Westinghouse Tube News

A-62318

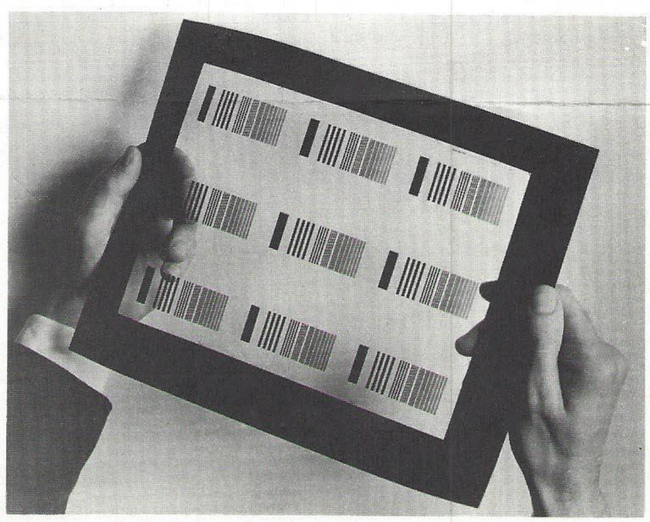
IMAGE TUBE RESOLUTION CHART AVAILABLE FROM WESTINGHOUSE

The square-wave aperture response curve of image tubes and systems can be obtained simply with a new resolution chart now available from the Westinghouse Electronic Tube Division. The chart was developed by the division for evaluating resolving power of new image tubes.

In use, the chart provides a resolution image which is picked up by a camera tube. The resulting video signal is fed into an oscilloscope set for a delayed sweep. It is thereby possible to obtain the information required for a complete square-wave aperture response curve with a single scope presentation.

The chart consists of nine identical groups of lines. Because of this arrangement, the resolving power can be measured and compared accurately at different locations on the target. The 100 percent contrast chart in an 8-inch-by-10-inch transparency is available immediately. It is priced at $15. Charts with other degrees of contrast are available by special request.

For a copy of the 100 percent contrast chart ET-1332, or for information on charts with other degrees of contrast, write to the Westinghouse Electronic Tube Division, Box 284, Elmira, N. Y.



Publications Section
Westinghouse Electronic
Tube Division, Elmira, N.Y.

# Westinghouse

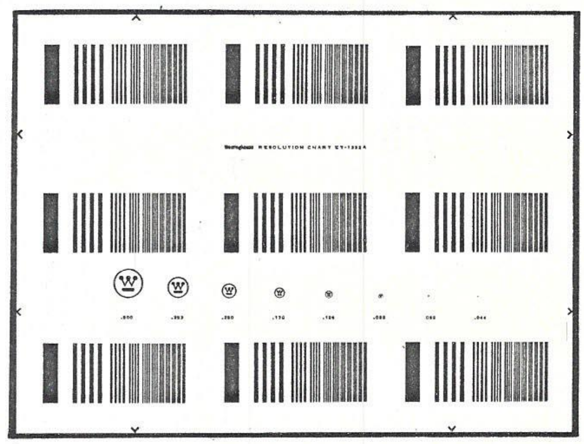
## RESOLUTION CHART ET-1332A

To simplify the taking of accurate and objective resolution data this new type of resolution chart ET-1332A was designed by Westinghouse. The chart in combination with a line selector oscilloscope makes it possible to obtain from a single oscilloscope presentation all the data necessary to plot a complete square-wave aperture response curve.

The basic format of the chart is 8 × 10" while the inside reference height is 7 inches and the width is 9⅓ inches. There are nine resolution patterns within the chart, each of which contains a wide black and white reference bar followed by ten sets of 4 black and 3 white bars. The wide bars represent 100% response factor and the ten bar-sets of decreasing width represent from 100 to 1000 TV lines per raster height in 100 line increments.

The bar width and TV lines per raster height equivalent are given below:

| TV Line Equivalent | Bar Width (Inches) |
|---|---|
| Wide Bar | 0.250 |
| 100 | 0.070 |
| 200 | 0.035 |
| 300 | 0.0233 |
| 400 | 0.0175 |
| 500 | 0.0140 |
| 600 | 0.0117 |
| 700 | 0.0100 |
| 800 | 0.0088 |
| 900 | 0.0078 |
| 1000 | 0.0070 |



The dimensional width of the bars which represent from 600 to 1000 TV lines is within ± 0.0003 inch while the tolerance for the remaining bars is better than ± 0.0005 inch. In addition to the bar groups the chart contains eight (W) patterns whose diameters decrease from 0.500 inch to 0.044 inch as a function of the square root of two.

The chart is normally set-up in a light box so that the area of the chart determined by the small triangular marks just fits the imaging region to be evaluated. The tube and/or system to be evaluated is than adjusted for the desired operating conditions while the video signal is fed into an oscilloscope with delayed sweep such as the Tektronix 545A. The oscilloscope is set to select the desired horizontal raster line and from its signal presentation all the data required to plot a square wave aperture response curve are available without recourse to oscilloscope settings, amplifier gains, etc.

Thus, this chart in coordination with an oscilloscope makes it possible to obtain, from even the simplest of imaging systems, complete and objective resolution measurements.

WESTINGHOUSE ELECTRIC CORPORATION, ELECTRONIC TUBE DIVISION, ELMIRA, NEW YORK

# A new resolution chart for imaging systems

**This pattern gives results superior to others now used. And its companion worksheet simplifies the process to boot.**

**By Igor Limansky,**
Aerospace Div., Westinghouse Defense and Space Center, Baltimore, Md. 21203.

A basic precept of an imaging system is that electrical and spatial frequencies are equivalent when a scanning process is used. When an image is scanned, any variations in its light flux are noted as different frequencies—the smaller the detail size (i.e., the faster the change of flux), the higher the apparent frequency. The scanning aperture's effect on definition is determined as an *aperture response* or frequency response characteristic.

In both the electrical and optical disciplines, the *square wave modulation* transfer function depends upon system bandwidth. Optical workers, though, prefer the *sine wave modulation* transfer function which more accurately represents the *spatial bandwidth.* They do use the square wave function, however, because it is relatively easy to generate a test pattern of bars. You must convert the square wave test results to sine wave information in order to accurately represent the frequency response of the unit under test, or to combine the responses of several units in cascade to get their total response. An example[2] of such a system of cascaded components is a fluoroscopic instrument using television techniques. To determine the total resolving power of the instrument, the spatial frequency response of each component is measured by square wave tests. These results are converted to sine wave response factors, and plotted against *line pairs/mm* (the spatial frequency). The three plotted curves (focal spot resolution, fluorescent screen resolution, and the TV camera chain resolution) are combined to give the overall resolution of the entire instrument system.

### New resolution chart

The new chart presented here is a maximum-contrast, diminishing-bar test pattern. The computation of the sine wave modulation transfer function uses each of the component bar groups. We also include a new worksheet which greatly simplifies the computation. The square wave response is converted to a sine wave response according to Coltman's method.[2]

### The conversion equation

The square wave to sine wave conversion depends upon a function[3] which transforms a series of points in the square wave response plane to the sine wave response plane. We resolve a square wave input into its Fourier components, multiplying each component by the sine wave response of the system R(N), which corresponds to the frequency N, of the component. This gives the square wave output response r(N), expressed as a series in R(kN). Solving for R(N), we get (from Coltman),

$$R(N) = \frac{\pi}{4}\left[r(N) + \frac{r(3N)}{3} - \frac{r(5N)}{5} + \frac{r(7N)}{7} + \cdots + B_k\frac{r(kN)}{k} + \cdots\right] \quad (1)$$

$R(N)$ is the output sine wave response
$r(N)$ is the output square wave response

$B_k = (-1)^m(-1)^{\frac{k-1}{2}}$, for $r = m$
$B_k = 0$, for $r < m$
$k = 1, 3, 5, \cdots$ (odd values only)
$m$ = the total number of prime factors of $k$
$r$ = the number of *different* prime factors of $k$
$N$ = the frequency of the test pattern

Note that only *odd* terms are present in equation (1). Presently used resolution patterns have *odd and even* multiples of some basic line number N. For example, Westinghouse chart ET-1332A[4] has ten test pattern frequencies—N, 2N, 3N, 4N, . . . 9N, 10N—of which only the odd frequencies are useful in computing R(N) by equation (1).

## Frequency response, imaging systems, aperture response, and test charts

We are all familiar with the concept of frequency response. If a system has a "flat" frequency characteristic, then the output signal amplitude doesn't vary until, at some high frequency, it begins to drop off. When it drops below the flat portion to some defined level (generally −3 dB), the frequency of this point is noted and called the cut-off frequency of the system. The cut-off frequency is a measure of the speed of response of the system—it tells us whether or not the circuitry can follow the changes of the input signal as the changes become faster and faster. (Pulse testing does exactly this. The relationships between the rise time of a pulse and the cut-off frequency of the amplifier passing it are well-known.)

We have been speaking of systems with electrical input and output signals, but the frequency response concept holds true for any kind of system. And we can always draw an analogy between the "frequency" response of a non-electrical system and that of an electronic system. Often, however, there is a two-fold problem: how to define the frequency limit, and how to measure it—how to put a number on it, if you will, that is meaningful and useful to others.

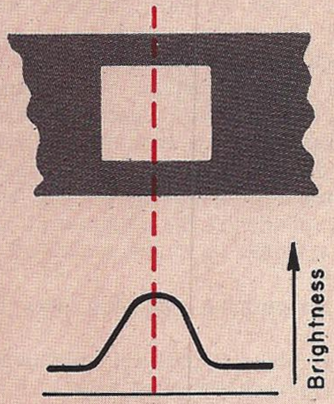
### Imaging systems

The importance of the resolution of a lens should be apparent when we think of television. In an imaging system, the *resolving power* of a lens is often the limiting response characteristic because it determines the smallest image detail we can see.

When the imaging system is linear (that is, the output is proportional to the input), it may be characterized by a single variable. One such variable is the *spatial frequency response*—the response to some test pattern that tells us the finest detail we'll be able to see. The bar chart is the generally agreed upon method to determine the resolving power of a lens. It is the tool usually used in spatial frequency response measurements.

### Aperture response

Schade's[1] work has popularized the term *aperture response*. Think of scanning the bar chart just mentioned. Each element of the scan may be considered an aperture. You can compute the characteristics of the response if the size and flux distribution of the aperture are known. The system limits are shown by, for example, the scan of a thin white bar on a black background. The scanned output will look as though the bar changed gradually, rather than sharply, from black to white. It is analogous to the response to a fast pulse of a system with a bandwidth too narrow for the pulse. The system degrades the rise and fall times of the input pulse, which emerges looking more triangular than rectangular. The aperture response of a scanning system is very significant. For example, you can calculate the bandwidth required for a television channel if you know the number of lines needed for a given resolution and the time per frame.




### Test charts

A resolution chart is made of light and dark bars with sharp transitions between them. They are grouped in sets of decreasing width and spacing. Scanning the chart gives rise to a series of pulses, and so such a method is known as *square wave* testing. Aperture response characteristics are properly associated only with square wave tests.

Aperture response curves are not too meaningful for patterns other than square waves, and can't be easily combined to get the overall spatial frequency response of a chain of imaging systems. For this purpose, a *sine wave* pattern is much more useful, because the overall response is simply the product of the individual responses, as in any electrical system.

Sine wave responses are easy to handle, but the test patterns are difficult to generate. On the other hand, square wave test patterns are easy to generate but the responses are difficult to handle. However, a square wave input (in a linear system) can be broken down into its Fourier sine wave components which, in turn, are operated upon by the sine wave response of each system in the chain. The outputs are then combined to give the total system response. Much work has been done in attempts to simplify the conversion of square wave measurements into sine wave responses. This article describes a new chart and an orderly method for obtaining such results.

# Resolution chart (continued)

## Making the chart

To make the new test pattern we prepare a chart with 10 or 11 frequencies that are odd multiples of some basic line number, N. The test pattern frequencies are N, 3N, 5N, . . . 21N, for an 11-group chart. Figure 1 shows the original and the new resolution charts, and Fig. 2 shows a monoscope target using the new pattern.

## The computation worksheet

Equation (1) tells us that to compute one point on the sine wave response curve we must know all the data points on the square wave response curve with lower spatial frequencies. To get the other points on the sine wave curve, we must substitute $kN$ for $N$ in equation (1). The resulting set of equations defines the sine wave response curve according to the experimental values found from the square wave response. It is shown in the form of a computation worksheet in Fig. 3. The worksheet lets us compute the sine wave response data directly from the experimental values we obtained from the resolution chart of Fig. 1b. Note that this worksheet eliminates the need to draw an estimated square wave response curve and to pick off appropriate values from it.

The new computation worksheet does these things for us:

- it defines the mathematical operations we must perform on each measured value
- it groups the data into positive and negative factors for each test pattern frequency
- it indicates the subsequent mathematical operations needed to produce the sine wave response curve points.

## Using the chart and worksheet

Let's use the new chart and worksheet to find the aperture response of a TV camera lens. The method we'll follow was described by Reininger et al,[5] and requires the equipment shown in Fig. 4. The complete measurement routine includes:

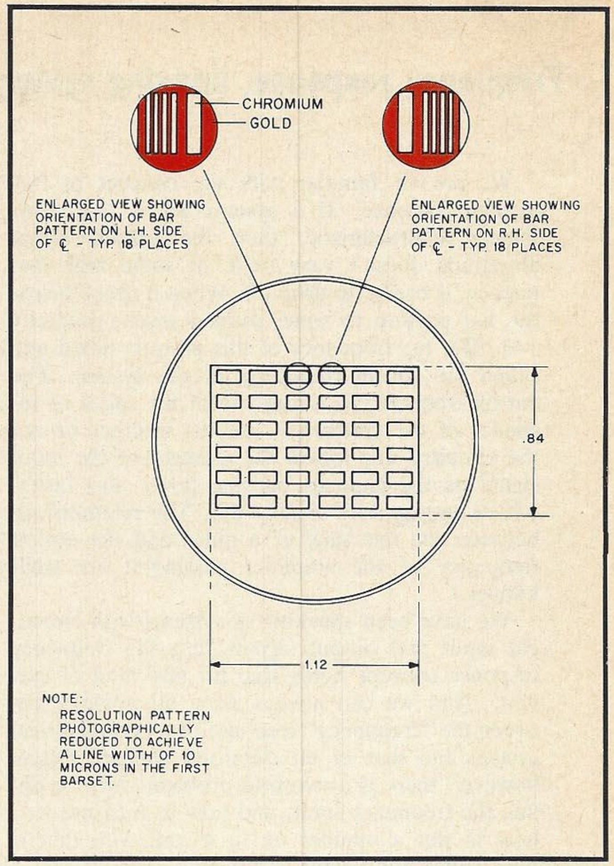



Fig. 2. This monoscope target uses the new resolution chart. Built into a TV camera tube and scanned, it generates test and alignment signals.

- a visual estimate of the limiting resolution (as a check on the final results)
- choice of object distance so that the limiting resolution falls at a high number group (d = 404.5 cm for this lens)
- computation of reduction factor R, (focal length

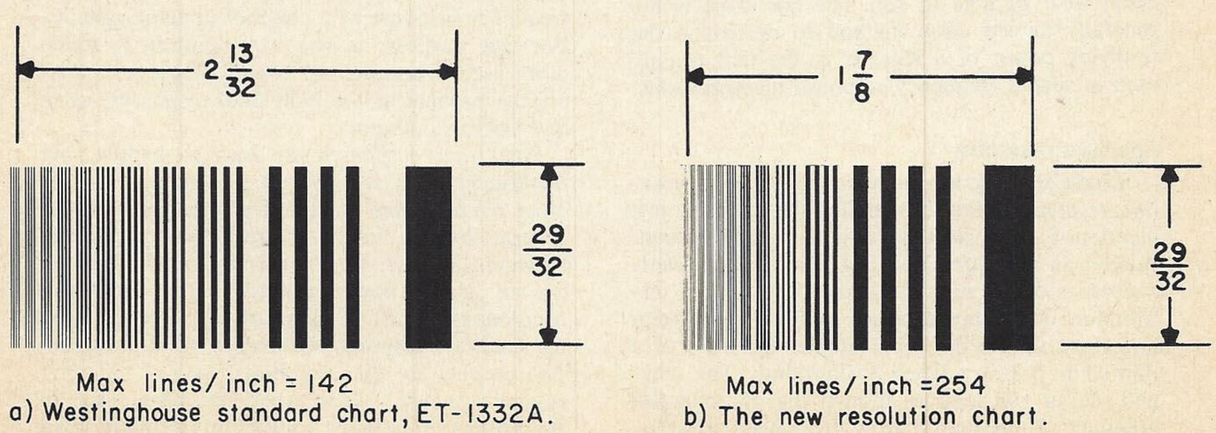



Fig. 1. Wide black and white bars represent 100% modulation (the extremes of illumination). Decreasing bar widths and spacings are groups of increasing line number.

| SQUARE WAVE RESPONSE VALUES | COMPUTATION OF R (N) | | COMPUTATION OF R (3N) | | COMPUTATION OF R(5N) | COMPUTATION OF R (7N) |
|---|---|---|---|---|---|---|
| | POSITIVE | NEGATIVE | POSITIVE | NEGATIVE | | |
| r(N) = 0.970 | r(N) = 0.97 | | | | | |
| r(3N) = 0.870 | $\frac{r(3N)}{3}$ = 0.29 | | r(3N) = 0.870 | | | |
| r(5N) = 0.720 | | $\frac{r(5N)}{5}$ = 0.144 | | | r(5N) = 0.72 | |
| r(7N) = 0.610 | $\frac{r(7N)}{7}$ = 0.087 | | | | | r(7N) = 0.61 |
| r(9N) = 0.520 | | | $\frac{r(9N)}{3}$ = 0.173 | | | |
| r(11N) = 0.430 | $\frac{r(11N)}{11}$ = 0.039 | | | | | |
| r(13N) = 0.330 | | $\frac{r(13N)}{13}$ = 0.025 | | | | |
| r(15N) = 0.260 | | $\frac{r(15N)}{15}$ = 0.017 | | $\frac{r(15N)}{5}$ = 0.052 | $\frac{r(15N)}{3}$ = 0.086 | |
| r(17N) = 0.210 | | $\frac{r(17N)}{17}$ = 0.012 | | | | |
| r(19N) = 0.160 | $\frac{r(19N)}{19}$ = 0.0084 | | | | | |
| r(21N) = 0.100 | $\frac{r(21N)}{21}$ = 0.0048 | | $\frac{r(21N)}{7}$ = 0.014 | | | $\frac{r(21N)}{3}$ = 0.033 |
| | $\sum_1(+)$ = 1.399 | $\sum_1(-)$ = 0.199 | $\sum_3(+)$ = 1.057 | $\sum_3(-)$ = 0.052 | $\sum_5(+)$ = 0.806 | $\sum_7(+)$ = 0.643 |
| | $\frac{4}{\pi}R(N)=\sum_1(+)-\sum_1(-)$ = 1.200; R(N) = 0.941 | | $\frac{4}{\pi}R(3N)=\sum_3(+)-\sum_3(-)$ = 1.005; R(3N) = 0.786 | | $\frac{4}{\pi}R(5N)=\sum_5(+)$; R(5N) = 0.633 | $\frac{4}{\pi}R(7N)=\sum_7(+)$; R(7N) = 0.505 |



$R(9N) = \frac{\pi}{4} r(9N) =$ 0.408

$R(11N) = \frac{\pi}{4} r(11N) =$ 0.338

$R(13N) = \frac{\pi}{4} r(13N) =$ 0.259

$R(15N) = \frac{\pi}{4} r(15N) =$ 0.204

$R(17N) = \frac{\pi}{4} r(17N) =$ 0.165

$R(19N) = \frac{\pi}{4} r(19N) =$ 0.125

$R(21N) = \frac{\pi}{4} r(21N) =$ 0.079

Fig. 3. The new worksheet brings order and simplicity to the computation of the sine wave response. Measured square wave data is entered into the column at the extreme left; all subsequent operations are clearly indicated in their appropriate positions.

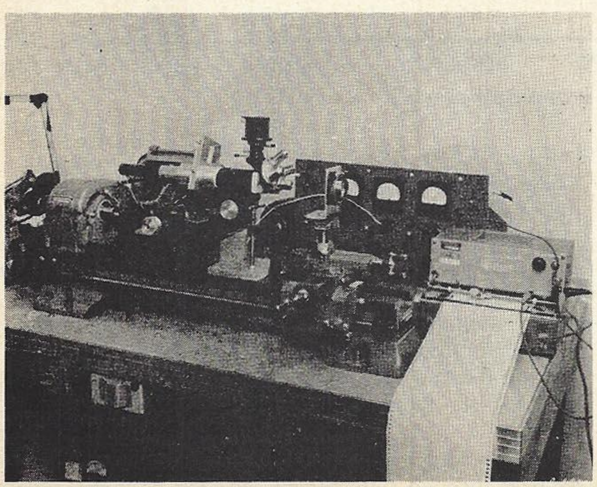
f = 6.3 cm for this lens; $R = \frac{d-f}{f} = 63$)

- calculation of the line numbers of the groups of bars in the image plane
- square wave test (aperture response).

The square wave response of the lens and the filled-in worksheet are shown in Figs. 5 and 3, respectively.

To fill out the worksheet, first enter the peak-to-peak amplitudes of each of the 11 pulse groups into the left-hand column. You can read these amplitudes directly

*(Continued on following page)*



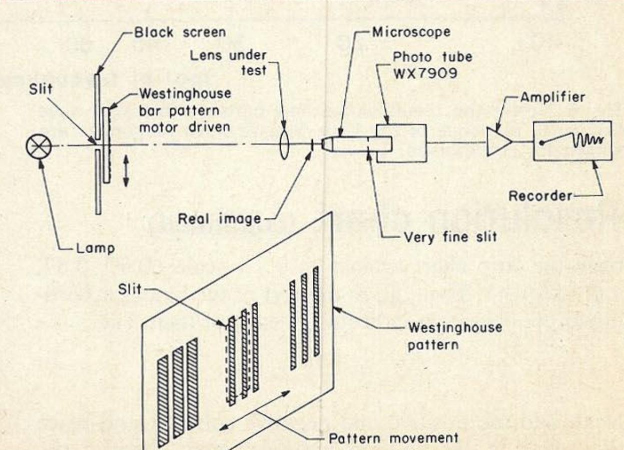



Fig. 4. Measuring the square wave response (aperture response) of a lens. Diagram shows equipment operation.

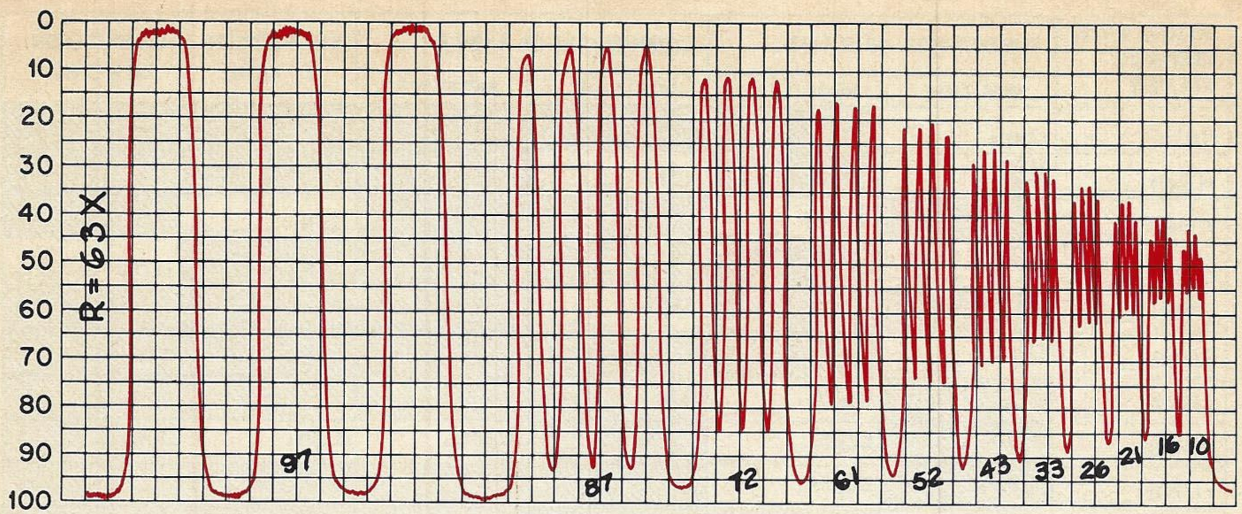



Fig. 5. This is the square wave response of the lens, measured with the equipment of Fig. 4. Note the 11 groups of pulses (the r(kN) ) and their odd-harmonic relationship. The peak-to-peak amplitude of each group is indicated.

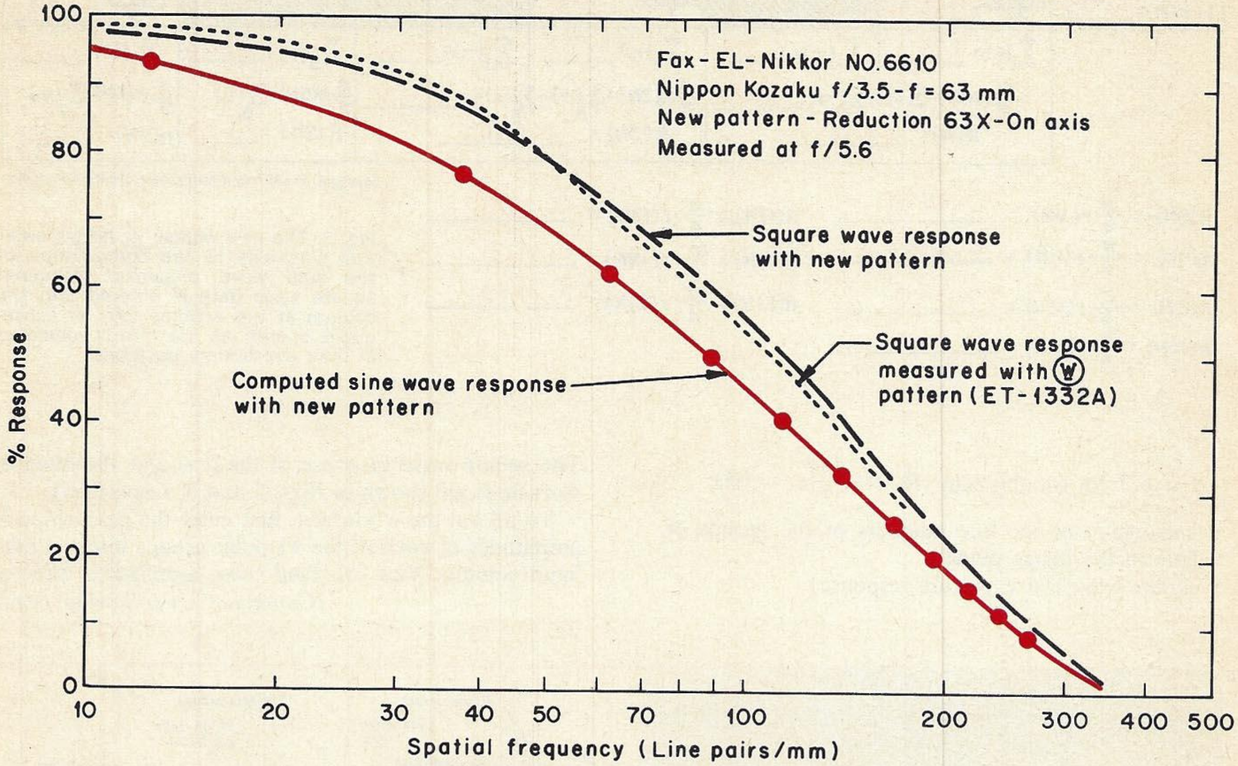



Fig. 6. Here's the result of the new pattern—the sine wave frequency response of the lens. Square wave responses are shown for comparison.

## Resolution chart (continued)

from the strip chart against its 0 - 1 scale (0.97, 0.87, and so forth). Then, fill in the rest of the blocks according to the operation indicated in each of them (i.e.,

$$\frac{r(3N)}{3} = \frac{0.87}{3} = 0.29).$$

Next, add the positive and negative columns and place the totals at the column bottoms. Now subtract the negative total from the positive total in each pair of columns for all R (kN), and multiply the results by $\frac{\pi}{4}$. These numbers are the sine wave responses for the frequencies R(N), R(3N), R(5N), and so forth.

R(9N) through R(21N) do not need additions or subtractions; they are computed as shown at the bottom of the worksheet.

We compute the frequencies of the bar groups by multiplying the line pairs/mm (1.p./mm) by the reduction factor (63 for our example). In the bar chart we used for these measurements, the line pairs were spaced 0.2, 0.6, 1.0, 1.4, . . . 3.8, and 4.2 1.p./mm (corresponding to the 11 odd harmonics of 0.2 1.p./mm from 1 through 21). Therefore, we plot the square wave responses r(kN), and the sine wave responses R(kN), at 12.6 1.p./mm (63 x 0.2), 37.8 1.p./mm

(63 x 0.6), and so forth. The curves are shown in Fig. 6.

### Sources of error

The mathematics of conversion between a curve in the square wave response plane and a point in the sine wave response plane is exact. But the bar chart and the mathematical transformation deal with a one- or two-dimensional system, whereas imaging is a three-dimensional process. We may, therefore, question using maximum-contrast bar patterns interchangeably with true sine wave test patterns. For example, sine wave response curves determined from positive and negative reproductions of the new resolution chart should, in theory, be identical. They are not, and the difference between them increases with spatial frequency. Several factors can cause errors in the measured responses. If a lens shows lens flare, for instance, the light level of the surroundings will influence the results. A high-contrast, high-line-number bar pattern can act as a Ronchi grating and produce spurious effects. It is also possible that the results from reflective and transmissive patterns can differ if the light is partially coherent.

### Superior features

The new resolution chart has definite advantages. Because it is a bar chart, it is relatively easy to ensure accuracy and reproducibility in its manufacture. One feature of the new chart is that it provides more range than some now used. Another is that with the new computation worksheet, we greatly reduce the numerical effort needed to get the sine wave response values. Further evaluation will determine whether or not the new bar chart gives the values with sufficient accuracy to use interchangeably with true sine wave test pattern results.


### Acknowledgement

W. G. Reininger made the measurements for this article following methods and techniques developed by him and G. W. Fath.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