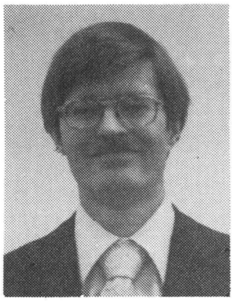

Editorial

H. J. Caulfield, Editor

On SPIE Reports

The SPIE Reports section of *Optical Engineering* is a vital part of the journal. I hope it serves the optics community in many ways the archival part of the journal cannot possibly serve. Appropriate goals include:

- technology alerts (hot new developments outlined and summarized)
- technology maps (who is doing what at various locations)
- book reviews
- personal, signed opinions by qualified experts (with opposing views welcome)
- computer program exchanges
- meeting notices
- new product and new literature announcements
- industry news
- news about people in the optics community
- placement exchange

Perhaps you can think of more. What would you like to know? How can we serve your needs?

In order to make SPIE Reports more vital, I have appointed a special editor for SPIE Reports: Joseph L. Horner of Hanscom Field, Rome Air Development Center. My belief and hope is that a special editor will bring new vitality to SPIE Reports. Reader support and encouragement are vital.

Please help Joe help you. Suggest topics and ideas. Help when called upon. We will all benefit. Write to me or, preferably, to

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OPTICAL ENGINEERING EDITORIAL SCHEDULE

SEPTEMBER/OCTOBER 1981

Photo-Optical Instrumentation Engineering
H. J. Caulfield, Guest Editor
Aerodyne Research, Inc.
Bedford Research Park
Bedford, MA 01730
617/275-9400

NOVEMBER/DECEMBER 1981

Electronically Tunable Optical Spectral Filters
I. C. Chang
Applied Technology
Div. of Itek Corporation
645 Almanor Avenue
Sunnyvale, CA 94086
408/732-2710

JANUARY/FEBRUARY 1982

Image Quality
Patrick J. Cheatham
The Aerospace Corporation
P. O. Box 92957, A2/1237
Los Angeles, CA 90009
213/648-6150

MARCH/APRIL 1982

Phase-Conjugate Optics
David Pepper, Guest Editor
Hughes Research Labs.
3011 Malibu Canyon Road
Malibu, CA 90265
213/456-6411

MAY/JUNE 1982

Coherent Optical Strain Analysis
F. P. Chiang
State University of New York at Stony Brook
Dept. of Electrical Engineering
Stony Brook, NY 11794

JULY/AUGUST 1982

Incoherent Optical Strain Analysis
F. P. Chiang
State University of New York at Stony Brook
Dept. of Electrical Engineering
Stony Brook, NY 11794

SEPTEMBER/OCTOBER 1982

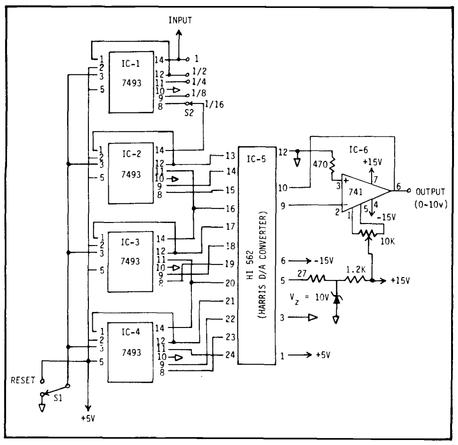
Two-Dimensional Signal Processing
Theo Kooij
DARPA
1400 Wilson Boulevard
Arlington, VA 22209
202/694-3611

Forum

TRICKS OF THE TRADE

I am starting a new column in *Optical Engineering* to be called "Tricks of the Trade," which will include laboratory-related ideas which are not generally known or publishable as formal papers. This could include circuits (with a schematic), mechanical devices, alignment procedures, chemical recipes or formulas, etc. Such material will not be refereed, and need not be original if credit is given where credit is due. I think of the new column as a mixture of "Amateur Scientist" *(Scientific American)*, "Ideas for Design" *(Electronic Design)*, and "Shop Talk" *(Applied Optics)*. The kinds of techniques or devices (tricks) used to get data for a formal journal paper, but which aren't described in the paper, are fine. I would welcome any contribution that you could make. Also, please pass the word on to your associates and students. *Joe Horner*

To start off "Tricks of the Trade," I submit the following circuit. This is the problem it solved in our lab. We own a stepper-motor driven translator which gives a normal TTL pulse (5 V) each time the motor is advanced by one step, for the purpose of computer controlling the unit. We wanted to drive a standard X-Y plotter which can only accept an analog voltage input for the X axis drive. The circuit for doing this was one furnished by Dr. Wm. Ewing of our laboratory, and is shown below. It consists of a string of



Analog drive circuit for X-Y plotter. Input is a TTL (5 V) pulse from a stepper motor circuit.

binary counters (IC1-IC4) driving a D/A converter (IC-5). The output is taken from an operational amplifier (IC-6), which outputs a 10 V (max) signal to the X axis drive of the X-Y plotter. Switch S1 resets the counters and switch S2 is a scaling switch which allows you to select every pulse, every other pulse, . . . or every 16th pulse, depending on the resolution required and the sensitivity of the recorder. Power requirements are a ±15 volt op-amp power supply and 5.0 volts for the logic chips.

The unit as shown only goes forward. A refinement would be to use up-down counter chips so the plotter could go in both directions.

We have been using this circuit for over a year and it has proved very reliable and, with a photodiode mounted on the translator, it makes an excellent instrument for scanning a light pattern.

ELECTRO-OPTIC DELPHI TECHNOLOGY FORECASTING RESULTS

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INTRODUCTION

A complete four-round Delphi technology forecasting study of electro-optics was begun in March 1980. There were three objectives. The first was to gather current projections in the electro-optic field to generally aid technology program planning. The second was to attempt new approaches to Delphi forecasting, including the grouping of questions into technology evolution stages (after Bright[1]) and the analysis of the resultant projections according to the groupings. The third was to specifically analyze the Delphi method for electro-optic management utility.

The forecasting results, reviewed herein, should be viewed for what they are, the thoughts of the individuals on the expert panel on what will happen and when it will occur. A forecast *does not* necessarily mean that the predictions will occur. The best of projections suffer from the unexpected event which changes the basic technology framework. The utility of any projection is to give a somewhat clearer, but not necessarily exact, picture of what may reasonably be expected in the future.

The basic objective of the Delphi technique is to gather technology forecasting information from an anonymous expert panel. This technique was developed by Gordon and Helmer[2] of the RAND Corporation in the early 1950s. Its attributes were characterized as improvements over the panel, committee, and poll.

The Delphi, as characterized by Gordon and Helmer, was a four-round exercise. The first round describes the Delphi process and asks the experts for their projections which will be distributed for date estimates on round two. The round-one question for this research was, "Would you please list the major events and developments in electro-optics which, in your opinion, may be expected over the next fifty years, in approximate order of occurrence, with estimated dates?" A compilation of these projections was then provided on round two for all of the experts to give their date estimates.

On rounds three and four, increasing amounts of feedback are given with the hope that a better consensus can be reached. For example, on round three the median and outer quartiles (the lower quartile is the lower 25% and the upper 25%) from round two are given for each projection as anonymous feedback. Those whose date estimates were either in the upper or lower quartile were also asked to provide rationale for their optimistic or pessimistic views. These rationale, along with the revised median and quartile data from round three, were then provided as anonymous feedback for the fourth round.

The original group for this research was comprised of 39 experts selected by the author as representative of the general electro-optic community. Of these, 25 agreed to participate in the various phases throughout the study. Consistent with the Delphi technique, their identities remained anonymous during the entire exercise. Those listed in Table I have expressly agreed to be recognized for their efforts. The rest wished to remain anonymous.

TABLE I. Alphabetical Listing of Delphi Participants*

David Casasent	Alan McGovern
John Caulfield	Joe McKay
Ivan Cindrich	William Oakley
Buddy Dace	Peter Poulsen
James Fienup	Thomas Rabson
Nicholas George	Robert Shannon
Milton Gottlieb	Denzil Stilwell
Peter Guilfoyle	William Stoner
David Hecht	Richard Vyce
Bruce Horwitz	Charles Wyman

*This is a partial listing of those who have agreed to be identified. The projections are the personal views of the experts and do not necessarily represent government, industry, or academia positions. There was a total of 11 participants from industry, 5 from academia, and 4 from the government.

The results of this electro-optic Delphi exercise are shown in Table II. These 52 projections cover wide areas of technology and, in several instances, represent significant breakthroughs. One of the major observations is that a consensus was reached very early. There were only five projections in which the median changed more than three years over rounds 2 to 4. A second observation is that the vast majority of these forecasts were projected over the next 20 years. The raw data also showed a tendency of date clustering. This was particularly true with dates ending in a 5 or 0. The date clustering made calculation of the outer quartiles somewhat insignificant. Their dispersion from the median does not neccessarily indicate a better or lesser consensus. This was an artifact of the method of calculation.

CONCLUSIONS

It is somewhat difficult and always risky to draw definitive conclusions from a technology forecasting exercise. The results, however, appear positive and indicate a bright future for the electro-optic community. The growth presently seems limited by the available funds and manpower. Even modest increases could greatly accelerate the fruition of many of these forecasts.

ACKNOWLEDGMENTS

The author would again like to thank all of the participants of the expert panel for their time and patience. Without them, this study could not have been completed. It is hoped that their efforts have shed significant light on where the electro-optic technology is headed. It is also hoped that the readers will find these projections interesting and possibly useful in furthering their professional goals. The validity of these data will be tried by the ultimate test: TIME.

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1. James R. Bright and Milton E. F. Shoeman, Eds., *A Guide to Practical Technology Forecasting*, Prentice-Hall, Englewood Cliffs, NJ, 1973.
2. T. J. Gordon and O. Helmer, *Report on a Long Range Forecasting Study*, P-2982, RAND Corporation, Santa Monica, CA, September 1964.

Table II is on page SR-106


VIDEO
at 200 f/s
HSV 200 COLOR
nac
HIGH SPEED VIDEO
HSV 200
HSV 200

TABLE II. DELPHI STUDY RESULTS FROM ROUNDS 2, 3, and 4

Here are the final results of the electro-optic Delphi study. As you can see, a consensus was reached early on many of the projections. This result was not anticipated. Several of the outer quartile ranges on the fourth round appear larger than those of the same projection on round three. This is an artifact of the method by which the upper and lower quartiles were calculated. This deviation actually indicates a better consensus than was achieved on round three.

a. DEMONSTRATED: The item or technique has proven valid in a laboratory environment.

a.1 10 GHz bandwidth, 10^8 spatial bandwidth product E-O processors are demonstrated.
Round 2 LQ 1984 M 1985 UQ 1999
Round 3 LQ 1984 M 1986 UQ 1999
Round 4 LQ 1984 M 1986 UQ 1999

a.2 Airborne optical pattern recognition systems on satellites and missiles are demonstrated.
Round 2 LQ 1984 M 1985 UQ 1989
Round 3 LQ 1984 M 1986 UQ 1990
Round 4 LQ 1984 M 1985 UQ 1989

a.3 Laser fusion using E-O demonstrated.
Round 2 LQ 1984 M 1987 UQ 1993
Round 3 LQ 1984 M 1987 UQ 1995
Round 4 LQ 1984 M 1987 UQ 1999

a.4 1000x1000 direct imaging Fourier transformer is demonstrated.
Round 2 LQ 1980 M 1983 UQ 1990
Round 3 LQ 1982 M 1983 UQ 1987
Round 4 LQ 1982 M 1983 UQ 1987

a.5 Solid state "perception" stages with programmable connections are demonstrated.
Round 2 LQ 1982 M 1985 UQ 1990
Round 3 LQ 1983 M 1986 UQ 1991
Round 4 LQ 1982 M 1987 UQ 1991

a.6 Fully integrated 2D processor demonstrated
Round 2 LQ 1982 M 1985 UQ 1986
Round 3 LQ 1981 M 1985 UQ 1986
Round 4 LQ 1983 M 1985 UQ 1990

a.7 Fully integrated 3D processor demonstrated
Round 2 LQ 1987 M 1990 UQ 2000
Round 3 LQ 1987 M 1990 UQ 2000
Round 4 LQ 1988 M 1990 UQ 2020

a.8 Time integrating acousto-optics on a chip are demonstrated.
Round 2 LQ 1981 M 1983 UQ 1987
Round 3 LQ 1981 M 1983 UQ 1987
Round 4 LQ 1981 M 1983 UQ 1990

a.9 Direct optical-to-optical sensors eliminating optical-to-electrical interface are demonstrated.
Round 2 LQ 1984 M 1988 UQ 1992
Round 3 LQ 1984 M 1988 UQ 1995
Round 4 LQ 1984 M 1987 UQ 1995

a.10 Continuously tunable laser sources from x ray to far infrared are demonstrated.
Round 2 LQ 1988 M 1993 UQ 2010
Round 3 LQ 1988 M 1995 UQ 2005
Round 4 LQ 1988 M 1995 UQ 2005

a.11 500 Million Instruction Per Second (MIP) optical/digital processor is demonstrated.
Round 2 LQ 1984 M 1989 UQ 1995
Round 3 LQ 1984 M 1989 UQ 1995
Round 4 LQ 1984 M 1988 UQ 1995

a.12 System Environmental Threat Simulator capable of several thousand high fidelity threat objects for real time radar/data processor simulation is demonstrated.
Round 2 LQ 1984 M 1988 UQ 2000
Round 3 LQ 1985 M 1990 UQ 1995
Round 4 LQ 1985 M 1989 UQ 1992

a.13 200 MHz, 150 cy/mm spatial light modulator is demonstrated.
Round 2 LQ 1982 M 1985 UQ 1988
Round 3 LQ 1980 M 1985 UQ 1987
Round 4 LQ 1983 M 1985 UQ 1987

a.14 1000x1000 detector element arrays are demonstrated.
Round 2 LQ 1981 M 1982 UQ 1990
Round 3 LQ 1981 M 1984 UQ 1987
Round 4 LQ 1981 M 1983 UQ 1990

a.15 Optical multiplexers for shifting and mixing large image elements are demonstrated.
Round 2 LQ 1980 M 1990 UQ 1995
Round 3 LQ 1982 M 1989 UQ 1992
Round 4 LQ 1983 M 1990 UQ 1992

a.16 Light controlled subnanosecond spatial light modulator is demonstrated.
Round 2 LQ 1982 M 1988 UQ 1999
Round 3 LQ 1983 M 1987 UQ 1995
Round 4 LQ 1984 M 1990 UQ 1999

a.17 Audio-visual man-machine interface which allows visual programming is demonstrated.
Round 2 LQ 1984 M 1995 UQ 2005
Round 3 LQ 1988 M 1994 UQ 2010
Round 4 LQ 1988 M 1990 UQ 2000

a.18 Direct human brain-to-computer communication is demonstrated.
Round 2 LQ 1980 M 1995 UQ 2050
Round 3 LQ 1980 M 1999 UQ 2020
Round 4 LQ 1990 M 2000 UQ 2020

a.19 Low voltage, electrically addressed, amplitude modulating spatial light modulator which is directly computer controlled is demonstrated.
Round 2 LQ 1981 M 1986 UQ 1990
Round 3 LQ 1980 M 1985 UQ 1987
Round 4 LQ 1981 M 1985 UQ 1986

a.20 Resonance detector which permits detection of light amplitude is demonstrated.
Round 2 LQ 1982 M 1993 UQ 2025
Round 3 LQ 1989 M 1995 UQ 2020
Round 4 LQ 1990 M 1995 UQ 2020

a.21 Megabit optical Erasable Programmable Read Only Memory (EPROM) is demonstrated.
Round 2 LQ 1982 M 1988 UQ 1993
Round 3 LQ 1982 M 1989 UQ 1993
Round 4 LQ 1982 M 1985 UQ 1993

a.22 E-O computer base technology at 100 GHz is demonstrated.
Round 2 LQ 1985 M 1996 UQ 2020
Round 3 LQ 1987 M 1996 UQ 2010
Round 4 LQ 1988 M 1995 UQ 2010

a.23 100 dB (100,000:1) optical analog computer at a GHz bandwidth using A-O technology is demonstrated.
Round 2 LQ 1982 M 1989 UQ 2000
Round 3 LQ 1983 M 1990 UQ 1999
Round 4 LQ 1985 M 1990 UQ 2000

a.24 "Cyclops," search for extraterrestial intelligence using massive optical spectrum analyses & direction finders, technology is demonstrated.
Round 2 LQ 1988 M 1994 UQ 2010
Round 3 LQ 1988 M 1995 UQ 2004
Round 4 LQ 1987 M 1995 UQ 2001

b. AVAILABLE: The item or technique has proven valid and its description is in the technical literature of the identified time period. This description must be sufficient to use or incorporate it into system designs.

b.1 Real time triple product processor becomes available.
Round 2 LQ 1981 M 1985 UQ 1992
Round 3 LQ 1982 M 1985 UQ 1990
Round 4 LQ 1983 M 1985 UQ 1990

b.2 US AST laser weapon becomes available.
Round 2 LQ 1982 M 1987 UQ 1995
Round 3 LQ 1984 M 1987 UQ 1990
Round 4 LQ 1985 M 1987 UQ 1998

b.3 Economic small quantity, high quality optics are available.
Round 2 LQ 1980 M 1984 UQ 2000
Round 3 LQ 1980 M 1985 UQ 2000
Round 4 LQ 1981 M 1985 UQ 2000

b.4 Micro-optical transistors and logic circuits are available.
Round 2 LQ 1983 M 1990 UQ 2000
Round 3 LQ 1984 M 1990 UQ 2000
Round 4 LQ 1983 M 1990 UQ 1995

b.5 Agile mirror laser radar is available.
Round 2 LQ 1983 M 1985 UQ 1995
Round 3 LQ 1984 M 1985 UQ 1993
Round 4 LQ 1984 M 1985 UQ 1993

b.6 Continuously addressable deformable mirrors are available.
Round 2 LQ 1982 M 1988 UQ 2000
Round 3 LQ 1984 M 1986 UQ 1992
Round 4 LQ 1984 M 1985 UQ 1990

b.7 Flat wall panel color TV is available.
Round 2 LQ 1982 M 1988 UQ 2000
Round 3 LQ 1984 M 1990 UQ 2000
Round 4 LQ 1984 M 1989 UQ 1995

c. PRODUCED: Item has evolved from developmental lab into a more advanced state. It is not necessary for large scale mass production. Fabrication in units of ten is sufficient for low volume items. Design has been standardized.

c.1 CCD spatial light modulators are produced.
Round 2 LQ 1983 M 1985 UQ 1990
Round 3 LQ 1983 M 1985 UQ 1987
Round 4 LQ 1983 M 1985 UQ 1987

c.2 E-O pattern recognition system using LCLV is produced.
Round 2 LQ 1983 M 1988 UQ 2000
Round 3 LQ 1984 M 1988 UQ 1990
Round 4 LQ 1984 M 1988 UQ 1990

c.3 Economical holographic memory systems are produced.
Round 2 LQ 1983 M 1989 UQ 2000
Round 3 LQ 1985 M 1989 UQ 1995
Round 4 LQ 1985 M 1989 UQ 1992

c.4 Solid state visible, highly coherent laser is produced.
Round 2 LQ 1982 M 1985 UQ 1990
Round 3 LQ 1983 M 1985 UQ 1987
Round 4 LQ 1983 M 1985 UQ 1986

c.5 Fiber optics are produced with sales of $Two Billion annually.
Round 2 LQ 1983 M 1990 UQ 2000
Round 3 LQ 1986 M 1990 UQ 2000
Round 4 LQ 1985 M 1989 UQ 2000

c.6 Radiation hardening fiber optic data links are produced.
Round 2 LQ 1983 M 1985 UQ 1992
Round 3 LQ 1983 M 1985 UQ 1990
Round 4 LQ 1984 M 1985 UQ 1990

c.7 Industrial lasers are produced with a value of $Two Billion annually.
Round 2 LQ 1983 M 1990 UQ 2010
Round 3 LQ 1985 M 1990 UQ 2000
Round 4 LQ 1982 M 1990 UQ 2000

d. COMMONLY USED. Item or technique can be found in existing hardware or designs in the designated time period. A reasonable characteristic is that there is a large replacement and repair market.

d.1 Use-specific filters compared to "matched filters" are commonly used.
Round 2 LQ 1984 M 1992 UQ 2000
Round 3 LQ 1986 M 1992 UQ 2000
Round 4 LQ 1988 M 1992 UQ 2000

d.2 Fiber optic data links are commonly used.
Round 2 LQ 1982 M 1985 UQ 1992
Round 3 LQ 1983 M 1985 UQ 1992
Round 4 LQ 1983 M 1985 UQ 1992

d.3 1000-element LED arrays commonly used.
Round 2 LQ 1983 M 1990 UQ 2000
Round 3 LQ 1985 M 1990 UQ 1995
Round 4 LQ 1987 M 1990 UQ 1995

d.4 Phased array radar or sonar signals processed holographically are commonly used.
Round 2 LQ 1987 M 1993 UQ 2000
Round 3 LQ 1988 M 1992 UQ 1999
Round 4 LQ 1989 M 1992 UQ 1999

d.5 Numerical optical processing is commonly used by the military and industry.
Round 2 LQ 1987 M 1999 UQ 2030
Round 3 LQ 1990 M 2000 UQ 2010
Round 4 LQ 1992 M 2000 UQ 2010

d.6 E-O voice analyzers are commonly used.
Round 2 LQ 1986 M 1995 UQ 2020
Round 3 LQ 1990 M 1995 UQ 2000
Round 4 LQ 1987 M 1994 UQ 1997

d.7 Charge transfer devices are commonly used as video cameras.
Round 2 LQ 1980 M 1985 UQ 1995
Round 3 LQ 1982 M 1985 UQ 1990
Round 4 LQ 1982 M 1985 UQ 1988

d.8 Integrated optics on a chip are commonly used.
Round 2 LQ 1986 M 1990 UQ 1997
Round 3 LQ 1989 M 1990 UQ 1997
Round 4 LQ 1989 M 1990 UQ 1997

d.9 High speed optical switches are commonly used in radar and data processing.
Round 2 LQ 1988 M 1990 UQ 1999
Round 3 LQ 1988 M 1990 UQ 2000
Round 4 LQ 1989 M 1990 UQ 2000

d.10 Holographic spectral filters are commonly used.
Round 2 LQ 1985 M 1995 UQ 2000
Round 3 LQ 1985 M 1993 UQ 2000
Round 4 LQ 1987 M 1990 UQ 2000

d.11 Coherent image amplifiers commonly used.
Round 2 LQ 1987 M 1998 UQ 2010
Round 3 LQ 1990 M 1999 UQ 2005
Round 4 LQ 1990 M 1998 UQ 2005

d.12 Non-semiconductor detector arrays are commonly used.
Round 2 LQ 1987 M 1995 UQ 2030
Round 3 LQ 1986 M 1995 UQ 2005
Round 4 LQ 1990 M 1997 UQ 2020

d.13 Fiber optic coupling from integrated optic chip to integrated optic chip is commonly used.
Round 2 LQ 1984 M 1990 UQ 1999
Round 3 LQ 1985 M 1990 UQ 1999
Round 4 LQ 1985 M 1990 UQ 1999

d.14 Television tuning using Bragg cells is commonly used.
Round 2 LQ 1987 M 1995 UQ Never
Round 3 LQ 1992 M 2013 UQ Never
Round 4 LQ 1995 M 2005 UQ Never

▪ TEACHING HOW TO INVENT ▪ —IS IT POSSIBLE?

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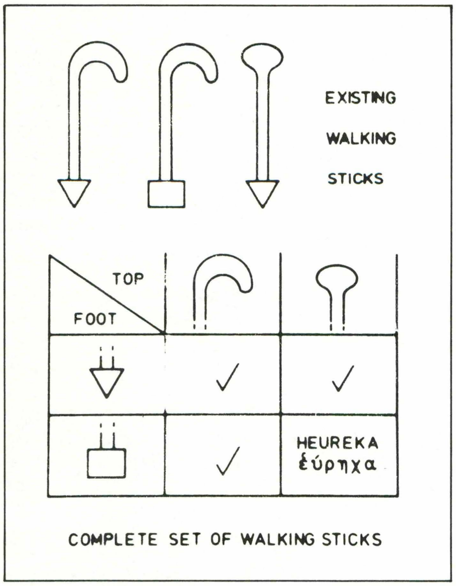
The fundamental scientist hopes to discover. The applied scientist wants to invent. Hence, a teacher of aspiring applied scientists should teach how to invent. Is it possible?

For me this question is related to Dennis Gabor in a personal manner. At an excursion trip during a conference in Florence 1968 I was sitting beside Dennis Gabor in the bus. The conversation touched on many subjects in science, culture, and politics. At a moment of silence I dared to ask: "Is it possible to learn how to invent?" I felt like Goethe's Wagner, asking Faust. To my surprise, Gabor laughed aloud.

Gabor apologized and explained that he once had asked the same question. At that time he was a graduate student of the Technical University in Berlin. His professor replied, "My dear Gabor, don't waste your time trying to invent, because in these days, all inventions are useless, either they would not work, or, someone else has invented it already long before."[1]

Stimulated by that conversation, I contemplated about the question and prepared a lecture for a Gabor Memorial Symposium in Haifa.[2] Here follow some of the thoughts of that lecture.

Suppose you want to invent a new walking stick. You will go into a shop for walking sticks and investigate the existing models (Fig. 1).



The existing sticks can be characterized by two binary-valued features: top and foot. But there exist only three models so far. Hence, it is quite obvious, how the newly invented stick should look like. This is a "morphological invention," in the terminology of the astrophysicist Fritz Zwicky.

Very interesting remarks on inventing have been made by J. Hadamard.[3] According to Hadamard, the essential step is the incubation of the subconscious mind with the goal of the invention, including a list of all desirable features. Then you must wait and hope.

Can everybody perform the act of incubation? I believe, yes. But you must be emotionally engaged. Let me give you an example of incubation. You may have lost your key, or you may have forgotten a name, which you dearly want to know. You concentrate, but probably in vain. You have to give up in order to do something else. After a while, your subconscious flashes the "interrupt" in your mental arena in order to announce the forgotten name. Apparently, the subconscious mind has performed a search mission without conscious control, simultaneously with other tasks of the conscious portion of the brain.

Are you curious? Some more thoughts and references on creativity can be found in the introduction of the ICO proceedings *Optics in Four Dimensions* (L. Narducci, M. A. Machado, editors, published by ATP 1981).

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▪ COMPUTATION IN OPTICS ▪

General Ray Tracing with a Pocket Calculator

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(Presented at OSA 1980 Spring Conference on Applied Optics, Workshop on Computer Programs, June 3, 1980.)

This manual describes the use of three optical ray-tracing and analysis programs (PARAX, CONIC SKEW, ASPHERE SKEW) which have been written for the TI-59 programmable calculator. The programs can be run with the PC-100C printer or without a printer by transcribing appropriate data. These three programs allow an optical designer to perform a complete third-order aberration analysis of virtually any rotationally symmetric optical system and trace completely general real rays through the system surface-by-surface.

The programs will accept rotationally symmetric reflecting or refracting spherical or aspheric optical surfaces (including the object and image surfaces) with up to tenth-order aspheric deformations. The user is prompted for appropriate surface data, thus allowing the ray trace of the optical system to be performed surface-by-surface for an unlimited number of surfaces. Default values are initialized by the programs to facilitate ease of use. A surface data print flag (or surface output prompt flag, when not using the printer) can be turned on/off at any stage by the user to eliminate any unnecesssary printed output or prompting.

The programs attempt to guard against some user-induced errors by automatically repartitioning the calculator, internally resetting the angular mode to degrees when angular output is produced, removing engineering (scientific) notation for a more uniformly formatted input/output, automatically setting FLAG 8 to halt processing in case of a serious error encountered during program execution, and displaying a flashing error code in case of a ray-trace failure condition. In this same regard, where the algebraic sign of certain input quantities is of no concern (refractive index and V-number), the programs disregard the sign, thus allowing the user to comfortably maintain his own preference on sign convention after reflection. If an uncorrectable mistake is made or if a completely new optical system is desired to be traced, simply pressing RST following by R/S will clear memory and reinitialize the program (including defaults) for reinput of the system.

Each program does many lengthy calculations, so for efficient use of the number of program steps and speed of processing, the programs are written with absolute and indirect addressing without labels. Additionally, some nonstandard programming has been used, basically out of necessity, which might appear confusing in spots to the casual user. Unfortunately this makes even the most simplistic program modifications an in-depth chore, and the author would caution anyone about casually attempting program changes. One nonstandard programming necessity which deserves special attention is the use of certain hierarchy operations in PARAX and ASPHERE SKEW. Memory space limitations in these programs require the use of the hierarchy registers for storage, the use of which is not covered in the TI Personal Programming Manual. Hierarchy operations are identified by the (normally unused) key code 82, followed by a two-digit number which identifies the hierarchy operation to be performed. The key code 82 cannot be entered directly from the keyboard in the learn mode. It must be entered indirectly, for example, by entering STO 82, then backstepping and deleting the STO, and then single stepping past the 82. The actual hierarchy operation argument number following the 82 can be entered in the same fashion by either entering and deleting another STO, or by using the appropriate key on the keyboard if the argument is a valid keyboard entry (for example, the SIN key is keycode 38, and the sequence 82 38 sums the current number into hierarchy register 8). This latter technique is discussed briefly on page V-54 of the TI Personal Programming Manual.

All three programs have been extensively tested against many simple and complex optical systems, and the results have been verified by ray tracing the same systems on ACCOS V. There are no known errors or limitations to the programs although it is the nature of computer code to be seldom free from "bugs."

The author would be interested in any errors found by users, as well as suggestions for improvements to the programs.

Book Reviews

Glow Discharge Processes (Sputtering and Plasma Etching)

Brian Chapman. 406 pp., 300 figures, index, bibliography. ISBN 0-471-07828-X. John Wiley & Sons, Inc., One Wiley Drive, Somerset, NJ 08873. (1980) $31.50.

Reviewed by G. F. Weston, Applied Physics Div., Philips Research Laboratories, Cross Oak Lane, Redhill Surrey RH1 5HA, England.

The first thing to note about this book is the small print after the main title, namely, "sputtering and plasma etching." The book is very much oriented towards such applications and the two chapters on sputtering and plasma etching make up nearly half the book. For the physicist or engineer whose interest in glow discharge lies outside these applications, for example in lasers or plasma panels, this book might prove disappointing. He will find sparse information on ionization coefficients, similarity laws, or modern theories on glow discharge characteristics. Nor will he find much data on current/voltage characteristics and their dependence on electrode materials, gas species, pressure, and geometry.

On the other hand, if his interests are on sputtering and/or related processes, this is a most useful book. In the first chapter, Chapman goes over the kinetic theory of gases and relates them to vacuum technology; a useful introduction since the vacuum system plays a prominant role in the sputtering and plasma etching processes. In the second chapter, gas phase collision processes are discussed, with special reference to ionization. From the ideas developed in this chapter, the reader is led on to the concept of the gas discharge plasma, the subject of Chapter 3. Here the emphasis is on the formation of sheaths around electrodes immersed in the plasma and the resulting space charge fields set up. The sheaths dictate the electron and ion energies with which they impinge on the electrodes and which is of relevance to later chapters.

Chapter 4 discusses the dc glow discharge, but with a rather different approach to most of the literature on the subject. Chapman draws on the concepts developed in the previous chapters to explain the "architecture" and electrical characteristics of the glow discharge. Thus, he uses the ionization collision cross section rather than Townsend's ionization coefficient when considering the current buildup and he draws on the model of the sheath and plasma when discussing the cathode fall and negative glow region. This is a valid approach which commends itself for the abnormal glow conditions of the sputtering system. The chapter on rf discharges which follows is rather brief. As Chapman points out, however, the rf discharge has not been studied in such depth as the dc discharge and the mechanism is less understood. More information on the impedance of glow discharges and the effect of magnetic fields, I feel, could have enhanced these two chapters.

Chapter 6 on sputtering is a comprehensive chapter with emphasis on the practical aspects of sputtering systems for deposition, etching, and plating. It is clear from this chapter where Chapman's experience and knowledge lies. No need here for the modest apologies for lack of depth or the "educated guesses" mentioned frequently in other chapters. There is a fund of useful information in this chapter which, for the engineer or scientist working in the field, would alone make the book worth purchasing. Thus the effect of biasing the substrate is discussed in some detail and there is information on monitoring techniques, etch topography, film adhesion, and the various system configurations including magnetrons. Plasma etching, the chemical combining of the solid surface with the gas in the discharge to form a volatile compound, is also well covered in the final chapter. Again Chapman draws on his own experience in discussing the triode plasma etching system and the effect of the gas flow rate. The method is particularly suitable to slice processing in the semiconductor industry, and the etching of Si or SiO_2 by CF_4 is discussed in some detail.

The book is of an introductory nature aimed at providing the basic information needed to read the "professional literature on the subject" and in this succeeds admirably. Chapman writes in an easy style which is very readable and would appeal to readers with a wide range of backgrounds. The style is a little too easy for me. Comparing the atom to a cricket ball on a cricket pitch (a surprising analogy for an American-published book), or the speed of an electron to that of Superman, or the diffusion of deposited atoms to two men tied together in a giant eggbox, is best left to the television reporter who feels that this is the only method of interesting the

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