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Color Separation Gratings

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1. ABSTRACT

In this paper, we describe the theory, fabrication and test of a binary optics "echelon." The echelon is a grating structure which separates electromagnetic radiation of different wavelengths, but it does so according to diffraction order rather than by dispersion within one diffractin order, as is the case with conventional gratings. A prototype echelon, designed for the visible spectrum, is fabricated using the binary optics process. Tests of the prototype show good agreement with theoretical predictions.

2. INTRODUCTION

Color discrimination, or the separation of electromagnetic radiation by wavelength, is a basic building block for many applications, both military and commercial. In general, the task of discriminating between objects based on their spectrum can be broadly divided into two classes, based on the fineness of the discrimination. In one class, the unknown spectrum is sampled at very fine intervals, essentially reconstructing the spectrum. Discrimination techniques based on spectroscopy fall in this class. Although this class is quite important, it is not the topic of this paper and will not be discussed further.

In the other class of color discrimination, the unknown spectrum is divided into a small number of bands (typically three or four), which are used to characterize the unknown spectrum. For strategic defense, the majority of applications are in the infrared portion of the spectrum. Separation of the infrared band into several sub-bands can be used to better discriminate between objects (e.g., space debris, decoys and re-entry vehicles) and to more accurately estimate temperatures of objects.

In the visible portion of the spectrum, the earliest example is the human visual system, which perceives color based upon a separation of the spectrum into three bands (the three types of cones in the retina). Partly because the human visual system operates in this fashion, there are a large number of applications which also use this type of color discrimination. Common examples are color printing (separation into cyan, magenta, yellow and black dyes), color photography and motion pictures (separation into red, green and blue-sensitive emulsions), and color television and monitors (separation into red, green and blue sources).

The echelon described in this paper is one device which can be used to achieve the separation of a spectrum into bands. Other devices which can also achieve this separation without loss of energy are gratings, prisms and dichroic beam-splitters [1]. If significant loss of energy is tolerable, then color filters are another device which can be used.

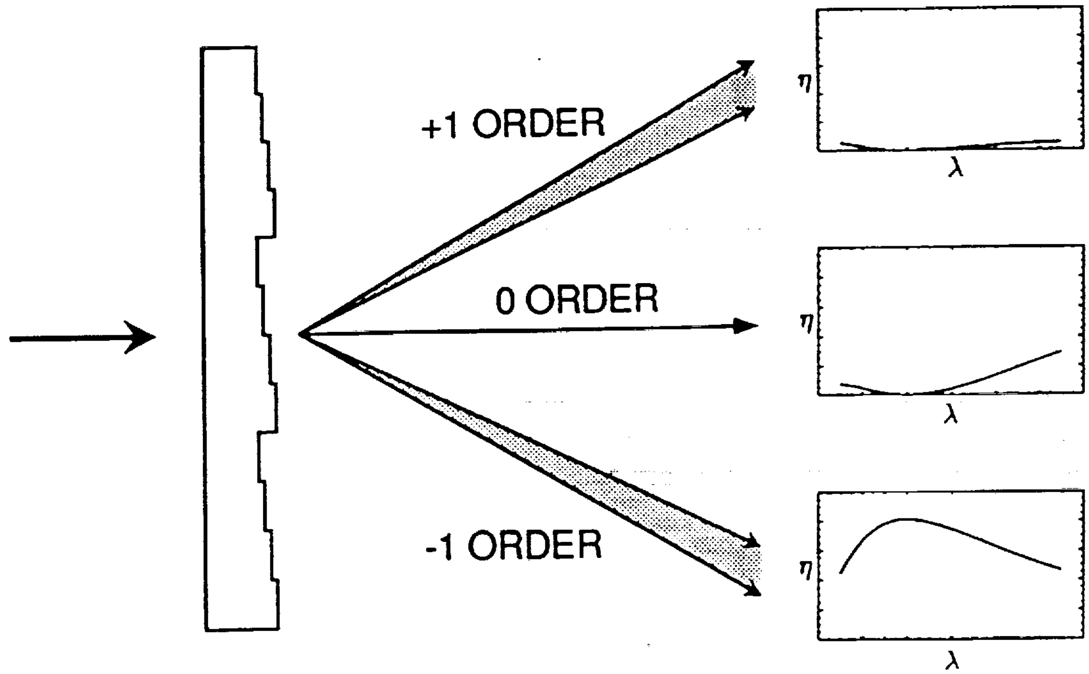

Figure 1: Conventional Binary Optics Grating.

The remainder of this paper describes the echelon in more detail. Section 3 describes the principle of operation of the echelon and the types of color separation it is capable of. Section 4 describes the fabrication of a prototype echelon using the binary optics process and section 5 describes the test of the prototype. Section 6 summarizes the paper.

3. THEORY

3.1. Conventional Grating

In order to better understand the operation of the echelon, it is instructive to examine the conventional method of separating colors via a grating. In binary optics, we approximate a blazed grating by a staircase profile with N steps [2], as shown in figure 1. In the figure, the η vs λ curves depict the spectral content of each order. Each step has a physical depth of

$$d = \lambda_0/[N(n_0 - 1)] \tag{1}$$

where n_0 is the index of the material at the design wavelength λ_0. Each step introduces a $2\pi/N$ phase shift for a total phase shift of 2π across one grating period. Therefore, at λ_0, the grating is blazed for the -1 order. For different wavelengths, the total phase shift introduced across one grating period (neglecting material dispersion) is $2\pi\lambda_0/\lambda$. For wavelengths close to λ_0 (e.g., $0.8 < \lambda/\lambda_0 < 1.3$), the total phase shift is still approximately 2π and the -1 order will contain the majority of energy at that wavelength, as shown by the efficiency curves in figure 1. Specifically, the efficiency of the ith order of an N-step conventional grating is [3]

$$\eta(i, \lambda) \quad = \quad \mathrm{sinc}^2(i/N)\, \mathrm{sinm}^2[\lambda_0/(N\lambda) + i/N, N] \tag{2}$$

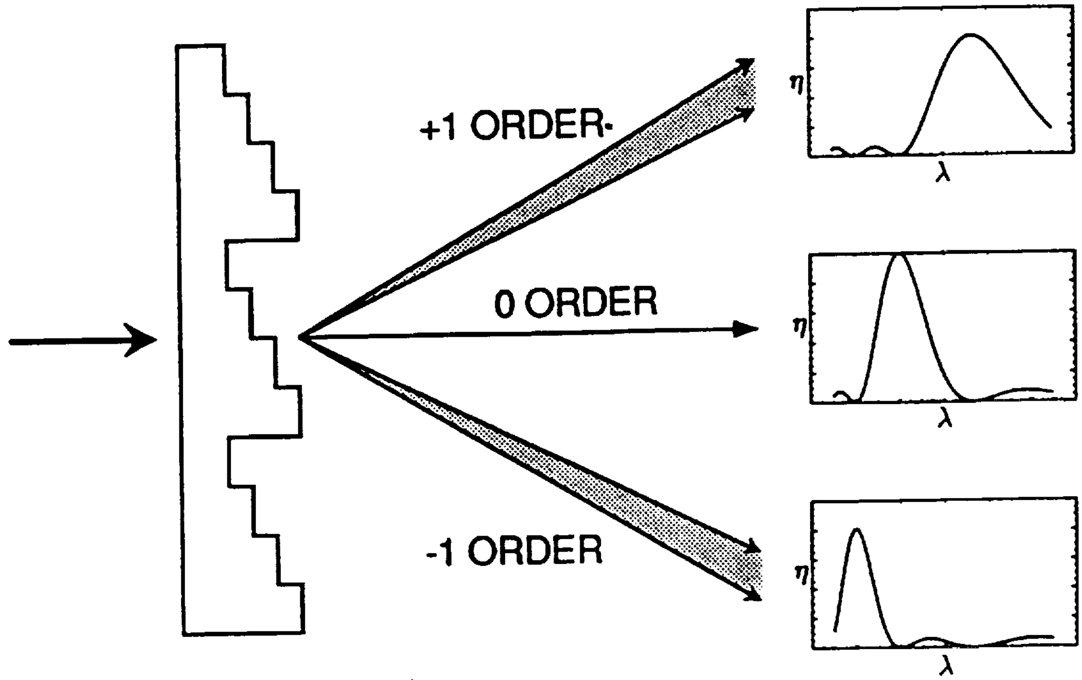

Figure 2: Binary Optics Echelon.

$$\text{where } \mathrm{sinc}(x) = \frac{\sin(\pi x)}{\pi x}$$
$$\text{and } \mathrm{sinm}(x, N) = \frac{\sin(N\pi x)}{N\sin(\pi x)}$$

The sinc term is the efficiency due to the stepped nature of the structure; while the sinm term is a result of the interference between the N phased steps.

In the conventional scheme, all wavelengths are diffracted primarily into the -1 order. However, the dispersion of the grating separates the wavelengths within the -1 order. As depicted by the shaded area in figure 1, the grating diffracts different wavelengths in different directions. Specifically, light of wavelength λ is diffracted at the angle

$$\sin\theta = i\lambda/T \tag{3}$$

where i is the diffraction order and T is the period of the grating.

3.2. Echelon

Now consider the "echelon" of figure 2. Strictly speaking, the structure is not an echelon [4], but we use the term to distinguish it from the conventional binary optics grating. This element also consists of N steps, but each step has a physical depth of

$$d = \lambda_0/(n_0 - 1) \tag{4}$$

Compared to the conventional grating (see equation 1), each step is N times deeper and therefore introduces N times the phase shift, which is exactly a phase shift of 2π at wavelength λ_0. However,

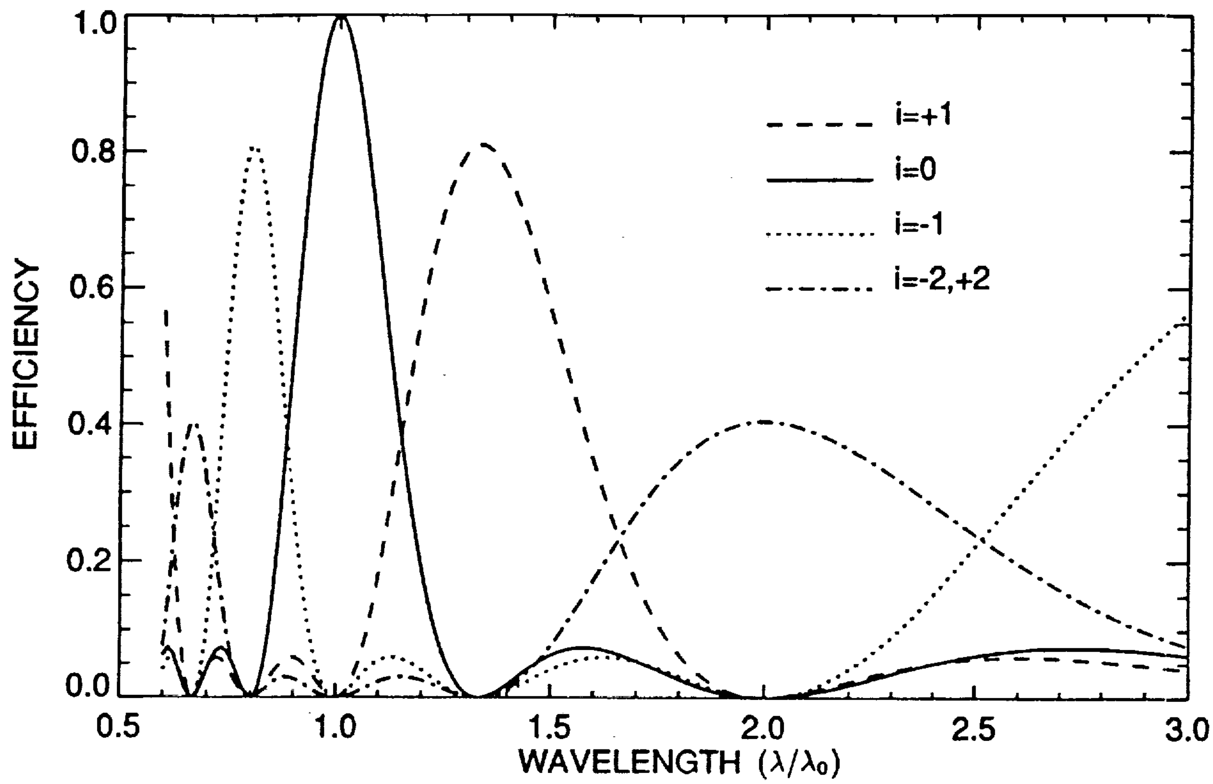

Figure 3: Diffraction Efficiency for 4-step Echelon.

for thin gratings, a phase shift of 2π is equivalent to a phase shift of 0. Therefore, at wavelength λ_0, the echelon behaves like a flat plate and is most efficient in the 0 order, as depicted by the peak in the 0 order efficiency curve in figure 2. Now consider the wavelength $\lambda_{-1} = \lambda_0 N/(N+1)$. At this wavelength, each step introduces a phase shift of $2\pi\lambda_0/\lambda_{-1} = 2\pi + 2\pi/N$, which is equivalent to a phase shift of $2\pi/N$. Therefore, at the wavelength λ_{-1}, the echelon is effectively blazed for the -1 order, as shown by the -1 order efficiency curve. For wavelengths between λ_{-1} and λ_0, the echelon will primarily split energy between the -1 and 0 orders. In a similar fashion, the echelon will be most efficient in the +1 order for wavelength $\lambda_{+1} = \lambda_0 N/(N-1)$. Since the spectrum around λ_{-1} is diffracted mainly into the -1 order, the spectrum around λ_0 mainly into the 0 order, and the spectrum around λ_{+1} mainly into the +1 order, the echelon can be used to separate colors into wavelength bands, as originally proposed by Dammann [5].

In a previous paper [6], Dammann has analyzed stepped-phase structures using scalar diffraction theory. Based on these results and neglecting material dispersion, the efficiency of the ith diffracted order of the N-step echelon is given by

$$\eta(i,\lambda) = \mathrm{sinc}^2(i/N)\,\mathrm{sinm}^2(\lambda_0/\lambda + i/N, N) \tag{5}$$

Figure 3 plots the efficiencies for different orders of a 4-step echelon. As with all the previous expressions, the efficiency $\eta(i,\lambda)$ is the fraction of light at wavelength λ which is diffracted into order i. Accordingly, $\sum_i \eta(i,\lambda) = 1$ for all wavelengths and $\int_\lambda E(\lambda)\eta(i,\lambda)d\lambda$, where $E(\lambda)$ is the incident spectrum, is the total power in order i. For the echelon shown in the figure, we can use the +1, 0 and -1 orders to separate colors in the $.7\lambda_0$ to $2.0\lambda_0$ region. Also note that the -2 and +2 orders have the same efficiency curves. If we include material dispersion, then equation 5 becomes

$$\begin{aligned} \eta(i,\lambda) &= \text{sinc}^2(i/N)\,\text{sinm}^2(\phi_0 + i/N, N) \\ \text{where } \phi_0 &= \frac{\lambda_0[n(\lambda)-1]}{\lambda[n(\lambda_0)-1]} \end{aligned} \tag{6}$$

and $n(\lambda)$ is the index of the grating material.

Examination of equation 5 reveals that the efficiency of order i will reach a peak when the sinm term is maximized. It can be shown that $\text{sinm}(x, N)$ reaches its maximum value of 1 at integer values of x. Therefore, the efficiency peaks of order i can be calculated by setting the argument of the sinm term equal to an integer and then solving for λ. The resulting peaks occur at

$$\lambda = N\lambda_0/(mN - i), \text{ where } m \text{ is an integer} \tag{7}$$

The width of each diffracted order (as defined by its half power points) can also be calculated (although requiring numerical methods) by use of equation 5. Table 1 tabulates these peak wavelengths and half power points and their corresponding efficiencies for designs with up to 8 steps. As an example, consider the +1 order of a 4-step echelon ($i = +1, N = 4$). From the table, the diffraction efficiency has a peak of 81% at a wavelength of $1.33\lambda_0$. The efficiency falls to half of this, or 40%, at $1.16\lambda_0$ on the short wavelength side and at $1.57\lambda_0$ on the long wavelength side. Note that the response is not symmetric with respect to λ. Instead, it is symmetric with respect to $1/\lambda$.

In table 1, we have set $m = 1$ in order to keep the grating thin. Also, we only consider orders $i < N/2$ for two reasons. First, orders higher than this have efficiencies below 50% as a result of the sinc term. Second, inclusion of these higher orders may result in spectral overlap. That is, two different orders may have relative peaks at the same wavelength (e.g., orders +2 and -2 in figure 3).

The following points summarize the design process for the echelon:

1. Choose the central wavelength λ_0 to determine the wavelength peak of the zero order.
2. Choose the number of steps N to determine the peak wavelengths, peak efficiencies and widths of the other diffracted orders (see table 1).
3. Choose the period T to determine the direction of the diffracted orders (θ in the following section).
4. The grating material determines the step depth d (equation 4).

3.3. Separation of Wavelengths

The purpose of the echelon is to separate wavelengths. As an example, consider the following case. Suppose that we require the wavelengths λ_0 and λ_{-1} to be laterally separated by Δx over a distance z (see figure 4). Then, by trigonometry and the grating equation:

Table 1: Wavelength Bands for an N-Step Echelon

	N											
i	3		4		5		6		7		8	
									1.97		1.76	
+3									1.75	52%	1.60	61%
									1.58		1.47	
					1.96		1.69		1.54		1.44	
+2					1.67	57%	1.50	68%	1.40	76%	1.33	81%
					1.45		1.35		1.29		1.24	
	1.96		1.57		1.41		1.32		1.26		1.22	
+1	1.50	68%	1.33	81%	1.25	87%	1.20	91%	1.17	93%	1.14	95%
	1.22		1.16		1.12		1.10		1.09		1.08	
	1.18		1.13		1.10		1.08		1.06		1.06	
0	1.00	100%	1.00	100%	1.00	100%	1.00	100%	1.00	100%	1.00	100%
	.87		.90		.92		.93		.94		.95	
	.85		.88		.90		.92		.93		.94	
-1	.75	68%	.80	81%	.83	87%	.86	91%	.88	93%	.89	95%
	.67		.73		.78		.81		.83		.85	
					.76		.79		.82		.84	
-2					.71	57%	.75	68%	.78	76%	.80	81 %
					.67		.71		.74		.77	
									.73		.76	
-3									.70	52%	.73	61%
									.67		.70	

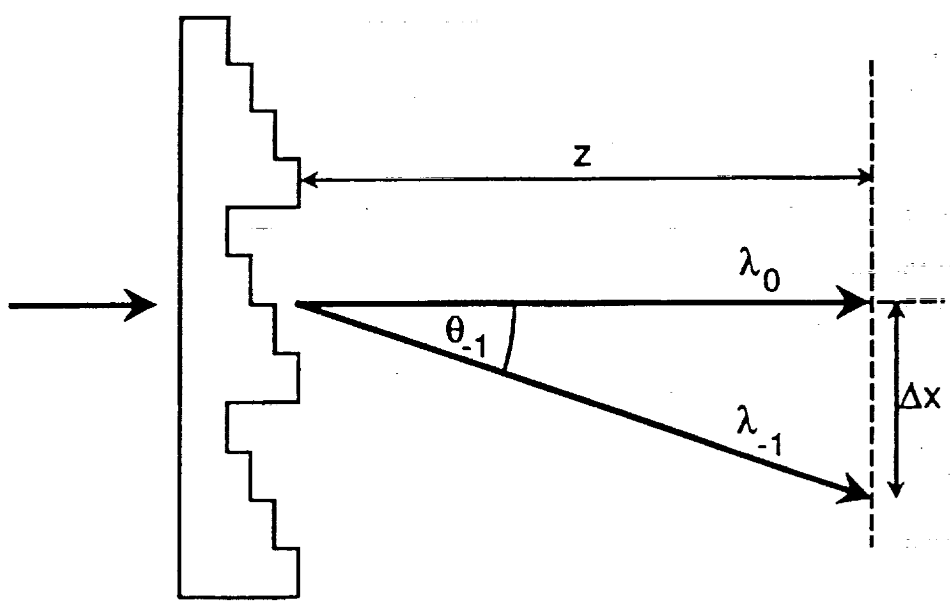

Figure 4: Separation of Wavelengths in an Echelon.

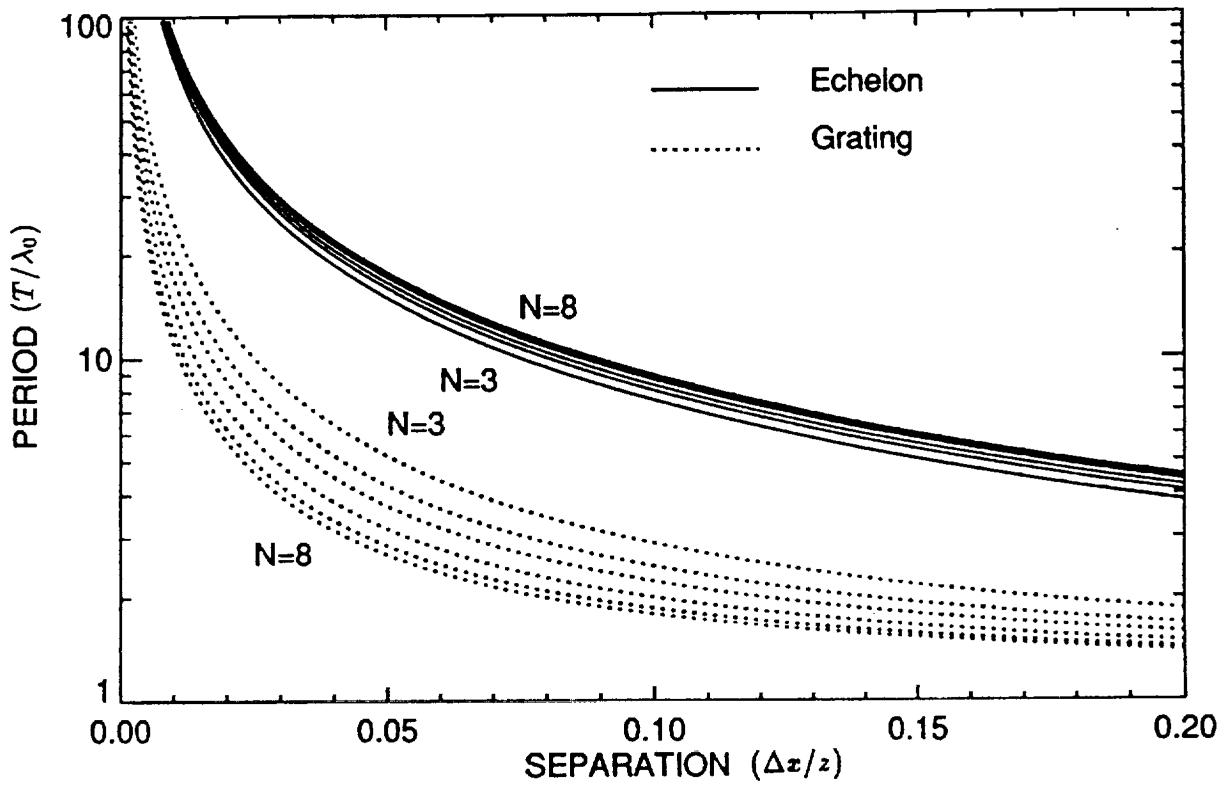

Figure 5: Period Required to Separate Wavelengths.

$$\tan\theta_{-1} = \Delta x/z \quad (8)$$
$$\sin\theta_{-1} = \lambda_{-1}/T \quad (9)$$

For an echelon, λ_{-1} varies with N (see table 1). If we fix N, then λ_{-1} is also fixed (relative to λ_0) and the above equations give the period T required to produce a given offset $\Delta x/z$. The solid curves of figure 5 plot this relationship for different numbers of steps.

Now compare this to the situation in a conventional grating (see figure 6). Again, by trigonometry and the grating equation, we have

$$\tan\theta_0 - \tan\theta_{-1} = \Delta x/z \quad (10)$$
$$\sin\theta_{-1} = \lambda_{-1}/T \quad (11)$$
$$\sin\theta_0 = \lambda_0/T \quad (12)$$

Again, we can plot T vs $\Delta x/z$ (dashed lines in figure 5). The figure shows that a much smaller grating period is required for a conventional grating to achieve the same lateral separation as the echelon. In addition, the conventional grating also laterally offsets the central wavelength by

$$x_0/z = \tan\theta_0 \quad (13)$$

as shown in figure 7. The dashed lines are used to show the correspondance with the dashed curves of figure 5.

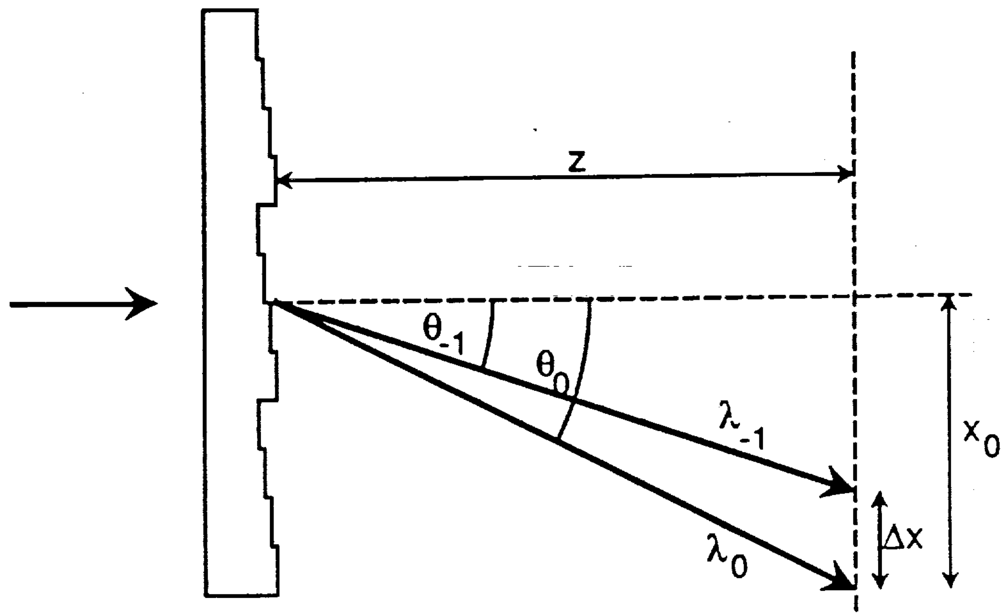

Figure 6: Separation of Wavelengths in a Conventional Grating.

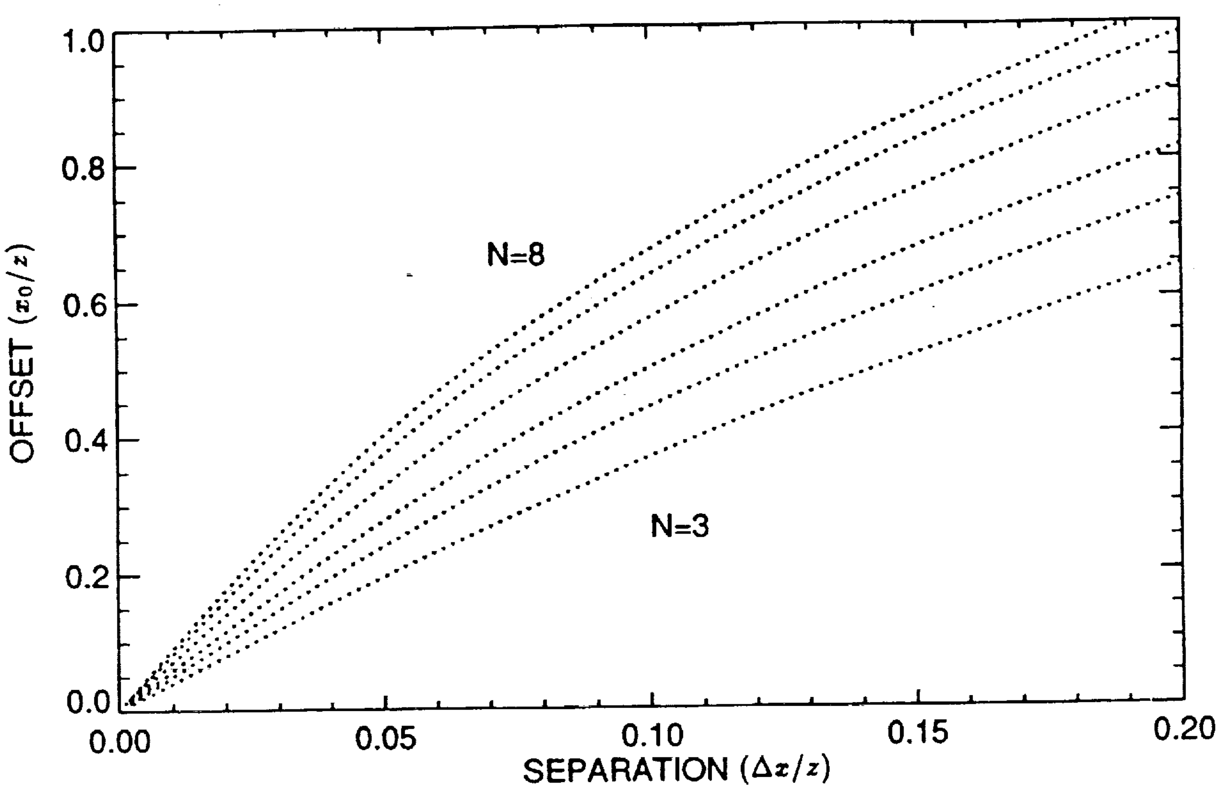

Figure 7: Offset Produced by Conventional Grating.

Table 2: Measured Etch Depths (μm).

Location	First etch	Second etch
Center	1.06	2.23
Edge	1.11	2.36
Corner	1.17	2.44
Target	1.14	2.28

4. FABRICATION

Using binary optics technology [2], we fabricated a 4-step echelon for use in the visible ($N = 4, \lambda_0 = 525nm, T = 16\mu m$). The process begins by transforming the optical design of the echelon into a set of amplitude photomasks; in this case, we use two Cr-photomasks with 50% duty cycle gratings of periods 8 and 16 μm, respectively, to produce the final 16 μm period echelon. These patterns are first replicated into a thin photoresist film (Shipley 1800 positive photoresist) by vacuum-contact photolithography, using a Karl Suss MA6 contact mask aligner operating at 365 nm. The resultant photoresist mask is then transferred into the substrate material to a precise depth by RIE. For substrates, we use 2" diameter, 6 mm thick Suprasil fused silica discs ($n_0 = 1.46$) polished on both sides, with a top surface flatness of $\lambda/10$. The step depth for this echelon is 1.14 μm, as given by equation 4, and the total depth of the echelon is 3.42 μm, three times the step depth.

The mask with the smaller features (the 8 μm period mask) is printed first to maintain linewidth fidelity. The substrate is loaded onto a 6" diameter quartz plate covering the RF powered cathode and then etched in a Perkin Elmer sputter-etch system operated in the RIE mode to the target depth of 1.14 μm. CHF_3 is introduced into the system via a feedback-controlled mass flow controller to a pressure of 10 mTorr. Typical quartz etching rates are 16.5 nm/min at 180 watts RF power and 220 volts bias voltage. Etch depths are controlled by etch time. Selectivity between the photoresist mask and the quartz substrate is approximately two to one.

Next, the coarser mask is aligned to the pattern previously etched into the substrate surface. A Cr film evaporated through a stencil mask onto the pattern edges enhances visibility during alignment. The second application of photoresist must be sufficiently thick to maintain photoresist linewidth across the previously etched 1 μm feature. That is, the photoresist must somewhat planarize the existing topography. Here, we are aided by the large and regular features of the grating. By using a single layer of 2.3 μm thick photoresist, we could preserve the pattern integrity without resorting to more complex multilayer resist techniques. The second mask is then etched to a target depth of 2.28 μm. The use of two masks results in a 4-step echelon, due to the binary coding scheme used to define the masks. The completed echelon covers an area of approximately 25 cm x 35 cm.

The actual etch depths are measured at different locations with a Tencor alpha-step 200 stylus profilometer and the results are tabulated in table 2. A sample measurement is shown in figure 8. The etch depth variation of approximately ±5% is mainly due to a radially non-uniform etch rate across the substrate.

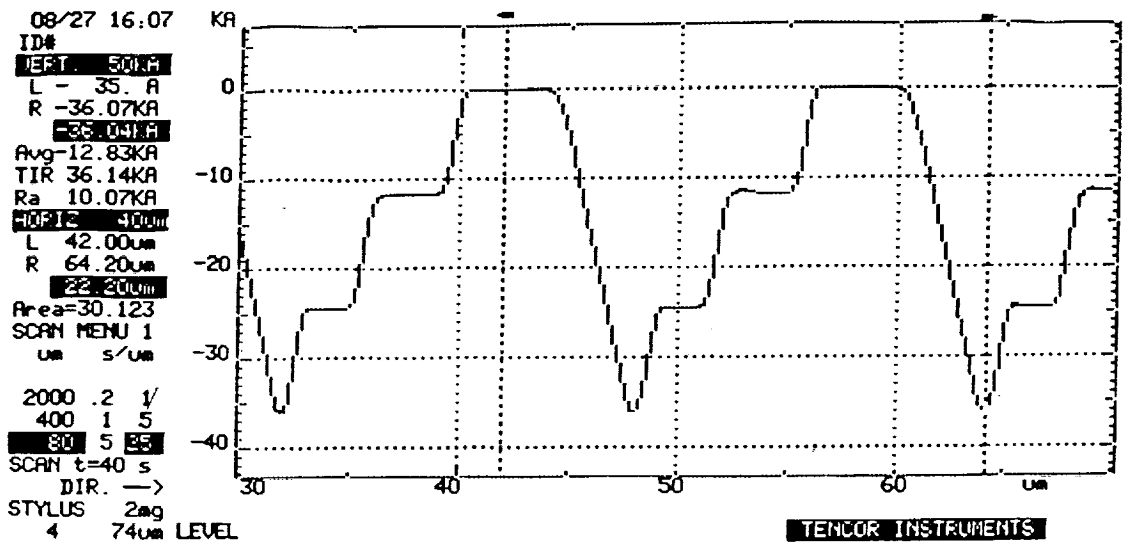

Figure 8: Stylus Profilometer Trace.

5. TEST

The fabricated echelon is tested using the experimental set-up of figure 9. We use a 12 W tungsten-halogen bulb with a diffuser as the source, with the aperture used to control the size of the source. The lens images the source onto the entrance slit of the spectrometer and the echelon splits the single image of the source into multiple images as shown by the dashed lines, each image corresponding to a diffracted order of the echelon. For the 4-step echelon, we are interested only in the -1,0 and +1 orders. The multiple images still fall on the entrance slit of the spectrometer. The aperture in the echelon plane is used to block off stray light and the spatial filter is used to block unwanted orders from entering the spectrometer. The photomultiplier produces a current proportional to the incident light. The load resistor converts this current to an output voltage, which is measured by the lock-in analyzer. The chopper is used in conjunction with the lock-in to increase the SNR of the system.

Initially, all orders are allowed to enter the spectrometer and this measurement is used as the reference. This reference measurement is shown in figure 10. Note that the spectrum is very weak at the shorter wavelengths ($\lambda < 400nm$).

Next, all orders except one are blocked and the spectral content of the unblocked order is measured. This is repeated for orders -1, 0 and +1. The results are shown in figure 11. The solid curves are the theoretical predictions based on equation 6, including the effects of the material dispersion. The connected crosses are the experimental measurements. The theory and experiment agree quite well, except at the shorter wavelengths. We believe this discrepancy is due to the weak reference at these wavelengths and the difficulty of making accurate measurements with respect to this reference.

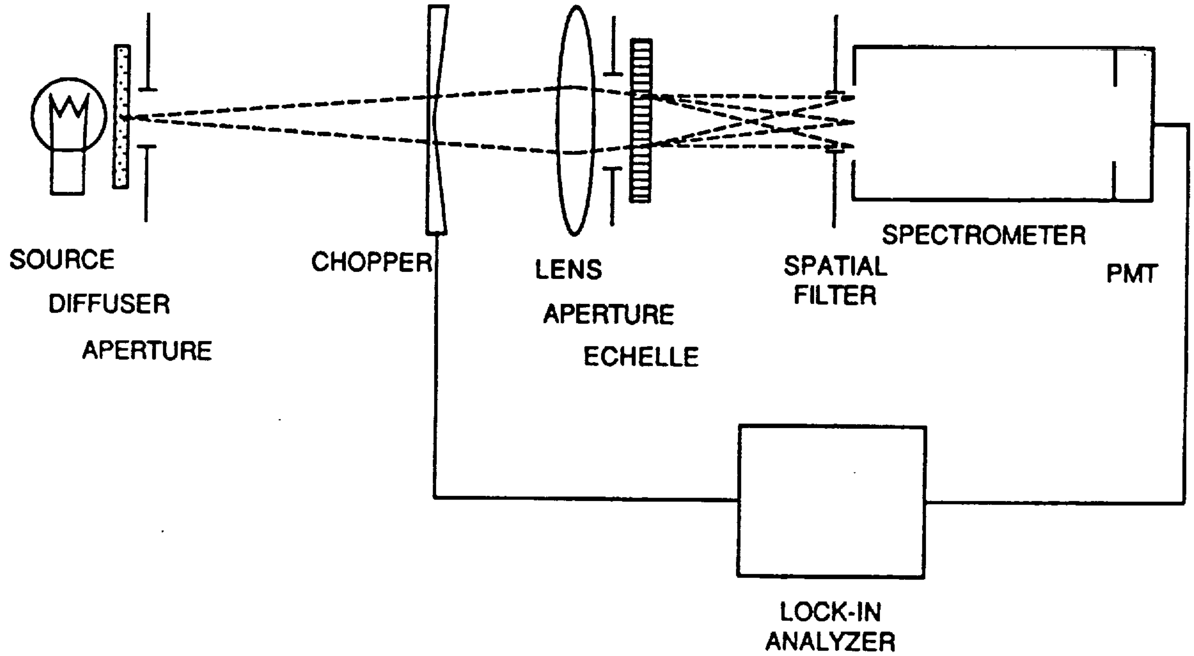

Figure 9: Experimental Set-up.

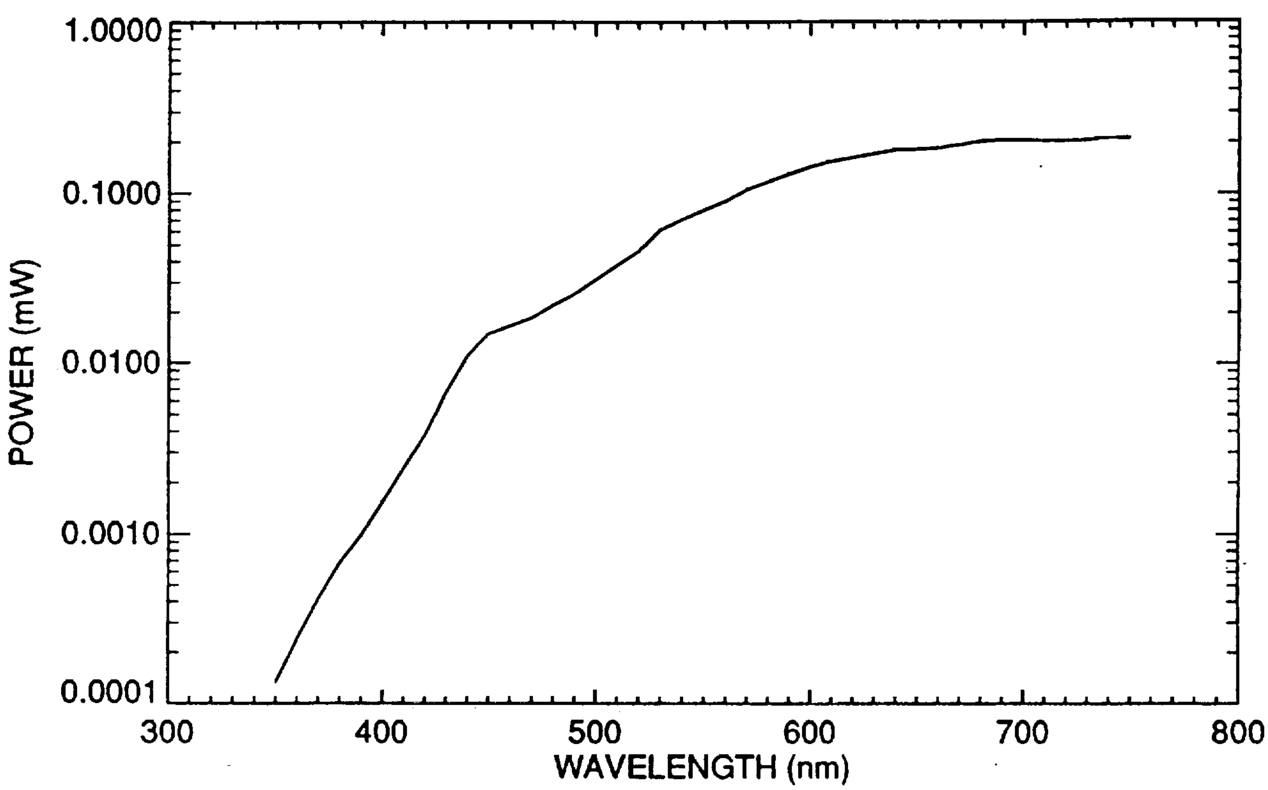

Figure 10: Reference Power.

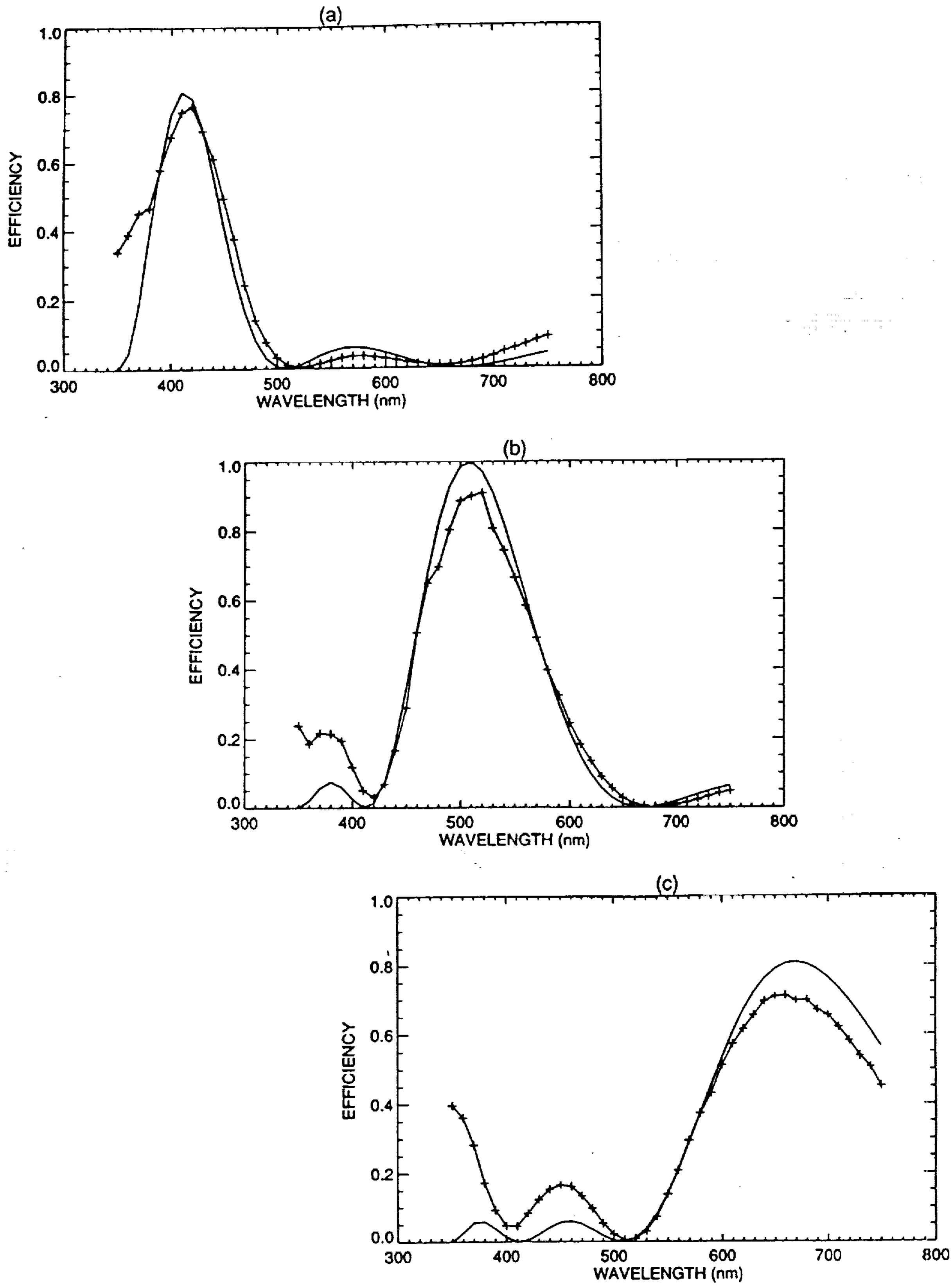

Figure 11: Spectral Composition of Orders (a) -1 Order (b) 0 Order (c) +1 Order

6. SUMMARY

The "echelon" is one device capable of separating a spectrum into several bands. We have analyzed the performance of the echelon, calculating the possible bands and the corresponding efficiencies for echelons of different numbers of steps (see table 1). We have also experimentally demonstrated the feasibility of using the "echelon" design for color discrimination. Using the binary optics process, we fabricated a 4-step echelon with center wavelength of $\lambda_0 = 525nm$. Measurements show that the echelon's spectral response agrees with the theoretical predictions.

7. REFERENCES

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FINAL PROGRAM

Topics and schedule subject to change due to cancellations or other circumstances beyond our control at the time of the meeting.

TUESDAY MORNING, 23 FEBRUARY 1993

0730 REGISTRATION

0830 CALL TO ORDER AND OPENING REMARKS
Program Co-Chairperson Helen Cole, NASA, Marshall Space Flight Center, Huntsville, AL

0835 WELCOME TO CONFERENCE
Dr. Joe Randall, Director, Astrionics Laboratory, NASA, Marshall Space Flight Center, Huntsville, AL
Mr. Buford Jennings, Associate Director for Technology, RD&EC, MICOM, Redstone Arsenal, AL

0850 KEYNOTE ADDRESS*
Dr. B.D. Guenther, Army Research Office, Research Triangle Park, NC

0930 Perspectives on Binary Optics Programs*†
Dr. Jasper Lupo, ODDR&E(RLM)/DARPA, The Pentagon, Washington, DC

0945 MORNING BREAK

1005 Binary Optics, Trends, and Limitations*
Michael Farn, MIT Lincoln Laboratory, Lexington, MA

1035 TUTORIAL: Design and Fabrication of Binary Optics*
Dr. Michael Morris, University of Rochester, College of Engineering and Applied Science, Institute of Optics, Rochester, NY

1135 LUNCH BREAK

*Indicates Invited Paper
†Withdrawn

TUESDAY AFTERNOON, 23 FEBRUARY 1993

SESSION A: MODELING AND DESIGN

Chairpeople: Dave Lanteigne, Weapons Sciences Directorate, U.S. Army Missile Command, Redstone Arsenal, AL
Steve Anderson, Hughes Aircraft Company, El Segundo, CA

1300	A–1	Review of Rigorous Coupled-Wave Analysis and of Homogeneous Effective Medium Approximations for High Spatial-Frequency Surface-Relief Gratings* Elias N. Glytsis, David L. Brundrett, and Thomas K. Gaylord, Georgia Institute of Technology, Atlanta, GA
1345	A–2	Scalar Limitations of Diffractive Optical Elements E.G. Johnson, M.G. Moharam, and D. Pommet, Teledyne Brown Engineering, Huntsville, AL, and University of Central Florida, Orlando, FL
1410	A–3	Sub-Wavelength Structured Surfaces and Their Applications Daniel H. Raguin and G. Michael Morris, University of Rochester, Institute of Optics, Rochester, NY
1435		AFTERNOON BREAK
1455	A–4	Diffractive Optical Elements for Generating Arbitrary Line Foci D.W. Prather, J.N. Mait, and J. Van der Gracht, Harry Diamond Laboratories, Adelphi, MD
1520	A–5	Finite Difference Time Domain Analysis of Chirped Dielectric Gratings D.H. Hochmuth and E.G. Johnson, Teledyne Brown Engineering, Huntsville, AL
1545	A–6	Asymmetric Three Beam Binary Optic Grating A.D. Kathman, E.G. Johnson, and M.L. Scott, Teledyne Brown Engineering, Huntsville, AL
1610	A–7	Scattering From Binary Optics Douglas W. Ricks, Naval Air Warfare Center, Weapons Division, China Lake, CA
1635	A–8	Mathematical Modeling for Diffractive Optics David Dobson, University of Minnesota, School of Mathematics, Minneapolis, MN; and J. Allen Cox, Honeywell Systems & Research Center, Minneapolis, MN
1700		END OF DAY

*Indicates Invited Paper

WEDNESDAY MORNING, 24 FEBRUARY 1993

0730 REGISTRATION

0800 CALL TO ORDER
Program Co-Chairperson William Pittman, U.S. Army Missile Command, Redstone Arsenal, AL

0805 TUTORIAL: Fabrication of Binary Optics*
Dr. Margaret Stern, MIT Lincoln Laboratory, Lexington, MA

SESSION B: FABRICATION
Chairpeople: John Davis, System Engineering and Production Directorate, U.S. Army Missile Command, Redstone Arsenal, AL
Steve Fawcett, NASA, MSFC, Huntsville, AL

0905 Binary Optics Fabrication Capabilities at HDOS
B–1 Mike Power and James Logue, Hughes Danbury Optical Systems, Inc., Danbury, CT

0930 MORNING BREAK

0950 Fabrication Techniques for Very Fast Diffractive Lenses
B–2 Anthony M. Tai and Joseph C. Marron, Environmental Research Institute of Michigan, Ann Arbor, MI

1015 Laser Figuring for the Generation of Analog Micro-Optics and Kineform Surfaces
B–3 Edward J. Gratrix, Hughes Danbury Optical Systems, Inc., Danbury, CT

1040 Diffractive Optics Fabricated by Direct Write Methods With an Electron Beam
B–4 Bernard Kress, David Zaleta, Walter Daschner, Kris Urquhart, Robert Stein, and Sing H. Lee, University of California at San Diego, Dept. of ECE, LaJolla, CA

1105 Phase Holograms in PMMA With Proximity Effect Correction
B–5 P.D. Maker and R.E. Muller, Jet Propulsion Laboratory, Pasadena, CA

1130 Circularly Symmetric, Surface-Emitting Semiconductor Laser
B–6 Rebecca H. Jordan, Oliver King, Gary W. Wick, and Dennis G. Hall, University of Rochester, Institute of Optics, Rochester, NY

1155 LUNCH BREAK

*Indicates Invited Paper

WEDNESDAY AFTERNOON, 24 FEBRUARY 1993

SESSION B (Continued)

1315 Micro-Optics Technology and Sensor Systems Applications Overview
B–7 G. Gal, B. Herman, W. Anderson, R. Whimey, and H. Morrow, Lockheed Missiles and Space Co., Palo Alto, CA

1340 Fabrication of Micro-Optical Devices
B–8 W. Anderson, J. Marley, D. Purdy, and G. Gal, Lockheed Missiles and Space Co., Palo Alto, CA

1405 Diffractive Optics in Adverse Environments
B–9 G.P. Behrmann, Harry Diamond Laboratories, Adelphi, MD

1430 Low Costs Paths to Binary Optics
B–10 Lawrence Domash and Art Nelson, Foster-Miller, Inc., Watham, MA

1455 AFTERNOON BREAK

SESSION C: APPLICATIONS I
Chairpeople: Paul Ashley, Weapons Sciences Directorate, MICOM, Redstone Arsenal, AL
Alan Kathman, Teledyne Brown Engineering, Huntsville, AL

1515 Diffractive Optics Design for Producibility
C–1 J. Steven Anderson, Hughes Aircraft Co., El Segundo, CA; and Robert Spande, Army Night Vision and Electro-Optics Directorate, Ft. Belvoir, VA

1540 Measurements of Microlens Performance
C–2 D. Shough, B. Herman, and G. Gal, Lockheed Missiles and Space Company, Palo Alto, CA

1605 Applications of Advanced Diffractive Optical Elements
C–3 W. Hudson Welch and Michael B. Feldman, Digital Optics Corporation, Charlotte, NC

1630 Laser Beam Steering Device
C–4 M.E. Motamedi, A.P. Andrews, and W.J. Gunning, Rockwell International Science Center, Thousand Oaks, CA

1655 SURPHEX: New Dry Photopolymers for Replication of Surface Relief Diffractive Optics (U) *
C–5 Felix P. Shvartsmen, Dupont Company, Wilmington, DE

1720 END OF DAY

*Indicates Invited Paper

THURSDAY MORNING, 25 FEBRUARY 1993

0800 REGISTRATION

0830 CALL TO ORDER
Program Co-Chairperson Helen Cole, NASA, Marshall Space Flight Center, Huntsville, AL

0835 Predesign of Diamond Turned Refractive/Diffractive Elements for IR Objectives*
Max Riedl, Optical Filter Corporation, Natick, MA

0905 Optical Storage System Design With Diffractive Optical Elements*
Prof. Ray Kostuk and Charles W. Haggans, University of Arizona, Tucson, AZ

SESSION D: APPLICATIONS II
Chairpeople: James Bilbro, Deputy Chief, Optical and RF Systems Division, NASA, MSFC, Huntsville, AL
Paul Maker, Jet Propulsion Laboratory, Pasadena, CA

0935 Theory of Dispersive Microlenses
D–1 B. Herman and G. Gal, Lockheed Missiles and Space Co., Palo Alto, CA

1000 BREAK

1020 Color Separation Gratings*
D–2 Dr. Michael W. Farn, Robert E. Knowlden, Dr. Margaret B. Stern, and Dr. Wilfrid B. Veldkamp, MIT Lincoln Laboratory, Lexington, MA

1045 Fiber Continuity Test Using Multi-Level Diffractive Elements†
D–3 Roshan Shetty and Tom Milster, University of Arizona, Optical Sciences Center, Tucson, AZ

1110 END OF CONFERENCE

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†Withdrawn

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13. ABSTRACT *(Maximum 200 words)*

The papers herein were presented at the Conference on Binary Optics held in Huntsville, AL, February 23-25, 1993. The papers were presented according to subject as follows: Modeling and Design, Fabrication, and Applications. Invited papers and tutorial viewgraphs presented on these subjects are included.

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