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PROPERTIES OF MULTILAYER FILTERS

Interim Report

Covering the Period

March 1, 1965 to August 31, 1965

Research Grant No. NsG 308-63

with

National Aeronautics and

Space Administration

Washington 25, D.C.

Principal Investigator:
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ABSTRACT

The theoretical properties of a band-pass filter which consists of a single metal layer surrounded by a stack of dielectric films (i.e. a "1-M" filter) was investigated. Graphs were prepared which predict the performance of such a filter, in terms of parameters such as the maximum transmittance, width of the spectral transmittance band, and the contrast. Once the thickness and optical constants of the metal film are known, the parameters mentioned in the foregoing paragraph can be determined. The experimental work included the completion of the electronic circuitry for the fast-shuttering apparatus for the rapid evaporation of the aluminum. A 1-M filter was constructed, using the 1849A of Hg as a monitoring wavelength.

The work which was accomplished during the previous six months is in two major areas:

(1) The theoretical work which appeared in the Ph.D. thesis of Dr. Verne R. Costich, which was completed in June, 1965.

(2) The experimental work on the production of filters, which included the installation of the new mercury discharge lamp for optical monitoring. Also, work progressed on the installation of the "automatic" shutter to terminate the evaporation of aluminum.

Each of these programs are discussed separately.

THEORETICAL STUDY OF THE 1-M BAND-PASS FILTER

Most of our efforts have been devoted to the study of a rather special type of band-pass filter, the "1-M" filter. As shown in Figure 1, it consists of a thin metal which is surrounded on either side by stacks of dielectric films. This filter is ideally suited as an ultraviolet band-pass filter for several reasons:

(1) It has a relatively narrow band-width.

(2) It has good "blocking" - i.e. low transmission at longer wavelengths.

In our previous work, we have only been concerned with the use of aluminum as the metal film. Indeed, all of our calculations and experimental work have only used aluminum. The question arises: Is it possible to predict the performance of metals other than aluminum?

GENERALIZATION OF THE STUDY

There are several reasons why it is desirable to expend these concepts so that they are more general and not confined to a single metal. There are several questions to be answered, such as:

(1) Is aluminum the best metal to be used in a "1-M" band-pass filter in this ultraviolet spectral region?

(2) Are there other metals which could be used other than aluminum?

In answering the latter question, there is no reason why we could not use these concepts to design ultraviolet band-pass filters of the "1-M" type which would function at wavelengths down into the 500A region! To do this, of course, we must select the proper optical materials for the band-pass filter. The theoretical discussion in the following paragraphs can be used to determine whether such a filter could be devised and what its properties would be.

PARAMETERS WHICH DESCRIBE A "1-M" FILTER

There are three parameters which are useful in describing the properties of a "1-M" filter. These are: (1) T_{max}, the maximum transmittance. (2) The "Q" of the filter which is related to narrowness of the pass-band. The "Q" is defined as: $Q = \lambda_o / \Delta \lambda$ where λ_o is the wavelength of the maximum transmission and $\Delta \lambda$ is the total width of the pass-band at one-half T_{max}. The larger "Q", the narrower is the pass-band of the filter. (3) The contrast, which is a measure of the effectiveness of the filter at rejecting the wavelength region away from the pass-band. We define the contrast as:

$$C = T_{max} / T_1$$

where T_{max} has been defined previously and T_1 is the transmittance of the metal film with a pure real unit admittance incident medium and substrate. In other words, T_1 is the transmittance of an "unbacked" thin film surrounded with air on either side of it. Of course in practice we rarely utilize the film under such conditions, but nevertheless this is still a useful criterion. Actually, there is usually little difference between the transmittance of a film which is surrounded by air on either side and a film which is cemented between two glass plates with an optical cement.

EXAMPLE

As an example, consider the properties of the "1-M" filter depicted in Figure 2. This shows the transmittance versus wavelength of a band-pass filter which was described in a previous report . Although it is not a particularly outstanding filter, it still serves as an example. The maximum transmittance is 19% and the width at $\frac{1}{2}T_{max}$ is 85A. The wavelength of the maximum transmittance is 2580A, which means that the "Q" of the filter is:

$$Q = 2580/85 = 30 \quad .$$

It is difficult to ascertain where exactly the admittance of the matching stack is 1 + j0, but it is probably this value close to 2800A, where $T_1 = 1.7\%$. Thus the contrast is

$$C = 0.19/0.017 = 11$$

In practice, we would like to attain a much higher contrast than this. A contrast of 100 or even 1000 is an attainable goal!

T_{max}, CONTRAST VERSUS N, K FOR METAL FILMS

Our goal is to tabulate the values T_{max}, and contrast for a given metal film, once the following parameters are given:

(a) The ratio of the physical thickness, d, of the metal film to the wavelength of the incident radiation. That is: d/λ

(b) The optical constants, n - ik of the metal film.

Once these parameters are specified, then both T_{max} and the contrast are completely determined. The method of presenting such data is to plot contours of constant T_{max} and contrast versus n, k for a given thickness wavelength ratio, d/λ .

GRAPHS OF T_{max}, CONTRAST

Figures 3, 4, 5 and 6 depict contours of both T_{max} and contrast versus n, k for thickness-wavelength ratios of 0.05, 0.1, 0.15 and 0.20, respectively. As an example on how these tables can be used, let us investigate whether an indium film could be utilized in an "1-M" filter in the wavelength region near 1000A. We assume the thickness of the indium film is 200A. According to the measurements of W.R. Hunter[1], the optical constants of indium at 1000A are n - ik = 0.46 - i 0.10. Since the thickness to wavelength ratio, d/λ is

200/1000 = 0.20, we utilize Figure 6. At first glance, the properties look quite promising: The T_{max} is in excess of 90%! However, although this film has a large T_{max}, the contrast is quite small, with a value of approximately 1.3. Hence, this film would definitely not function well as the metal film in a "1-M" filter.

ANOTHER PRESENTATION OF T_{max} VERSUS CONTRAST

Another convenient method of presenting this information is to plot T_{max} and contrast on the same graph for given contours of n - ik. As in the previous graphs, the thickness-wavelength ratio, d/λ is constant for a given graph. Figures 7, 8, 9 and 10 depict such plots. The chief value of such a plot is that it immediately defines the range of n and k values which the metal film must have to provide a given contrast and T_{max}. For example, suppose that we determine that the ratio d/λ is 0.20. This might be dictated by the fact that the thinnest metal film which we can evaporate is about 100A in thickness. This means that at short wavelengths as for example at 500A in the extreme ultraviolet, d/λ must be greater than 0.20. We see from Figure 10 that if we specify that T_{max} must be 10% and the contrast be 100 or greater, that the n of the metal can be 0.8 or greater and that the k must be greater than 3.0. Thus it is possible to examine the measured optical constants of actual metals and see if they could be utilized in a "1-M" filter.

PART II

Experimental Program

OPTICAL MONITORING AT 1849A

The mercury discharge lamp which emits the 1849A radiation has been installed in the bell jar in which we deposit the thin films. With this source we monitor the optical thickness of the cryolite and thorium fluoride films as they are being deposited. The design of this filter is quite similar to the 1-M filter which is used at 2536A. We excite the lamp with 400 cps from an Invar-Behlman inverter. This inverter converts from mains power to a variable frequency output at a power output of 150 va. A set of "1-M" filters at the 1849A wavelength have been evaporated. The transmission in the wavelength region above 1900A has been measured on the Cary model 14 spectrophotometer. We are preparing to measure the transmittance below 1900A and are constructing the necessary holders which will move the filters in and out of the exit beams of a vacuum monochromator which is loaned to us by Dr. Kenneth Teegarden.

RAPID SHUTTERING OF THE ALUMINUM

As has been pointed out in previous reports, it is necessary to deposit the aluminum film quite rapidly - the 300A thick film should be deposited in a few seconds and its thickness should be controlled at an accuracy of at least 10%. To accomplish this, we have constructed an electromechanical shutter. It consists of a rotary solinoid which is "potted" inside a vacuum tight can. The potting is important for two reasons. First, it prevents the high-vapor pressure insulation materials from contaminating the vacuum. Second, the inductive "kick" of the solinoid current causes the voltage across the solinoid to rise to large values when it is turned on and off. This high voltage can cause a local glow discharge in the gas surrounding the solinoid, provided the gas pressure is in the micron range.

ELECTRONIC SYSTEM FOR THE AUTOMATIC SHUTTER

The electronic system for the automatic shutter is designed to close the shutter automatically when the thickness of the aluminum attains a predetermined level. It functions as follows: The transmittance at 2536A of a quartz plate is measured as an aluminum film is deposited upon its surface. As the transmittance decreases, the output from the photomultiplier which is monitoring the 2536A radiation also decreases. When the transmittance drops to a predetermined level, the electronic system "fires" a power transistor which in turn closes the solinoid shutter. This electronic system has been designed and constructed. We are in the process of checking it out and calibrating it.

PERSONNEL

Dr. Philip Baumeister	worked 35% during the academic year and six weeks at full time during the summer.
Dr. V. R. Costich	worked one-half time as a Graduate Research Assistant until he received his Ph.D degree in June, 1965.
Mr. Duncan Brown	worked as a full-time electronic technician from February to June.
Mr. Cyrus Markley	Worked as a full-time electronic technician from June 1 to August 30.

REFERENCE:

1. W.R. Hunter, Naval Research Laboratory. Private communication.

CAPTIONS TO THE FIGURES:

1. The design of a "1-M" filter, showing the metal film surrounded on either side by a dielectric stack. The admittance, Y, is measured at the interface between the metal film and the dielectric stack.
2. The measured transmittance of a "1-M" filter, showing the parameters which characterize the performance of the filter, such as T_{max}, band-width "Q", and contrast.

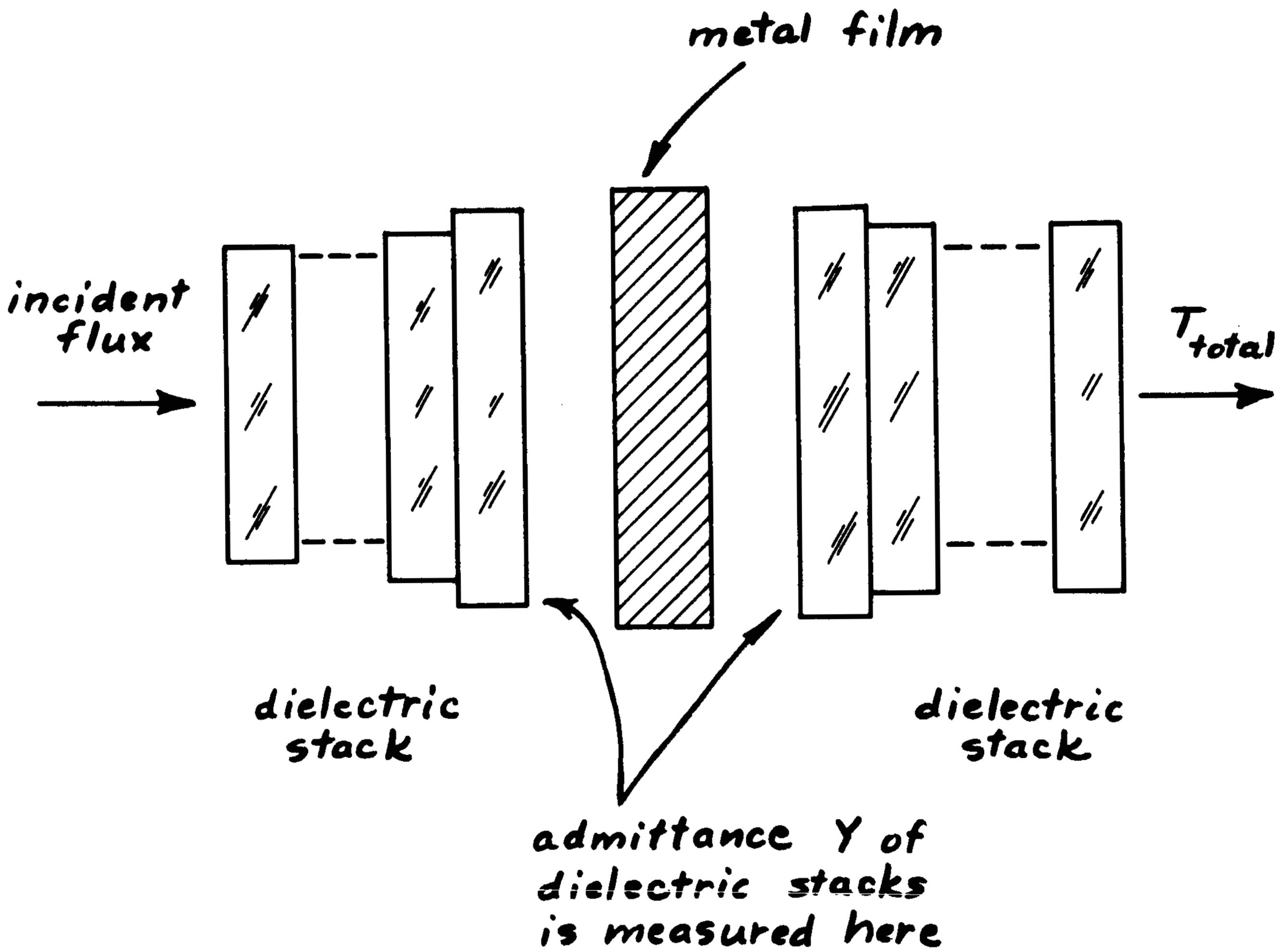
metal film
incident flux
T_{total}
dielectric stack
dielectric stack
admittance Y of dielectric stacks is measured here

Fig. 1

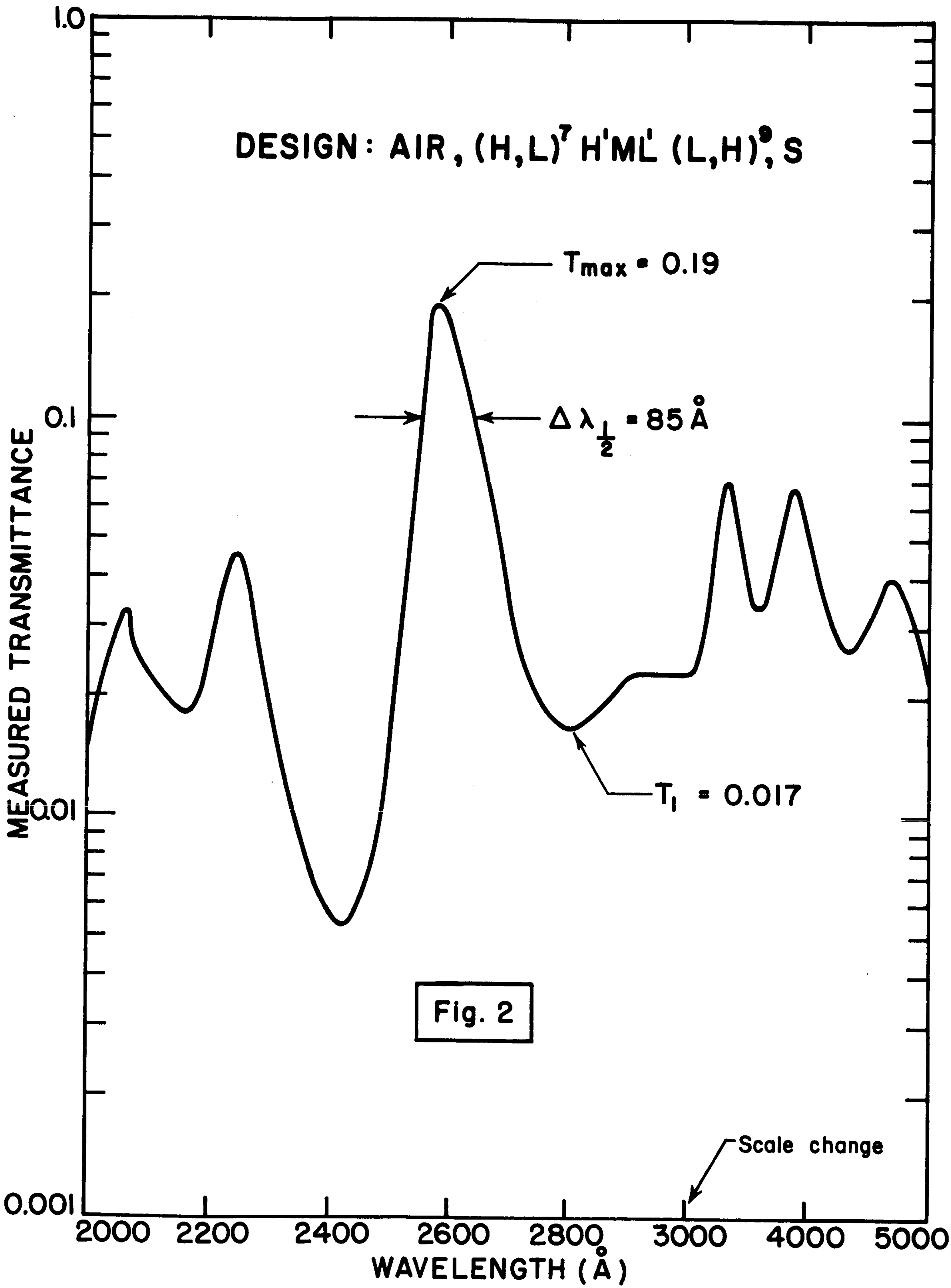
DESIGN: AIR, (H,L)⁷ H'ML' (L,H)⁹, S
Tmax = 0.19
Δλ½ = 85 Å
T1 = 0.017
Scale change
MEASURED TRANSMITTANCE
1.0
0.1
0.01
0.001
2000
2200
2400
2600
2800
3000
4000
5000
WAVELENGTH (Å)

Fig. 2

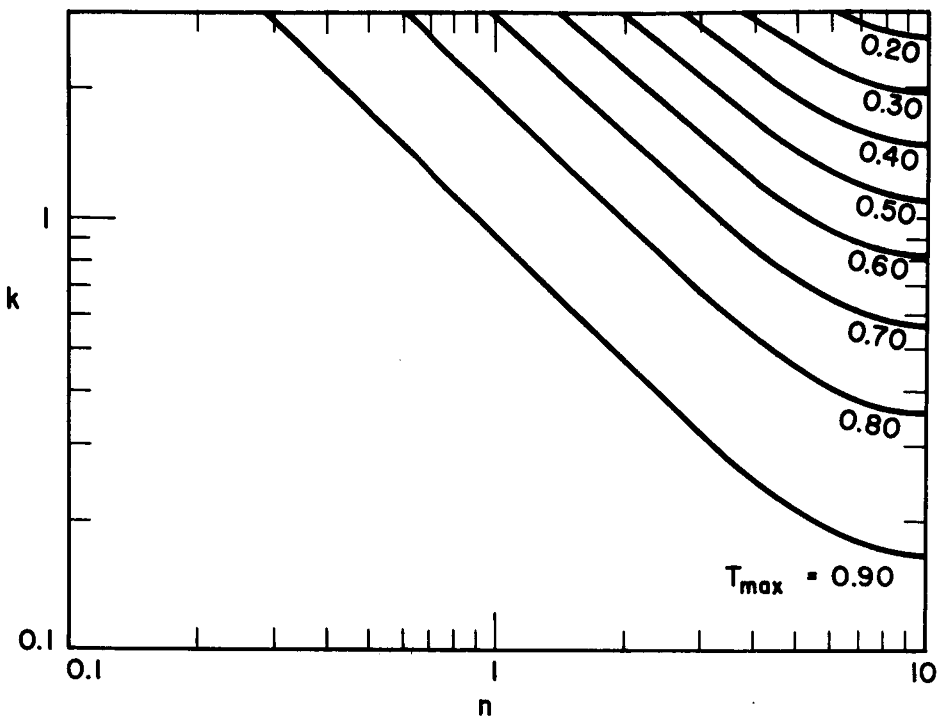

Figure 3 a. T_{max} Contours on the Complex N Plane for d = 0.05λ

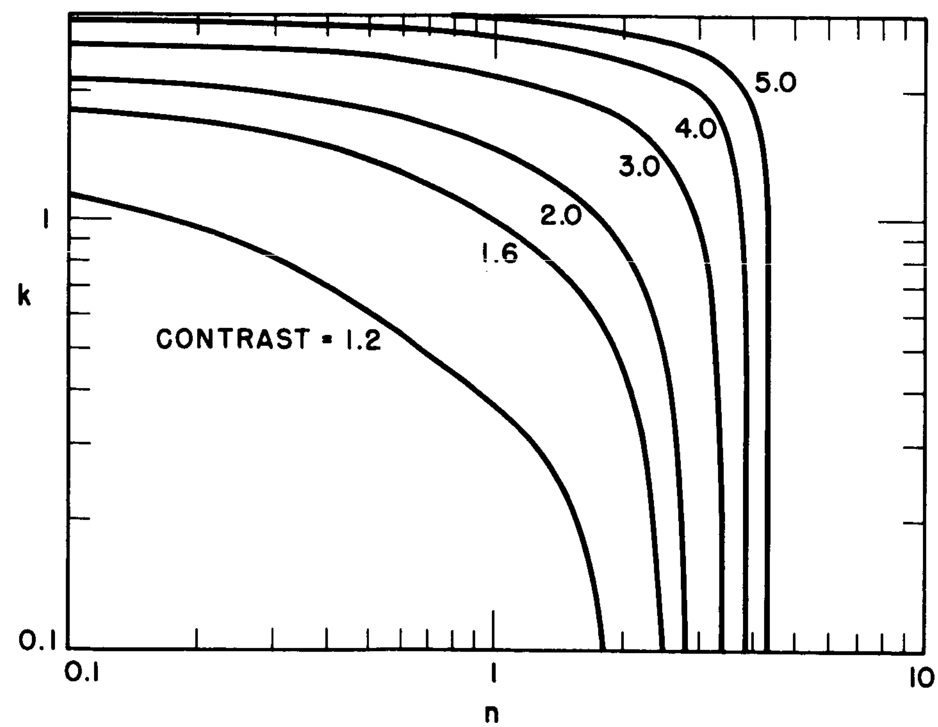

Figure 3 b. Contrast Contours on the Complex N Plane for d = 0.05λ

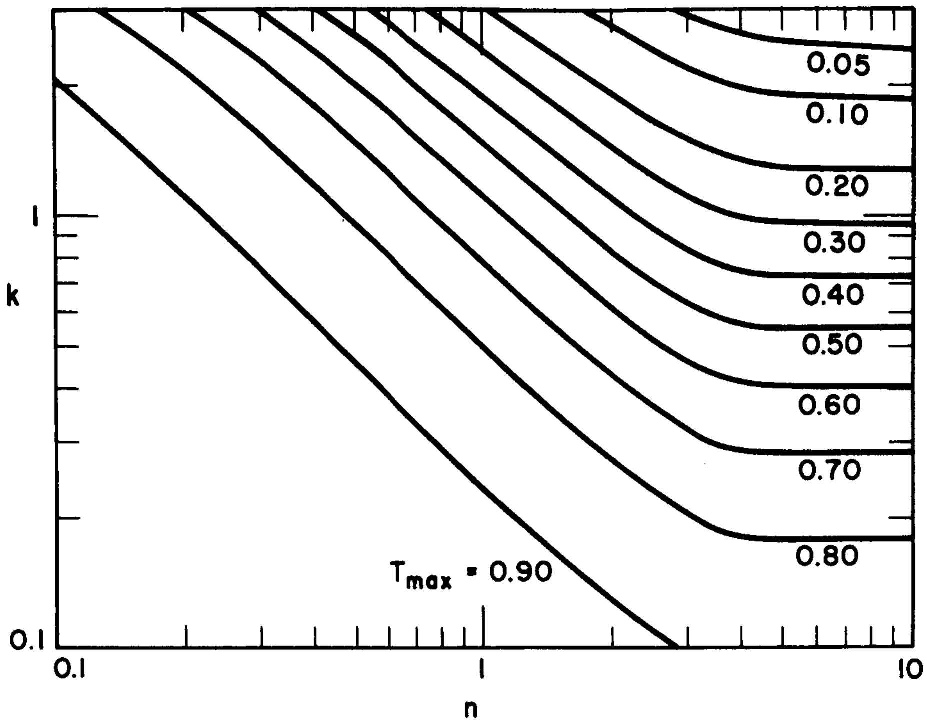

Figure 4a. T_{max} Contours on the Complex N Plane for d = 0.10λ

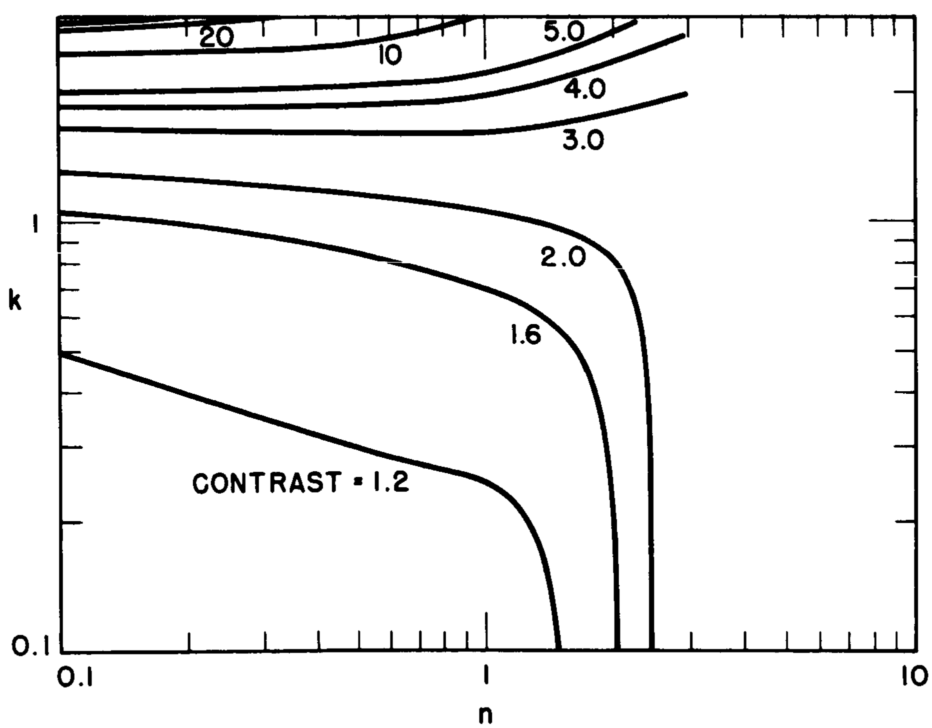

Figure 4b. Contrast Contours on the Complex N Plane for d = 0.10λ

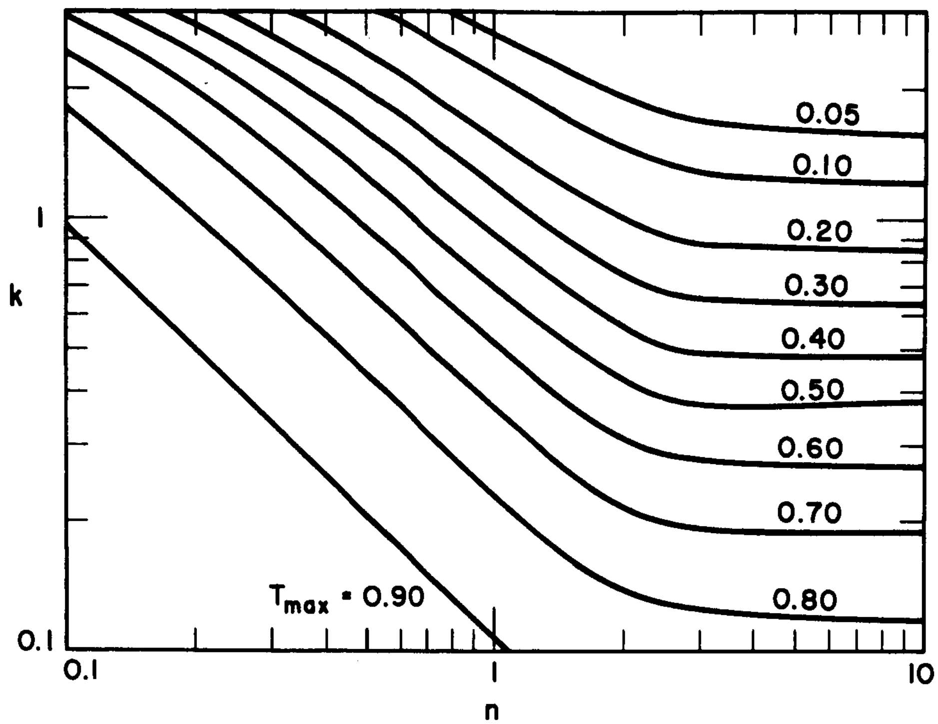

Figure 5a. T_{max} Contours on the Complex N Plane for d = 0.15λ

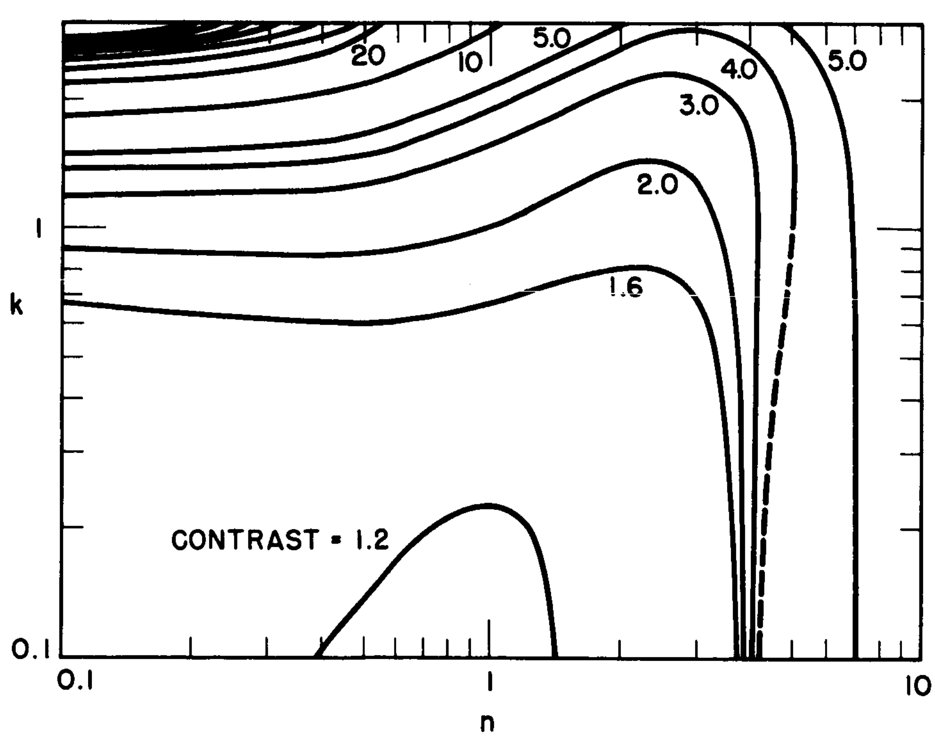

Figure 5b. Contrast Contours on the Complex N Plane for d = 0.15λ

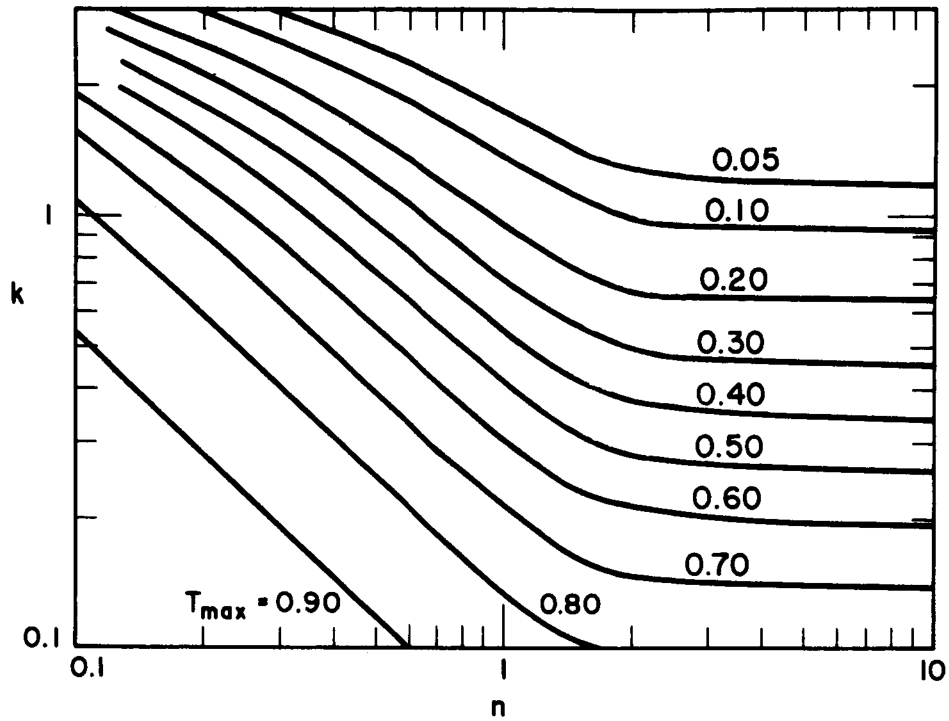

Figure 6 a. T_{max} Contours on the Complex N Plane for d = 0.20λ

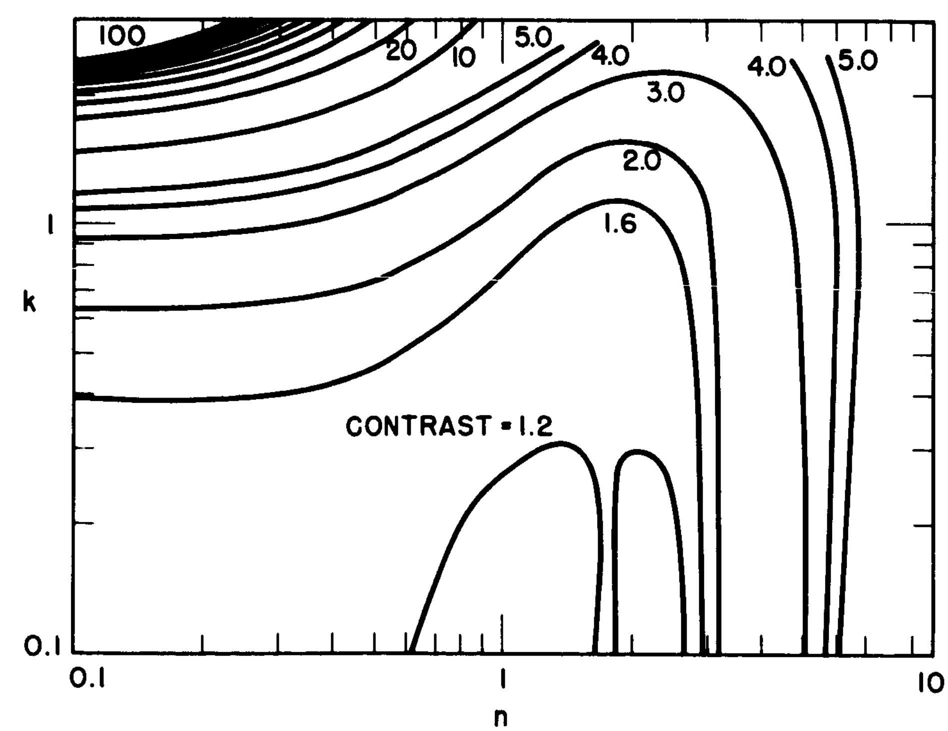

Figure 6 b. Contrast Contours on the Complex N Plane for d = 0.20λ

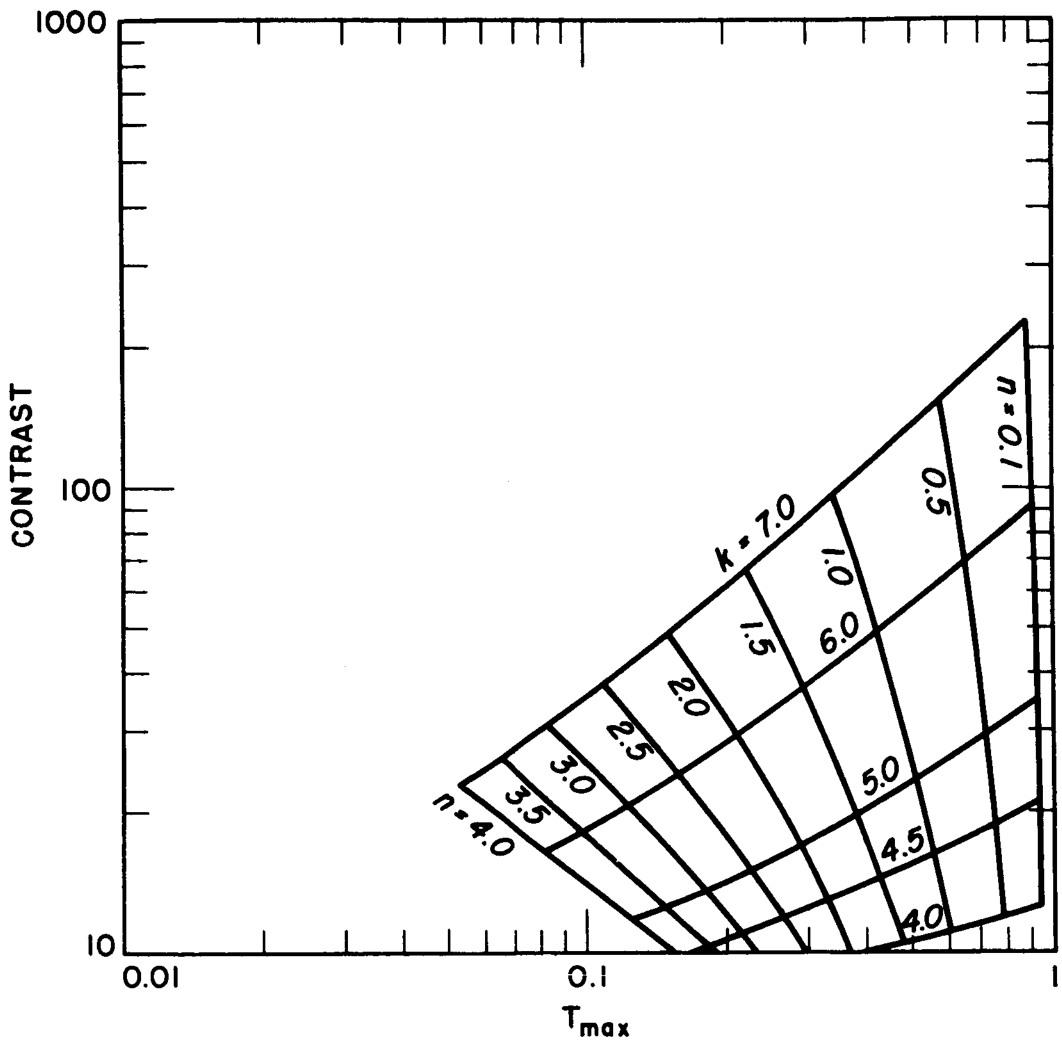

Figure 7. Complex N Mesh on Contrast versus T_{max} Coordinates for $d = 0.05\lambda$

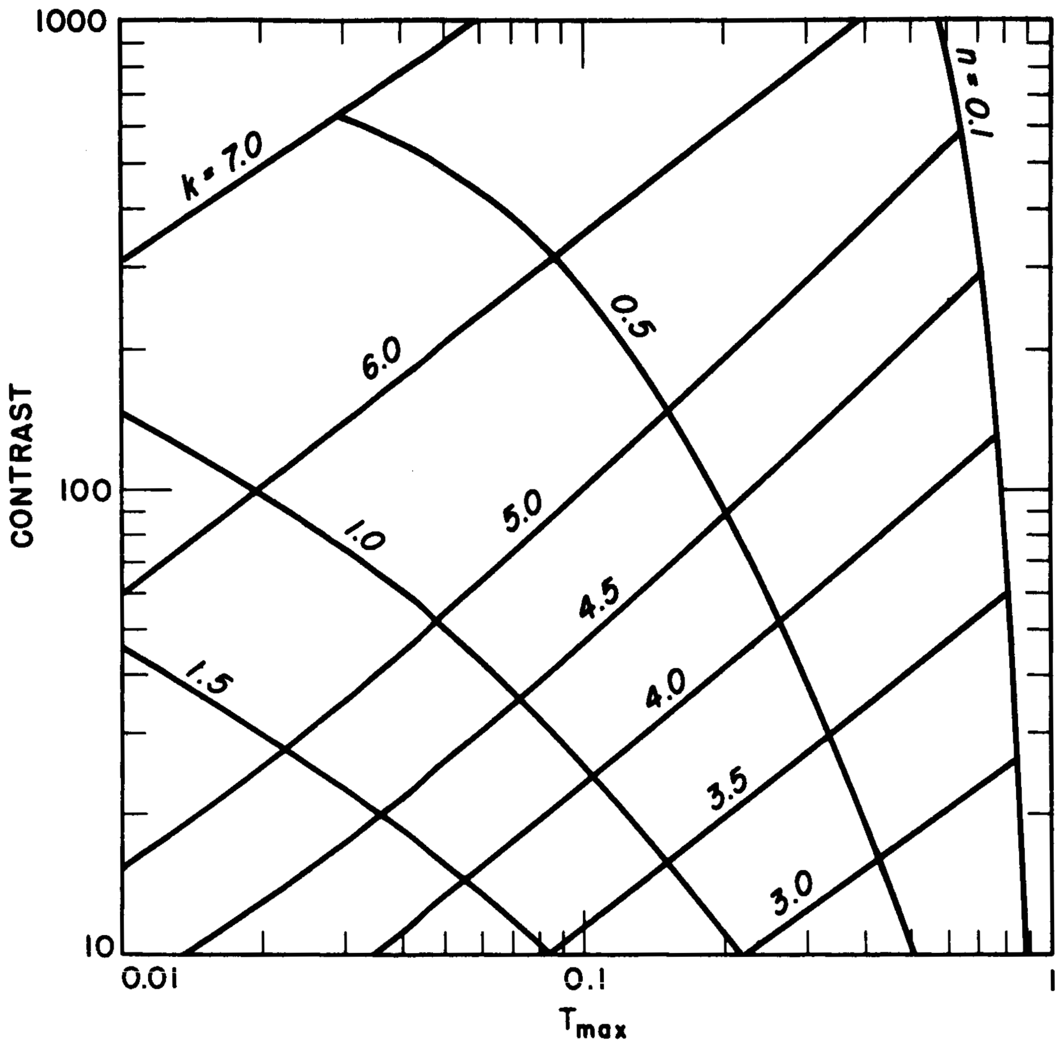

Figure 8. Complex N Mesh on Contrast versus T_{max} Coordinates for d = 0.10 λ

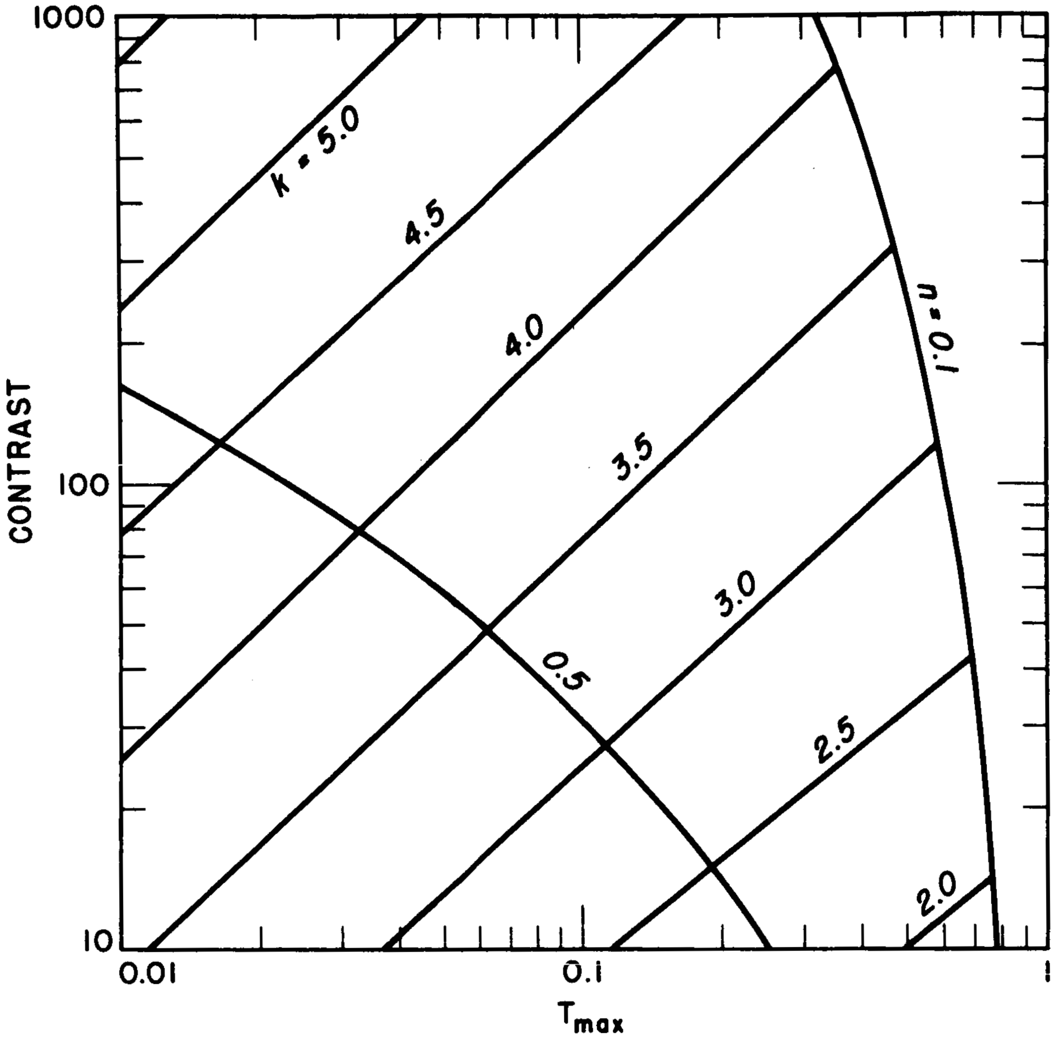

Figure 9. Complex N Mesh on Contrast versus T_{max} Coordinates for $d = 0.15\lambda$

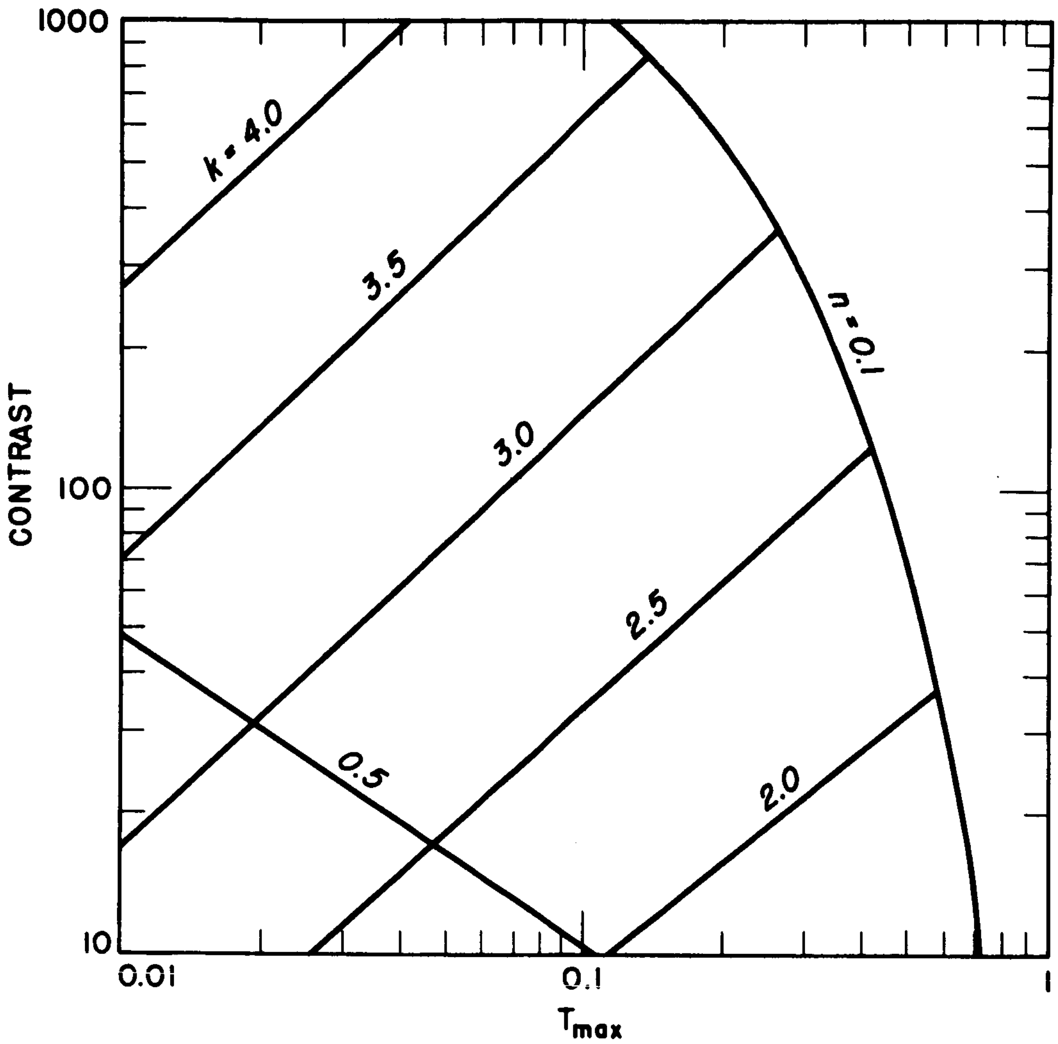

Figure 10. Complex N Mesh on Contrast versus T_{max} Coordinates for $d = 0.20\lambda$