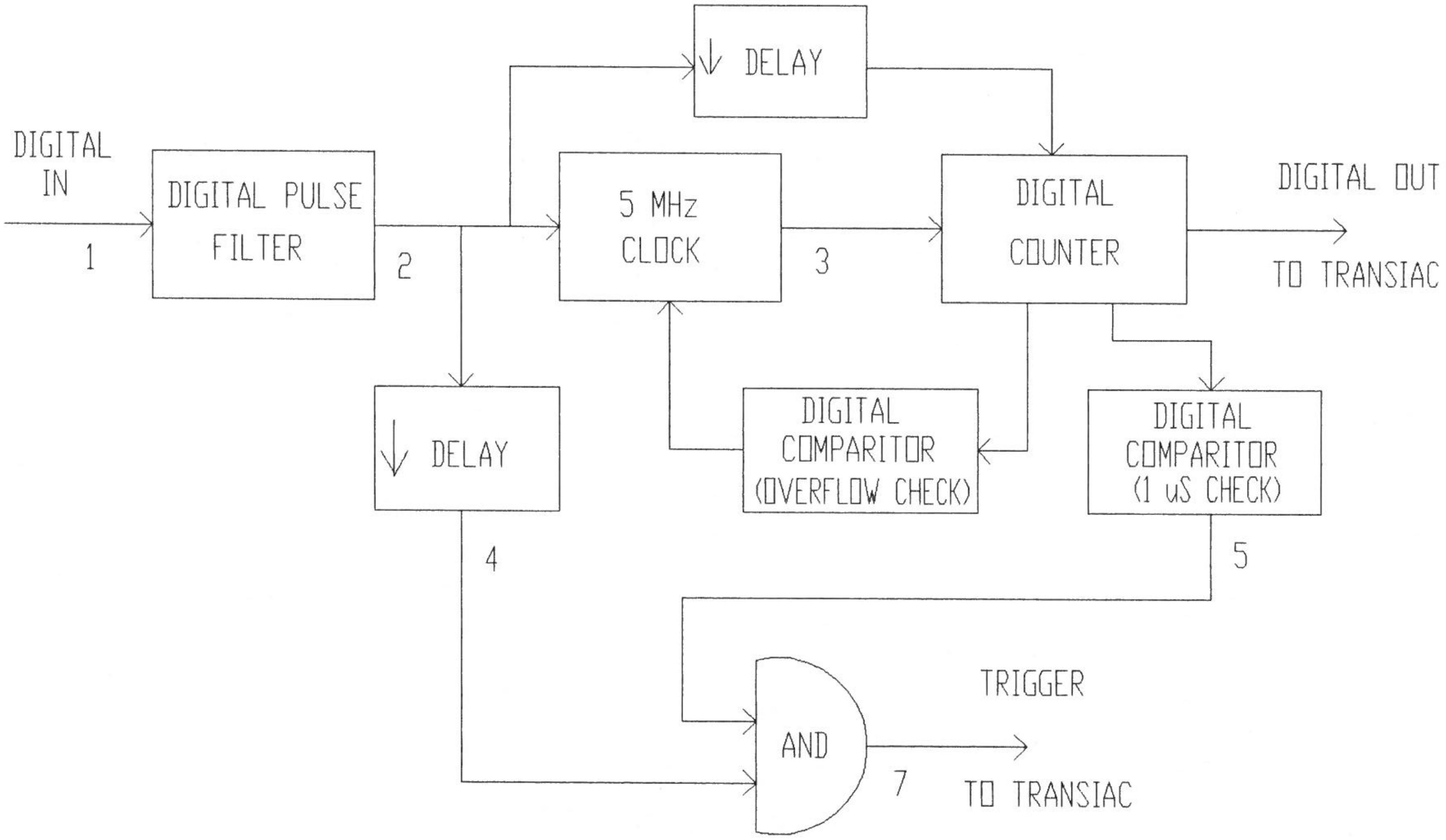


Figure 21

# Digital Timing Diagrams

## Transmission Channel

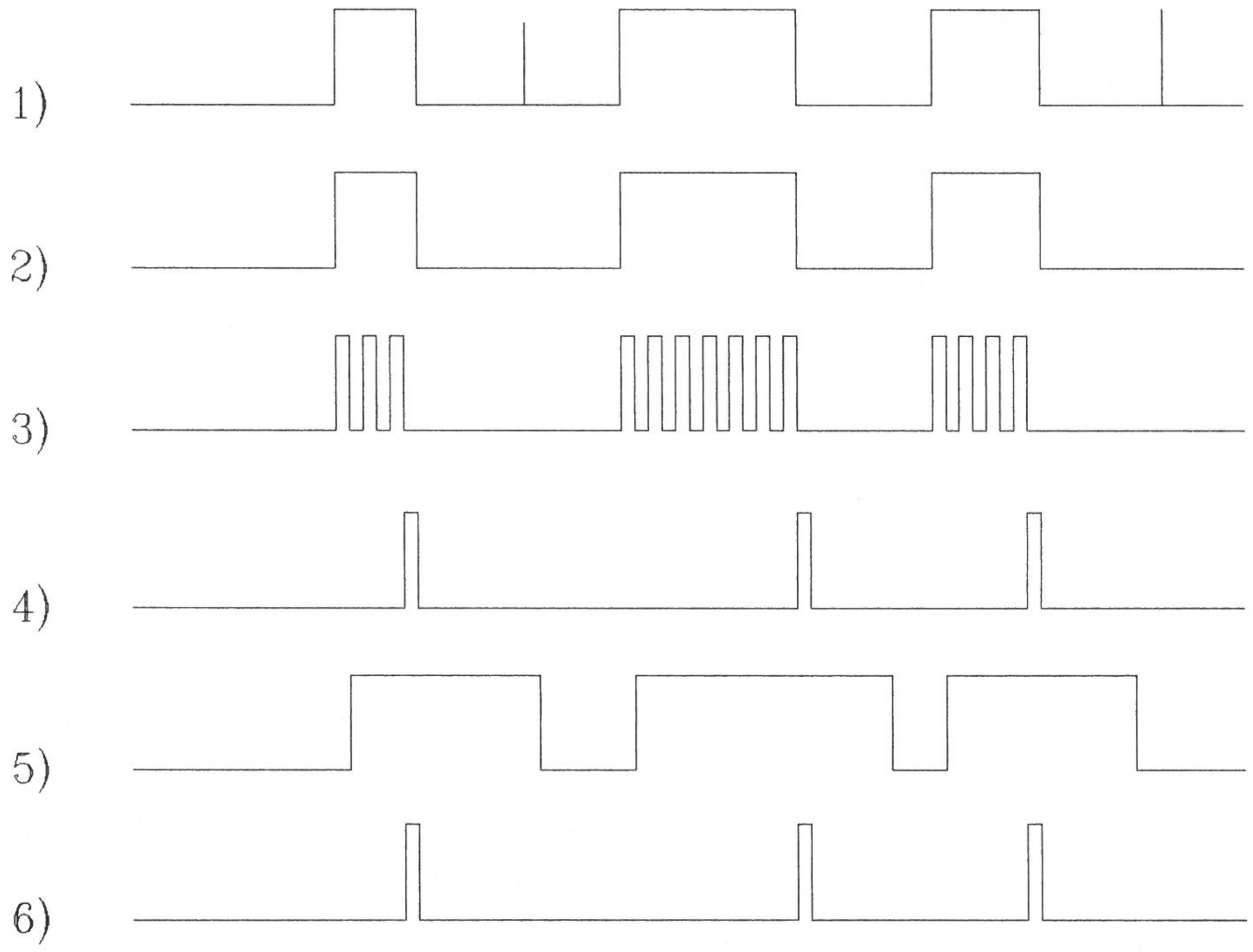


Figure 22

problems in reading and writing the disk, and they could also be the result of noise. The signal from point 2 is fed to a delay that will go high at the end of each defect. This signal is shown in Figure 22, curve 4. The signal at point 4 and point 5 are "ANDED" together producing a trigger for the CAMAC interface (as shown in Figure 22, curve 6). This signal triggers the CAMAC interface to store the value from the digital counter in its memory.

# REPEATABILITY TESTS

Once the building of the tester was complete, the next step was to prove that it was reliable. Therefore, before any correlation studies were conducted, a repeatability study was completed.

In order to study the variations of the tester and its repeatability, two different tests were run. One test was run with four disks over a five day period to check for variations in the electronics of the tester. Another test, of both transmission and reflectivity defects for repeatability, was run using one disk over approximately 2 months (the middle of March to the beginning of May, 1989).

Repeatability Graph A, Figure 23 shows the results of the repeatability tests of four disks which were run several times per day over a five day period. Disks with a wide range of reflectivity defect totals were chosen (600 -2111 defects). Four different disk formats were used to demonstrate repeatability on all types of disks. Each disk tested repeatable to less than +/- 15%. The test's over all repeatability was approximately +/-10%.

Repeatability Graph B, Figure 24 shows the same four disks run during a two day test for transmission defects. These disks tested repeatable to approximately 35%. Because the transmission defect counts were low, a small variation

## Repeatability Graph (A)

### Reflectivity

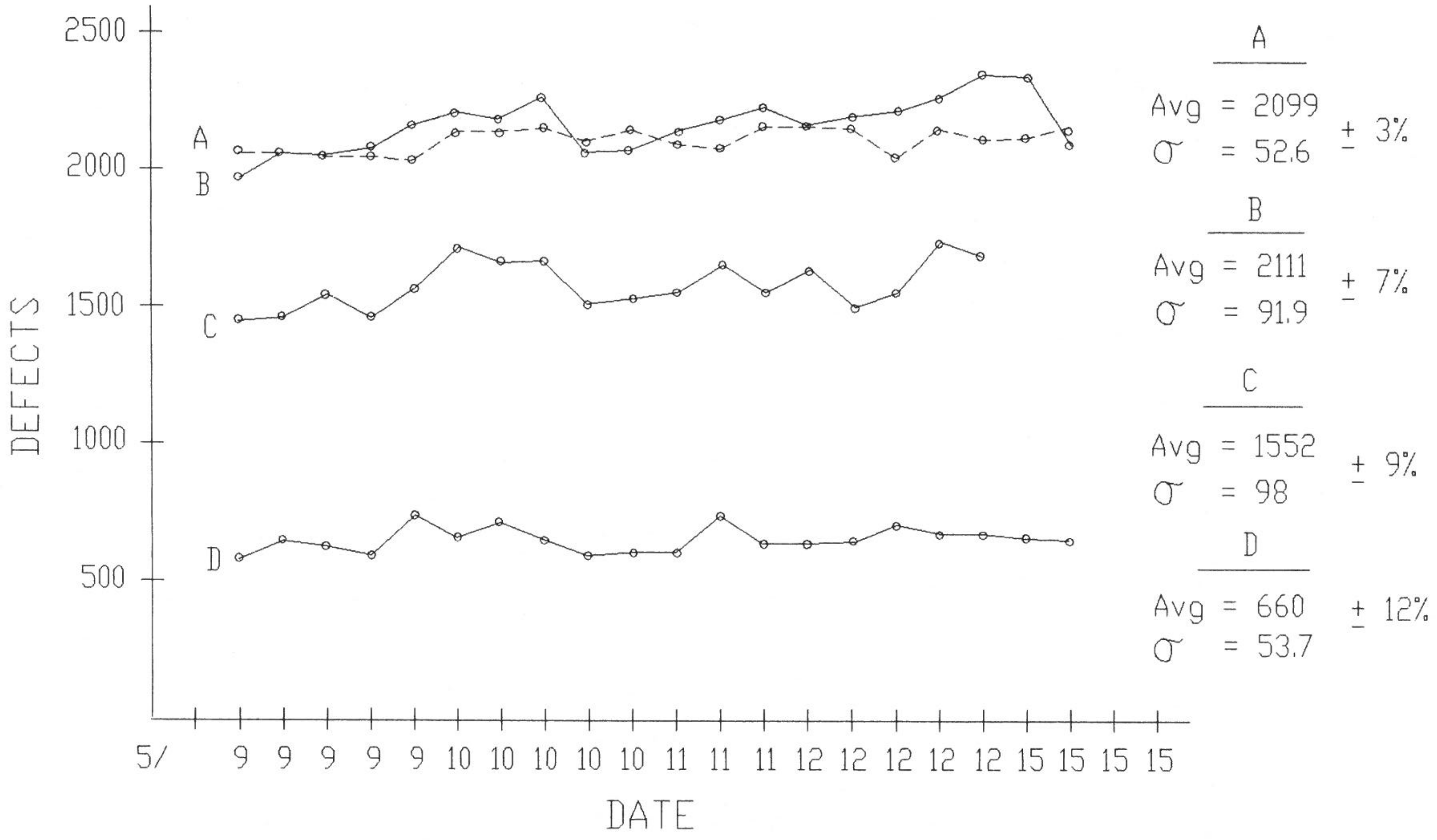
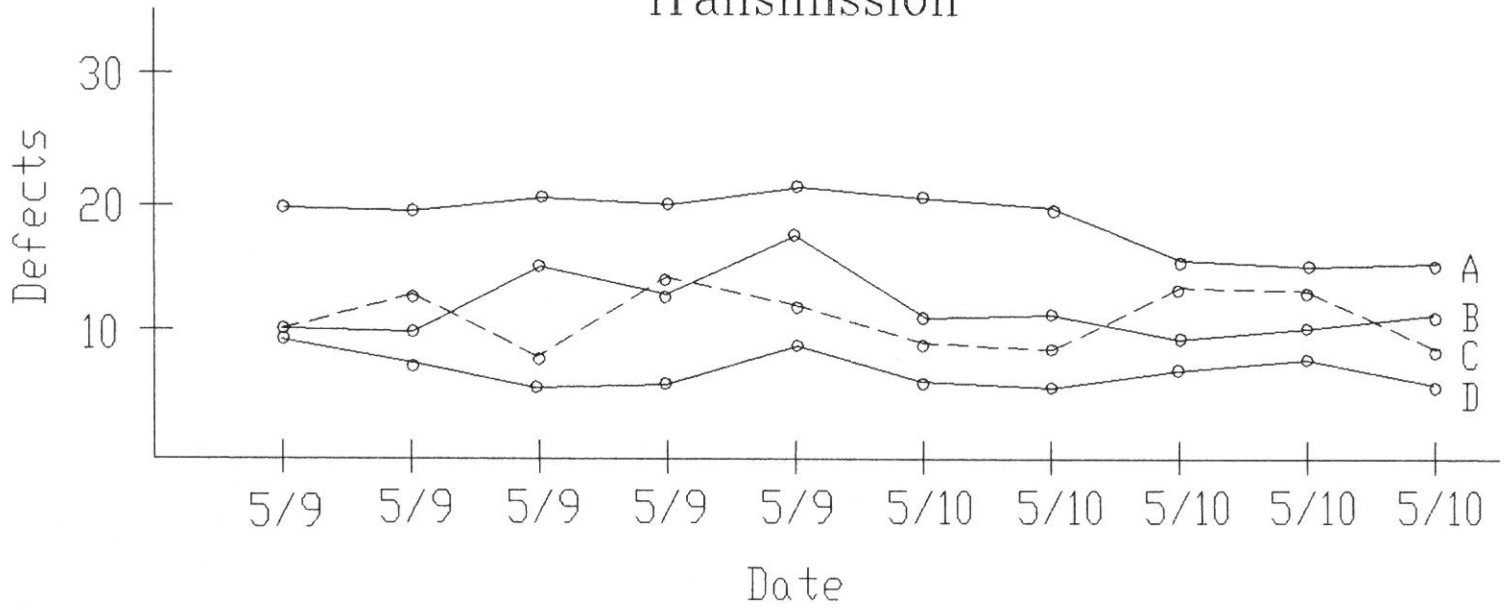


Figure 23

# Repeatability Graph (B)

## Transmission



**A**

Avg = 19 ± 20%
σ = 2.9

**B**

Avg = 11.5 ± 36%
σ = 3.1

**C**

Avg = 10 ± 32%
σ = 2.6

**D**

Avg = 6.9 ± 13%
σ = .93

Figure 24

caused a large percent error.

Repeatability Graph C, Figure 25, shows the results of the long term repeatability test. This disk has been tested various times over a 2-1/2 month period (middle of March through the first of May, 1989). Over this period the disk tested repeatable to about +/- 3%.

These three graphs show that the electronics and optics of the tester are reliable. The tester is now ready to be correlated with the Mirrorless Tester, the current standard.

Repeatability Graph (C)

Reflectivity

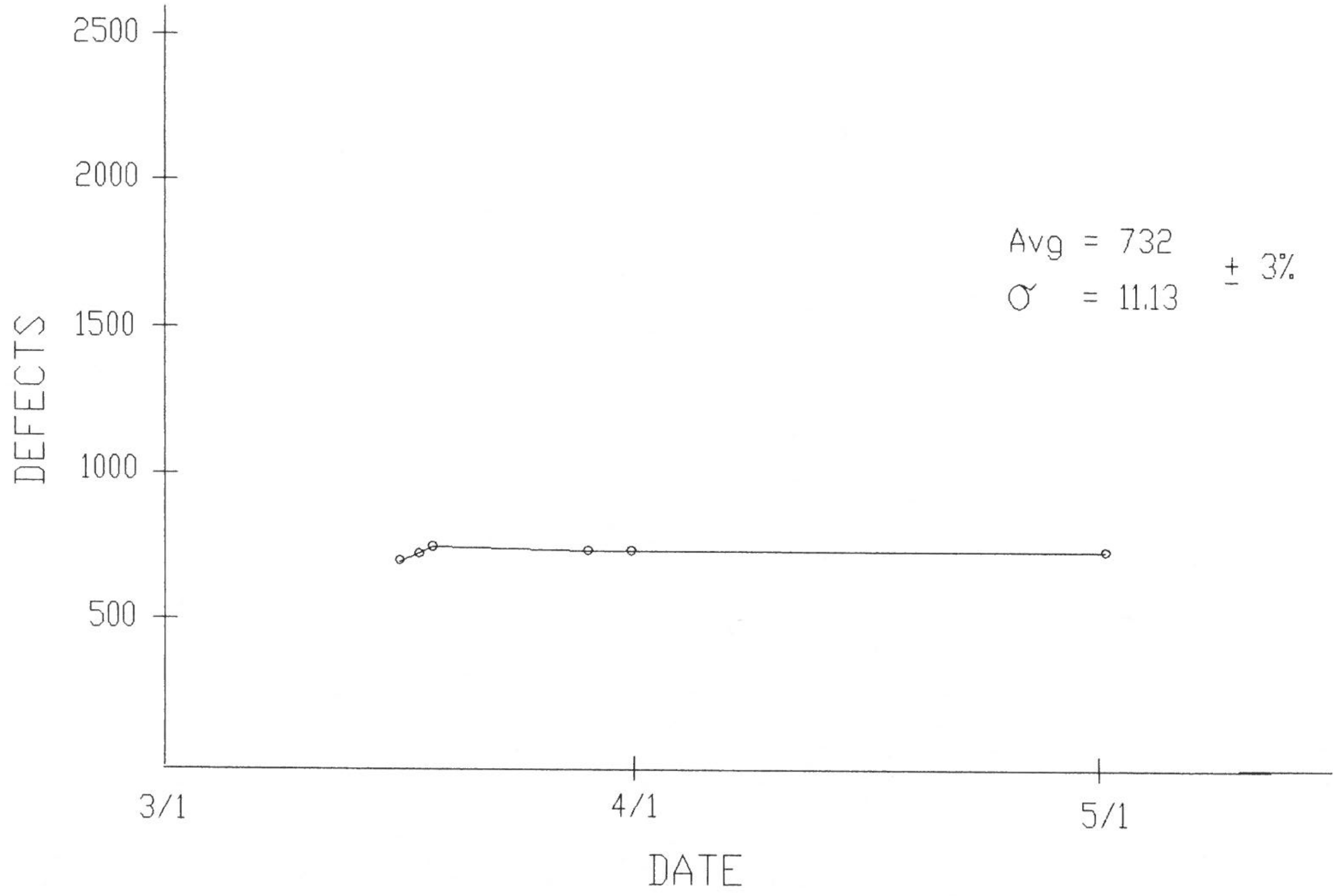


Figure 25

# CORRELATION STUDIES

The most important part of this project was to show that the Large Beam Scanner could provide valuable and meaningful information. The easiest way to do this was to correlate the results of the Large Beam Scanner with those of a reliable and proven tester. Because magneto-optic disks were still in the development stage, there was no tester that was completely trusted. The best tester available was a small beam tester (1um), the Mirrorless Tester.

The ultimate test of a tester is to predict the performance of a disk in an actual player. During the development of the disks, players were not available. So, all correlation efforts were focused around the Mirrorless Tester. The Mirrorless Tester was proven to be accurate to about +/- 15%, and was assumed as the standard. Testers were used basically to define the manufacturing and developmental progress of the disks. Once players were available for the disks there seemed to be no significant correlation between the Mirrorless tester and the readability and recordability of the disks on an actual player. But the Mirrorless Tester was invaluable at providing information about the manufacturing process of each disk. The following will discuss the testing procedure and results of the correlation studies.

At the end of a 30 second scan, the Large Beam Scanner is capable of displaying and printing both the number and the size of reflectivity and transmission defects. The defects are then binned in six categories according to the size of the defect, in the following manner:

| Small | Medium | Large | X-Large | Bigger | Jumbo |
|---|---|---|---|---|---|
| 1-5us | 5-10us | 10-15us | 15-20us | 20-25us | 25-50us |

A total defect count is also included.

One method of correlating a small beam scanner with a large beam scanner is to simply compare total defect counts. This may seem unlikely at first because a large defect might cover many tracks and be read as many defects by a small beam scanner, where as a large beam scanner would count the defect as only one large, or X-large defect. This is true, but the correlation does not have to be on a one to one basis. We simply want to know that both testers detect the same population of defects. Therefore, we are looking for any reasonable straight-line correlation between defect totals detected by the two scanners.

As the disks are being developed and changes are being made, manufacturing trials are conducted in the clean rooms with the new "formulas" or "recipes". Each month several hundred disks are made and submitted to testing to determine if a particular process has improved. Many different tests are run on these disks, but not all tests can be run on all disks, as tests take too much time and money to conduct.

All of the disks that were scanned by the Mirrorless Tester were also scanned by the Large Beam Scanner during a period of two months. Results were calculated for the first month separately and for the two months together. These months were April and May,1989.

Data gathered during these two months were plotted on the two defect correlation graphs, Figures 26 and 27. Total defect counts of the Mirrorless Tester were plotted against the total defect counts of the Large Beam Scanner. A straight line with a slope of 0.47 and a Y-intercept of 227 was found to best fit the data. This suggests the Mirrorless Tester will detect defects that the Large Beam Scanner will not detect. If the line is forced through the origin, a slope of 3/5 is found without as good a fit. This is also shown in Figures 26 and 27. A correlation factor of 0.7 was calculated.

Some possible reasons for the correlation obtained are:

1) The Mirrorless is repeatable to about +/- 15%
2) The Large Beam Scanner is repeatable to about +/- 10%
3) Defect size must be taken into consideration, in addition to defect total.
4) The Mirrorless Tester may be sampling a different population of defects, or a different portion of the same population.

The repeatability graphs of Figures 26 and 27, show a

# Defect Correlation Graph (A)

April

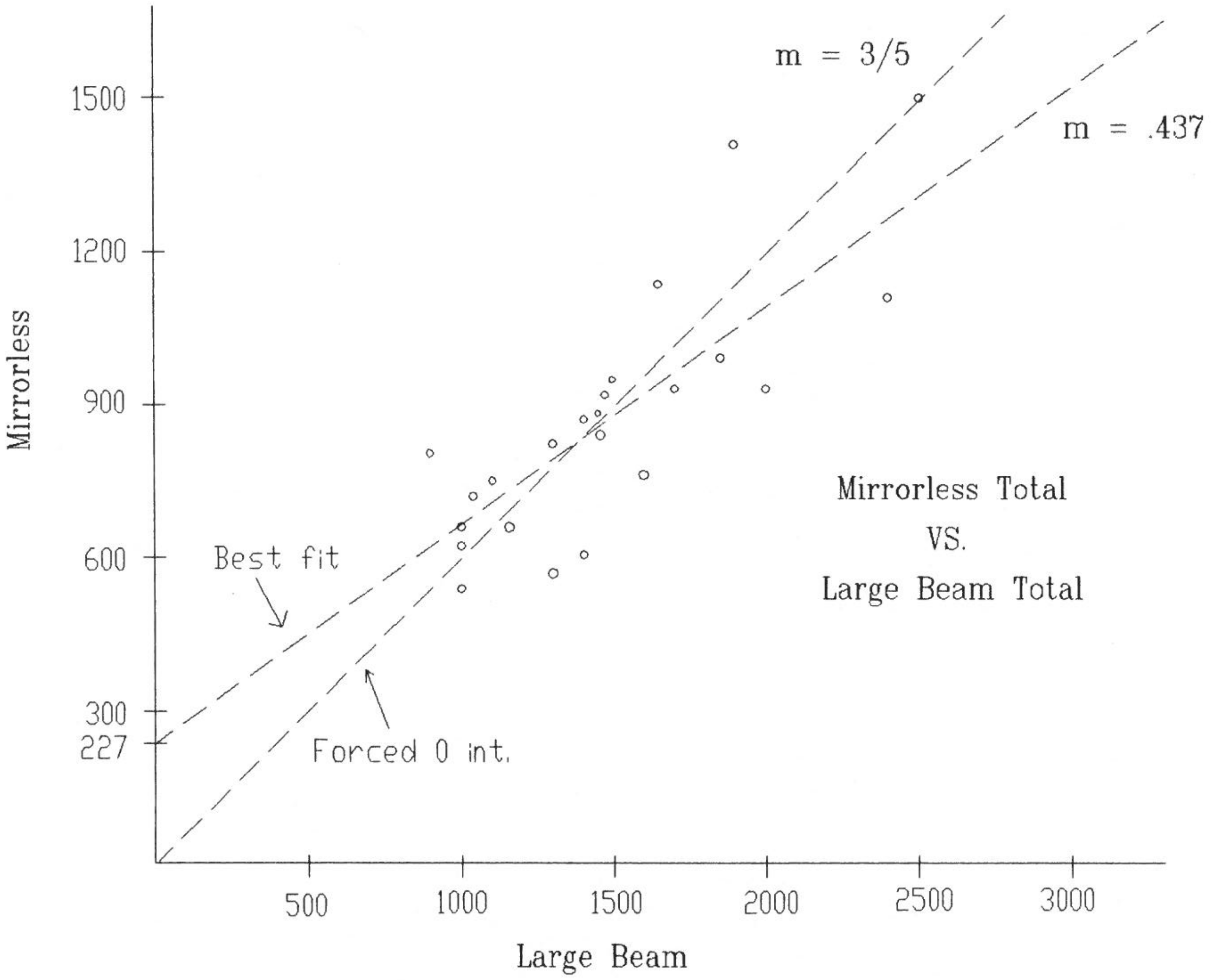


Figure 26

# Defect Correlation Graph (B)

April and May

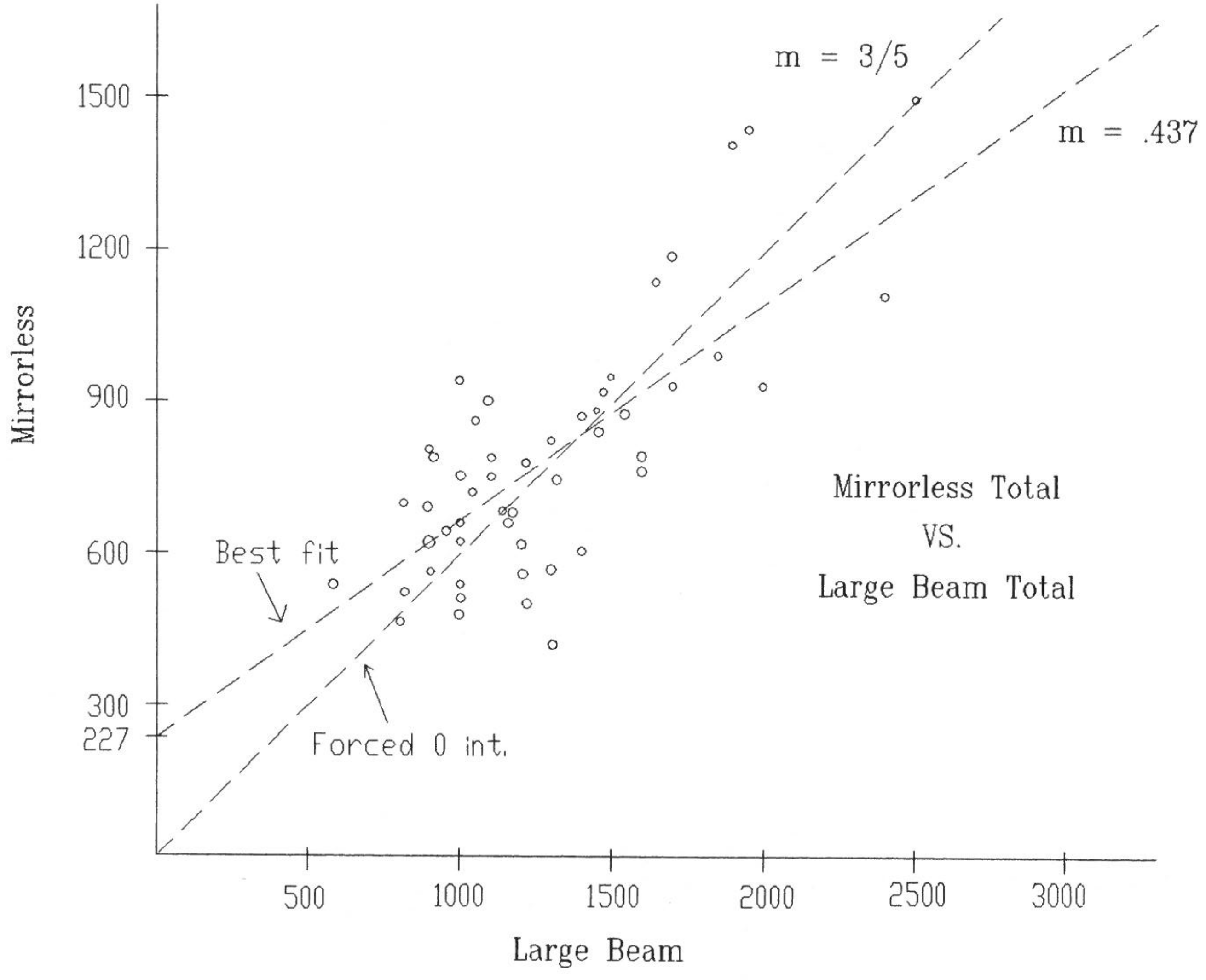


Figure 27

correlation between the Mirrorless Tester and the Large Beam Scanner, with a correlation coefficient of 0.7. Although this is not an excellent correlation, the Large Beam Scanner can definitely distinguish "good" disks from "bad" disks. The Large Beam Scanner is very repeatable, (approximately +/-10%). The data shows variations as low as +/-3% on one disk. One possible application of this tester would be a quick scan to distinguish good disks from bad disks. Good disks could then be tested with the Mirrorless Tester for a more precise defect count.

## CONCLUSION

This paper described the development of an alternative method for defect scanning magneto-optic media. A Large Beam Scanner was proposed to complement the use of the slow and complicated small beam scanner already in existence. An overall view of the system for a large beam scanner was presented with timing diagrams and block diagrams to help clarify the design. After a look at the overall design, the system was discussed in three major sections: the optics, the analog electronics, and the digital electronics. Although, these are only three of many major parts of the tester, important sections were omitted to keep the paper within reasonable length. The three sections presented in this paper are adequate to give the reader an idea of the work that went into designing and developing a Large Beam Scanner, without drowning them in unnecessary details.

The last part of this paper discusses results of tests conducted on and with the tester. The tester was first proven repeatable and then studied for meaningful results with a correlation study. The tester's electronics proved very solid and repeatable to approximately +/-10%. Previous testers reached only +/-15% repeatable. Finally the tester was correlated with a trusted small beam scanner to find out if the results of the large beam scanner yielded valuable information. A 0.7 correlation factor was calculated and correlation graphs presented.

The Large Beam Scanner is now being used for early warning of sputtering malfunctions in the manufacturing and developing of magneto-optic disks at Wilmington, Delaware. In as little as 30 seconds it can be determined if there are major problems with the manufacturing (sputtering) process. A large improvement has been made compared to the 12 minute test that was previously performed. The possibility now exists that the tester will be duplicated for use in an industrial environment at Kings Mountain, North Carolina, where plans for a magneto-optic disk plant are being considered.

# APPENDIX A

## Magneto-Optic Disk Theory

The family of erasable optical disks include both those that use a thermo-magnetic effect and those that use a phase change effect to record data. Here we will describe a thermo magneto-optic disk system. An example of the type of optical pick-up assembly used in a thermo magneto-optic system is shown in Figure 28.

The object of this appendix is to provide a brief overview of the theory of operation on magneto-optic (MO) erasable disks. There are two techniques for erasable optic recording. The first is based on the polar magneto-optic (MO) Kerr effect. The laser is linearly polarized and the circular birefringence causes the plane of polarization of the reflected light to rotate, (approximately .5 degrees). There is also circular dichroism of the MO material which introduces a small amount of ellipticity into the reflected light. This could also be used to detect the state of magnetization of the MO material, but we are only interested in the Kerr effect.

The MO disks are coated with a magnetic film which permits magnetic recording perpendicular to the disks surface. The disk is considered to be erased when the entire surface is magnetically oriented in the same direction (Figure 29a). A magnetic field is applied to the surface and a laser is focused to a point on the disk, raising the temperature of the

# Optical System of Magneto-Optic Disk System

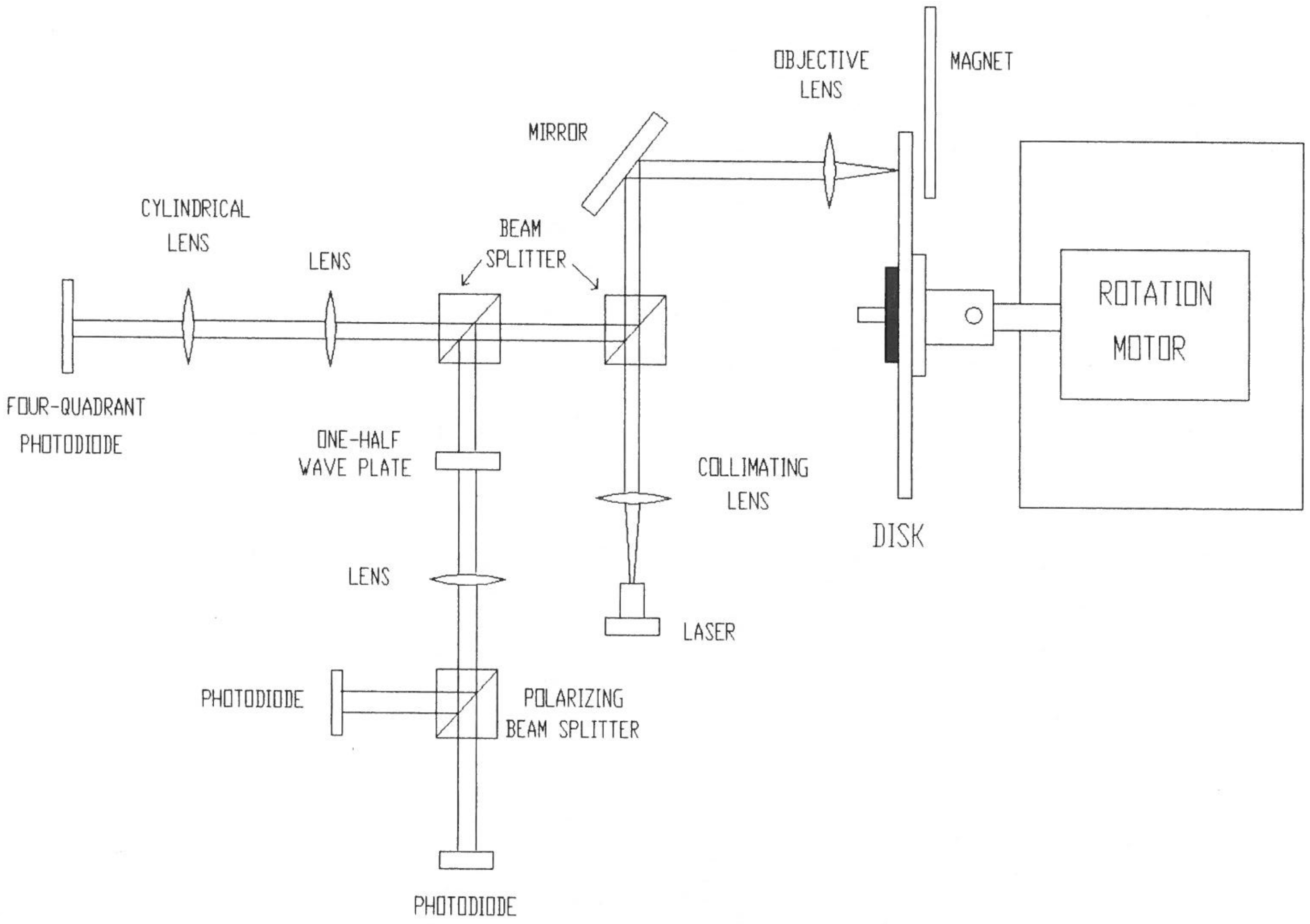


Figure 28

# Recording Principle

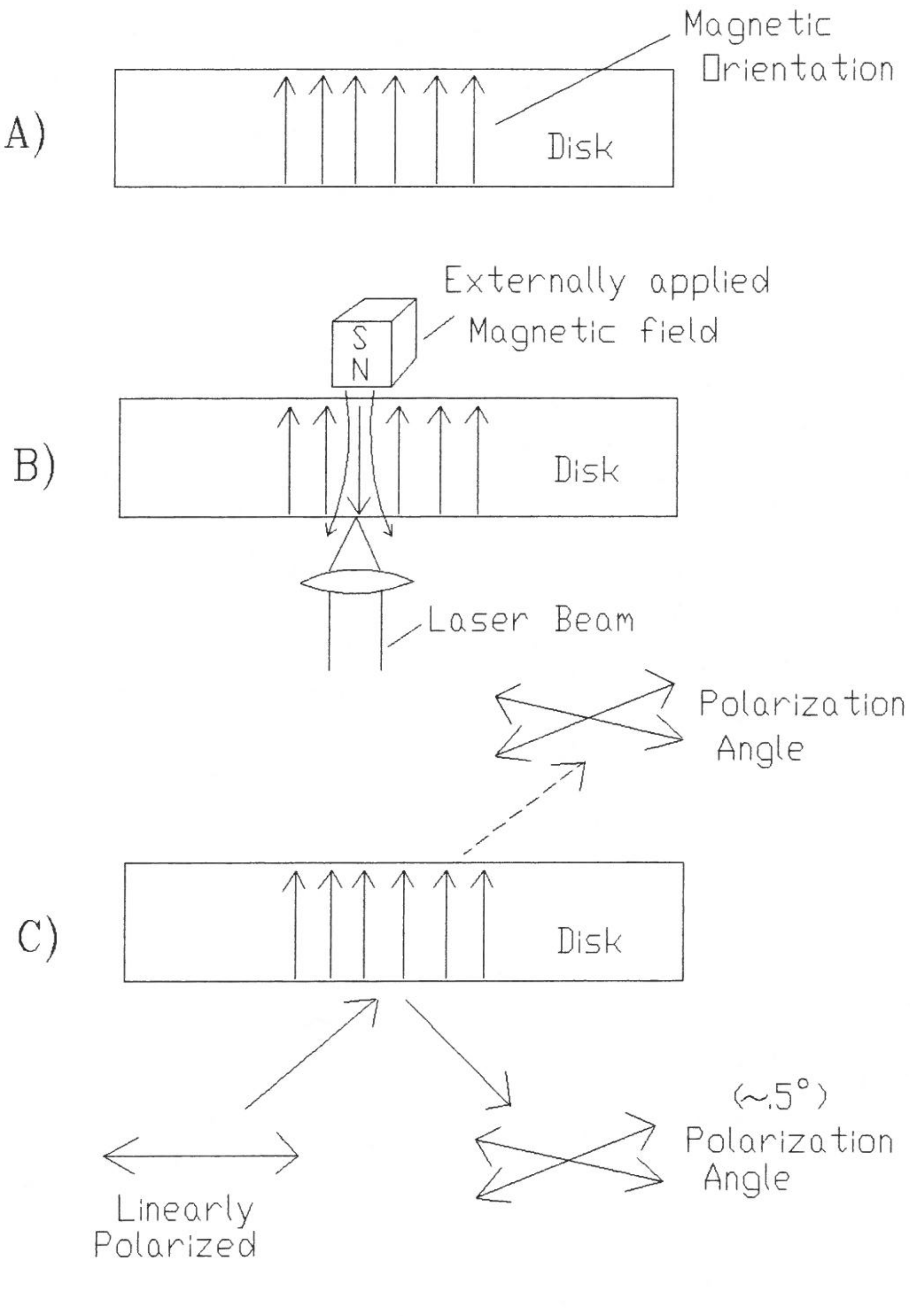


Figure 29

disk. When the temperature exceeds the Currie point, the area of the focused beam becomes magnetized in the orientation of the applied magnetic field (Figure 29b). By applying a magnetic field and turning a laser on and off according to a digital signal, the signal is recorded in the form of magnetic orientations on the disk. Information is read from the disk by shining a low power laser with a known polarization on the disks surface, and detecting the polarization of the reflected beam (figure 29c). The direction of this polarization rotation depends on the direction of the magnetization of the reflecting surface. In Figure 28, the section with the polarized beam splitter is used to read the data from the disk. A five inch disk has a capacity of 500 megabytes of data and a transfer rate of 1 megabyte per second.

# APPENDIX B

## Typical Megneto-Optic Signal

The purpose of Appendix B is to describe a typical electrical signal from a diode detector. When the substrate for an optical disk is molded, headers are stamped into it. After headers are stamped on a disk, a highly reflective coating, called a mirror mark, is placed directly behind each header. An example of the signal as seen by a large laser beam is shown in Figure 30a. A header has high frequency information in it to tell the player its location on a disk. Since a large beam scanner covers many tracks, an average of the header is seen, (Figure 30a). Each header is followed by a mirror mark, which tells the player that the header is over. The signal seen by the large beam scanner has the mirror mark before the header; with good reason. When looking for defects with a large beam scanner, information or data cannot be read off the disk because of the large beam, so it does not matter which way the disk rotates. In order not to count headers as defects it was convenient to spin the disk backwards and set up the electronics to detect the mirror mark. We could then disable the defect circuitry for a set amount of time after each mirror mark, thus eliminating headers.

Between headers there should be a perfectly flat electronic signal, eg. ( a DC signal). Figure 30b. When the disk is manufactured it is impossible to achieve a perfectly flat response. Fluctuations appear in the signal, and a

# Typical Magneto-Optic Signal

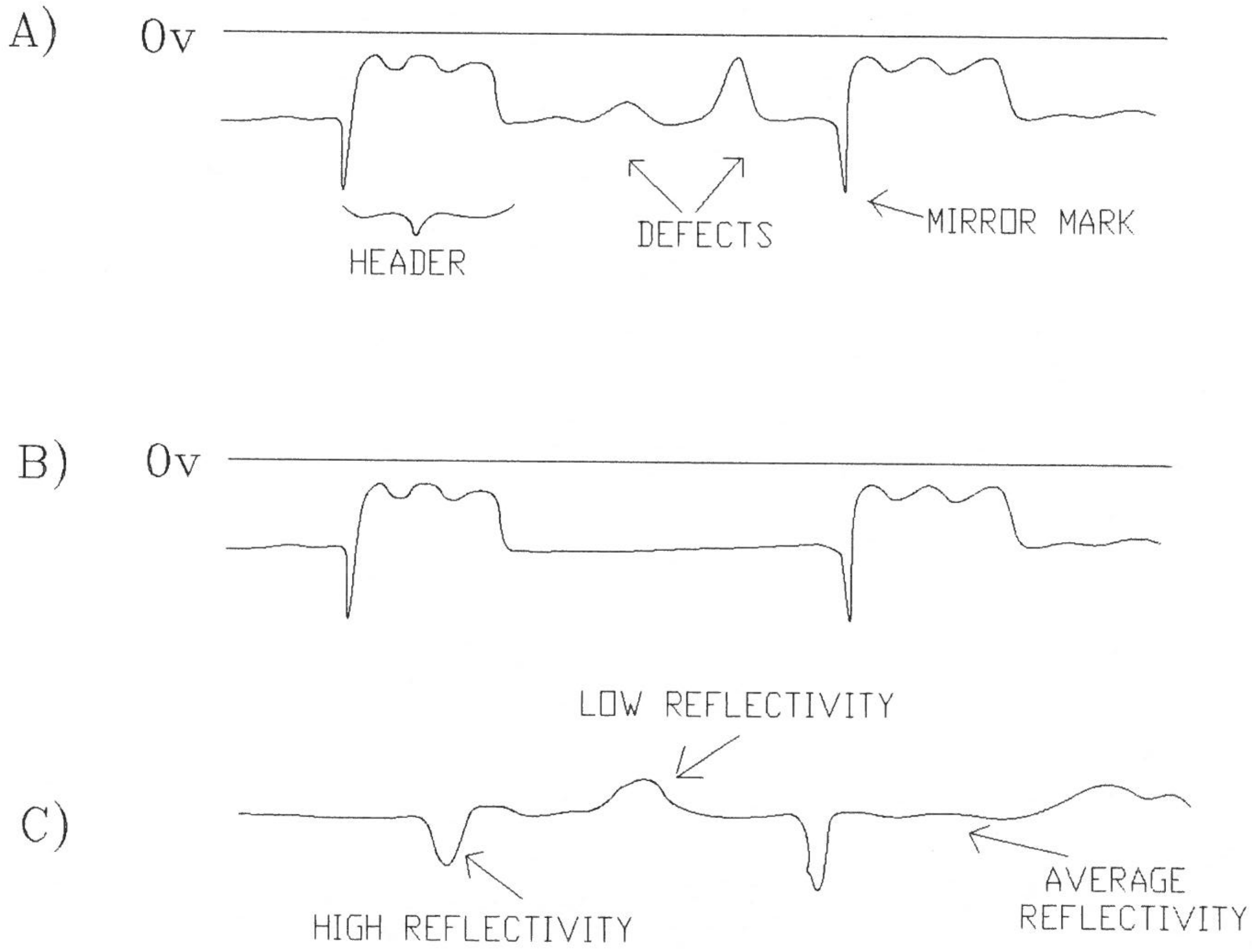


Figure 30

method must be designed to measure these fluctuations and determine if they are or are not harmful. These fluctuations are called defects, and a width greater than 1 microsecond is considered no good and must be counted.

The mirror marks in the signal are points on the disk at which more than an average amount of light is seen by the detector. These signals will, therefore, point downward. Defects are the opposite of mirror marks. Defects are points on the disk at which less then the average amount of light is seen by the detector, thus defects will point upward. High and low reflectivity points are shown in Figure 30c.

# APPENDIX C

## Electronic Schematics

The following pages detail the actual schematics for the analog and digital electronics used in the design of the Large Beam Scanner.

# Analog Schematic : Reflectivity Channel

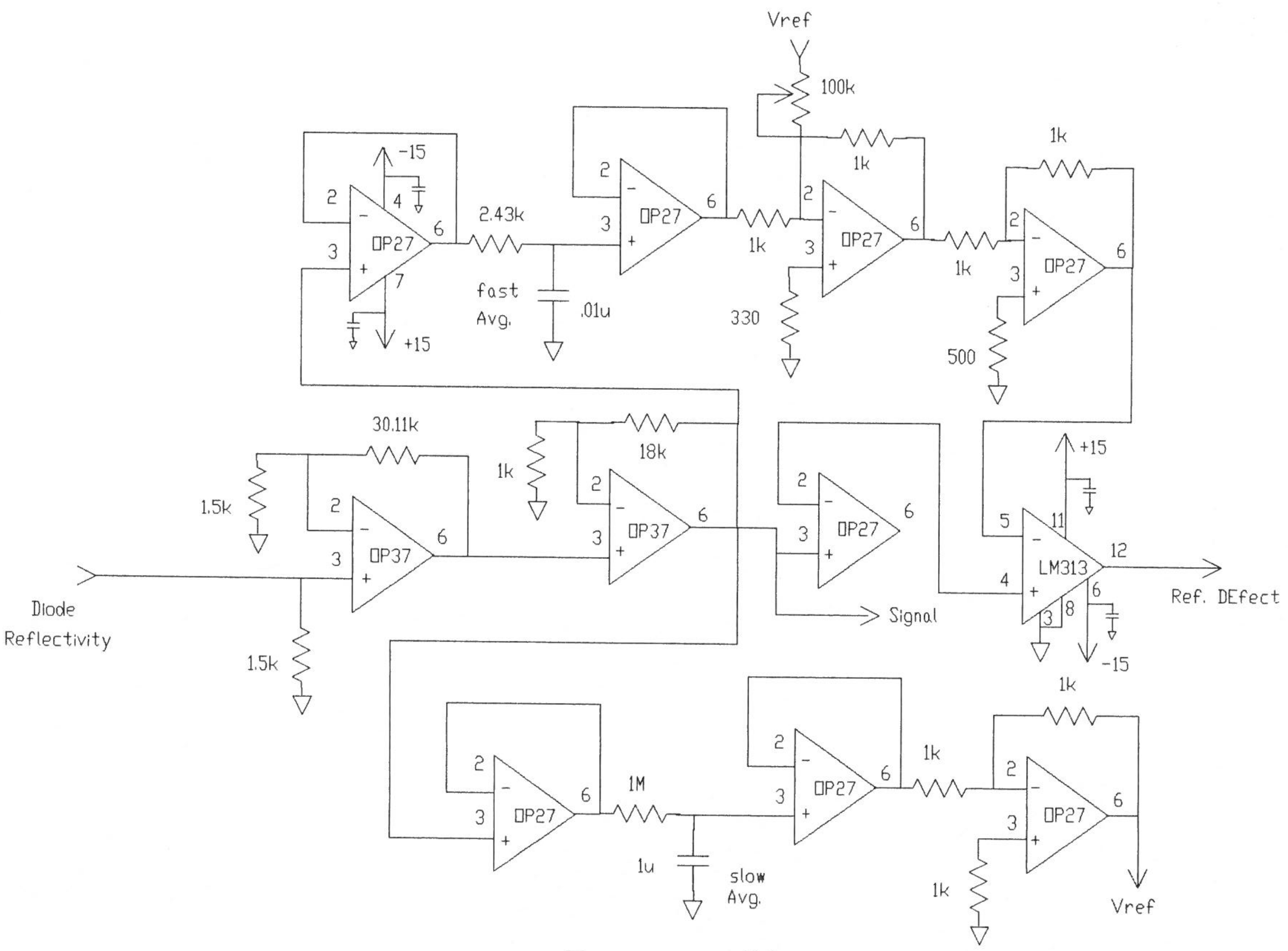


Figure 31

# Analog Schematic : Transmission Channel

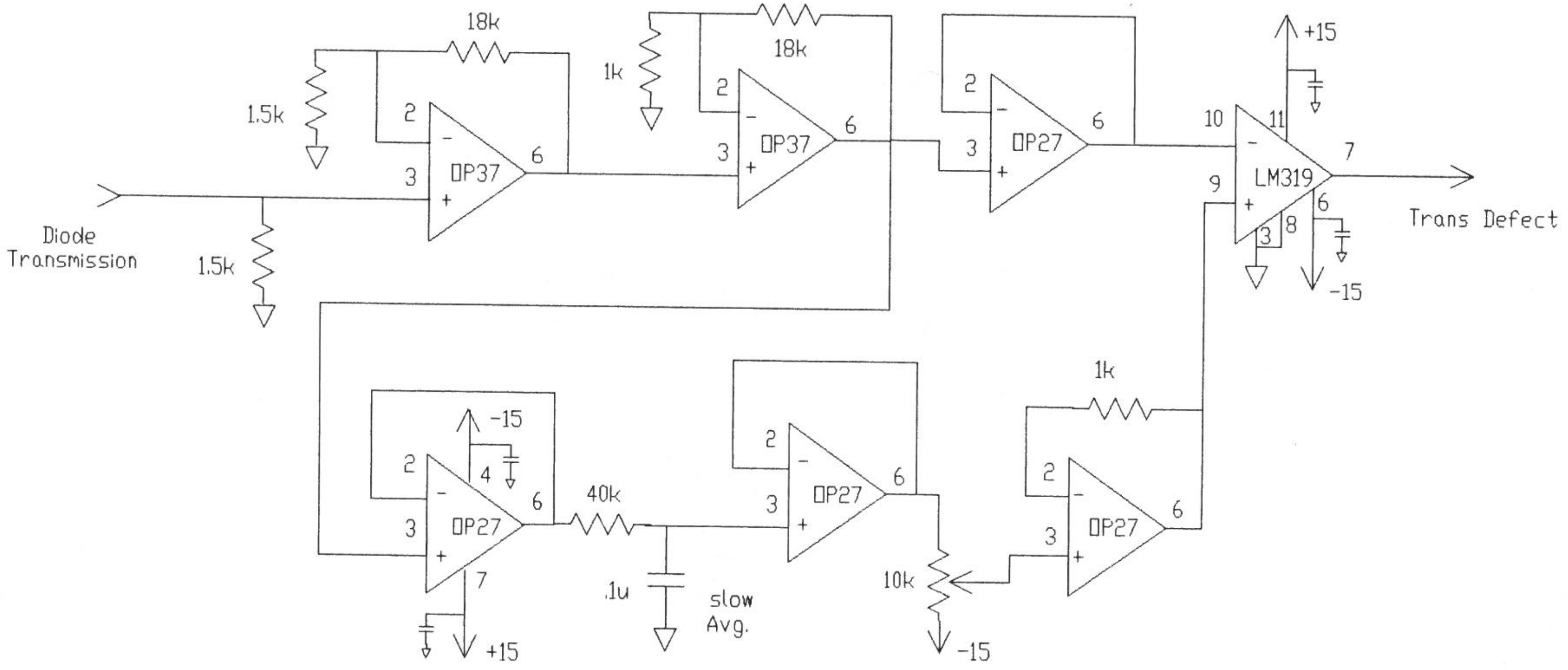


Figure 32

# Analog Schematic : Mirror Mark Channel

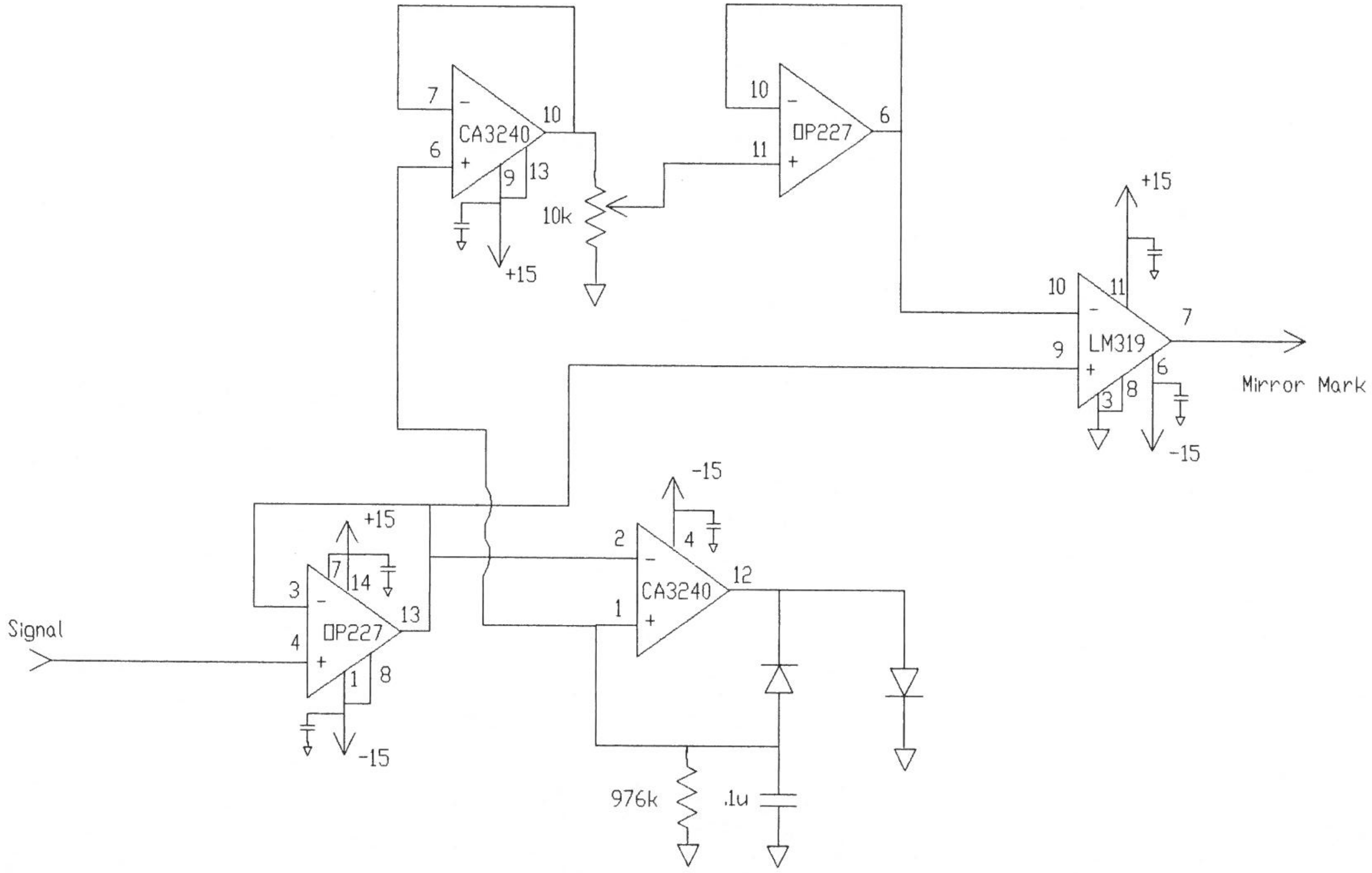


Figure 33

# Digital Schematic : Reflectivity Channel

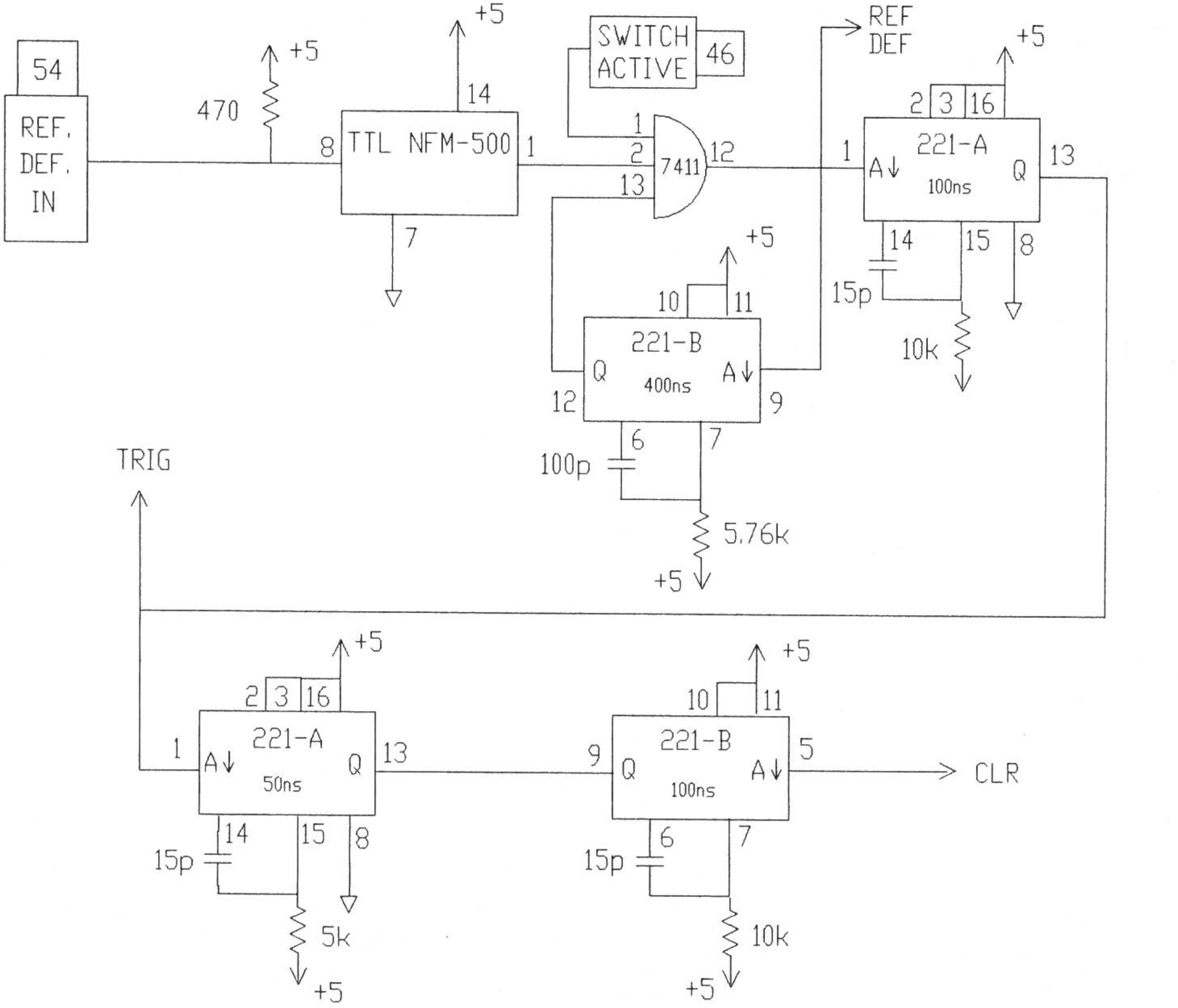


Figure 34

# Digital Schematic : Reflectivity Channel

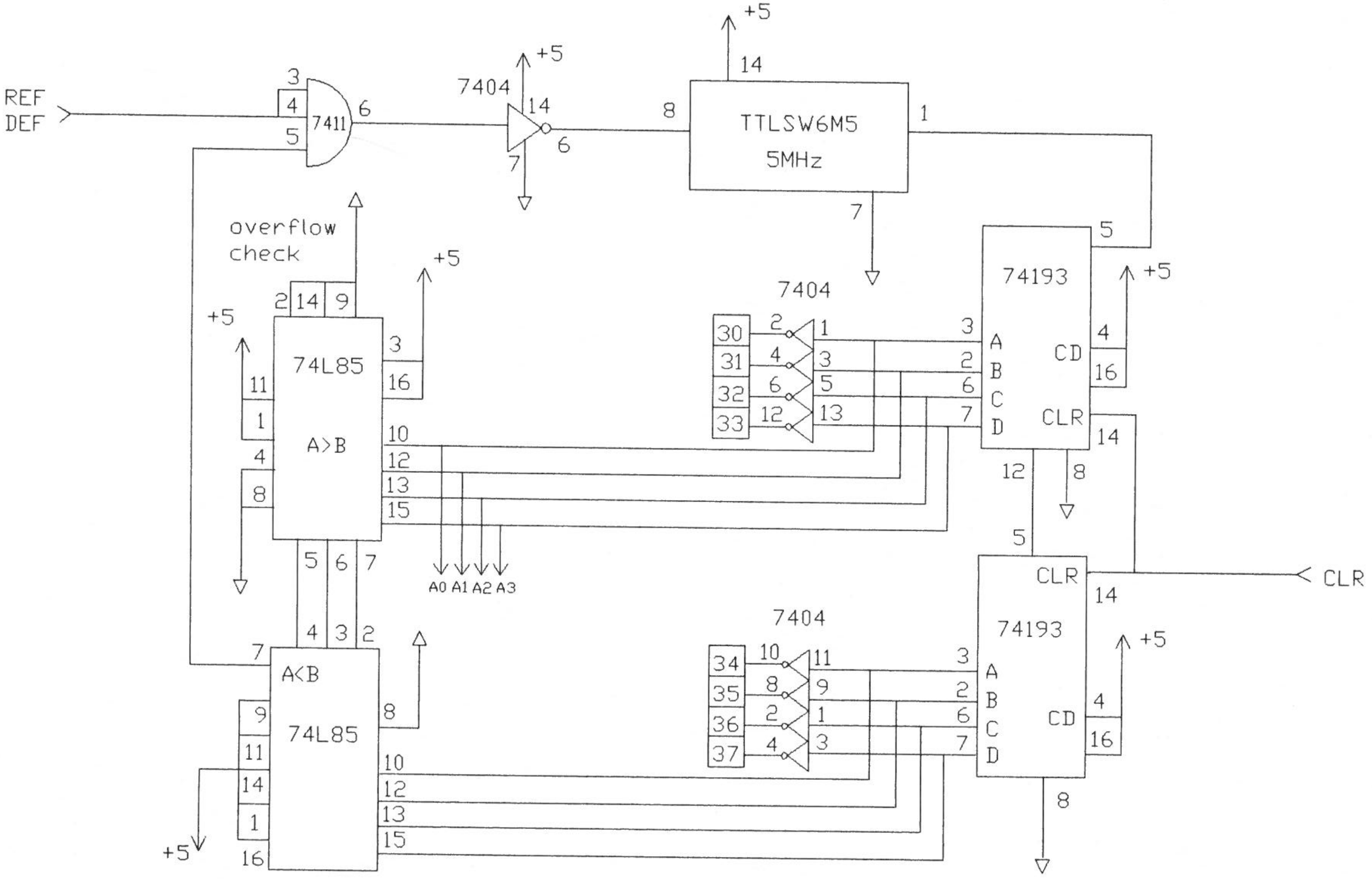


Figure 35

# Digital Schematic : Reflectivity Channel

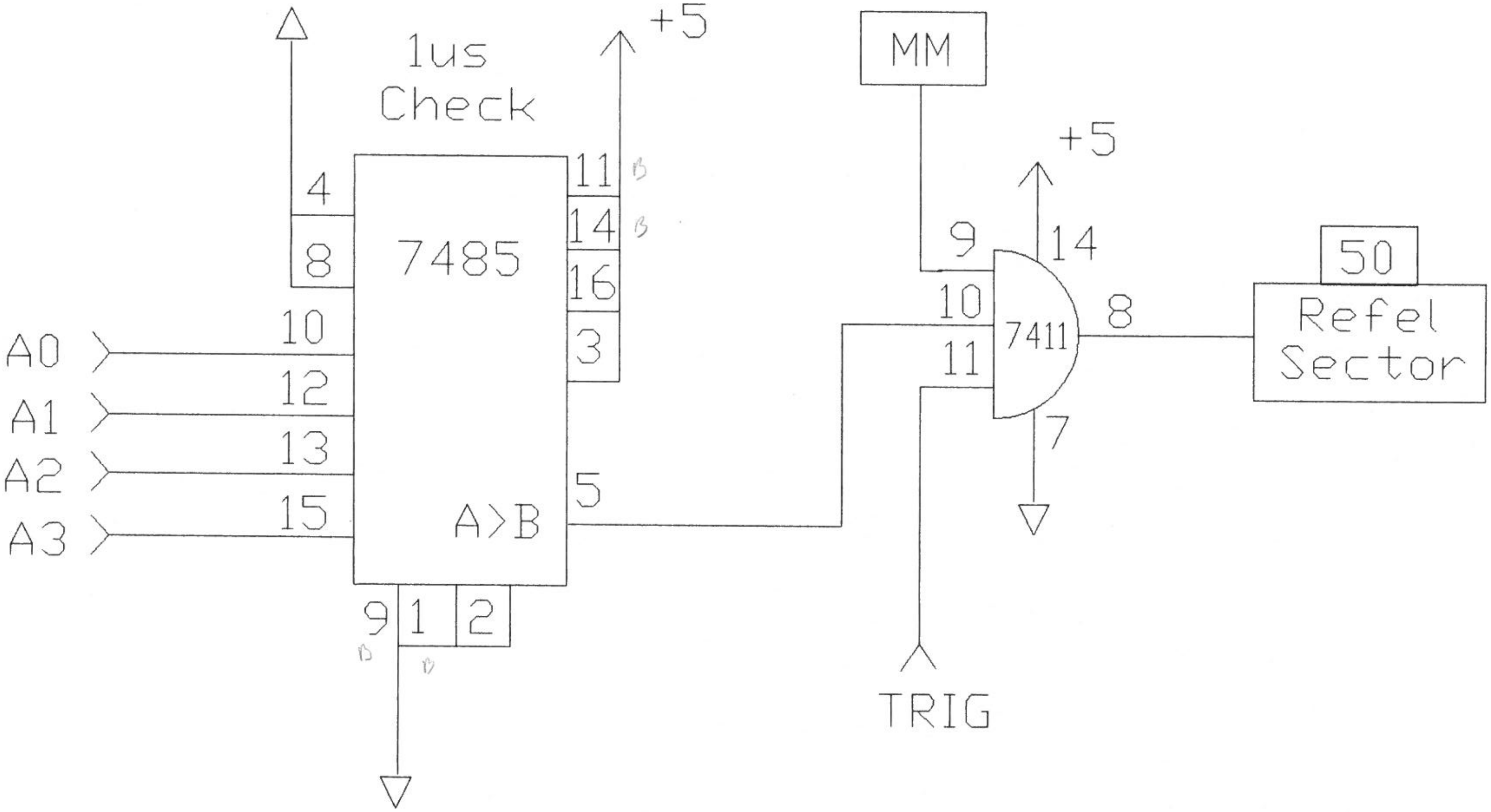


Figure 36

# Digital Schematic : Transimission Channel

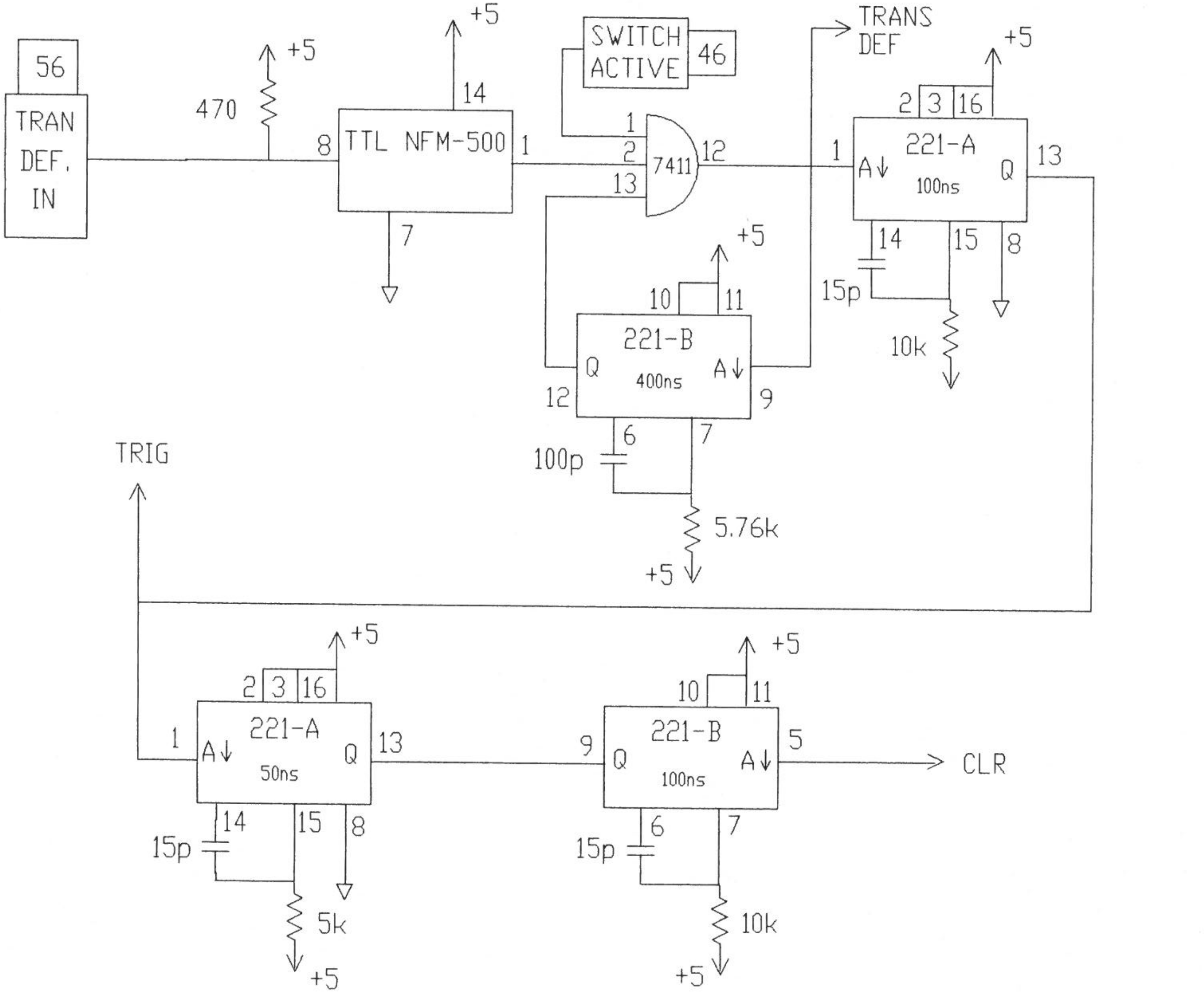


Figure 37

# Digital Schematic : Transmission channel

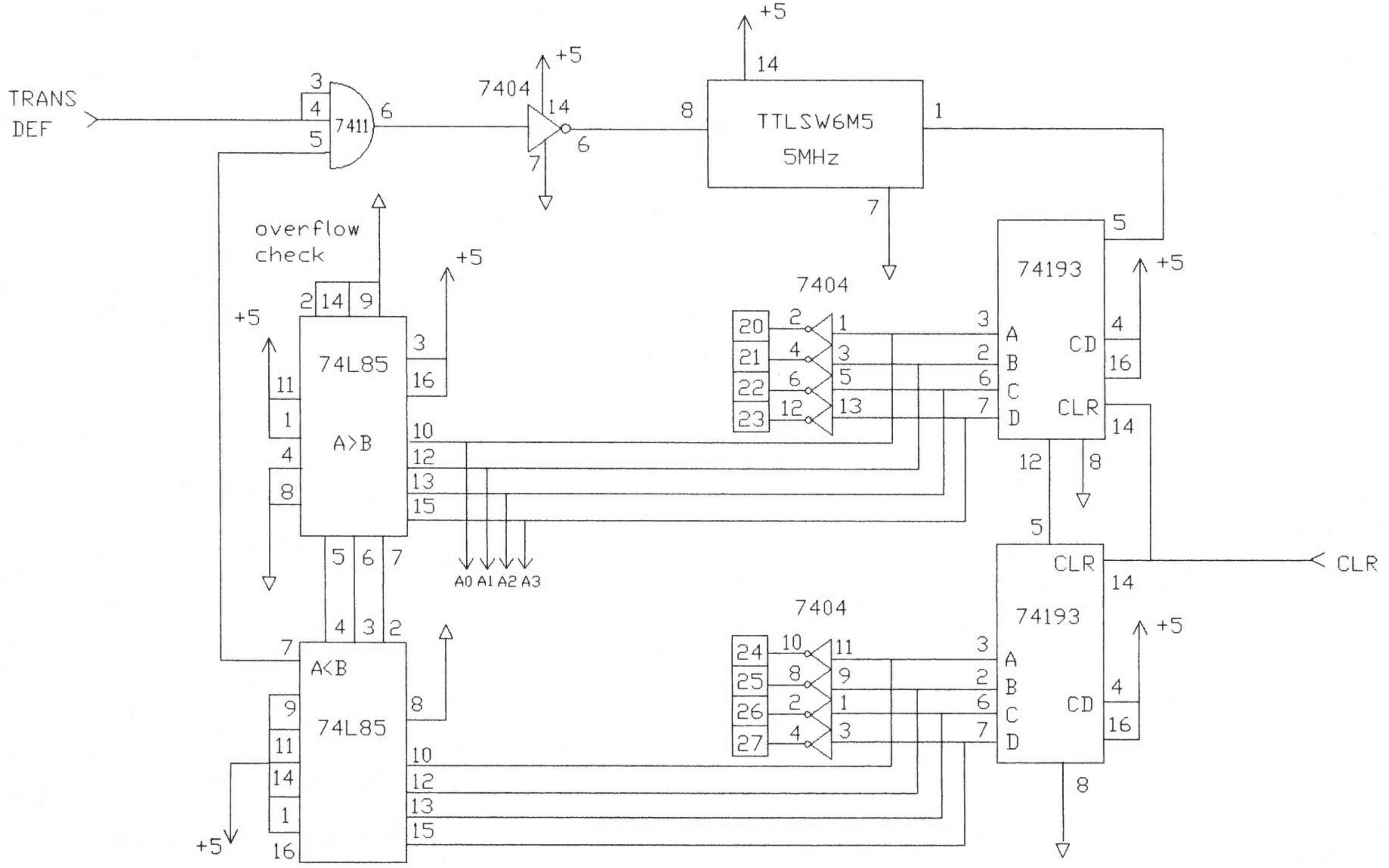


Figure 38

# Digital Schematic : Transmission Channel

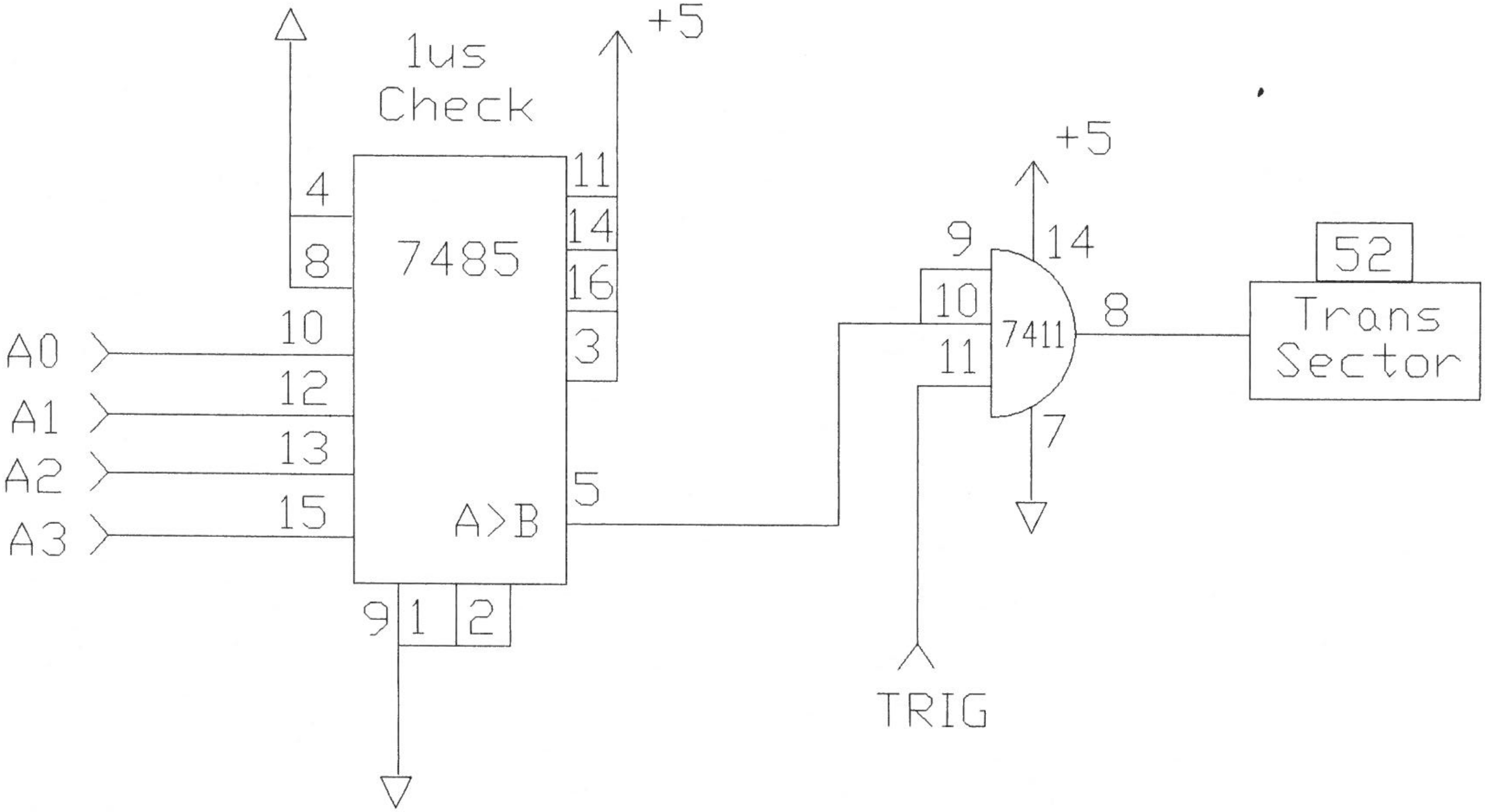


Figure 39

# Digital Schematic : Mirror Mark Channel

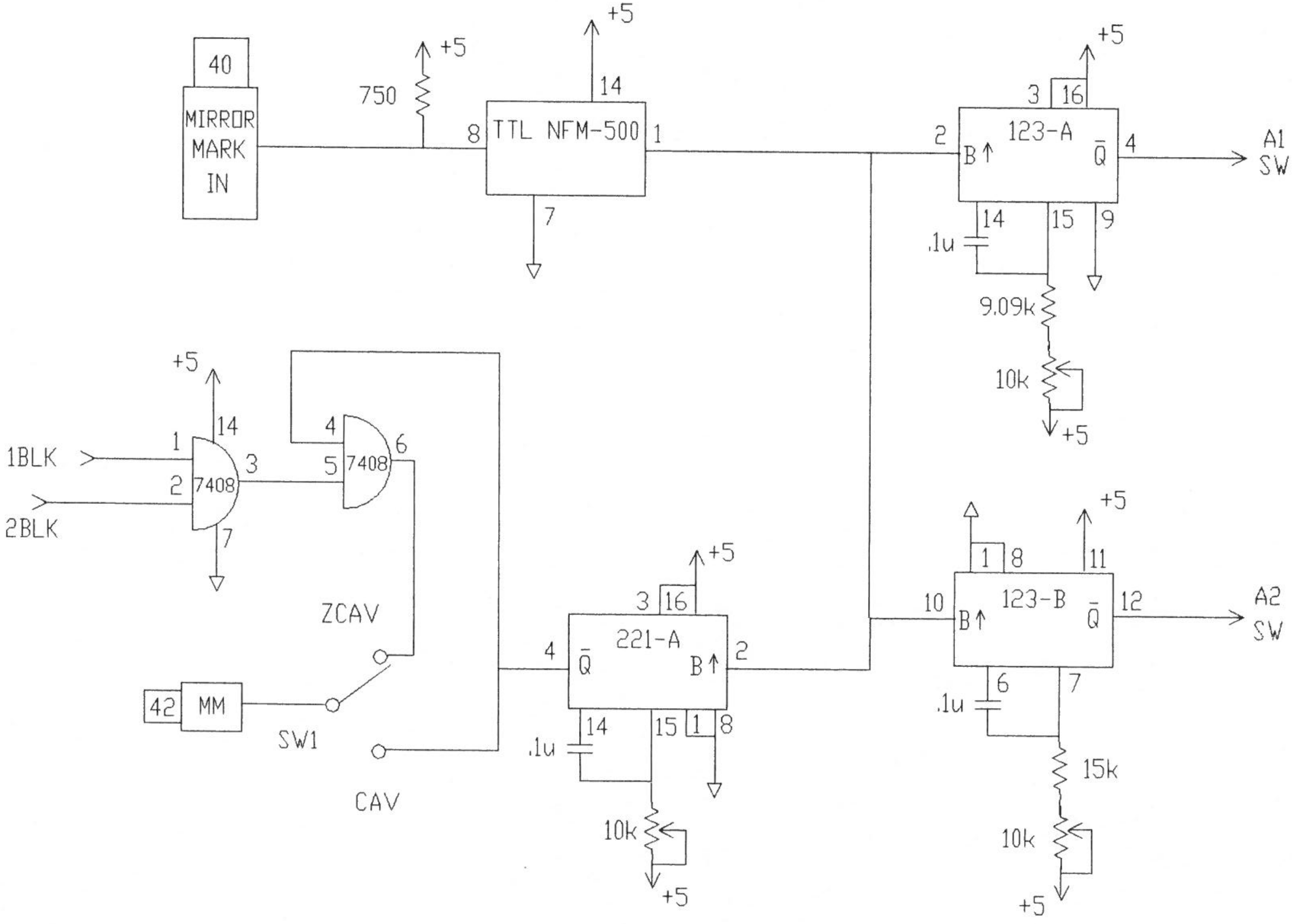


Figure 40

# Digital Schematic : Mirror Mark Channel

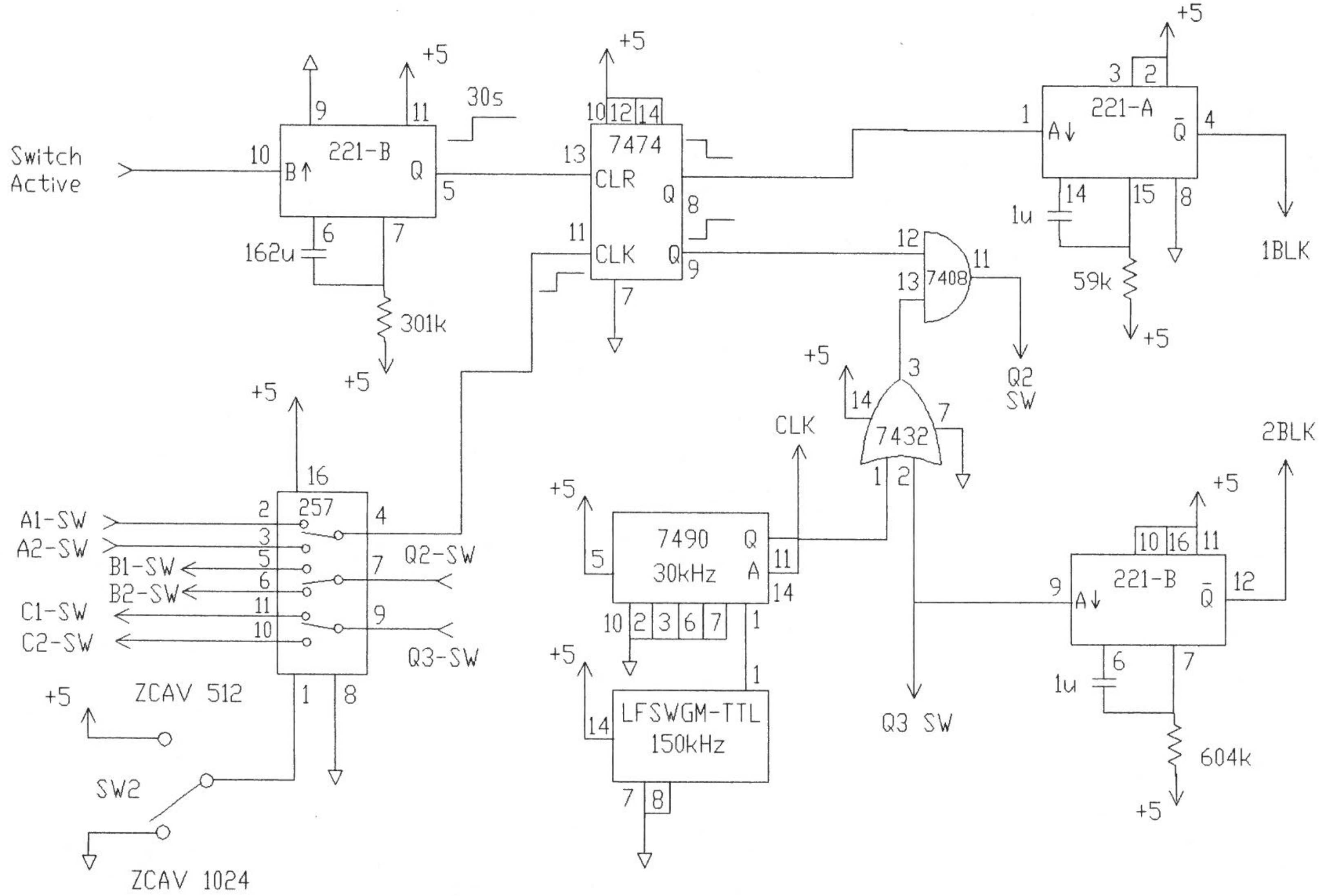


Figure 41

# Digital Schematic : Mirror Mark Channel

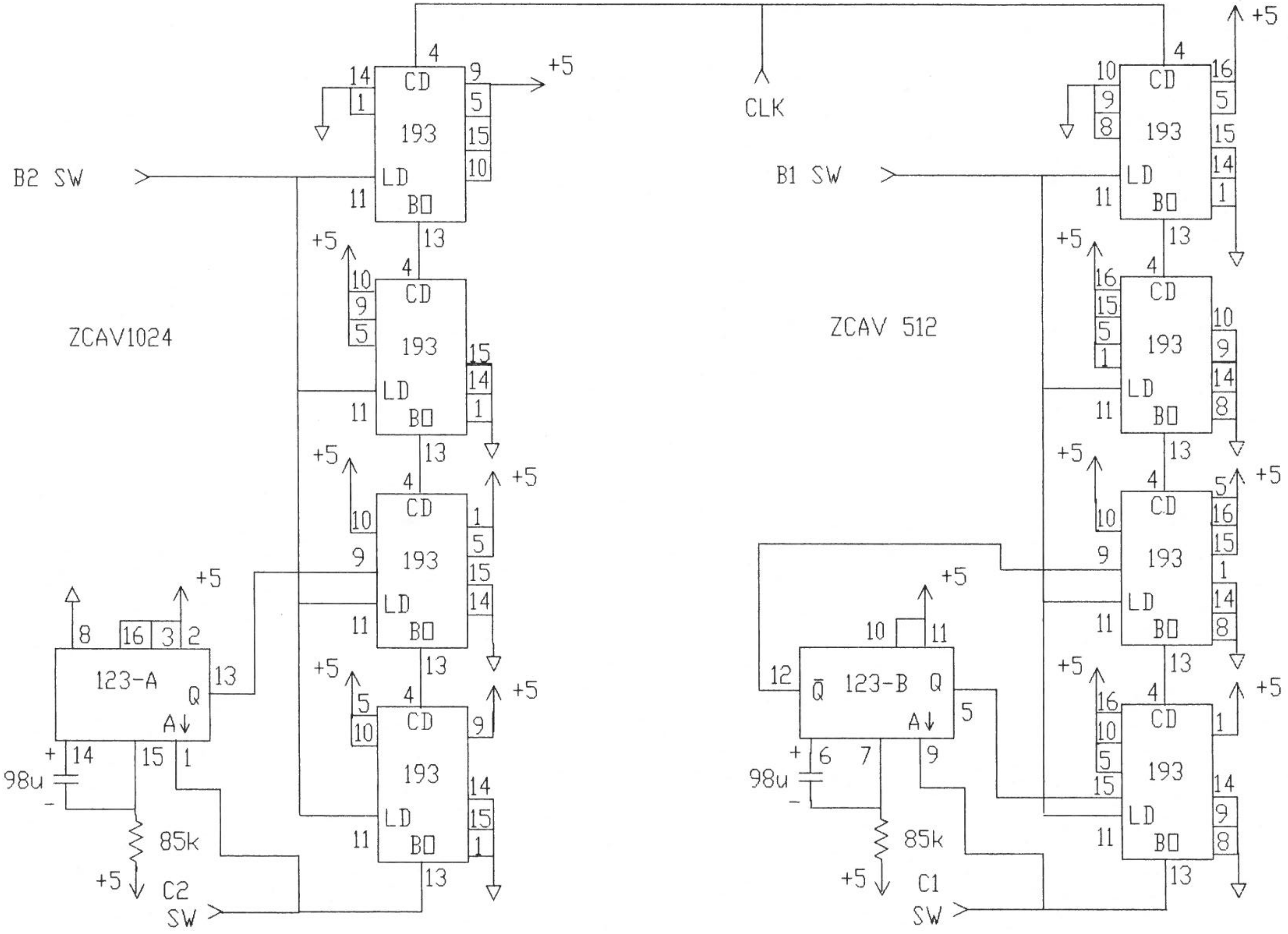


Figure 42