DEVELOPMENT OF A STABLE
ELECTRO-OPTICAL MODULATOR[1]

Nathan Wilkins
Mustafa A. G. Abushagur
Department of Electrical and Computer Engineering
University of Alabama in Huntsville
Huntsville, Alabama 35899

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ABSTRACT

The electrical/optical characteristics of longitudinal KD*P modulators have been studied to determine what physical construction would be best for use in the MSFC vector magnetograph. Obtaining high quality KD*P modulators that could withstand the DC modulation requirements of the MSFC vector magnetograph has, in the past, been at best a game of chance. This report summarizes a study which investigated problems that have been seen in these devices and presents the conclusions that were reached.

INTRODUCTION

Various anomalies in the performance of KD*P modulators being used in the MSFC solar vector magnetograph had been observed. One such anomaly was an apparent loss of modulation capability of certain devices which seemed to occur when applying a modulation voltage with a dc bias. In other words, under certain conditions, the modulation would begin as expected, but the output amplitude would decrease so that with time, no detectible modulation was occurring. Most often the devices were able to recover their modulation capability.

Another problem was performance variation which appeared to be due to mechanical pressure on the crystal. It had been suspected but not rigorously shown that polarization cross pattern separation could be induced by applying pressure to the crystal.

In order to investigate and attempt to determine definitive causes for these anomalies and work toward implementing solutions into the solar vector magnetograph,

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it was desired to establish a KD*P test facility. This final report on the KD*P characterization effort, UAH-MSFC contract ending 6/13/91, reviews the test station setup and discusses the tests that were performed. Investigations into the effects of crystal coatings are discussed. A model is developed to simulate KD*P behavior, and the simulation results are compared with measured results. The last section of this report gives the conclusions that were reached during the course of this investigation.

KD*P Test Station

The initial thrust of our research involved development of an automated test facility for characterization of KD*P modulation. Subroutines were written on the HP9845B controller to utilize an HP54501A digitizing oscilloscope which had not previously been part of the test setup. Several other less significant subroutines and program sections had to be written, tested, and debugged and the program was integrated with existing sections such as the graphics and data storage routines.

The test station, whose block diagram is shown in Fig. 1, consists of two primary sections, the optical setup and the electrical modulation capability. The optical source is a Particle Measuring Systems NeNe laser. The crystal under test is placed between crossed polarizers and the modulated light through the system is measured by an EMI PM tube. To provide the electrical modulation capability, a Fluke high voltage power supply is modulated by a network of high voltage relays whose timing is controlled by an Intel computer. The applied modulation voltage and PM tube output are both monitored by an HP 54501A digitizing oscilloscope. The controller closes a mechanical shutter and receives an optical background level measurement from the scope. A signal is then sent to the Intel

to begin the desired modulation sequence. The applied voltage and PM tube signals are read and when the modulation sequence has been completed, the background level is once again measured.

Before actual testing could begin a versatile fixture was required to mount the crystals that were to be tested. Such a fixture was designed and constructed in house of plexiglass. The fixture is held in place on the optical bench with a standard NRC base and was designed to allow controlled variation of pressure on the crystal under test. This was done because we wanted to verify and if possible quantify KD*P performance anomalies that had been observed due to stress on the crystal and was accomplished by designing the holder such that screws could be tightened down by a very fine torque measuring screwdriver whose setting could be directly related to the pressure on the crystal.

Once the program had been completed and all the test equipment was in place, actual testing could begin.

Coatings on the Crystal

It had been suspected that some of the problems with the KD*P modulators could be related to coatings on the crystal surfaces. Some of the modulators had conductive or semiconductive coatings directly on the crystal surface. We wanted to determine whether a nonconductive coating such as SiO2 applied prior to the electrodes might eliminate some of the problems.

Several crystals had been coated with MgF on both sides in a previous effort and there were still several uncoated crystals remaining from Cleveland Crystals which had never been touched. We decided to have five crystals coated with SiO2 by the Center for

Applied Optics. Samples 0-3 and 9-4 were given 876 Angstrom coatings on both sides and samples 0-7, 5-1, and 9-3 were given 2627 Angstrom coatings on both sides.

During the course of testing several KD*P modulator failures were documented in which square wave modulation with a dc bias caused the modulation capability of the crystal to gradually decrease. Fig. 2 shows such a test run. The failures of this type were observed with modulators having a conductive coating applied directly on the crystal surface. When the modulators were disassembled it was found that the resistivity of the coating on either side of the crystal did not match. In one case the resistivity differed by an order of magnitude from one side of the crystal to the other. Efforts were made to duplicate these failures by sandwiching various coated and uncoated crystals between electrodes of matched and unmatched resistivities, but no failures were induced. We could not actually duplicate the conditions under which the failures occurred because we did not have the proper type of electrodes.

One of the modulators that failed and was disassembled was 1919B. When this crystal had conductive coatings on both sides, gold rings around the edges of the conductive coatings, and glass windows cemented onto both coated sides. To dissolve the cement holding the windows, the assembly was soaked in Methylene Chloride overnight beginning 3/18/91. With the windows removed, the resistances of the coatings were measured from the center to the edge. One side measured 2 KOhms while the other side measured 20 KOhms.

Another modulator which had exhibited chronic failures was 6044-103. When this modulator was disassembled, it was found that the glass windows were not glued. The

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resistance of one coated side measured 8.5 KOhms, but no conduction was observed on the other side.

When the disassembled 1919B was placed between our own electrodes, no failures were observed. It is also noteworthy that the shape of the output waveform changed. Fig. 2 shows a test run of 1919B in its original holder. Note the slow response of the crystal and the failure which is indicated by the modulation going to zero. Fig. 3 shows the same crystal in our own electrodes. Note the change in the shape of the waveform. We believe this is due to capacitive effects of the added electrodes and is described in more detail in the simulations section. Also note that no failure was observed. The output amplitude jumping into the saturation area of the PM tube was caused by current arcing from the outer electrodes to the hold rings on the crystal.

Testing of the Cleveland crystals that had been coated with $SiO2$ turned up nothing conclusive. This did not seem to have an effect on the shape of the waveform. The upshot of all this is that none of the modulators failed except those that were prepackaged with conductive or semiconductive coatings directly on the crystals surface, and that the two that we looked at closely, chosen because of their poor characteristics, had grossly mismatched coating resistivities.

Computer Simulations

We developed an electrical model of the KD*P modulation setup in an attempt to simulate the observed waveforms on a computer. Implicit in this analysis are the assumptions that the KD*P retardance is proportional to the applied voltage and that the PM tube response is approximately linear. We also assume that it is possible to model the

KD*P output waveform with an ideal squarewave applied to an electrical network. To first order, we will approximate the network response by considering the response to a step function input. The output for each cycle is the step function response while the input is on, and zero while the input is off. While this approximation ignores transient effects and the effect of the periodicity of the waveform, we expect it to be adequate to give us a rough idea of the magnitudes of the components necessary to produce the observed output waveforms, especially since the modulation frequency is relatively slow for the values of the components that we expect to use.

Perhaps the most obvious choice of an electrical model for the KD*P is a parallel resistor and capacitor combination. Fig. 4 shows the schematic diagram for this model. RO is a function of our test setup and is known to be 1 MOhm. The resistance and capacitance of KD*P crystals have been measured directly and nominal values are on the order of 100 MOhms and 100 pF respectively. This model must be rejected since it is only a first order system (it is described by a first order linear differential equation) and cannot produce the types of output waveforms with negative slopes that have been observed.

A second order system results if we add a stray capacitance CE in series as in Fig. 5. It was found using this model that CE = 10 nF resulted in an output waveform shape across Rk similar to that which we had observed. With these component values, the output magnitude is approximately the same as the input magnitude. The output waveform shape can be maintained while significantly decreasing the output magnitude if Rk is increased while at the same time Ce is decreased. In any case, increasing Rk alone causes the negative slope to decrease, or flattens the waveform.

In our experiments, we observed that typically when a modulated waveform exhibited the negative slope, it did so at relatively low applied voltages, but as the applied voltage was increased, the waveform flattened. Fig. 6 shows a sequence of simulations in which only Rk is changed. The first simulation has Rk = 100 MOhm and each successive simulation has Rk increased by an order of magnitude. The output is the fine line in the KD*P voltage graph. We believe that free ions in the crystal affect its resistance, and that when the applied voltage is increased, the ions migrate more rapidly to the edge of the crystal thus causing the effective resistance to be greater.

We tried to locate the stray capacitance by measuring our test setup, but were unable to find any capacitance anywhere near the expected level. We decided to observe the actual waveform across the KD*P electrodes in hopes of finding a clue, and to our surprise, the waveform was flat, even when the modulated signal exhibited the negative slope. In Fig. 6 the voltage of the parallel Rk and Ck in series with Ce is shown by the bold lines in the KD*P voltage graph. This flat waveform matches those observed by directly measuring the electrode voltage. This evidence suggests that Ce may actually be an electrode capacitance, and although the waveform applied to the electrodes is flat, the waveform applied to the crystal itself may under certain conditions have a negative slope. This conclusion is consistent with the fact that when we used the modulators that had the electrode deposited directly on the crystal surface it was possible to observe a modulated waveform with a slow response such as that shown in Fig. 2 for 1919B before it was disassembled.

Conclusions

As a result of this study we have been able to derive several major conclusions. First of all, physical pressure should not be maintained on the KD*P. The modulator housing should be designed in such a way as to eliminate such stress.

Secondly, if conductive coatings are to be applied directly to the crystal surface at all, they should be uniform and be the same on both sides. Ideally, electrode configuration might entail electrode capacitance.

Finally, if a flat output waveform is desired, the applied voltage should be high enough to eliminate free ion migration effects.
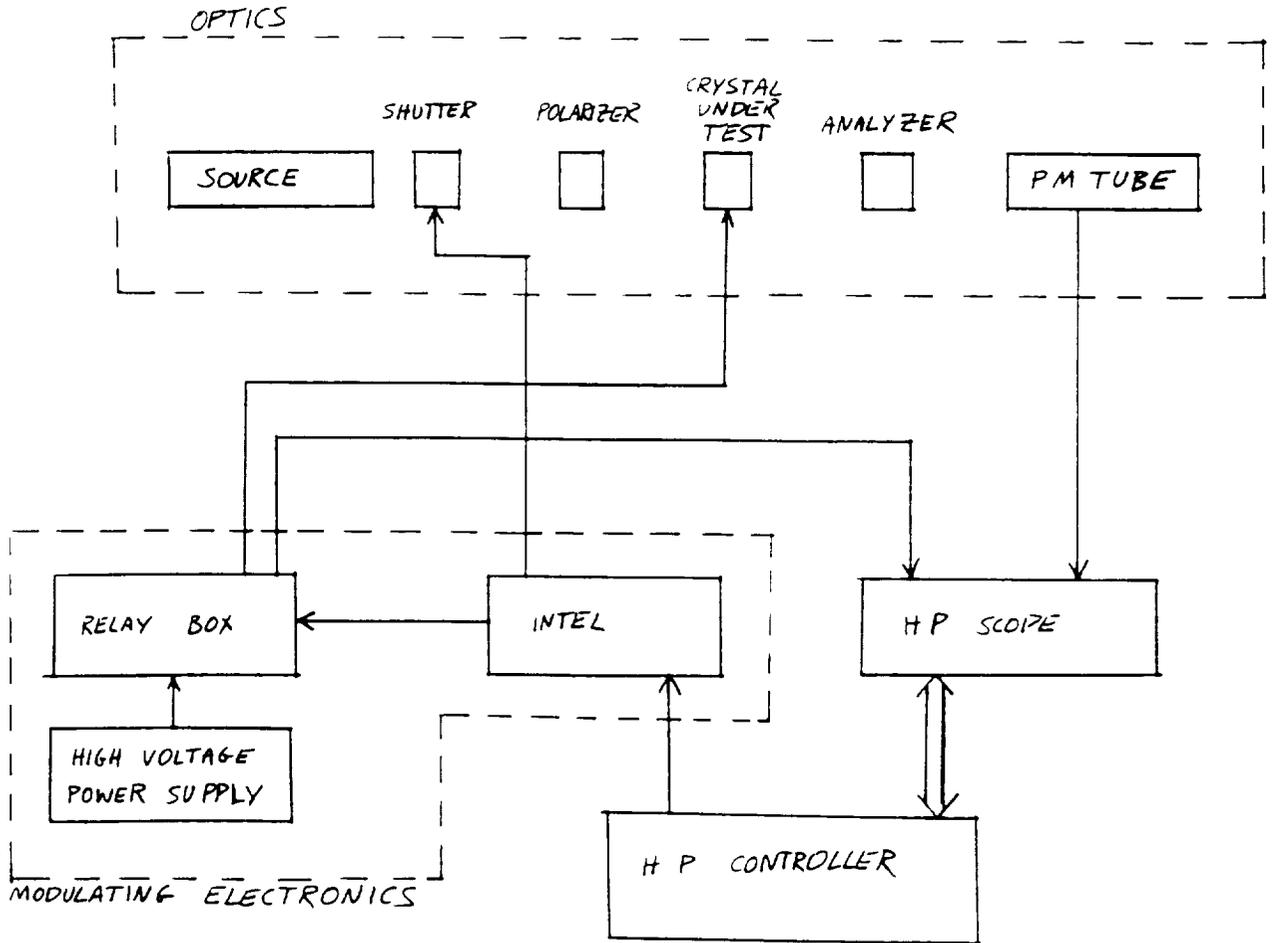
Fig. 1   Test Station Block Diagram

Fig. 2

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Fig. 3a

12

03:27:12:01:37   Pos.: 3 , 3

Exposure time: :30.0 Delay time: 0.0

Applied voltage: 29.00
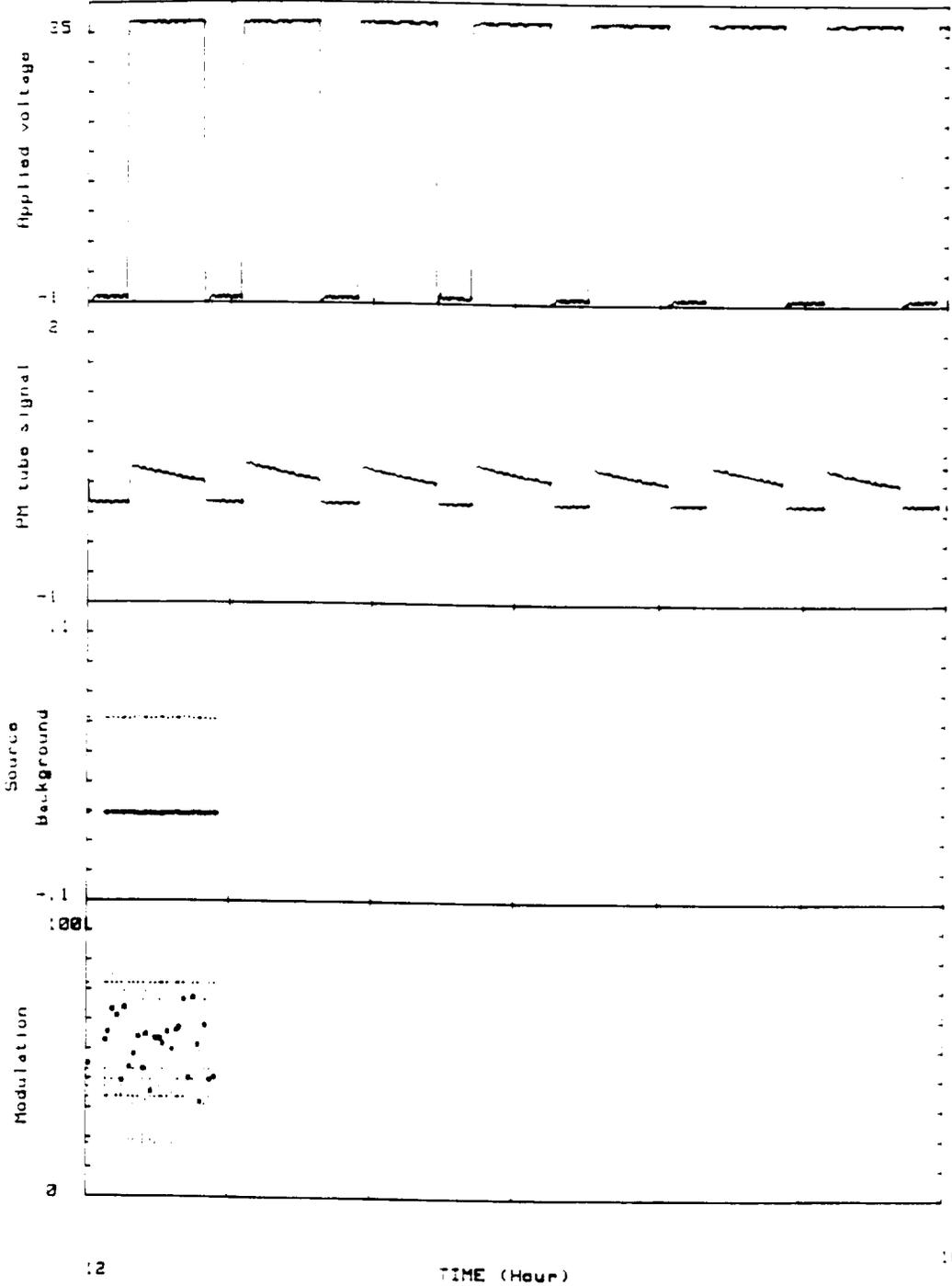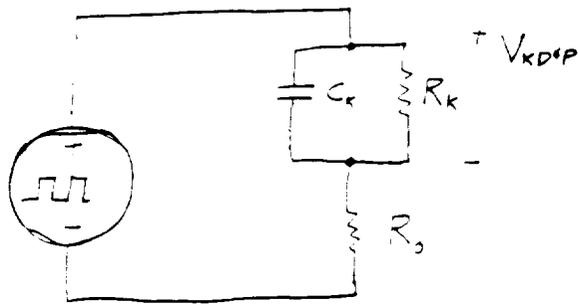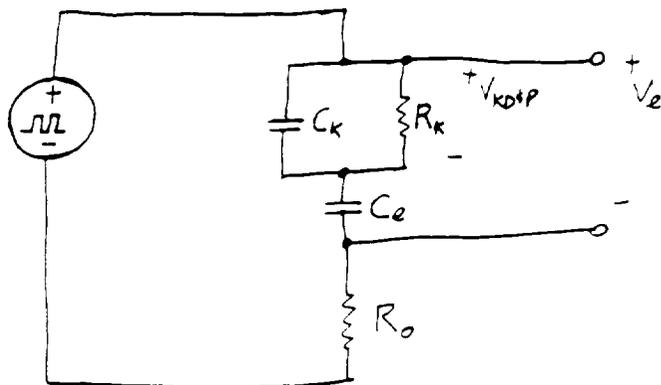
Fig. 3b

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Fig. 4

Fig. 5

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Fig. 6a

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Fig. 6b

Fig. 6c

$R_K = 10 \, \Omega$

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NASA
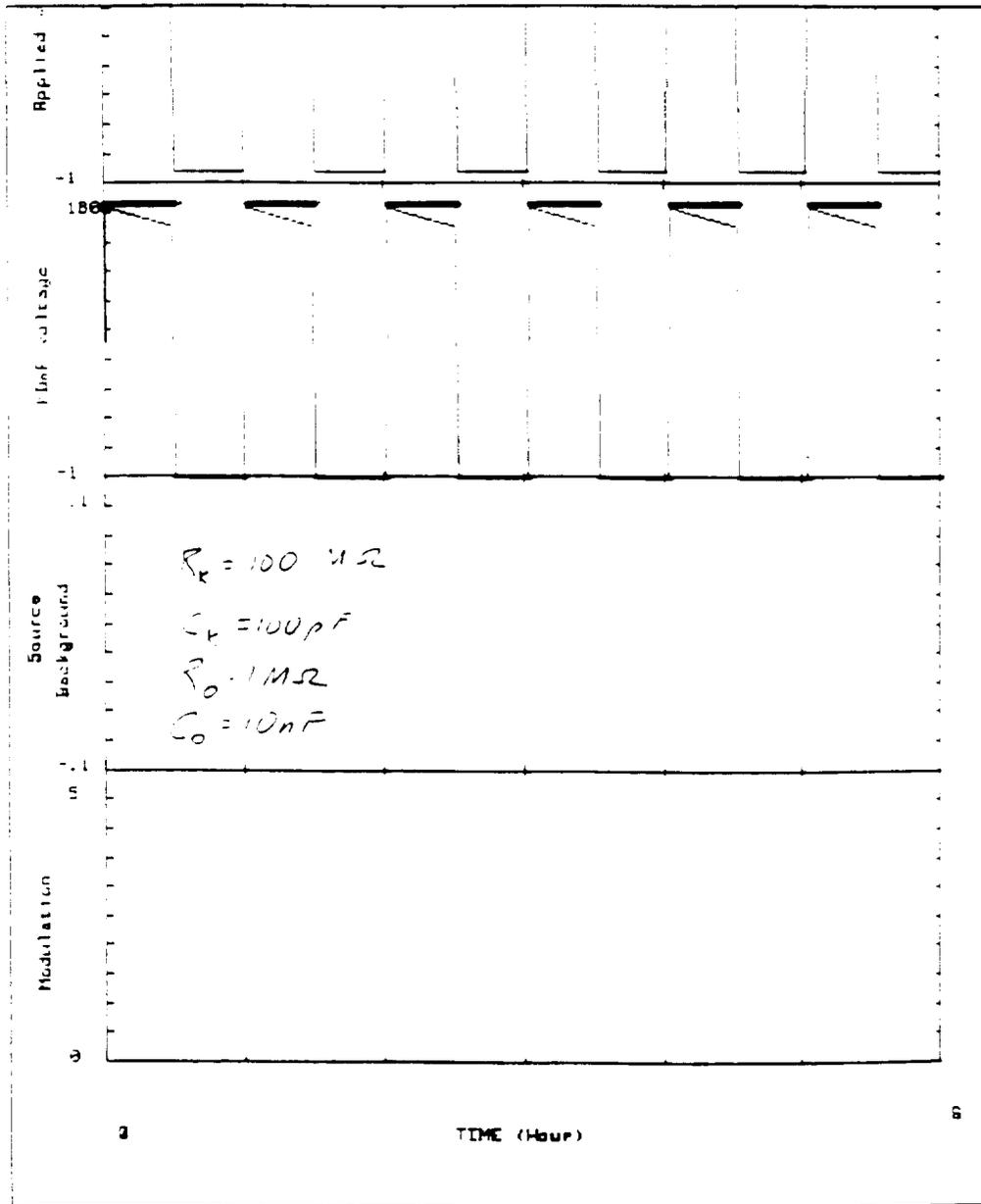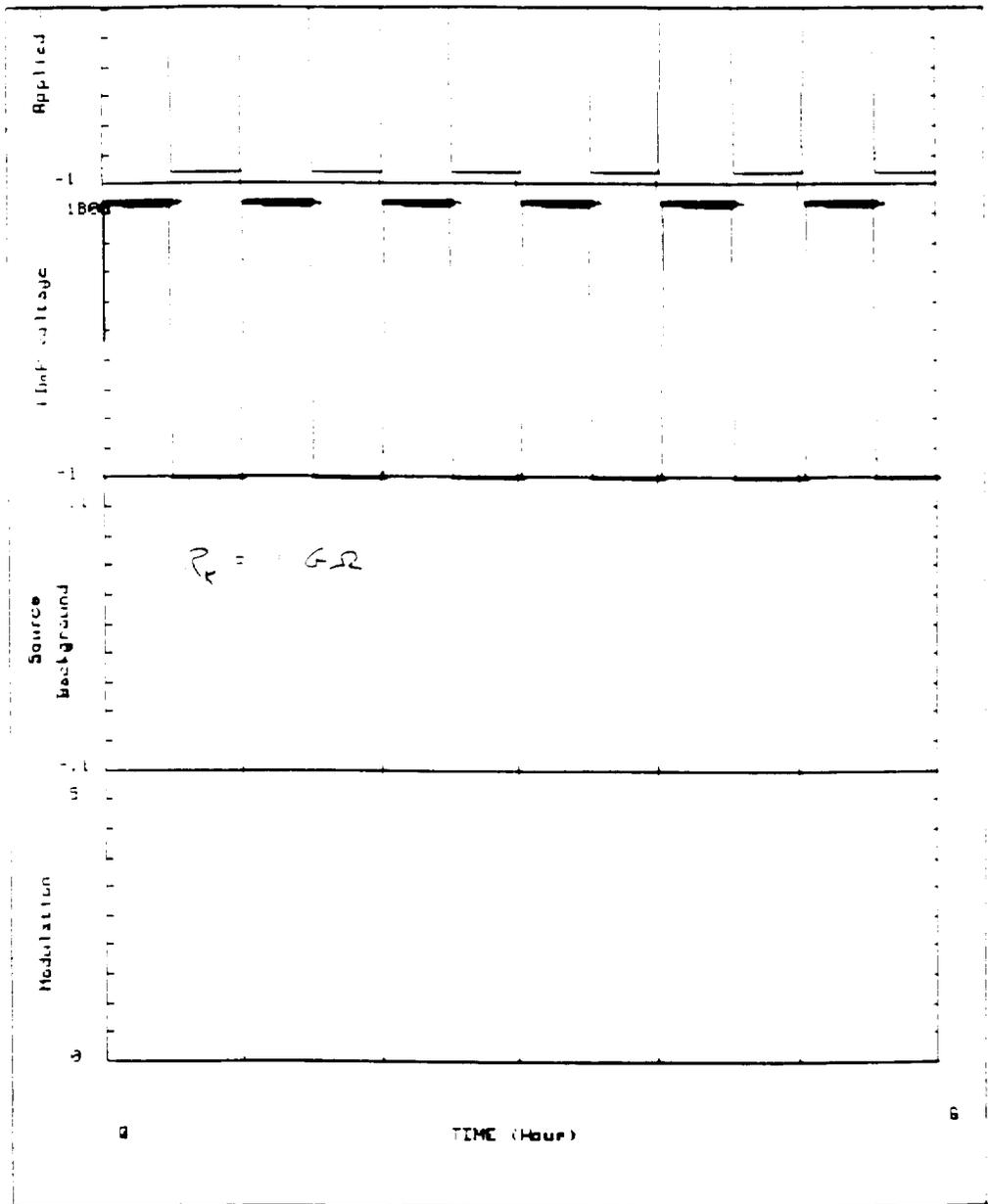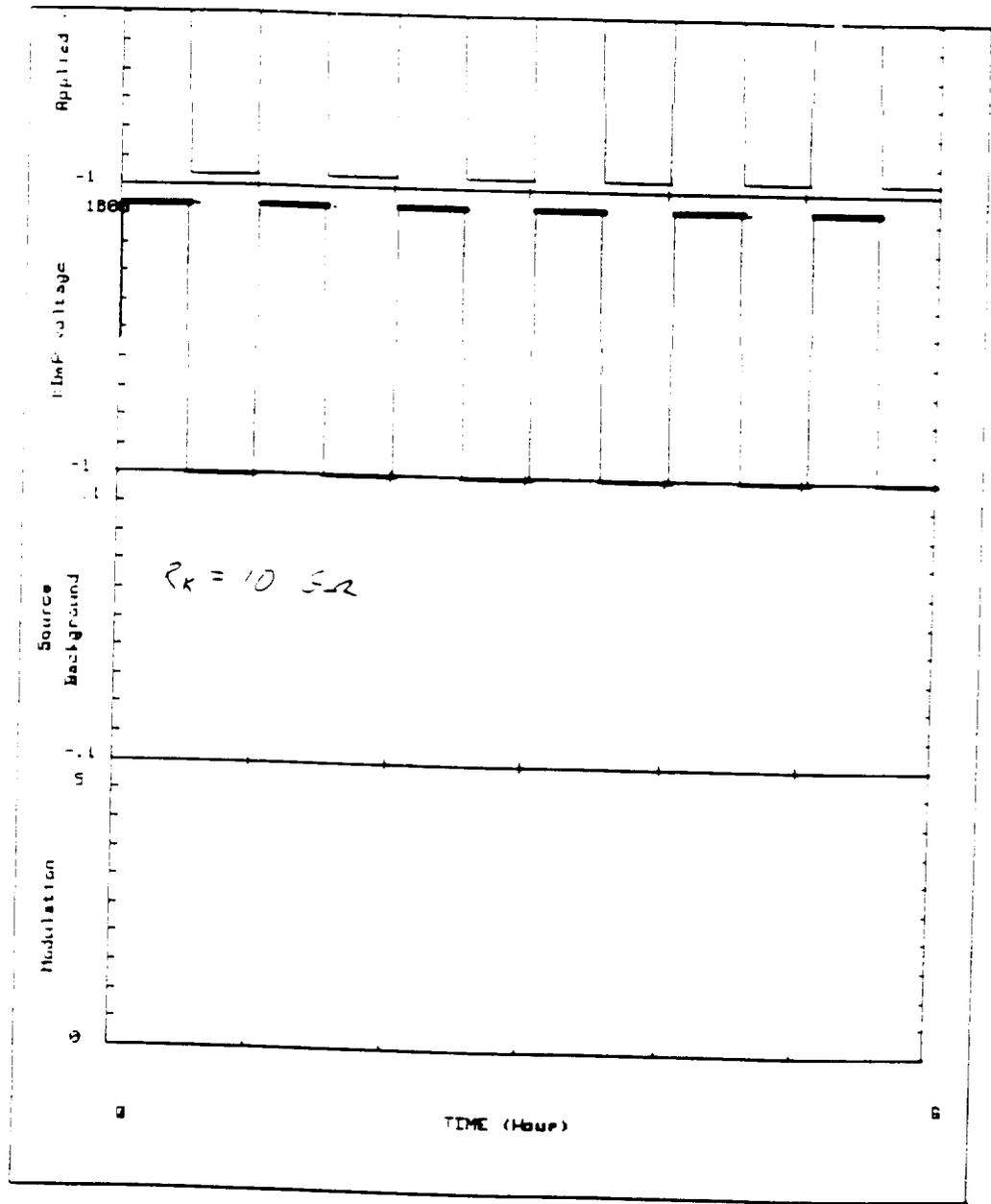
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15. Supplementary Notes

16. Abstract

The KD*P modulator forms the heart of the polarimeter assembly which is used for measuring the linear polarization of the sun. Coating the KD*P crystals with non-conductive transparent protective material to increase the resistivity of the modulator was studied. Some preliminary experiments to study the effect of the coating on the stability of the modulator were performed

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