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MEASURING THE CONDUCTOR SPACING IN FLAT CONDUCTOR CABLES

Wilhelm Angele
Manufacturing Engineering Laboratory

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16. Abstract

The need for accurate conductor spacing in flat conductor cables (FCC) calls for appropriate inspection methods and equipment. A simple visual display of the positions of the conductors within the cable can be accomplished by superimposing the test cable over a standard cable. This forms an optical interference pattern called moiré. The quantitative analysis of several moiré patterns is explained in some detail. The moiré is a fast and accurate tool for inspecting the conductor spacings in translucent FCC.

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MEASURING THE CONDUCTOR SPACING IN FLAT CONDUCTOR CABLES

SUMMARY

The need for accurate conductor spacing in flat conductor cables (FCC) calls for appropriate inspection methods and equipment. A simple visual display of the positions of the conductors within the cable can be accomplished by superimposing the test cable over a standard cable. This forms an optical interference pattern called moiré. The quantitative analysis of several moiré patterns is explained in some detail. The moiré is a fast and accurate tool for inspecting the conductor spacings in translucent FCC.

INTRODUCTION

The collating process mostly used in manufacturing FCC has an inherent problem of accomplishing proper center spacing of flat conductors. The problem is caused by temperature expansion and shrinkage of the dielectric tapes and adhesives used in the process. Individual conductors may occasionally be out of line because of a slight camber or a kink. Faulty conductors of this nature should be corrected in a wire conditioner if used for FCC [1]. Also, in some cases, additional slippage of the outer conductors requires extra attention. As an aid in remedying these problems, a measuring device has been developed to conveniently display the spacing errors of the conductors in a cable.

CONDUCTOR SPACING REQUIREMENT

Establishing practical tolerances for various FCC has been a problem from the very beginning. For economical reasons, the cable producer is interested in wide tolerances to keep the rejection rate small. The connector industry engaged in designing practical FCC termination hardware is faced with the problem of overcoming the cable tolerances. The sensitivity for cable tolerances varies with the applied connector principle. In general, cables with small conductor spacing and narrow gaps require tighter tolerances. A cable with conductors of 40 mil width and 10 mil gap (50 mil center to center) should have not more than ±2 mil tolerance. The present Mil Spec for FCC allows for all types and sizes of cables ±5 mils noncumulative spacing tolerance. This may have to be improved as cable terminations are required to be made on a production basis. However, before the conductor tolerances can be improved, practical means of measuring the spacings are required.

MEASURING OF SPACING WITH A CONVENTIONAL METHOD

The standard method of measuring the conductor positions in a cable is to use a toolmaker's microscope. The cable to be measured is moved across the objective by a calibrated spindle. The measuring results must be tabulated and plotted for evaluation and better visibility. A typical example is listed in Table 1. All measurements are referenced to the first conductor edge.

The table shows the position and spacing errors of the conductors. The conductor positions and spacing errors are graphically recorded in Figures 1 and 2. Conductor no. 25 is 51.7 mils misplaced with regard to the first conductor; however, using the Mil Spec, which allows ±5 mils error, only conductors nos. 2, 24, and 25 are outside the permissible tolerance with 9.3, 5.5, and 13.0 mil, respectively. Typically, the worst spacing errors are large spacings and are at the margins of the cable.

The interferometric error presentation by moiré of the same cable is discussed later.

MEASURING BY THE INTERFEROMETRIC METHOD

From the foregoing description, table, and graph, it is obvious that a more convenient and time-saving method should be used to produce a fast visual presentation of the conductor spacing errors. The comparison with a standard grating (standard cable) using the interference effect, which produces a pattern called moiré, is very convenient and in most cases easy to accomplish. The only requirement is translucency of the cable. Shielded cables should be tested for spacing accuracy before the shields are added.

For comparison, the moiré principle requires a standard pattern of high accuracy for each cable design. A standard cable pattern was made with a tape-controlled Gerber x-y plotter, with an accuracy of 0.0005 cm (0.0002 inch), and copied as a negative. The black lines, 35 mil wide, represent the gaps between the copper conductors (Fig. 3).

The simplest way of measuring the spacing of a test cable is to superimpose it in parallel position to a standard cable negative in front of a light source. If the test cable spacing is different from the standard, small cracks of light will appear. Assume the conductor center line spacing of the cable to be tested is 76 mil instead of 75 mil. The test will show an increasing light gap across the cable width (vernier effect). The 10th conductor has shifted 10 mil, causing a crack of 10 mil.

Figure 3 shows a standard cable of 75 mil spacing. Figure 4 shows the parallel superimposure of a 78 mil cable. The gap of 35 mil has disappeared at the 12th conductor and opens progressively until it is completely open at the 25th conductor, forming a dark zone along the middle of the cable.

If the spacing error is much less and the parallel conductor vernier effect is not visible, a small angle between the test and standard cable should be introduced to amplify the reading. An interesting pattern with dark and light bands, a moiré, appears. The gaps between the conductors feather out to zero, forming rhomboids. Their width-to-length ratio is a function of the angle α between the two cables. If the lengths of the rhomboids across the cable widths are equal and the dark bands have no slant angle, the cables have equal spacing. Figure 5 shows a moiré produced by two standard cables of 0.075 c/c with an angle $\alpha = 3\ 1/2$ degrees or 1:16.25. The white rhomboids form dark bands across the cables at a distance of 3.3 cm (1.3 inches). The white lines of the cable negative are 0.1 cm (0.40 inch) wide and the angle is

1:16.25; thus the lines must intersect at 0.04 times 16.25 from the center. The total length of the rhomboid is $2 \times 0.04 \times 16.25 = 1.300$ inches. The 3.3 cm (1.3-inch) moiré spacing, being square to the cable edge and uniform, indicates that the test cable is free of errors and identical to the standard cable. Superimposure of standard cables with different center spacings produces slanted moiré patterns. Figure 6 shows a 75 mil and 78 mil cable superimposed at an angle $\alpha = 3.7$ degrees. This produces a moiré slanted to the 75 mil cable width by $\beta = 32$ degrees. The calculation of center spacing from the moiré slant angle β is explained in the next section.

CALCULATION OF THE CONDUCTOR CENTER SPACING FROM THE MOIRÉ SLANT ANGLE

The previous section mentioned the moiré patterns and the use of moiré for inspecting the conductor spacings, regularity, and accuracy of FCC. This section explains the moiré geometry and gives formulas and a graph for direct application to determine the numerical values of the test cables conductor spacings.

For the following calculations and graph, a standard cable with 75 mil conductor center spacing is used and an angle $\alpha = 2$ degrees between standard cable and test cable is applied to form the moiré pattern by superposition. Figures 7 and 8 represent diagrams showing the conductors as single lines of cables crossed by angle α. Figure 7 applies for test cables where c_2 is larger than c_1. In Figure 8, $c_2 < c_1$. In both cases, the cable conductors intersect at points A and B. The distance BC represents c_1. BD represents c_2, AB is the moiré center line, and ABC is the moiré slant β.

The derivation of the c_2 formula is simply made from the geometry as follows: Case: $c_2 > c_1$.

$$c_2 = (c_1 + a) \cos \alpha \; ; \; a = h \cdot \mathrm{tg}\, \alpha \qquad \text{distance AC} = h$$

$$h = c_1 \cdot \mathrm{tg}\, \beta$$

$$c_2 = (c_1 + h \cdot \mathrm{tg}\, \alpha) \cos \alpha$$

$$= (c_1 + c_1\, \mathrm{tg}\beta \cdot \mathrm{tg}\, \alpha) \cos \alpha$$

$$= c_1 (1 + \mathrm{tg}\, \alpha\; \mathrm{tg}\beta) \cos \alpha$$

$$= c_1 (\cos \alpha + \sin \alpha \cdot \mathrm{tg}\beta)$$

Since $\cos\alpha$ is near unity for small angles up to 5 degrees, c_2 can be calculated from

$$\boxed{c_2 = c_1 (1 + \sin\alpha \operatorname{tg} \beta)}$$

c_1 = conductor center spacing of cable 1

c_2 = conductor center spacing of cable 2

α = angle between cables 1 and 2

β = angle of the moiré band to the width of cable 1. (Line B-C in Figures 7 and 8.)

To expedite quality control and inspection operation, it is recommended that charts or graphs be used for standard spacing (c_1 = 0.050, 0.075 and 0.100 inch) for determining the center spacing c_2 of the test cable. Figure 9 is calculated for c_1 = 75 mil and α = 2 degrees.

SPECIAL CABLES AND THEIR MOIRÉS

Figure 6 shows the slanted moiré caused by interference of two cables with constant but slightly different conductor spacings. If a cable having continuously increasing spacing from the center conductor toward the margins is compared with a standard cable with constant spacing, a moiré, as shown in Figure 10, occurs. The moiré resembles a series of sine waves. The amplitude of the sine waves increases with the decrease of the angle between the two cables. It may also be of interest to know what kind of moiré will appear if such a cable with increasing pitch from the center conductor towards the margins is compared with itself. Figure 11 shows the result. The pattern somewhat resembles the Chevron sign, having a series of arrows. The arrow center angle reduces with the reduction of the angle between the two cables. Figure 11 is based on a cable angle α = 3.6 degrees. The arrow angle becomes zero at $\alpha = 0$. On the other hand, for a fixed cable angle α, the arrow angle opens to 180 degrees as the moiré distance from the cable pivot point becomes zero.

A MORE COMMON MOIRÉ PATTERN

The cable measured and described previously is now tested by using the moiré principle. It is compared with a standard cable of precise and regular spacing. Figure 12 presents in moiré language the errors of the cable shown in Figures 1 and 2. The following can be observed:

1. The slant angle of the moiré indicates the overall spacing is too wide.

2. The rhomboids are much shifted at the margins, meaning extra large spacing of the conductors near the margins.

3. Minor irregularities exist across the cable.

A comparison of the ideal moiré of two standard cables in Figure 5 with the moiré in Figure 12 shows a variety of errors.

EQUIPMENT FOR MOIRÉ TESTING

Figure 13 shows a temporary moiré tester made for preliminary use. The box, about 18 × 13 × 9 cm (7 × 5 × 3.5 inches) contains 3 small light bulbs (120 volts, 7 watts) behind a frosted glass pane. A standard cable, exchangeable for cables with other dimensions, is fixed on top of the glass. The cable to be tested can be inserted to lay in a groove on top of the standard cable with intimate contact to avoid parallax errors between the two cables. The test cable can be adjusted to be parallel to the standard cable, and it can be rotated to any desired angular position between 0 and 10 degrees.

In addition to the parallel vernier position of the cables, it is advisable to use a fixed cable angle for a certain cable; e.g., for a cable with 75 mil conductor spacing, a cable angle $\alpha = 2$ degrees gives sufficient moiré band distance for convenient evaluation. Figures 12 and 13 show considerable moiré irregularities, indicating various sizes of spacing errors. The details are given in Figures 1 and 2.

CONCLUSIONS

It has been demonstrated that the superimposure of the test cable over a standard cable produces an interference pattern (moiré). The moiré slant angle, the distance, and the irregularities of the moiré band show the tolerance image of a cable, and the conductor spacing can be calculated from the moiré slant angle.

The immediate appearance of a moiré image, which is the error image of the test cable, is a striking example of time saving. Equipment cost can be drastically reduced from an expensive precision toolmaker's microscope to an inexpensive, small light box with two adjustment screws.

TABLE 1. TABULATION AND EVALUATION OF MICROSCOPE READINGS
(All dimensions in mils, 1 mil = 0.025 mm)

Conductor No.	Should be Position	Actual Position	Position Error	Actual c/c Spacing	Spacing Error	
					-	+
1	0	0	0	0		0
2	75	84.3	9.3	84.3		9.3
3	150	163.7	13.7	79.4		4.4
4	225	242.0	17.0	78.3		3.3
5	300	317.2	17.2	75.2		0.2
6	375	393.2	18.2	76.0		1.0
7	450	468.7	18.7	75.5		0.5
8	525	544.5	19.5	75.8		0.8
9	600	619.1	19.1	74.6	0.4	
10	675	698.5	23.5	79.4		4.4
11	750	772.2	22.2	73.7	1.3	
12	825	849.0	24.0	79.8		1.8
13	900	923.9	23.9	74.9	0.1	
14	975	1000.2	25.2	76.3		1.3
15	1050	1074.2	24.2	74.0	1.0	
16	1125	1147.1	22.1	72.9	2.1	
17	1200	1221.6	21.6	74.5	0.5	
18	1275	1299.5	24.5	77.9		2.9
19	1350	1375.9	25.9	76.4	1.4	
20	1425	1435.3	28.3	77.4		2.4
21	1500	1527.8	27.8	77.5		2.5
22	1575	1605.8	30.8	78.0		3.0
23	1650	1683.2	33.2	77.4		2.4
24	1725	1763.7	38.7	80.5		5.5
25	1800	1851.7	51.7	88.0		13.0

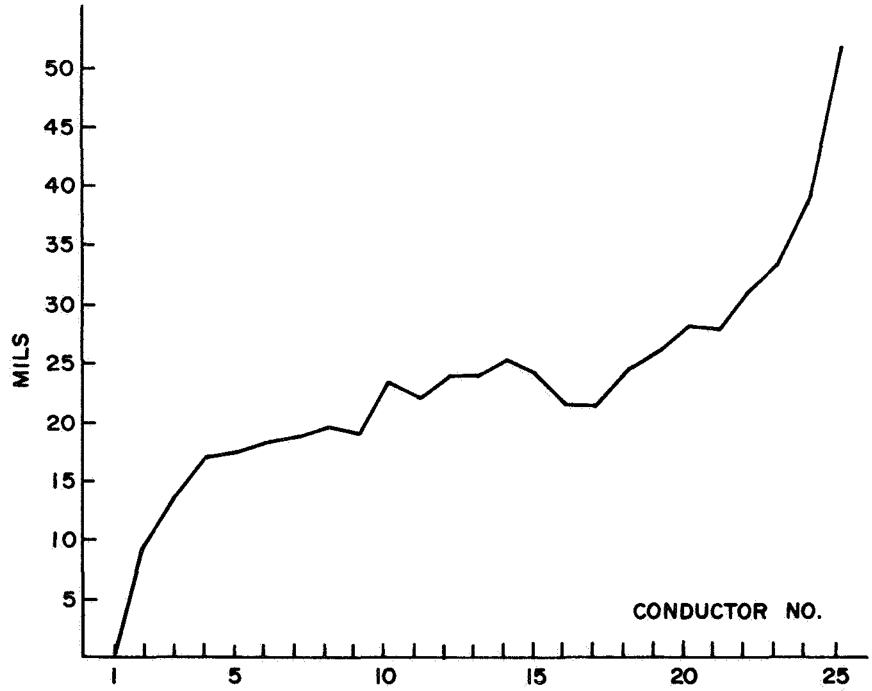


Figure 1. Typical conductor positions in FCC.

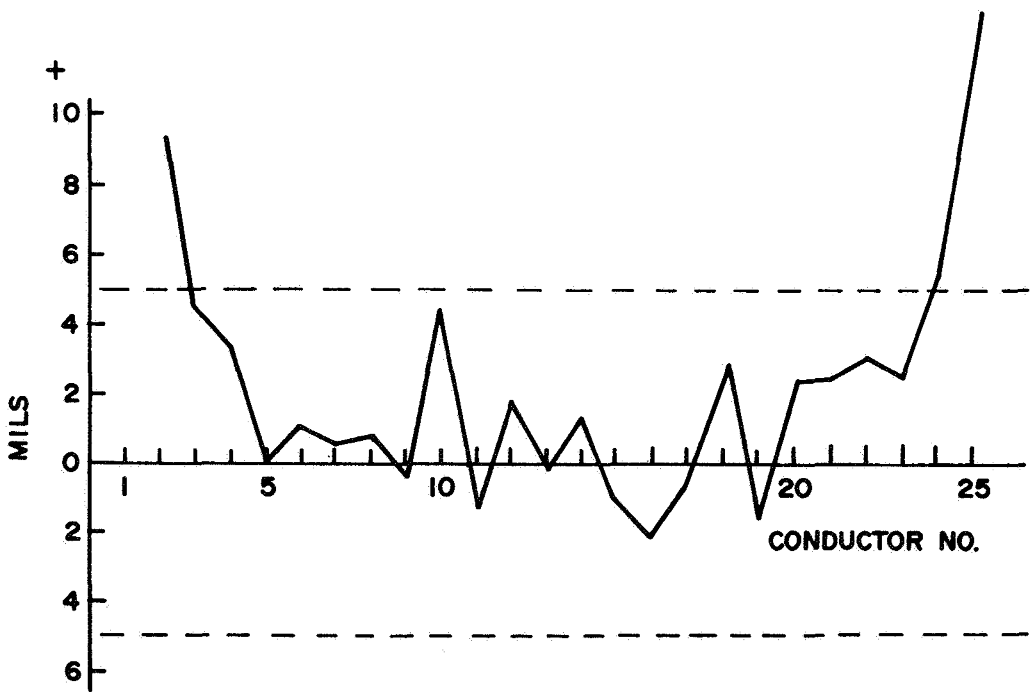
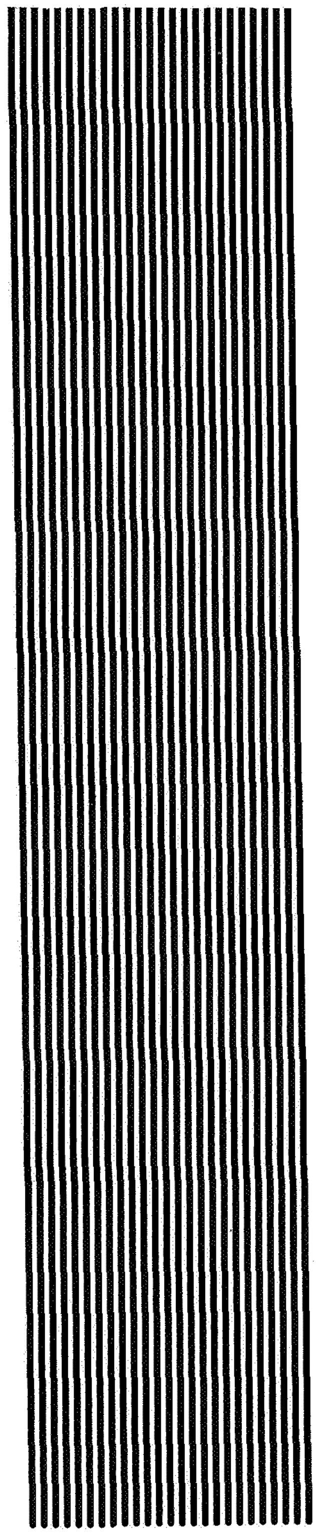
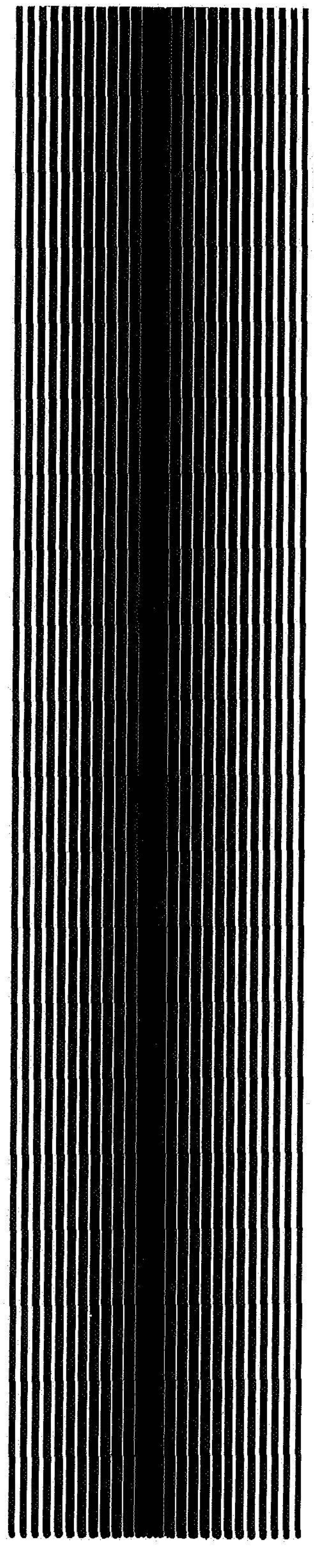


Figure 2. Conductor spacing errors in FCC.



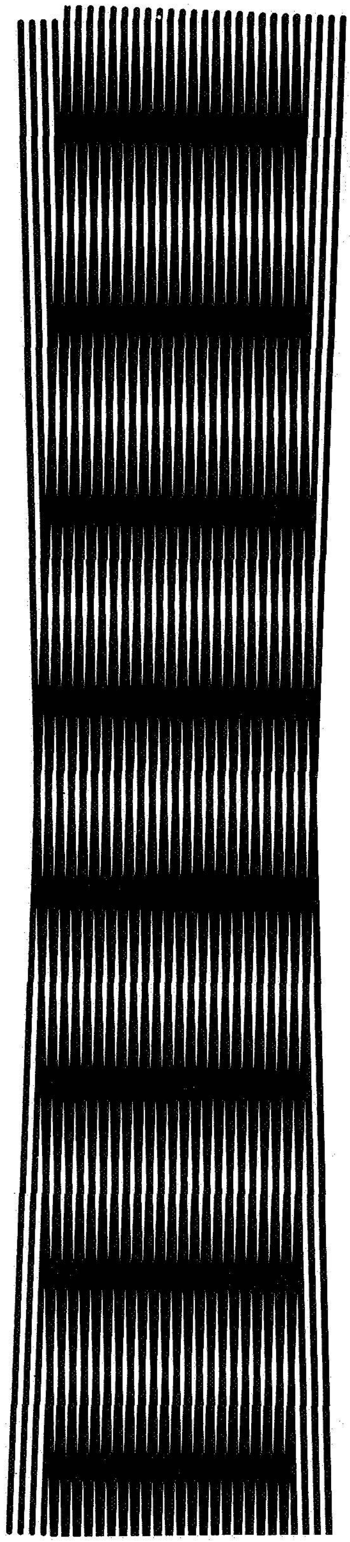
Standard Cable
25 conductors
40 mil wide
75 mil center spacing
plotted with tape controlled Gerber x-y
Plotter. Copied as a negative.

Figure 3. Standard cable with 75 mil spacing, 25 conductors.



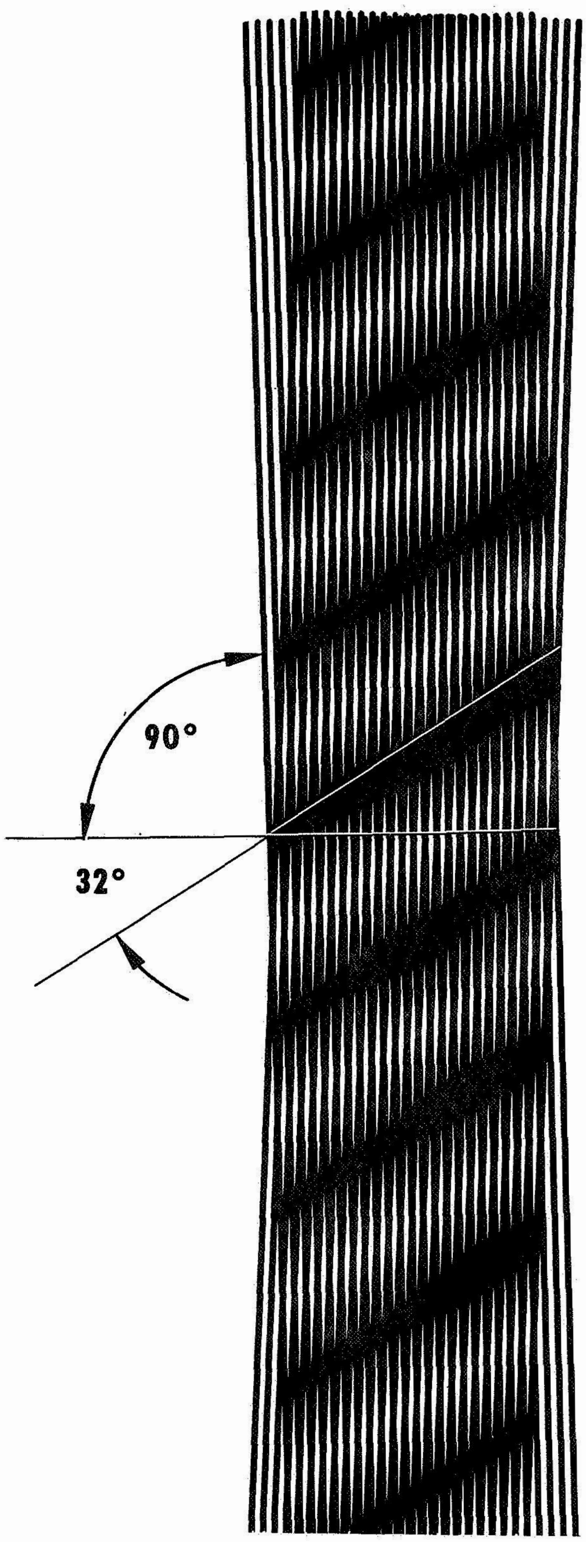
A test cable with 78 mil center spacing is superimposed over a standard cable with 75 mil center spacing forming a beat frequency of 24 conductors.

Figure 4. A 75 mil cable parallel superimposed by a 78 mil cable, vernier effect.



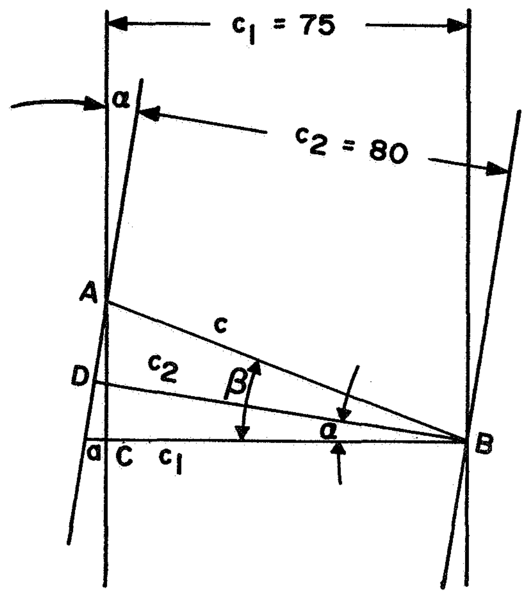
Two standard cables of identical dimension are superimposed at $\alpha = 3\frac{1}{2}°$. The moiré patterns are square to the conductors and equally spaced and totally uniform. The two cables are identical standards.

Figure 5. Moiré formed by two identical standard cables.



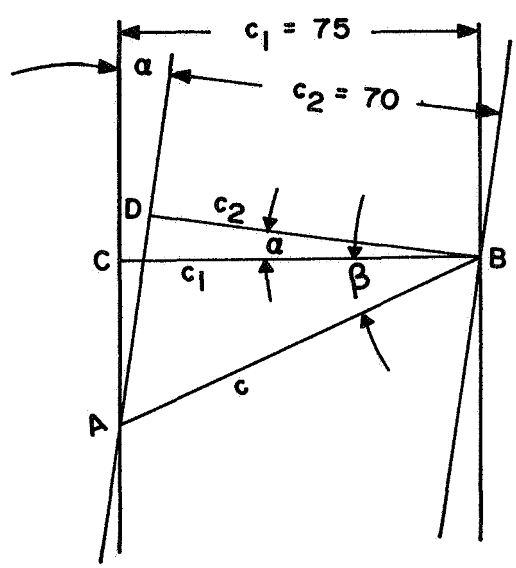
2 standard cables c_1 = 75 mil and c_2 = 78 mil center spacing are superimposed at $\alpha = 3.7°$. The moiré slant angle $\beta = 32°$.

Figure 6. Slanted moiré formed by two different cables.



$$\frac{c_2}{c_1} = \cos\alpha + \sin\alpha \,\mathrm{tg}\,\beta$$

Figure 7. Diagram for calculating the spacing c_2 from slant angle and c_1, $c_2 > c_1$



$$\frac{c_2}{c_1} = \cos\alpha - \sin\alpha \,\mathrm{tg}\,\beta$$

Figure 8. Diagram for calculating the spacing c_2 from slant angle and c_1, $c_2 < c_1$

c_2	70	71	72	73	74	75	76	77	78	79	80
β	-62	-57	-48	-36	-19	-1	+20	+37	+49	+57	+62

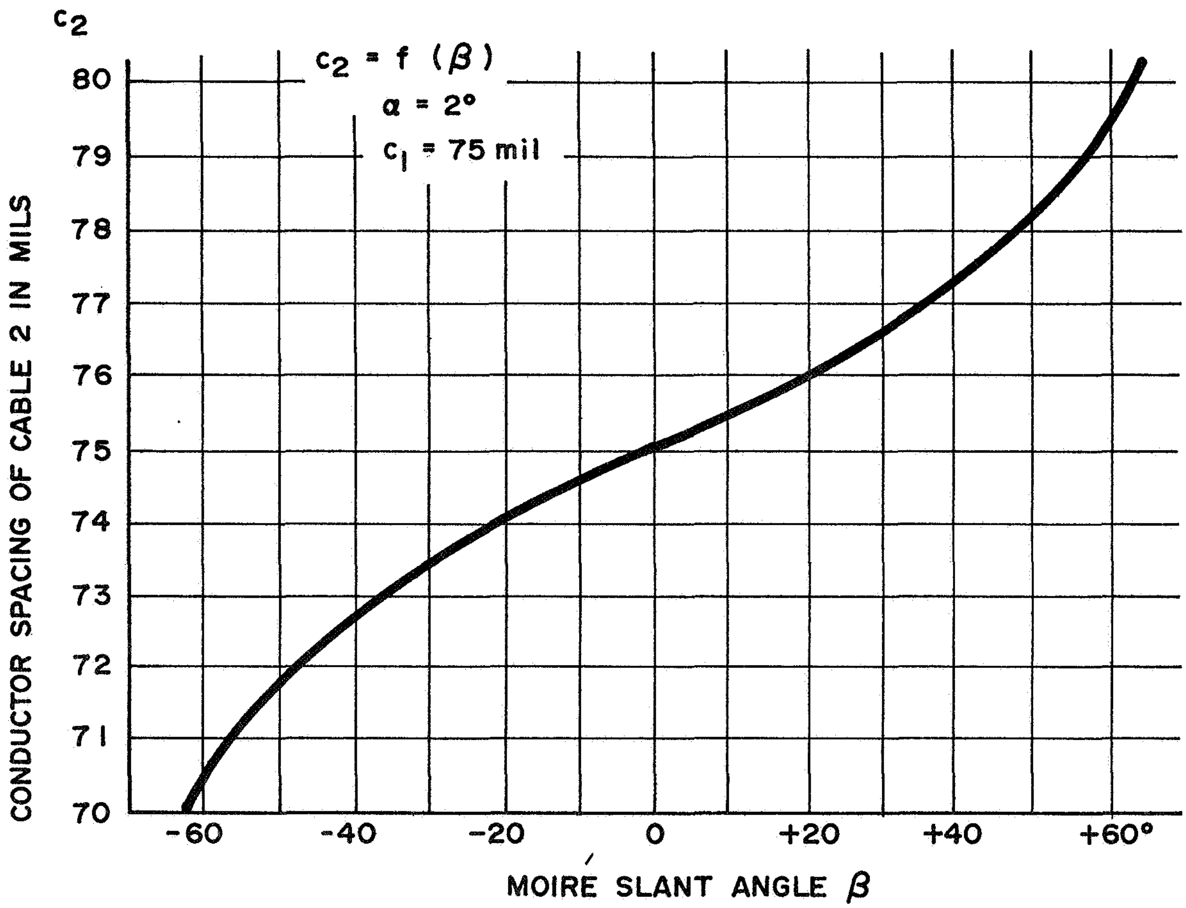
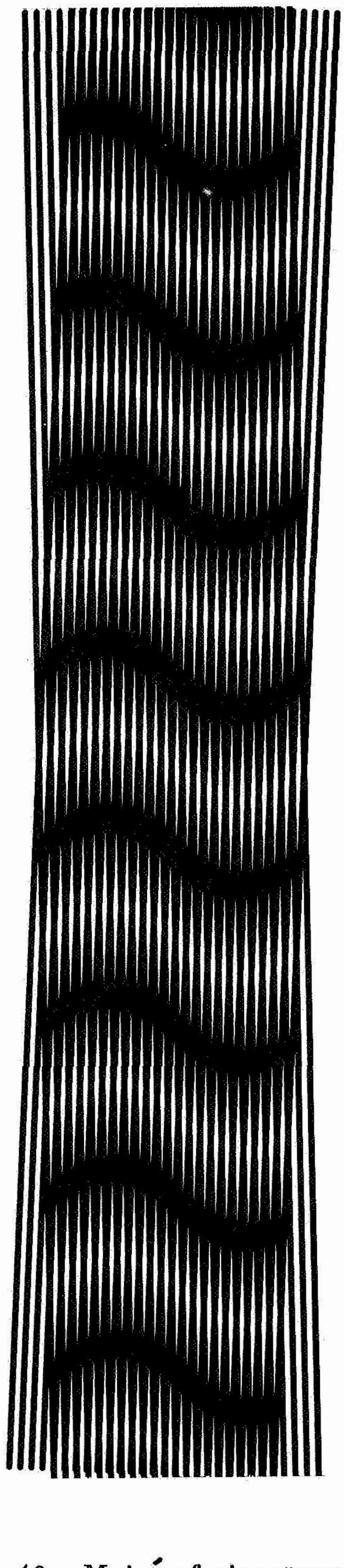
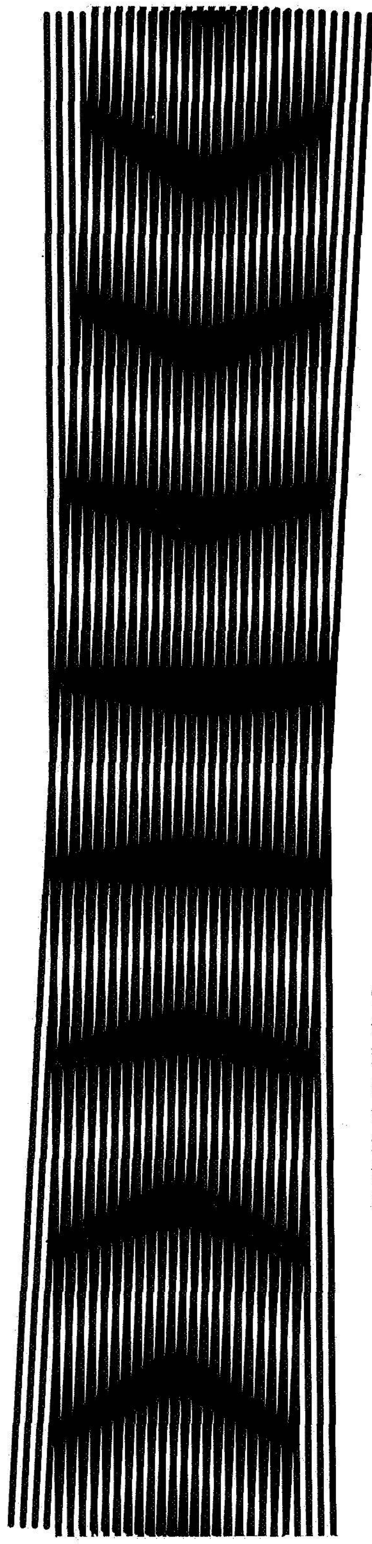


Figure 9. Moiré slant angle as function of spacing difference.



The sine wave moiré is formed by a standard cable with c_1 = 75 mil and a test cable having a spacing which changes linearly from the center to the margins from 75 mil to 78 mil. The cable angle $\alpha = 3.6°$.

Figure 10. Moiré of sine wave form.



The Chevron moiré pattern is formed by two identical cables having a linearly changing spacing of 75 to 78 mil from the center towards the margins.
Cable angle $\alpha = 3.6°$.

Figure 11. Moiré with arrow pattern.

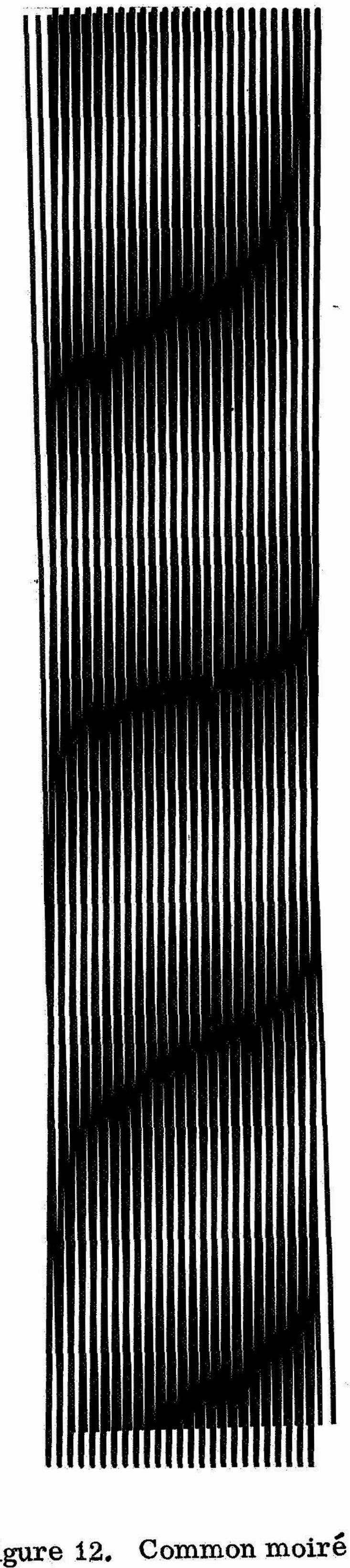


Figure 12. Common moiré pattern.

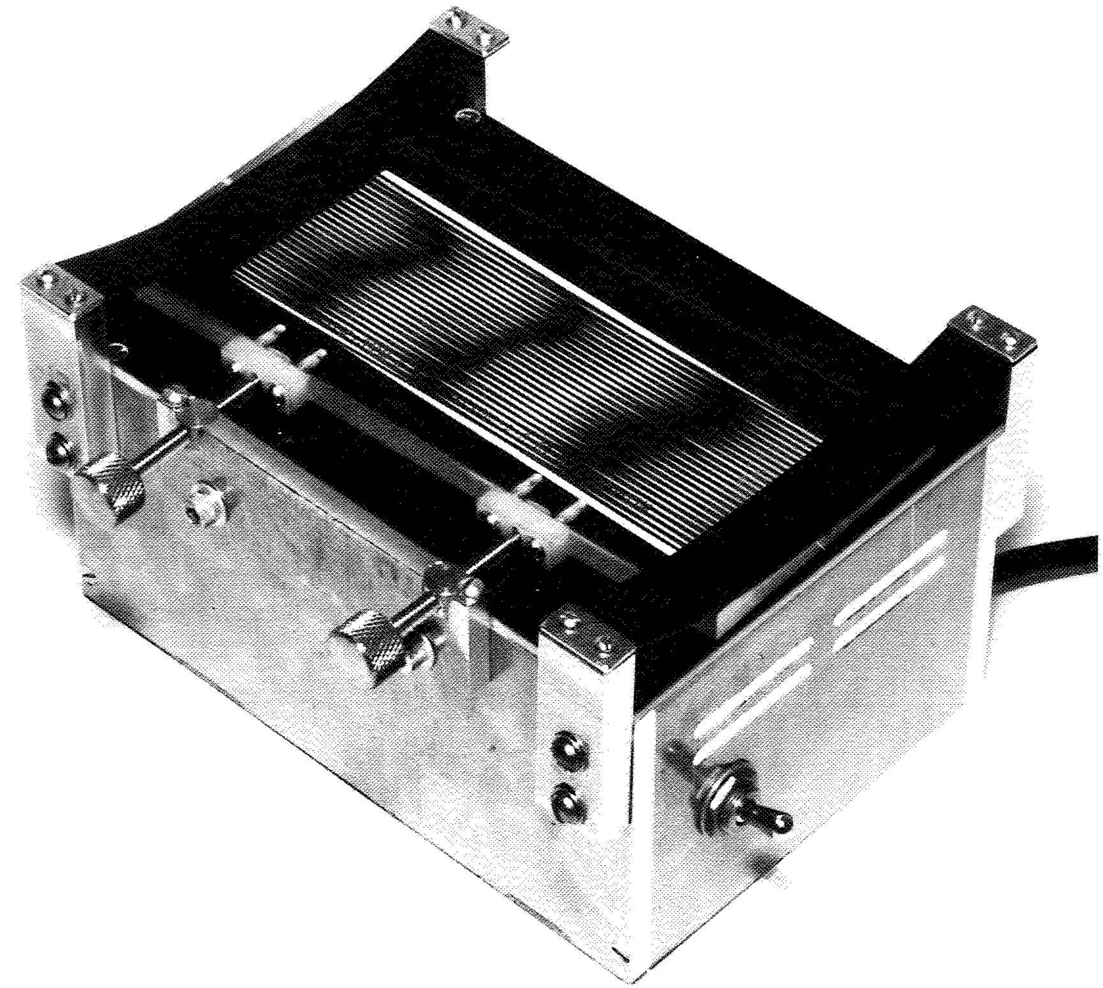


Figure 13. Moiré tester.

REFERENCE

1. Angele, Wilhelm: Flat Conductor Cable Manufacture and Installation Technique. NASA TM X-53586, March 1967, pp. 9 and 10.

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APPROVAL

MEASURING THE CONDUCTOR SPACING IN FCC

By

Wilhelm Angele

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

M. P. L. SIEBEL
Director, Manufacturing Engineering Laboratory

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