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The determination of metameric mismatch limits of industrial colorant sets

Michael Beering

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THE DETERMINATION OF METAMERIC MISMATCH LIMITS OF INDUSTRIAL COLORANT SETS

BY
Michael M. Beering

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Photographic Arts and Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology.

Signature of the Author M. M. Beering
Imaging and Photographic Science

Certified by Name Illegible
Thesis Advisor

Accepted by Name Illegible
Coordinator, Undergraduate Research

Rochester Institute of Technology
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THE DETERMINATION OF METAMERIC MISMATCH
LIMITS OF INDUSTRIAL COLORANT SETS

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Michael M. Beering

Date: 4/24/85

THE DETERMINATION OF METAMERIC MISMATCH LIMITS OF INDUSTRIAL COLORANT SETS

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ABSTRACT

The metameric mismatch limits for two industrial colorant sets, a set for Acrylonitrile Butadiene Styrene polymers and a set for an acrylic enamel paint system, were determined for a reference illuminant, D65 and test illuminants of FS42, FN40, and Illuminant A. An overlap in color gamuts was found in all cases of similar test conditions between the two sets. Trends in the size, shape, and location of the gamuts were illustrated in 1976 CIE u'v' color space. The results show vastly dissimilar gamuts for all three of the test illuminants.

ACKNOWLEDGEMENT

The author would like to express his appreciation to the following for their cooperation and assistance with this thesis.

Dr. Roy S.Berns of the ISCC, committee #27

E.I. Dupont de Nemours Corporation

Monsanto Corporation

Dr. Franc Grum

Nitin Sampat and Terry Peplaski

DEDICATION

Time it was and what a time it was; those memories will never die.

To those who were understanding, patient, helpful, supportive, and remained close.

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I. Introduction

Color is a perceptual occurrence, a subjective interpretation of a scene. In order for this perceptual process to occur three basic components must be present. The components include a light source, an object, and an observer. Light, the narrow band of the electromagnetic spectrum to which the eye responds, creates a stimulus for the human eye and is interpreted by the brain. Any changes in one or more of the three components will usually result in a change in the color perceived.

From an industrial viewpoint, a change in observer is expected but could not possibly be compensated for. Due to the fact that there is such a vast number of potential observers, each possessing their own response functions, industry assumes the response function of the standard observer[1]. The reflectance function of an object is determined by the substrate and the colorants used during manufacture. Colorants are responsible for the physical modification of the light incident upon them. The illuminant may be selected intentionally or at random. As an illuminant is changed, the stimulus created is also changed. Illuminants differ from one another by their spectral power distributions. A phenomemon which can be attributed to this type of change is illuminant metamerism[2]. Illuminant metamerism is of great concern in the color matching industries of today[3].

There exists some differences in exactly how metamerism should be defined[4]. Metamerism, as used here, will follow the CIE definition: the situation where two colored samples have identical color coordinate values for a given illuminant and observer, but possess dissimilar spectral reflectances [5]. The requirement of at least three crossovers of the reflectance curves of metameric samples is a mathematical proof using the CIE definition[6]. It follows from this definition that, in general, these spectrally dissimilar samples may result in a colorimetric mismatch under a secondary illuminant.

There are many industrial situations which involve color matching of components made from different materials. An example is the automotive industry; the interior of an automobile serves to illustrate this situation. Polymeric materials, painted surfaces, and textiles are all present to some degree in the interior. Each has its own manufacturing requirements and accordingly, different colorants are used for each material. The colorant sets for most cases are not interchangeable[7]. In the cases where the colorants are interchangeable, the different electronic environments of the two materials can be the same as having two different but similar colorants. Each material must be formulated to provide a matching interior for the automobile. Because of the differences in colorants, spectral matches are infrequent and as a consequence, metamerism often occurs. Quality control can only limit the problem of metamerism.

These colorant formulations are selected for a match under a cool white fluorescent source, such as the lighting in a showroom. A problem with this type of color matching presents itself when the automobile is viewed under another source, such as daylight or a tungsten source. The current practice of first formulating a single colored component of a product and then contracting out to have others achieve an acceptable match for the remaining components increases the chances of metamerism.

In 1975, the results of work completed by N. Ohta and G. Wyszecki on the theoretical chromaticity-mismatch limits of metamers was published[8]. The work states that colored materials, which match under a reference illuminant, no longer had equivalent coordinates, but were found to fall within a certain region of color space when viewed under another illuminant. The method used for this work assumed a visible wavelength span from 400nm to 700nm. The boundaries of these regions, or gamuts are the theoretical mismatch limits. The shape and location of these theoretical limits were calculated using a linear-programming technique[9]. The mismatch limits calculated in this work resulted in large regions of color space. The size and shape of the limits were found to be dependent upon both the illuminants selected and the color of the metamers used. The volume of these theoretical regions of color space were approximated by the smallest inner-lying rectangular box to provide a better idea of their size.

R. Kuehni conducted an experiment in 1977 comparing the practical limits of metamerism to the theoretical limits calculated by Ohta and Wyszecki[10]. Kuehni's work was done using only commercial textile dyes on textile substrates. The position and shape of the practical limits found by Kuehni agreed with the previously published theoretical limits. The size of the practical limits were much smaller, usually one-third to one-fourth of the calculated limits. Exact color matches were calculated using CIE Illuminant D65 and the CIE 10 degree observer. A visible spectrum of 400nm to 700nm was also used. Matches were generate for a gray of 10% constant reflectance and for 25 other colors distributed evenly within the color space. Color differences were calculated for the set of matches found under CIE Illuminant A and for those under a standard warm white fluorescent illuminant. The number of crossovers of the metameric reflectance functions were observed to be fairly random.

When a pair of samples are viewed under a primary illuminant and then a test illuminant there can be no direct comparison between the appearance of the samples and their colorimetric values[11]. The same holds true when comparing the results of different test illuminants. This is because there is no color space which provides a uniform appearance space for the different illuminants[12]. A paper written by R. Berns and F. Billmeyer, Jr. suggested a solution to the above stated problem[13]. The proposal states that when a correlation is to be drawn between appearance and color differences calculated for several illuminants, chromatic-adaptation transformations should be used. This would provide color differences based on constant chromatic adaption to a single illuminant. The result would eliminate the need to consider the nonuniformities of the color space for each illuminant. The work suggests that color differences and indices of color constancy and metamerism would be more useful if calculated at constant chromatic adaptation

Proper application of the previously completed work would allow the unique determination of the extent of metamerism between any two given colorant sets for various illuminants. By plotting of the relative size, shape, and location of various practical mismatch limits a route for assessing the extent of metamerism could be determined. If two materials yield mismatch limits which overlap greatly, metamerism could be readily controlled; if the mismatch limits fail to overlap appreciably, control of metamerism would not be a simple task and suggests a need for greater inter-industry communication. concern.

II. Experimental

A. Selection of Reference and Trial Data

In accordance with the CIE guidelines[14], five reference chromaticities were chosen. These correspond to a gray and four chromatics. The chromatics were a blue, a green, a red, and a yellow. The Colour Difference Subcommittee of the CIE proposed these values to limit one parameter, namely the reference stimuli of color difference experiments. The reference stimuli tristimulus values are listed along with reflectances at ten nanometer increments in Table 1. The reflectance functions shown were chosen arbitrarily from several which were found to yield the required tristimulus values. These functions were used as references for the computer color matching routine and were not reported as matches. The same values were used for the standards which required a twenty nanometer increment. The end points at 400 and 700 nanometers remained the same while the remaining values were averaged in sets of three to obtain the necessary sixteen final values.

The reference illuminant under which all matches were generated was CIE Illuminant D65; the CIE 1964 Supplementary Standard Colorimetric Observer was used as the observer function. The test illuminants were chosen on the basis of industrial importance. The illuminants chosen include FS42, FN40, and CIE Illuminant A [15]. FS42 is a standard cool white fluorescent which will be referred to as F2 in this paper. FN40 is a three-narrow band fluorescent which will be referred to as F11 in this paper.

B. Colorant Data Bases

The first of the two colorant sets used for this project was obtained from the E.I. Dupont de Nemours Corporation. This was a colorant set for paint line 981. The paint line was discribed as an acrylic enamel system. There were 31 colorants which were used from this set. The number of metameric matches generated with this set was dependent upon the reference tristimulus values desired. This data was in the form of unit K and S at ten nanometer increments on magnetic tape.

The second colorant data base received was also in the form of unit K and S but was provided at twenty nanometer increments on hard copy. This colorant set was for use in ABS polymers (Acrylonitrile Butadiene Styrene). This data base was received from the Monsanto Corporation. It included 69 colorants which were used for this experiment. The larger number of colorants in this set is responsible for the greater number of matches achieved.

Table 1: Reference Data Used in Generating Metamers

```
COLOR:  BLUE   TSV:  X=8.9222   Y=8.8000   Z=23.0185
Reflectance values:
(400-450nm)  21.5359 22.0369 23.0891 24.1739 23.8510 22.4994
(460-510nm)  20.8291 20.0420 18.9104 16.4100 13.7265 11.7164
(520-570nm)   9.8621  8.2685  7.1969  6.6312  6.2883  6.1616
(580-630nm)   6.0206  5.9583  6.0042  6.1501  6.3490  6.5752
(640-690nm)   6.7212  6.7030  6.4869  6.3615  6.3615  6.5433
(700nm)       6.8824

COLOR:  GRAY   TSV:  X=28.4592  Y=30.0000  Z=32.1752
Reflectance values:
(400-450nm)  33.1529 31.9554 31.2476 31.0390 30.5843 30.0976
(460-510nm)  29.5770 29.1096 28.2651 28.7637 29.4230 29.3347
(520-570nm)  29.2443 30.0647 30.6112 31.0353 30.9506 30.6398
(580-630nm)  30.2480 30.2438 29.6225 29.7223 29.5291 29.1631
(640-690nm)  28.7520 28.8999 28.0242 27.4193 27.3779 27.6003
(700nm)      27.5330

COLOR:  GREEN  TSV:  X=16.4420  Y=24.0000  Z=25.8564
Reflectance values:
(400-450nm)  20.6686 20.3154 20.6150 21.2944 22.1530 22.7775
(460-510nm)  23.3909 25.6561 29.6594 34.2578 36.9887 35.4146
(520-570nm)  33.9941 34.2643 32.3339 27.9833 22.8748 17.9304
(580-630nm)  14.2060 12.2755 10.8366 10.5896 10.3293 10.2010
(640-690nm)  10.2195 11.1610 12.0911 12.9665 13.6259 13.7049
(700nm)      13.1127

COLOR:  RED    TSV:  X=19.9544  Y=14.1000   Z=7.1737
Reflectance values:
(400-450nm)   9.8994  8.9257  8.0766  7.4170  6.9647  6.5063
(460-510nm)   6.1402  6.0987  6.1223  5.8583  5.6751  5.7194
(520-570nm)   5.7188  5.5286  5.6187  6.2805  8.3912 13.5725
(580-630nm)  21.0552 27.8841 31.9310 34.2840 36.3253 37.9495
(640-690nm)  39.0680 39.6742 39.0635 38.3994 38.6709 40.0797
(700nm)      42.0791

COLOR:  YELLOW TSV:  X=62.8234  Y=69.3000   Z=29.7925
Reflectance values:
(400-450nm)   25.7496 24.9744 25.0553 25.6170 26.2615 26.4501
(460-510nm)   26.6119 26.9152 28.1329 34.4601 47.0670 59.6145
(520-570nm)   67.0488 73.7630 79.9286 83.3670 83.3171 80.9293
(580-630nm)   77.4136 74.7796 72.2782 72.0258 71.2694 70.8440
(640-690nm)   71.0486 72.7412 74.9579 75.8686 76.9652 77.4511
(700nm)       76.1897
```

C. Generation of Metamers

The metamers were generated using a standard computer color formulation software package. This color formulation program was supplied by Eugene Allen to RIT for academic use only. It is based on two constant Kubelka-Munk theory[16] and is designed to match paint. The program used was modified by R. Berns for the present study.

The program was first editted to run for the paint colorant set at ten nanometer increments and then at twenty nanometer increments for the ABS polymer colorant set. The software generated exact tristimulus matches to the CIE reference tristimulus values. The D matrix used in Allen's color matching software was calculated using the reference reflectances while the reference tristimulus values were used in the delta t matrix to insure the generated metamers indeed integrated to exact matches. Exact tristimulus matches were within .001 tristimulus units of the references. Each match consisted of a white pigment and three chromatic colorants. The program used a combinatorial approach of trying every possible selection of colorants to obtain a match. The number of matches obtained was dependent upon the number of colorants in the data set and the desired reference color. Often in industry matches for grays are generated using only white and black colorants. The calculation of grays using only white and black colorants was abandoned as the high absorption of the titanimum dioxide around the 400 nanometer region was having adverse effects on the Z tristimulus values. The output of the program was in the form of reflectance values of the achieved mix at either ten or twenty nanometer increments.

D. Calculation of color coordinates

The tristimulus values for each formulated match were calculated for the selected test illuminants using the reflectance functions generated with the color matching software. In an effort to reduce the error introduced by approximating the tristimulus equations with summations, weighting functions were used in the calculation of these values. The weighting functions used for this project were the ASTM ten degree observer weighting functions for the selected test illuminants.

A chromatic adaptation transformation subroutine was written by R. Berns to transform all values to their corresponding colors under the primary illuminant, CIE Illuminant D65. This was to allow the calculation of all color coordinates, color differences and indices in an common color space. This method is based on a non-linear transformation as suggested by Nayatani, et al.[17].

CIELAB coordinates were then calculated from the match data. These values were calculated using the adapted tristimulus values of the matches under each of the test illuminants. The calculation of these coordinates was necessary for the determination of color differences on an easily recognizable scale.

CIE 1976 u′ v′ chromaticities were also calculated. The adapted tristimulus values were again used for these calculations. These were used for the plotting of the color gamuts. This system was selected as it provides a fairly uniform color space and enables the sampling and plotting of the achieved gamuts at specific Y values.

A color constancy index was computed for each formulation of both the paint and the ABS polymer set under each test illuminant. The value of the index was computed by taking the CIELAB color difference between the coordinates of the formulation under D65 and those obtain under the test illuminant. This is the amount any one formulation changed its position with the change in illuminant.

A metameric index was also computed for each of the formulations. This followed the CIE recommended special index of metamerism[18]. The formulation which presented the minimum color constancy index for a given data set and test illuminant was chosen as the standard for the calculation of the metameric index for those same conditions. The index value is the CIELAB color difference between the match being indexed and the match of minimum color constancy under the test illuminant.

E. Presentation of gamuts and gamut overlap

The total number of matches for any given colorant set and selected test illuminant were represented in each plot, every point being a single formulation for a match to that reference under D65. Mismatch limits were plotted for both data sets used under each test illuminant. These plots were drawn in the 1976 CIE uniform-chromaticity-scale diagram, u′ v′ (Figures 1-30). A mismatch limit is defined here as the color gamut formed by all the possible matches generated for a specific substrate. The software package, DISSPLA, was utilized for all the plotting necessary on the VAX-11/780 system, the system used for all the computer orientated work.

The overlap between color gamuts, gamuts for the same reference point and test illuminant but different substrates, was estimated with the use of a relative frequency histogram (Figure 31). The histogram represents the relative frequencies of the CIELAB color difference values as they are determined for each pair of formulations between the two colorant sets. This method was chosen over a volumetric estimation because of the discrete nature of the data.

III. Results

Table 2. Y Tristimulus Value Range and Number of Matches Generated For Paint Set

COLOR	MATCHES	TEST ILLUMINANT	MIN Y	MAX Y	DELTA Y
BLUE	218	F2	7.2655	8.0852	0.8197
		F11	7.5984	8.1596	0.5612
		ILLA	7.5482	7.5836	0.0354
GRAY	814	F2	27.4690	31.7043	4.2353
		F11	28.6017	31.9104	3.3087
		ILLA	29.9256	30.0574	0.1318
GREEN	381	F2	20.3734	22.2777	1.9043
		F11	21.2296	23.3038	2.0742
		ILLA	20.7431	20.8115	0.0684
RED	668	F2	13.1737	16.6719	3.4982
		F11	15.0896	17.1387	2.0491
		ILLA	18.2309	18.4610	0.2301
YELLOW	88	F2	72.3408	73.8513	1.5105
		F11	72.4262	73.9264	1.5002
		ILLA	72.8566	72.9165	0.0599

Table 3. Y Tristimulus Value Range and Number of Matches Generated For ABS Polymer Set

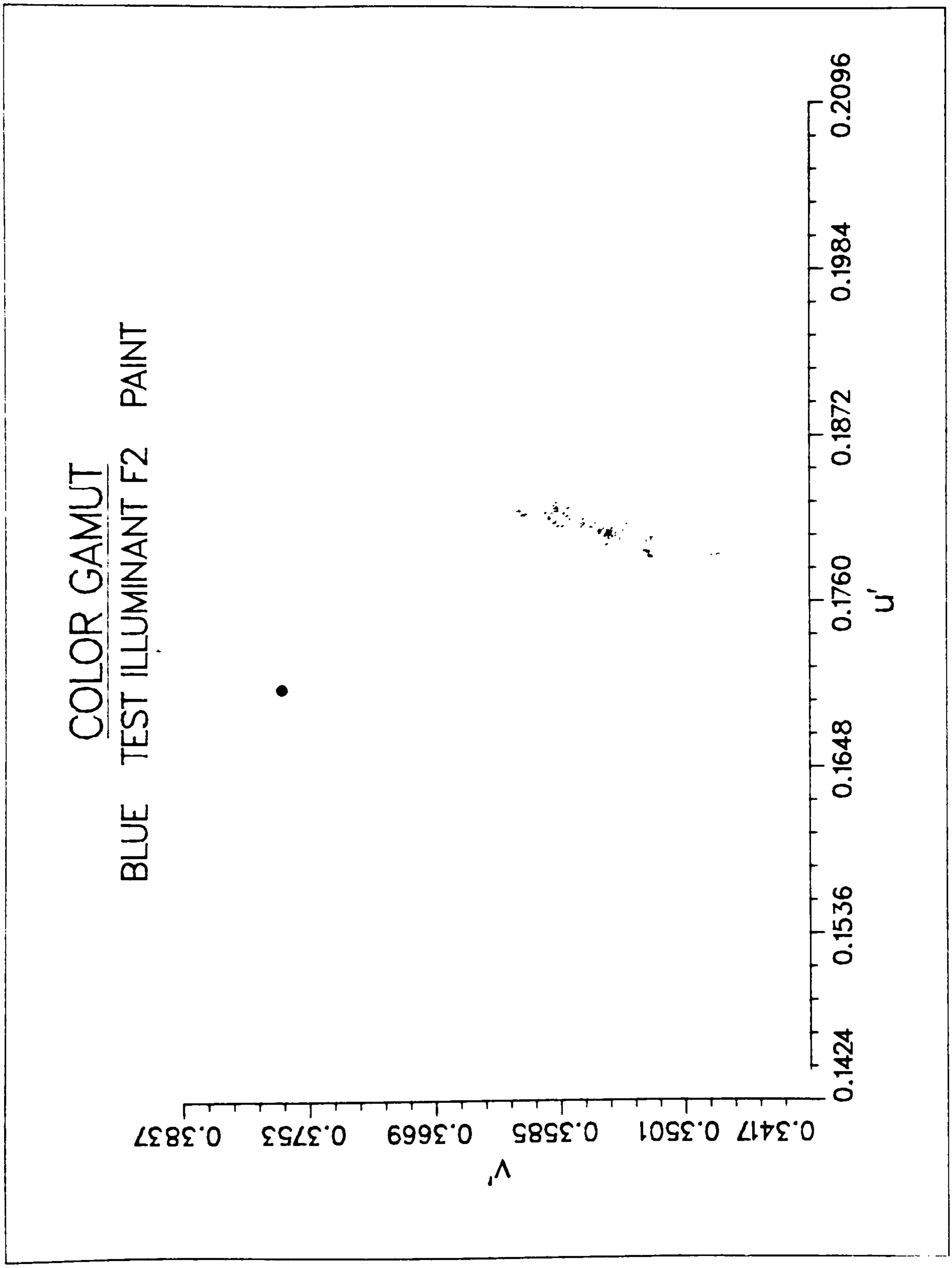
COLOR	MATCHES	TEST ILLUMINANT	MIN Y	MAX Y	DELTA Y
BLUE	1049	F2	7.6707	7.8165	0.1458
		F11	7.6795	7.9495	0.2700
		ILLA	7.5639	7.5889	0.0250
GRAY	11185	F2	28.2133	32.1690	3.9557
		F11	27.8750	30.8784	3.0034
		ILLA	29.9113	30.1103	0.1990
GREEN	2644	F2	20.3231	21.7766	1.4535
		F11	20.8099	22.6530	1.8431
		ILLA	20.7214	20.7932	0.0718
RED	3629	F2	13.6505	16.4511	2.8006
		F11	14.3017	16.8397	2.5380
		ILLA	18.2373	18.5234	0.2861
YELLOW	729	F2	70.4046	74.0443	3.6397
		F11	69.5727	74.3726	4.7999
		ILLA	72.7969	72.9352	0.1383

Table 4. Maximum and Minimum Color Constancy and Metameric Indices for Paint Matches

COLOR	TEST ILL.	MIN CCI	MAX CCI	MIN MI	MAX MI
BLUE	F2	8.8185	11.8345	0.1693	3.8426
	F11	8.2544	10.4048	0.2302	2.4374
	ILLA	3.8188	9.9222	0.1433	7.5028
GRAY	F2	0.2178	3.7676	0.0425	3.7641
	F11	0.2471	6.3108	0.0368	6.2948
	ILLA	0.4839	9.5972	0.3875	9.2213
GREEN	F2	3.7693	9.2136	0.0610	5.7943
	F11	2.2780	7.3697	0.0999	6.3867
	ILLA	8.3223	13.8608	0.0878	8.5521
RED	F2	5.3895	11.2107	0.2027	6.1210
	F11	1.7268	9.1513	0.1631	8.7430
	ILLA	7.6435	14.8735	0.3580	11.6680
YELLOW	F2	7.9264	9.1619	0.0341	1.5734
	F11	7.9630	11.9756	0.0113	4.5270
	ILLA	4.5215	8.4406	0.0252	4.0937

Table 5. Maximum and Minimum Color Constancy and Metameric Indices for ABS Polymer Matches

COLOR	TEST ILL.	MIN CCI	MAX CCI	MIN MI	MAX MI
BLUE	F2	9.1780	10.6897	0.2319	1.8109
	F11	8.4835	10.6857	0.1987	2.3310
	ILLA	4.8380	7.1484	0.1410	2.6857
GRAY	F2	0.1045	5.8544	0.0616	5.7773
	F11	0.1278	8.0275	0.0363	8.0744
	ILLA	0.3715	9.7247	0.0286	9.7838
GREEN	F2	4.1522	11.1965	0.5143	7.9628
	F11	1.9741	10.3161	0.1496	10.0726
	ILLA	7.8566	11.9200	0.0446	8.4932
RED	F2	7.1708	12.4081	0.0512	5.7209
	F11	0.7021	7.2305	0.5255	6.6962
	ILLA	8.0237	13.8288	0.0483	9.6441
YELLOW	F2	5.7060	12.0067	0.0443	7.0610
	F11	3.4214	14.0063	0.5515	10.6628
	ILLA	1.7894	9.0637	0.2968	8.5630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0.1760
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v'
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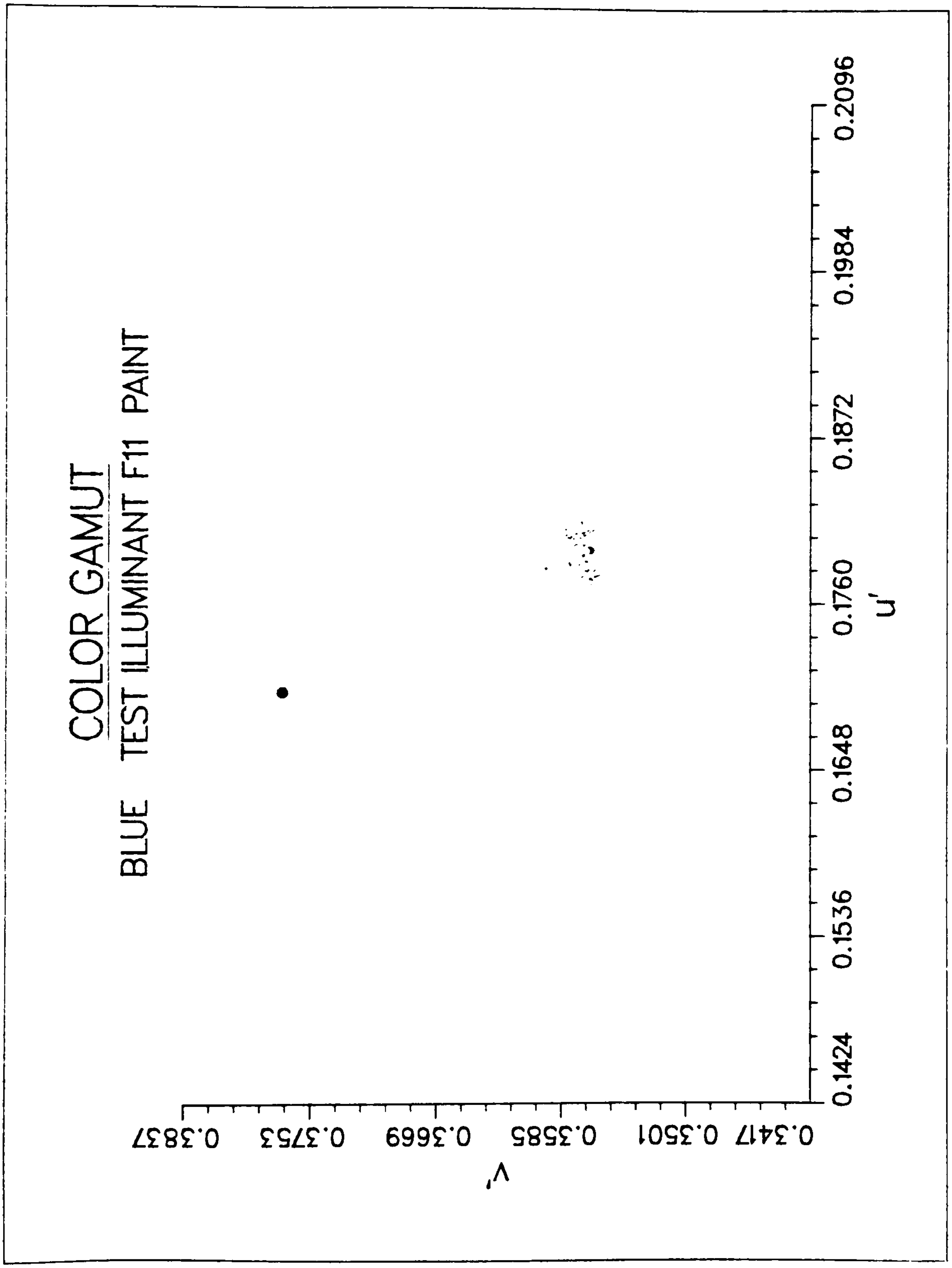
0.3669
0.3753
0.3837

FIGURE 1.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v'
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0.3501
0.3585
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0.3753
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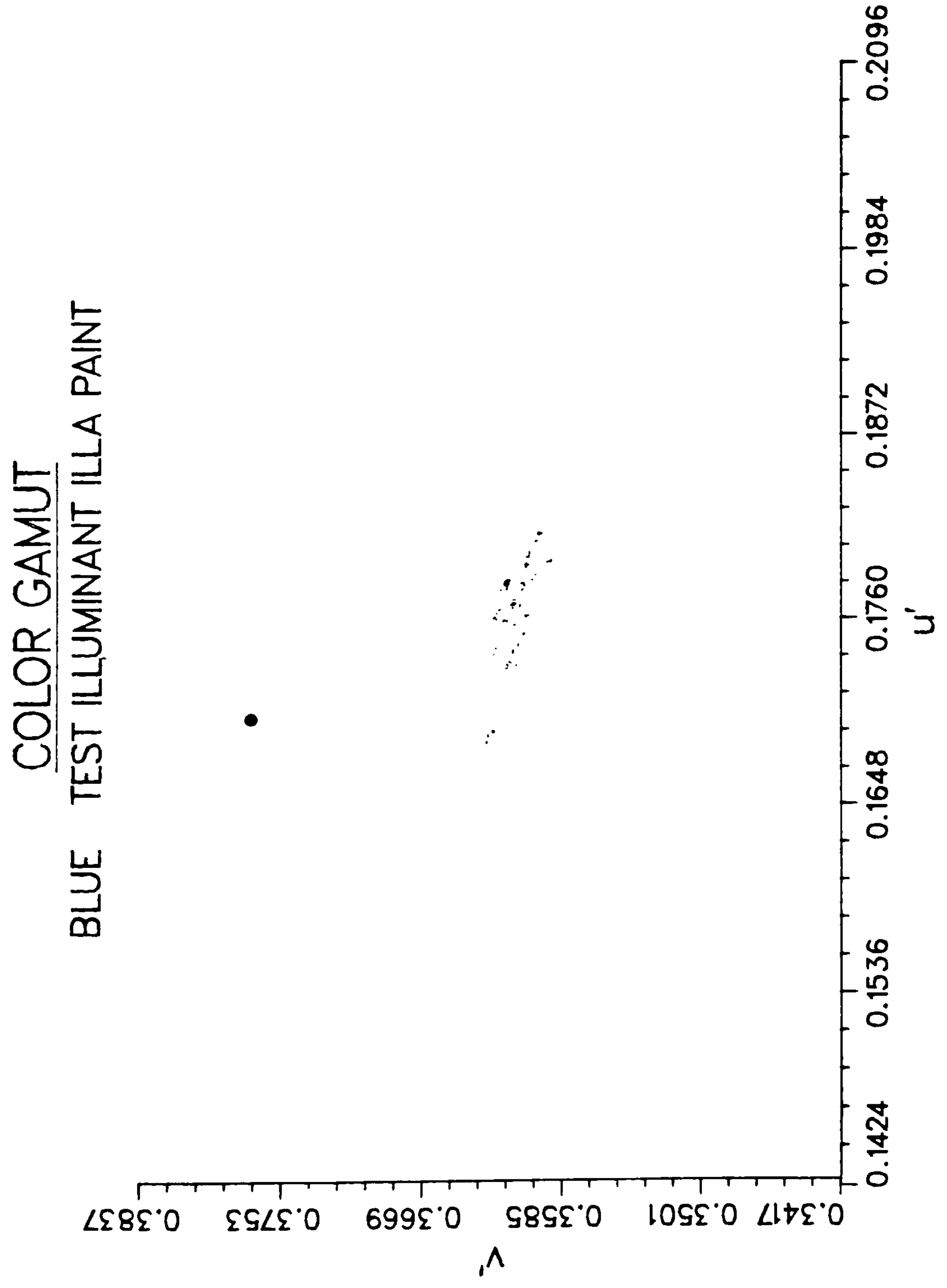
FIGURE 2.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BLUE TEST ILLUMINANT ILLA PAINT
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u'
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v'

FIGURE 3.

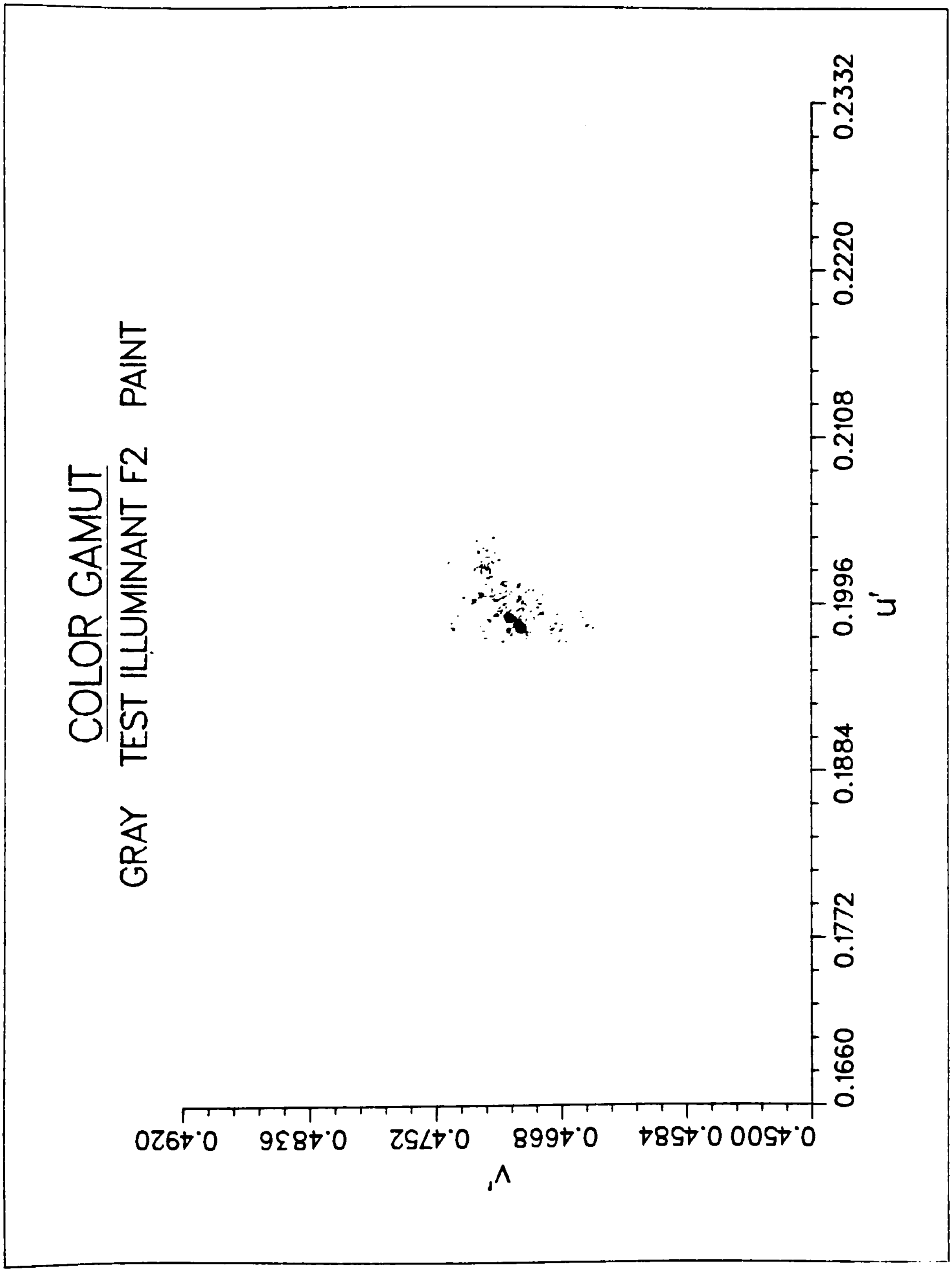
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FIGURE 4.

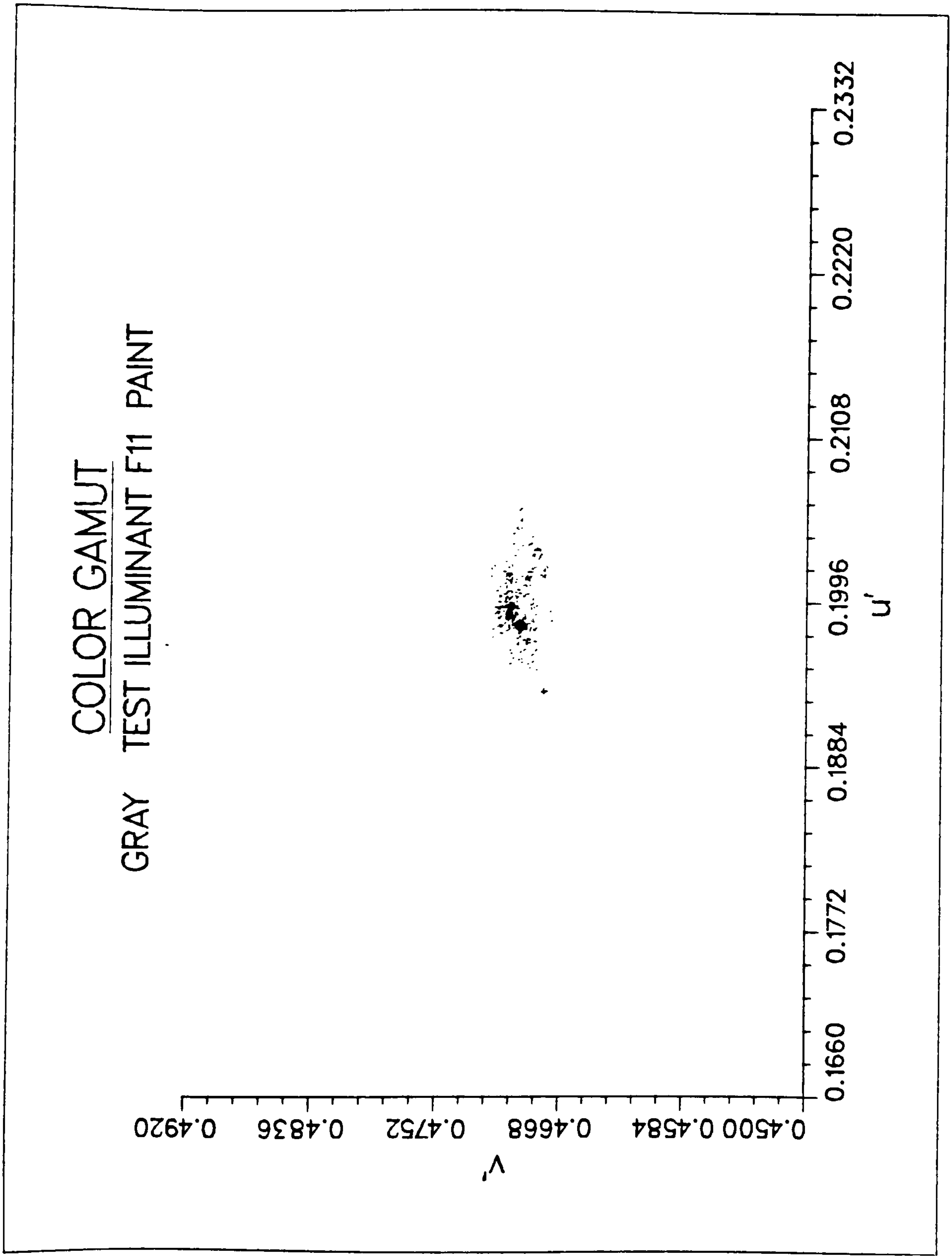
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FIGURE 5.

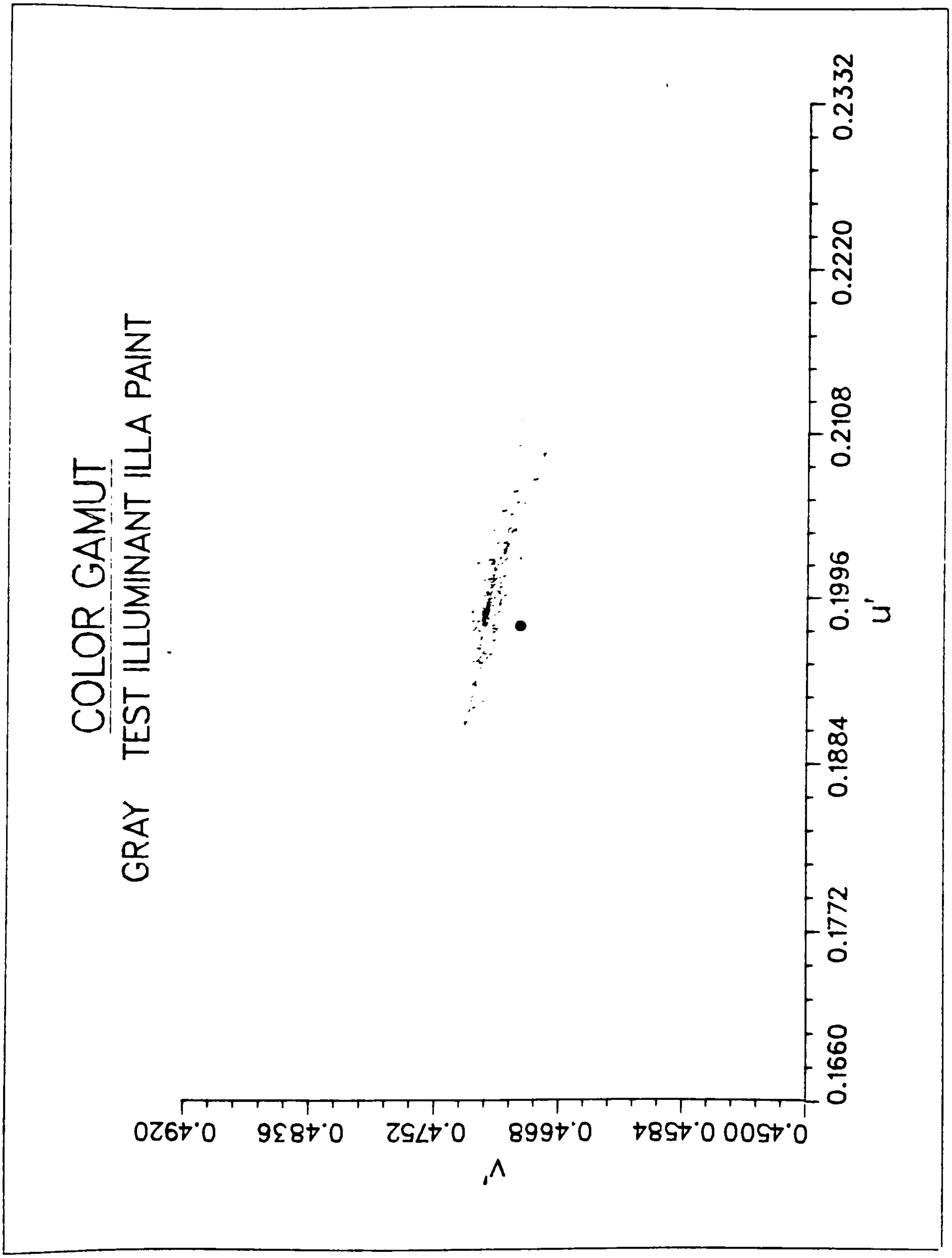
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FIGURE 6.

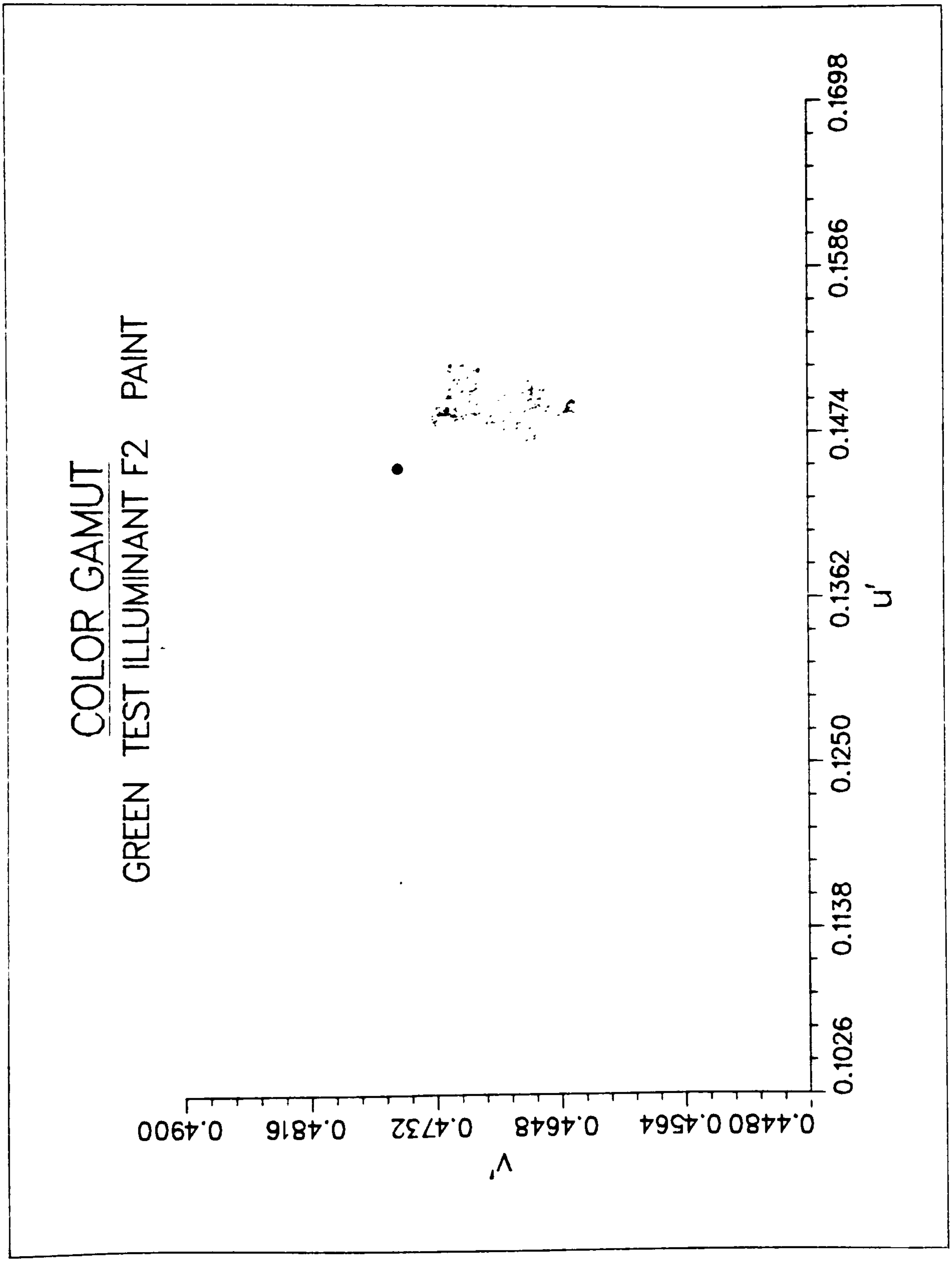
COLOR GAMUT
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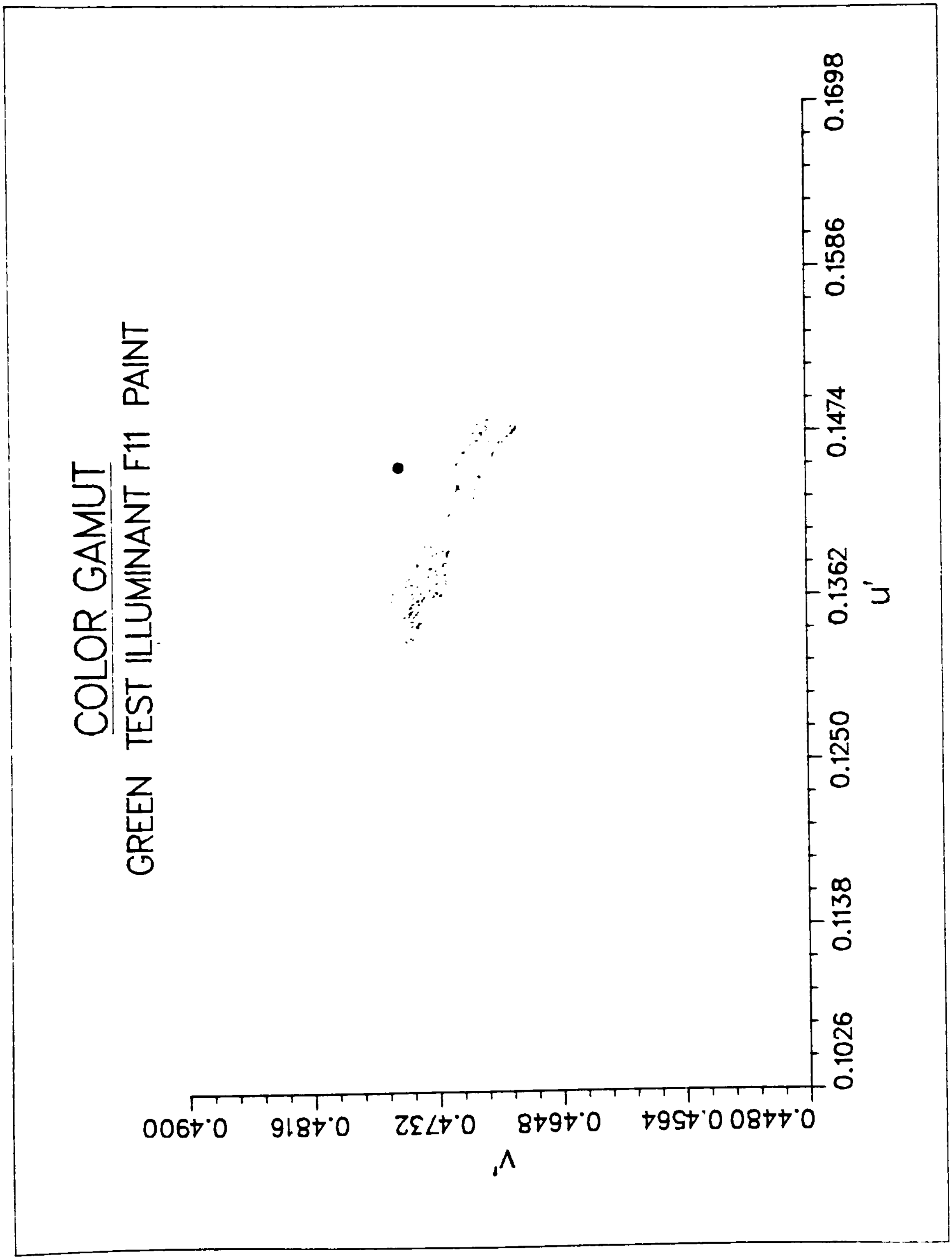
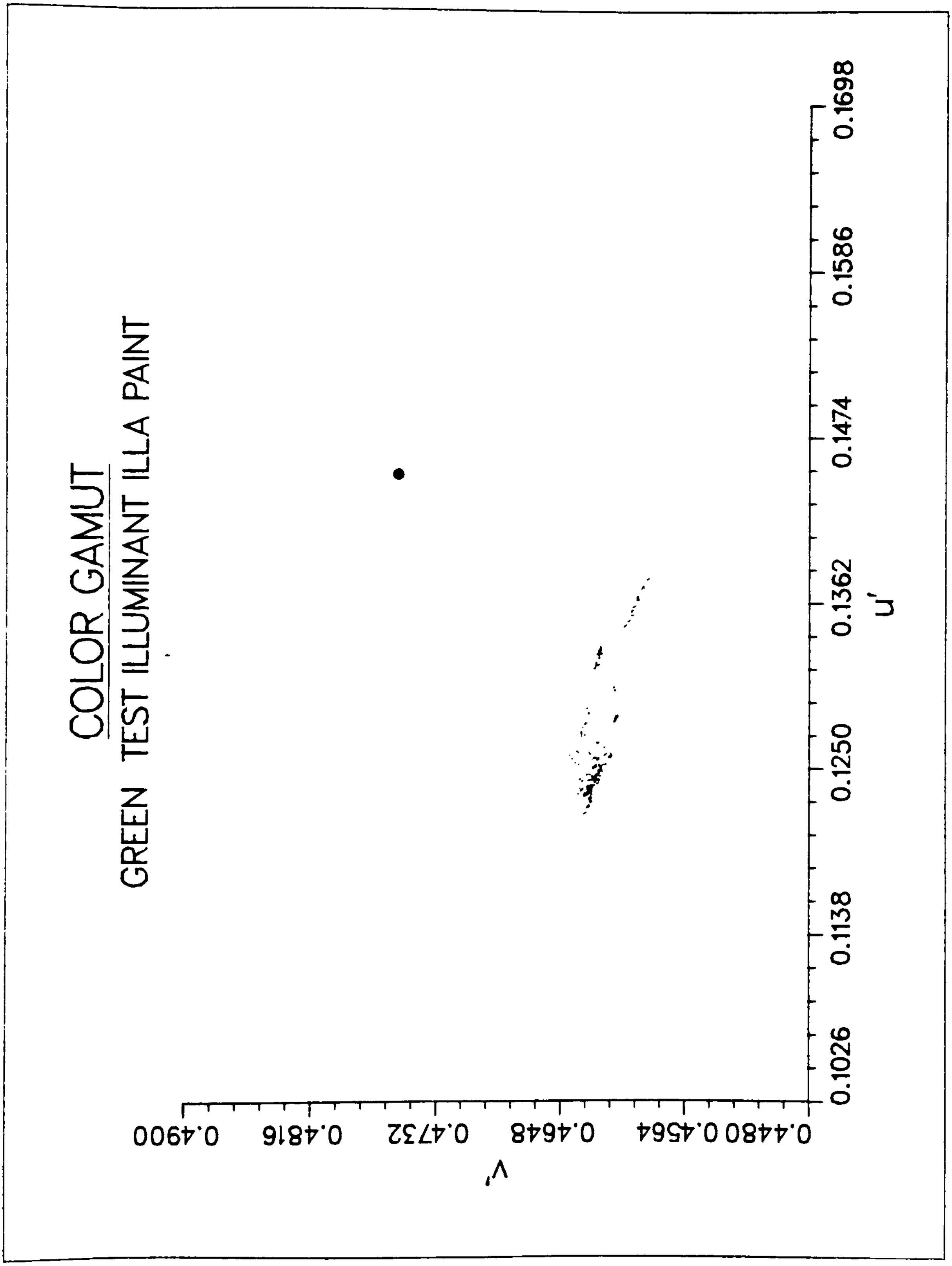
FIGURE 7.



COLOR GAMUT

GREEN TEST ILLUMINANT F11 PAINT

FIGURE 8.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0.4648
0.4564
0.4480
v'
0.1026
0.1138
0.1250
0.1362
0.1474
0.1586
0.1698
u'

FIGURE 9.

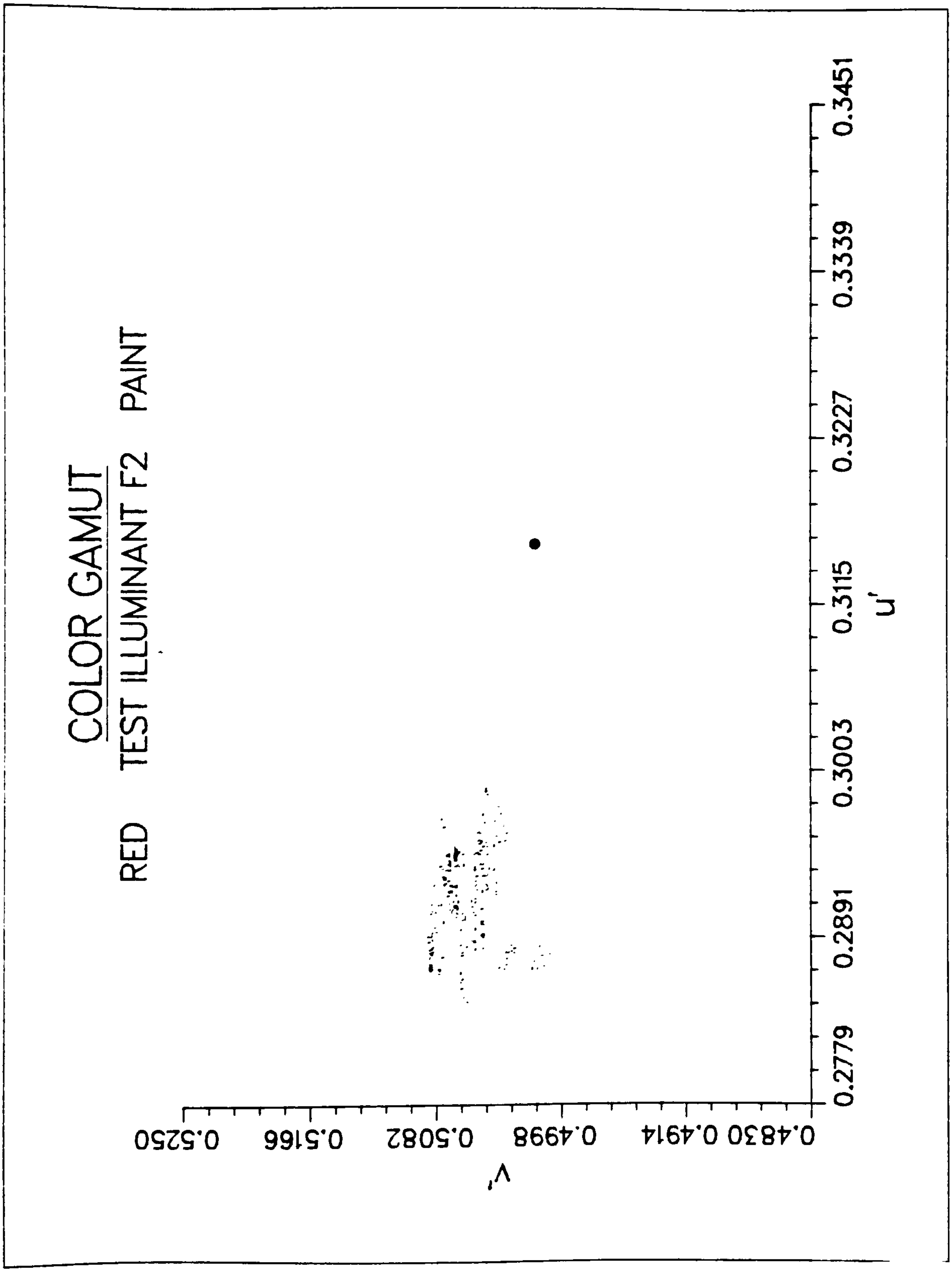
COLOR GAMUT
RED TEST ILLUMINANT F2 PAINT
u'
0.2779
0.2891
0.3003
0.3115
0.3227
0.3339
0.3451
v'
0.4830
0.4914
0.4998
0.5082
0.5166
0.5250

FIGURE 10.

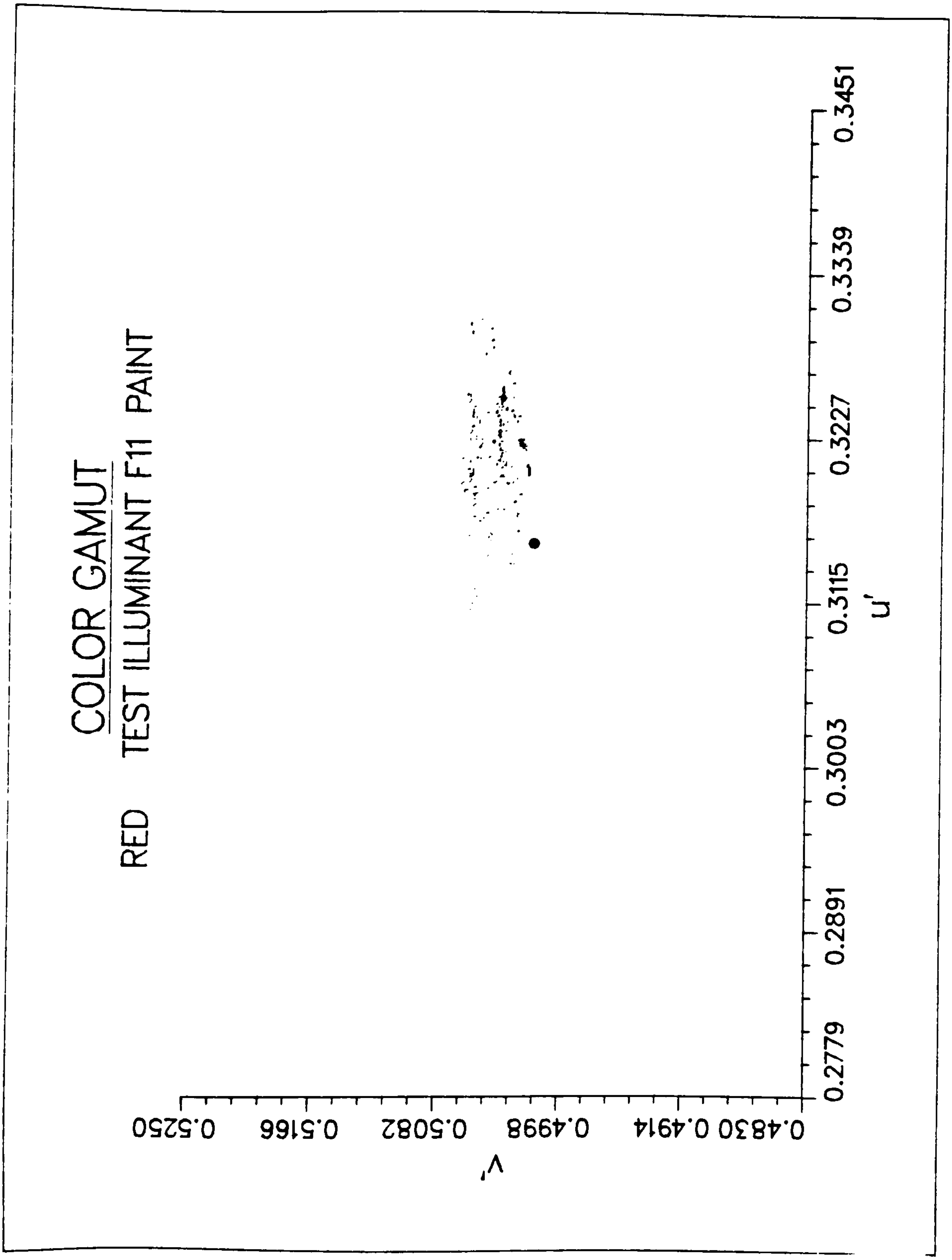
COLOR GAMUT
TEST ILLUMINANT F11 PAINT
RED
0.2779
0.2891
0.3003
0.3115
0.3227
0.3339
0.3451
u'
0.4830
0.4914
0.4998
0.5082
0.5166
0.5250
v'

FIGURE 11.

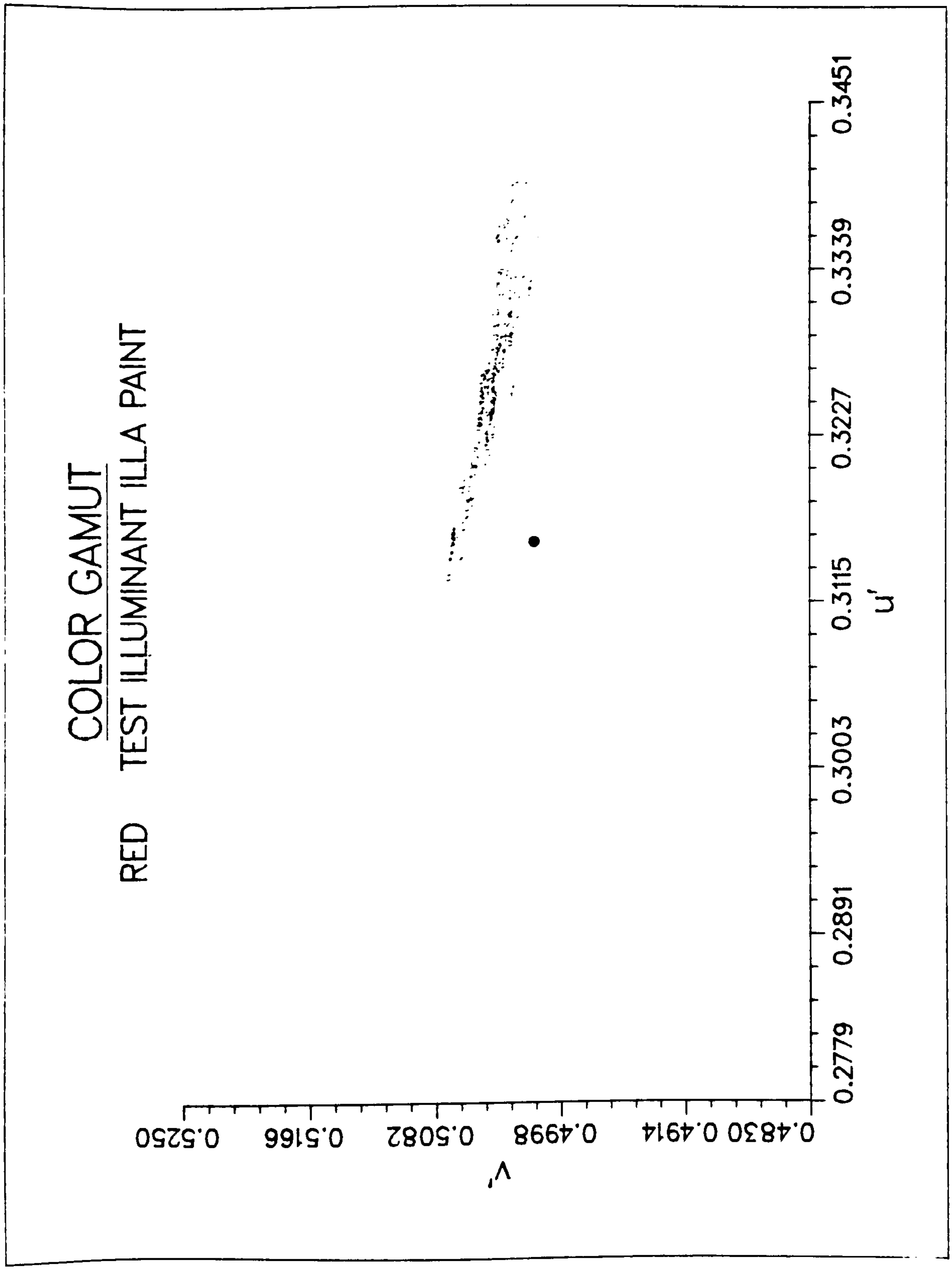
COLOR GAMUT
RED
TEST ILLUMINANT ILLA PAINT
u'
0.2779
0.2891
0.3003
0.3115
0.3227
0.3339
0.3451
v'
0.4830
0.4914
0.4998
0.5082
0.5166
0.5250

FIGURE 12.

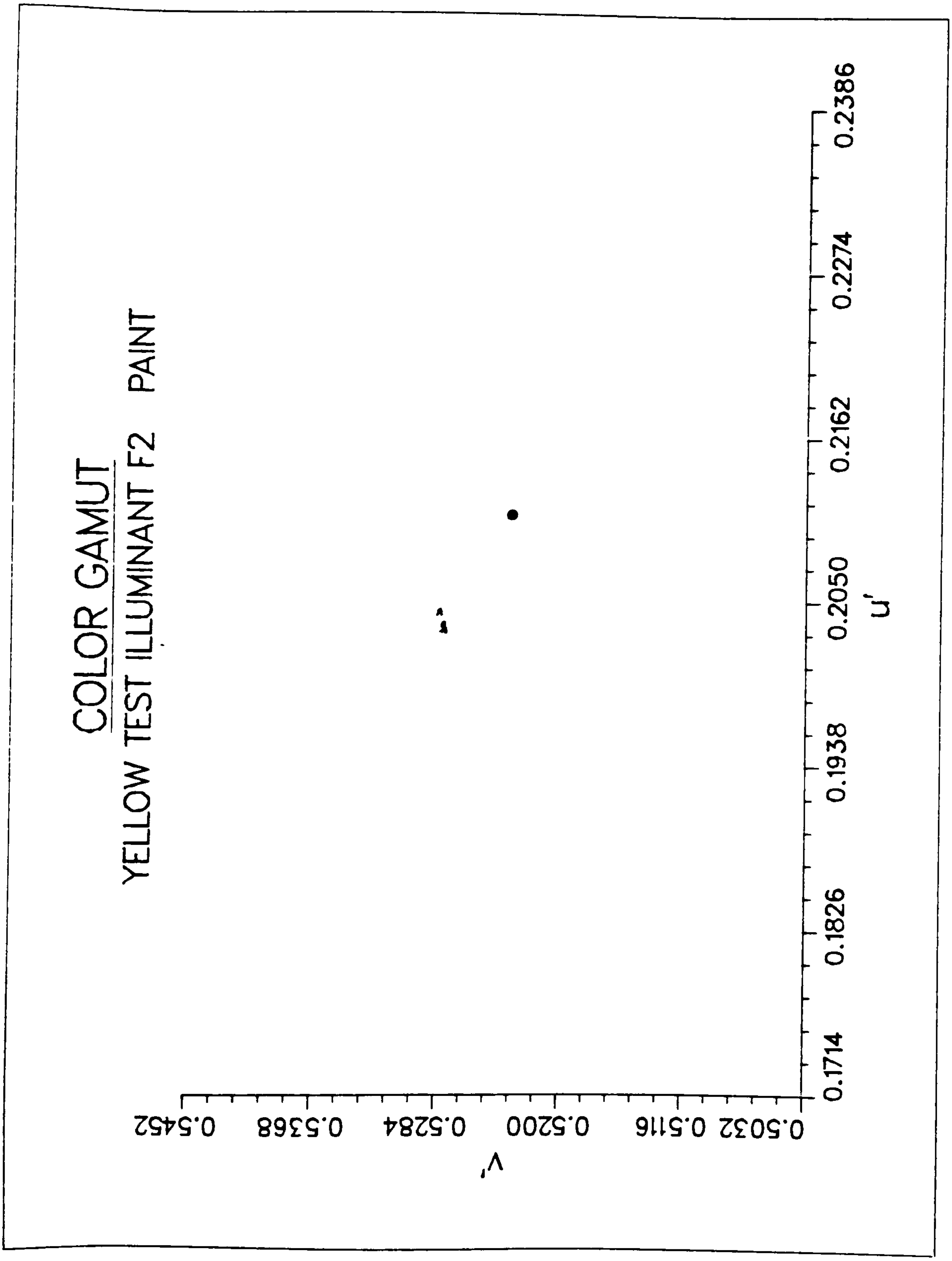
COLOR GAMUT
YELLOW TEST ILLUMINANT F2 PAINT
0.1714
0.1826
0.1938
0.2050
0.2162
0.2274
0.2386
u′
0.5032
0.5116
0.5200
0.5284
0.5368
0.5452
v′

FIGURE 13.

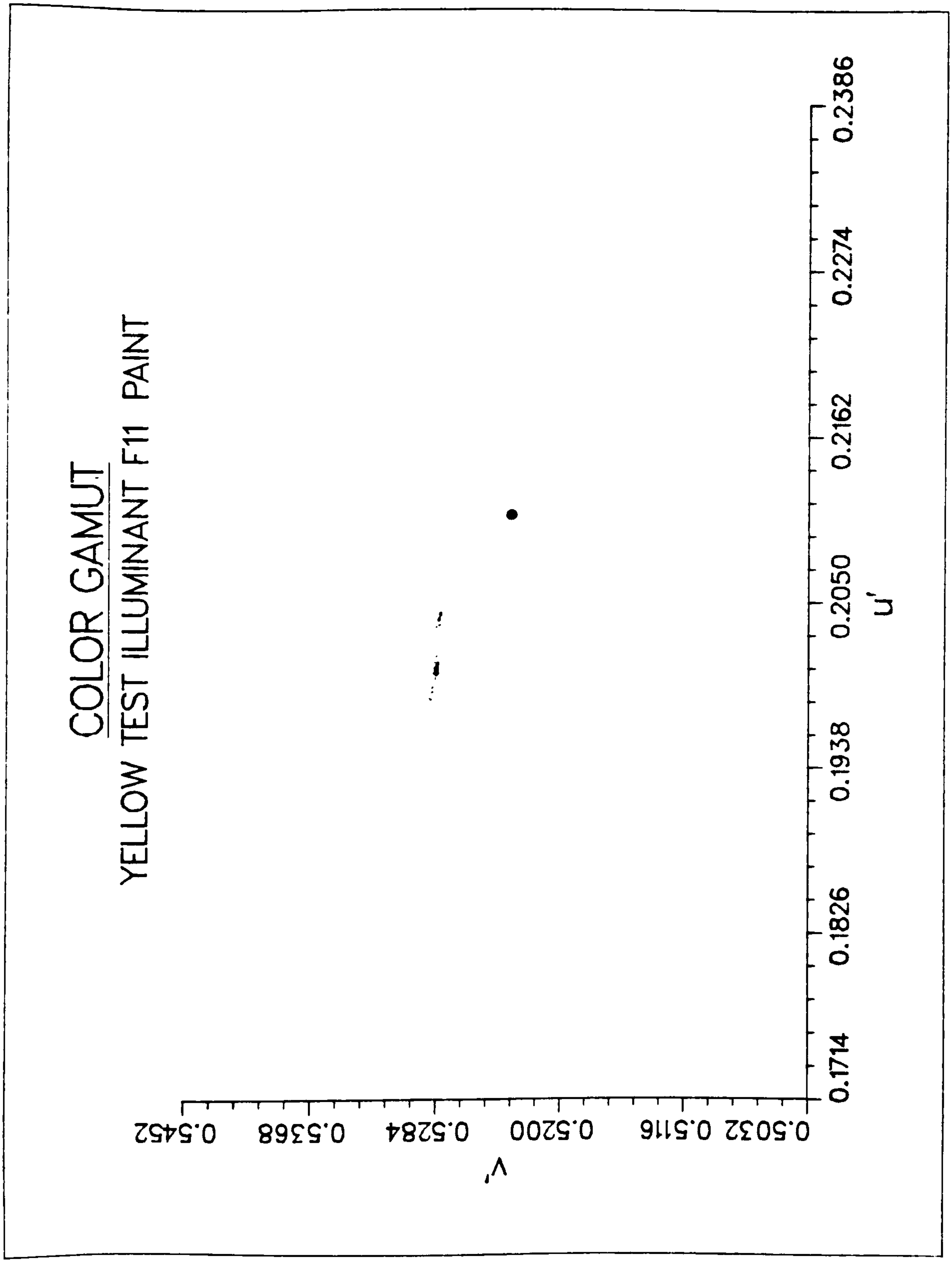
COLOR GAMUT
YELLOW TEST ILLUMINANT F11 PAINT
u'
0.1714
0.1826
0.1938
0.2050
0.2162
0.2274
0.2386
v'
0.5032
0.5116
0.5200
0.5284
0.5368
0.5452

FIGURE 14.

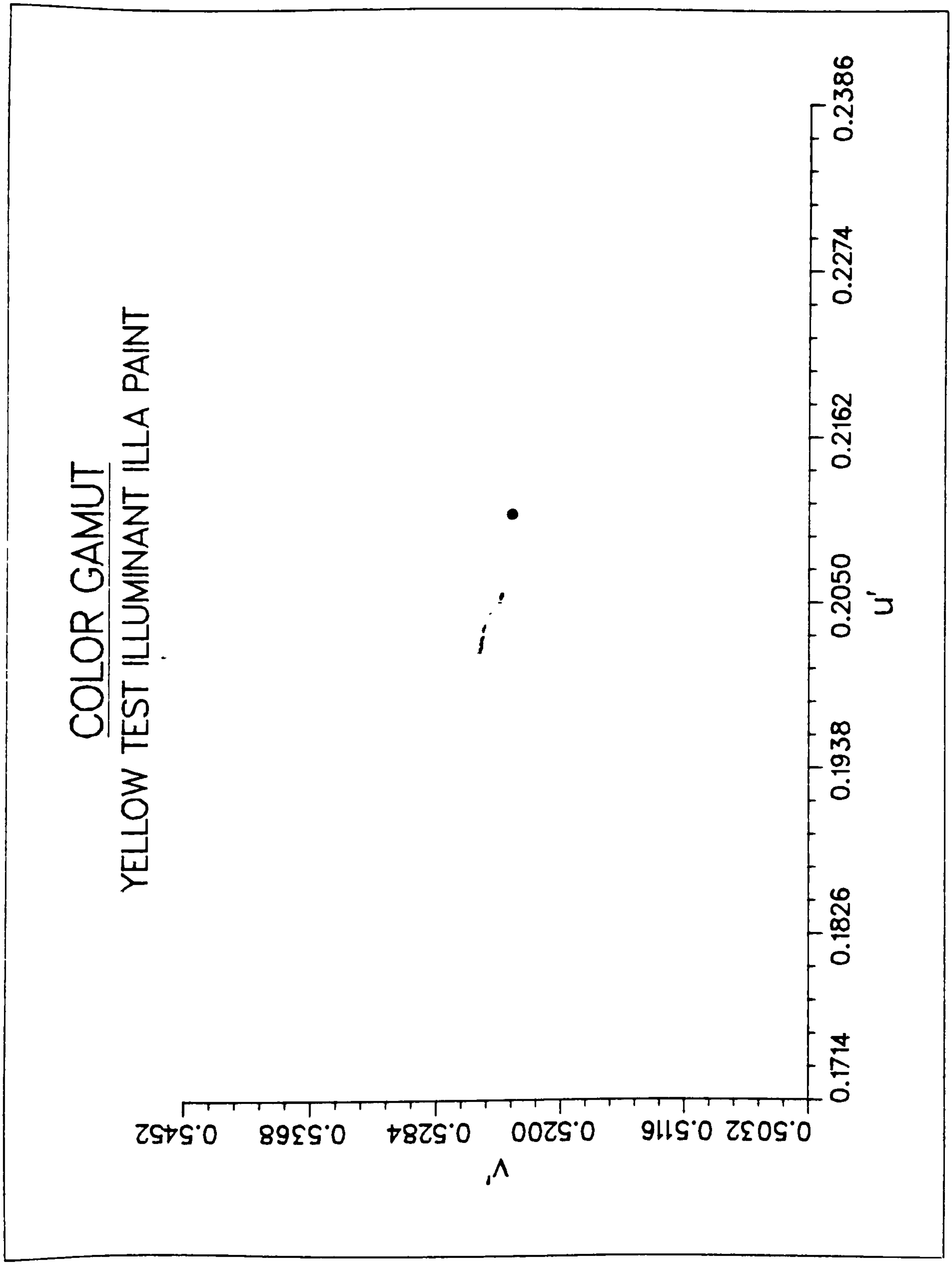
COLOR GAMUT
YELLOW TEST ILLUMINANT ILLA PAINT
u'
0.1714
0.1826
0.1938
0.2050
0.2162
0.2274
0.2386
v'
0.5032
0.5116
0.5200
0.5284
0.5368
0.5452

FIGURE 15.

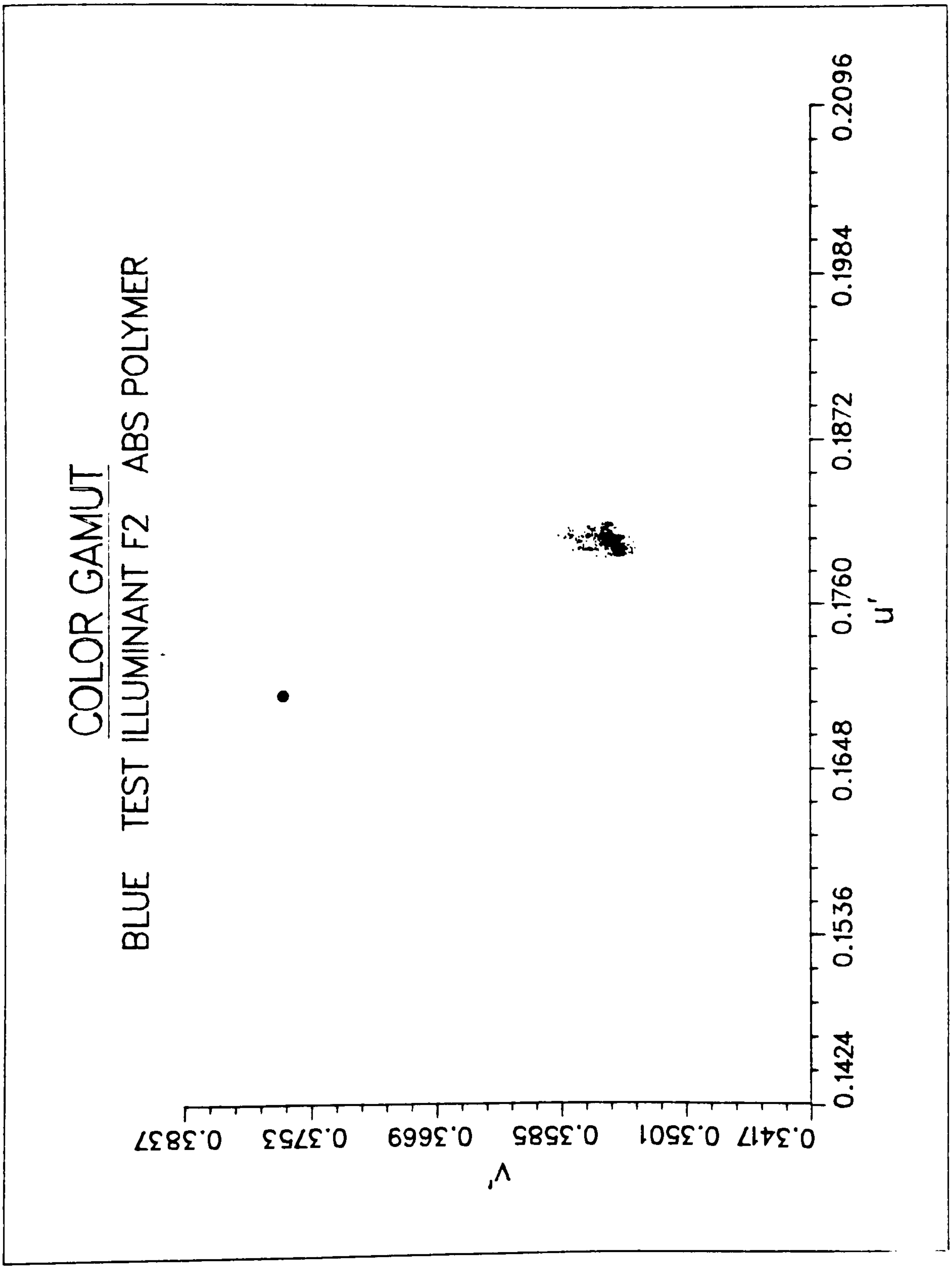
COLOR GAMUT
BLUE
TEST ILLUMINANT F2
ABS POLYMER
u'
0.1424
0.1536
0.1648
0.1760
0.1872
0.1984
0.2096
v'
0.3417
0.3501
0.3585
0.3669
0.3753
0.3837

FIGURE 16.

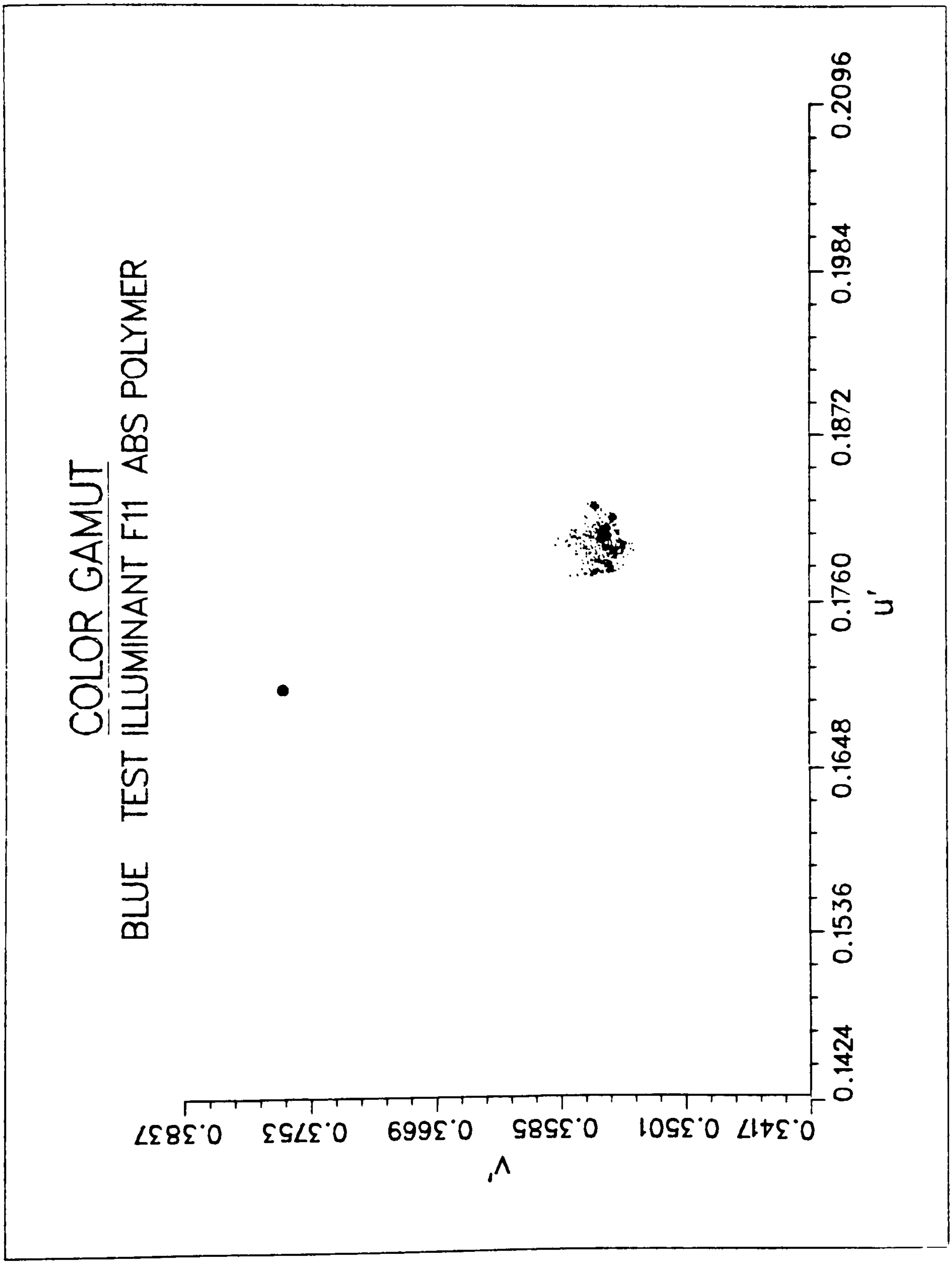
COLOR GAMUT
BLUE TEST ILLUMINANT F11 ABS POLYMER
u'
0.1424
0.1536
0.1648
0.1760
0.1872
0.1984
0.2096
v'
0.3417
0.3501
0.3585
0.3669
0.3753
0.3837

FIGURE 17.

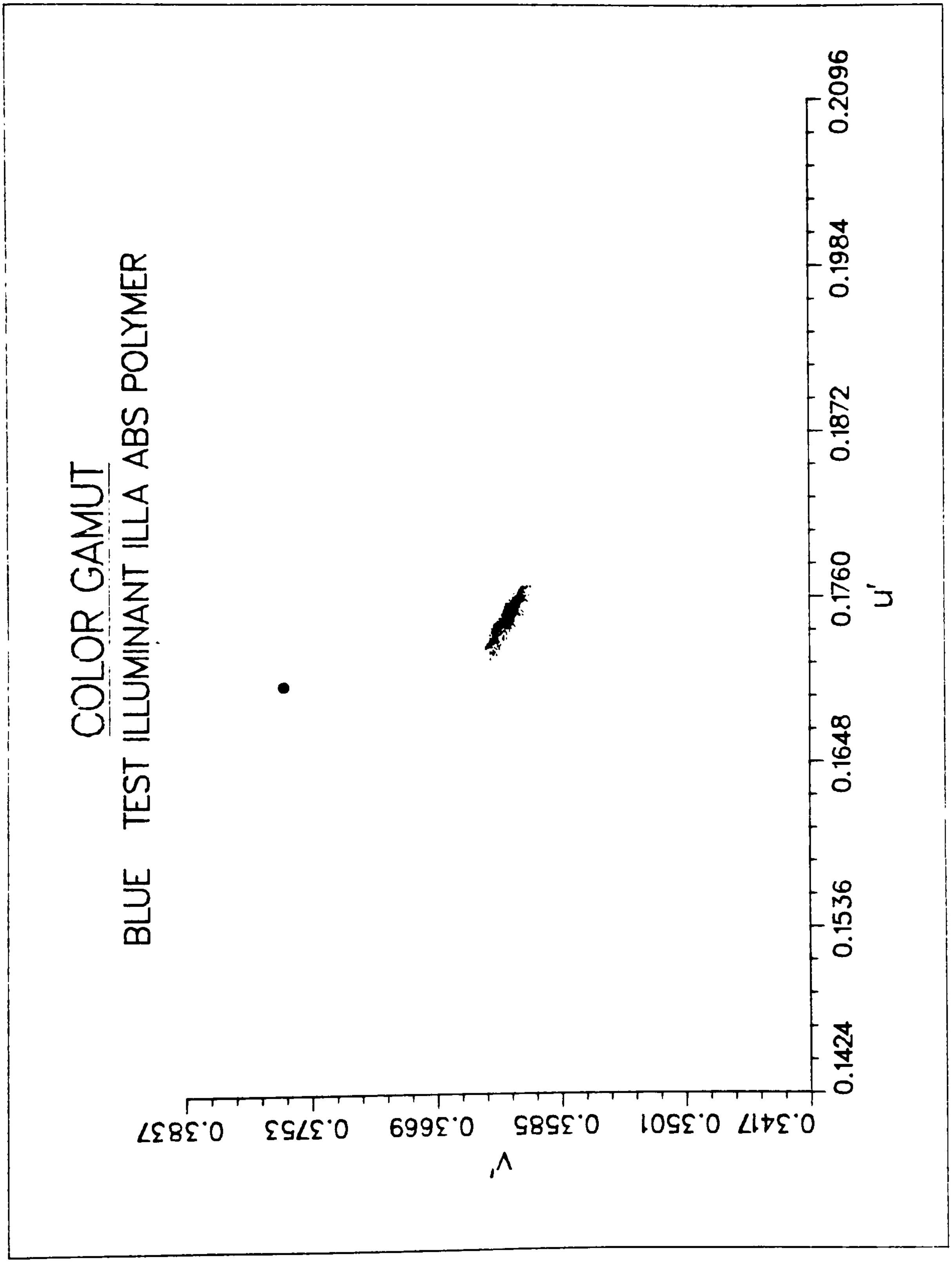
COLOR GAMUT
BLUE TEST ILLUMINANT ILLA ABS POLYMER
u'
0.1424
0.1536
0.1648
0.1760
0.1872
0.1984
0.2096
v'
0.3417
0.3501
0.3585
0.3669
0.3753
0.3837

FIGURE 18.

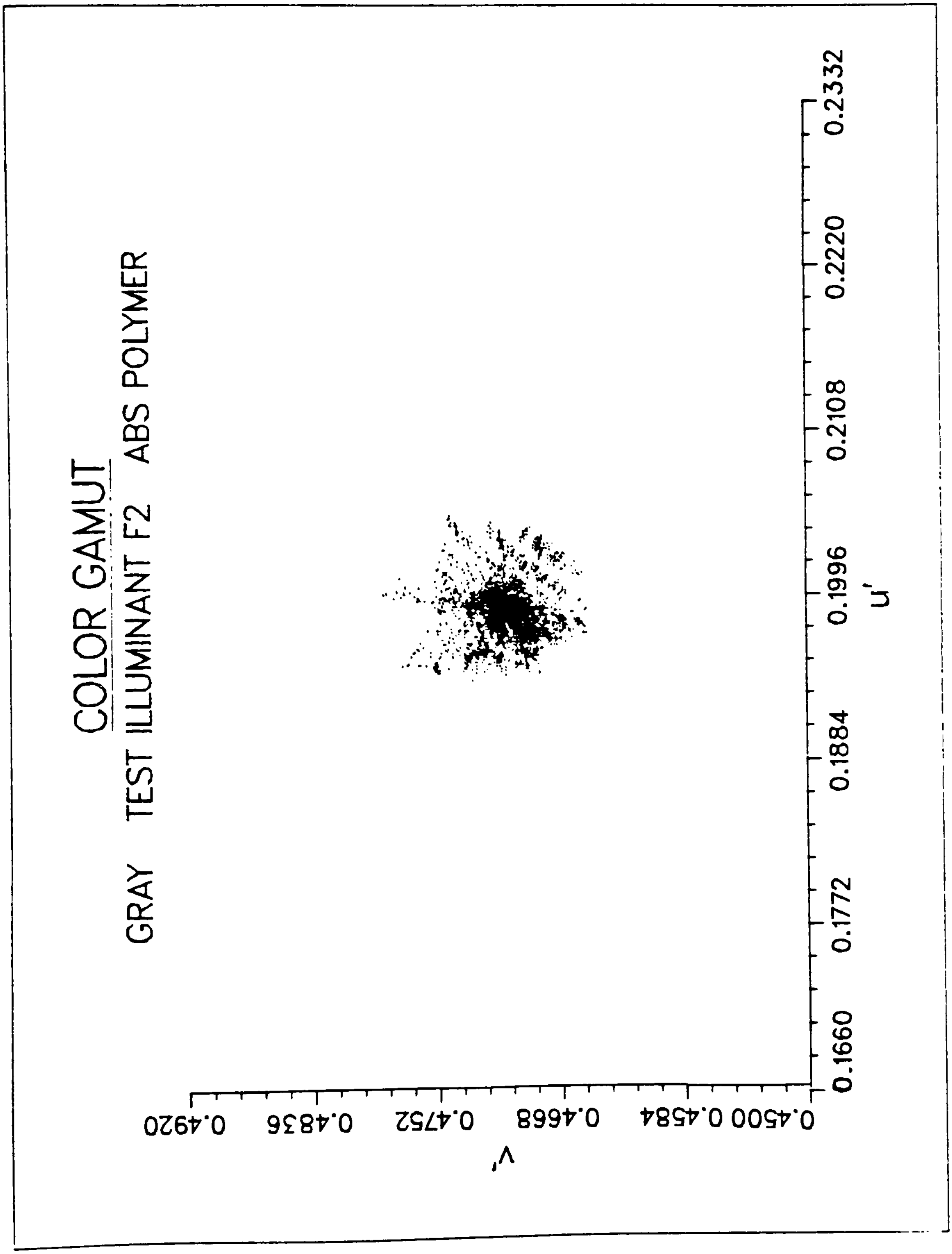
COLOR GAMUT
GRAY TEST ILLUMINANT F2 ABS POLYMER
u'
0.1660
0.1772
0.1884
0.1996
0.2108
0.2220
0.2332
v'
0.4500
0.4584
0.4668
0.4752
0.4836
0.4920

FIGURE 19.

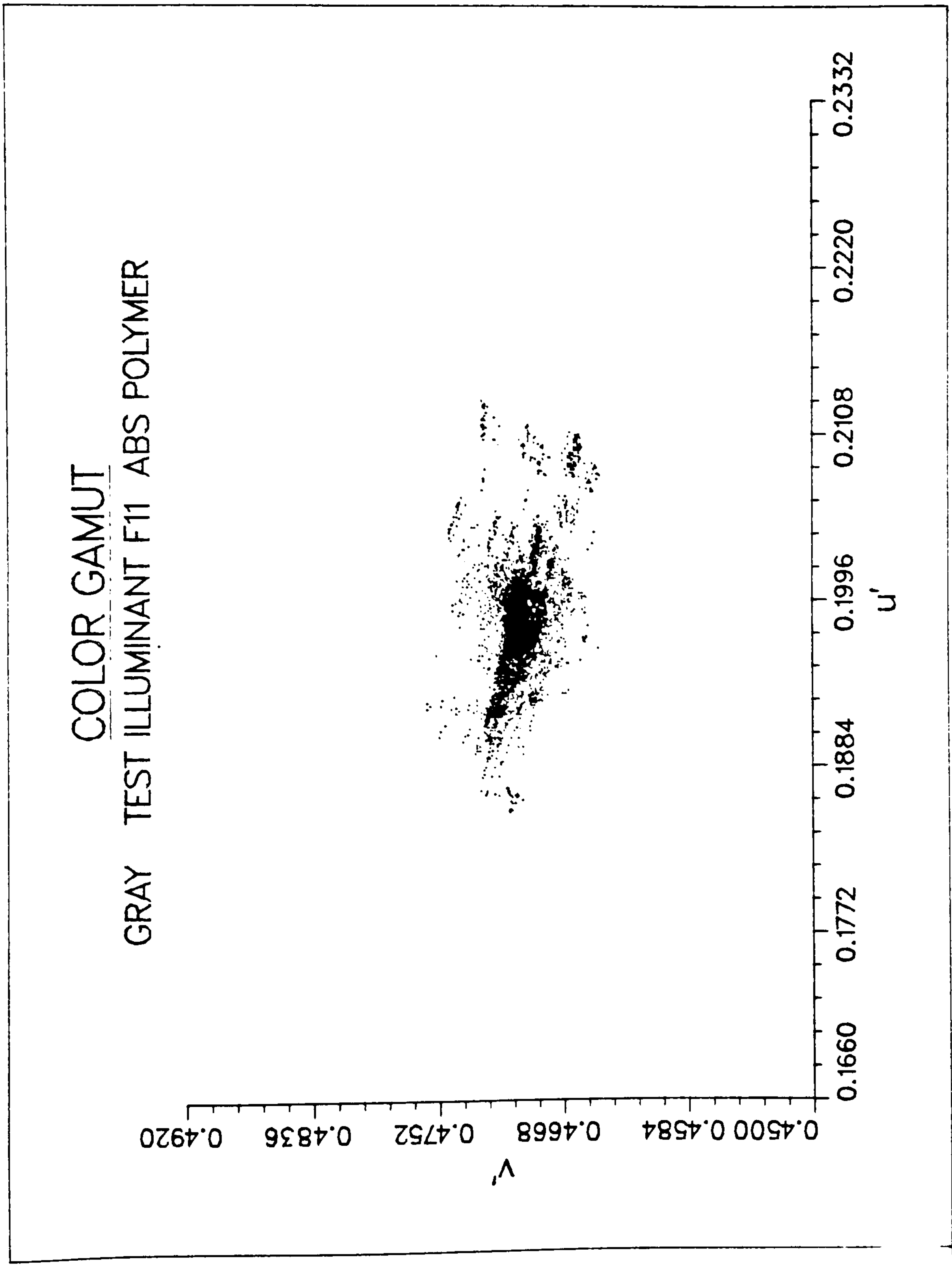
COLOR GAMUT
GRAY TEST ILLUMINANT F11 ABS POLYMER
u′
0.1660
0.1772
0.1884
0.1996
0.2108
0.2220
0.2332
v′
0.4500
0.4584
0.4668
0.4752
0.4836
0.4920

FIGURE 20.

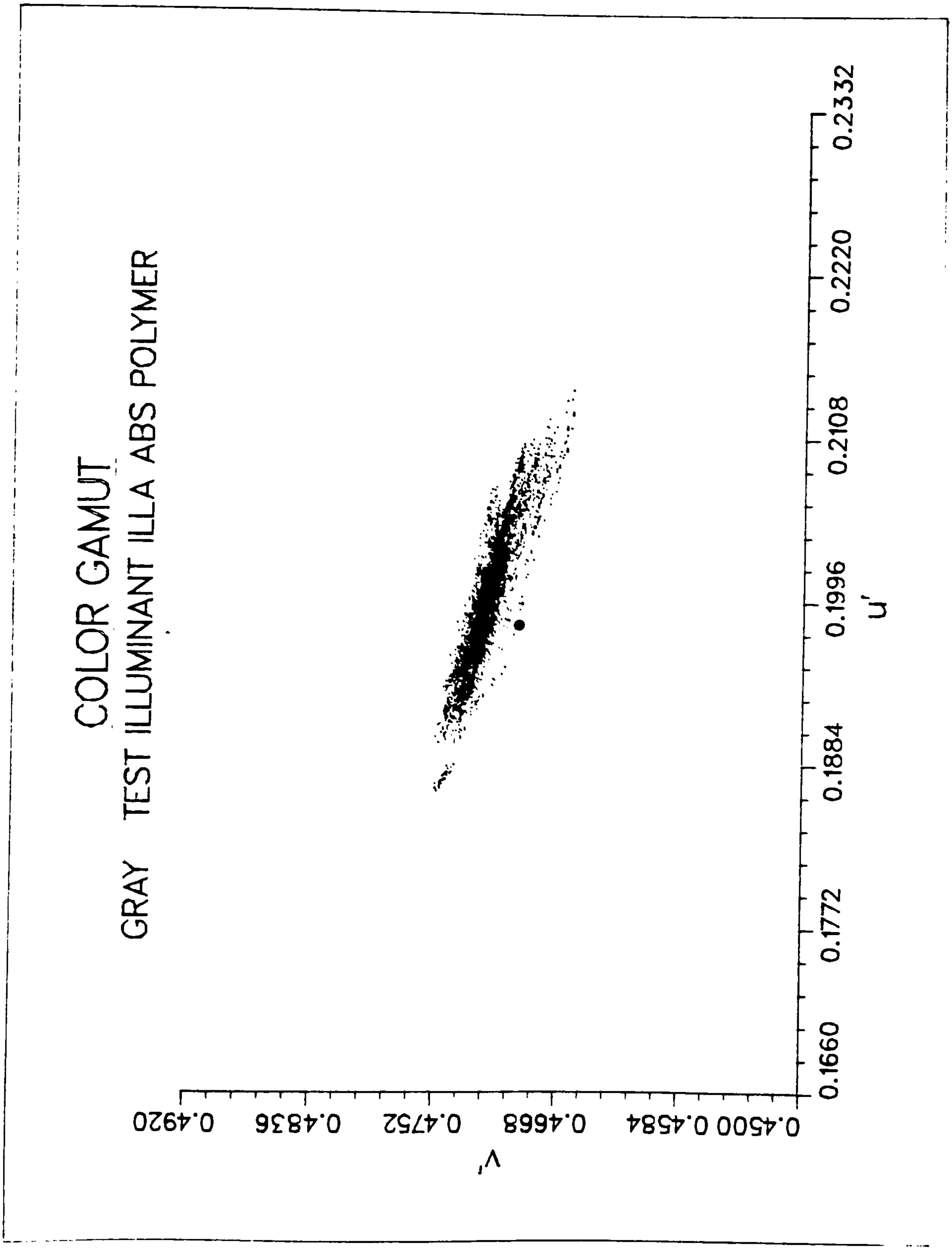
COLOR GAMUT
GRAY TEST ILLUMINANT ILLA ABS POLYMER
0.1660
0.1772
0.1884
0.1996
0.2108
0.2220
0.2332
u'
0.4500
0.4584
0.4668
0.4752
0.4836
0.4920
v'

FIGURE 21.

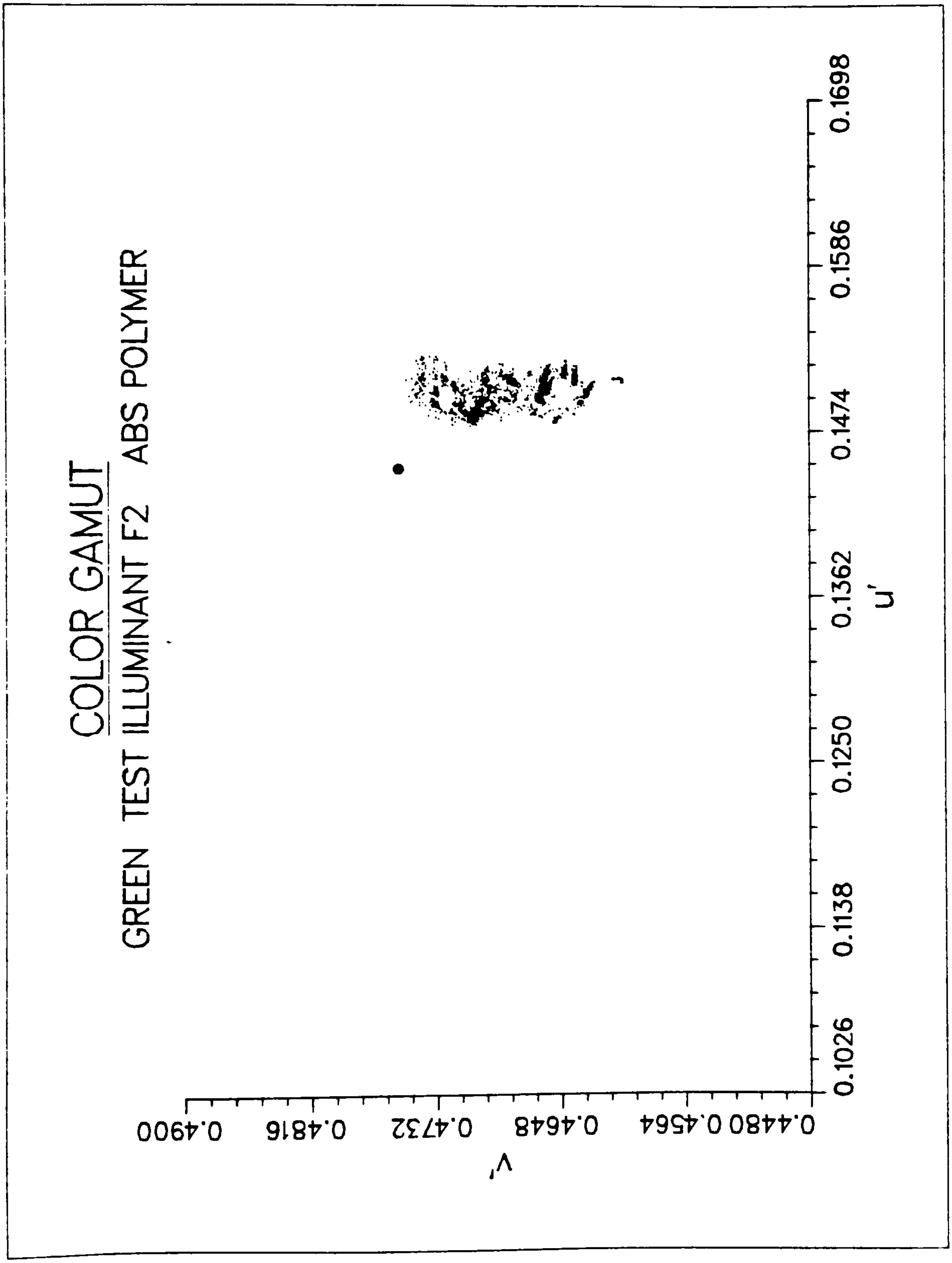
COLOR GAMUT
GREEN TEST ILLUMINANT F2 ABS POLYMER
u'
0.1026
0.1138
0.1250
0.1362
0.1474
0.1586
0.1698
v'
0.4480
0.4564
0.4648
0.4732
0.4816
0.4900

FIGURE 22.

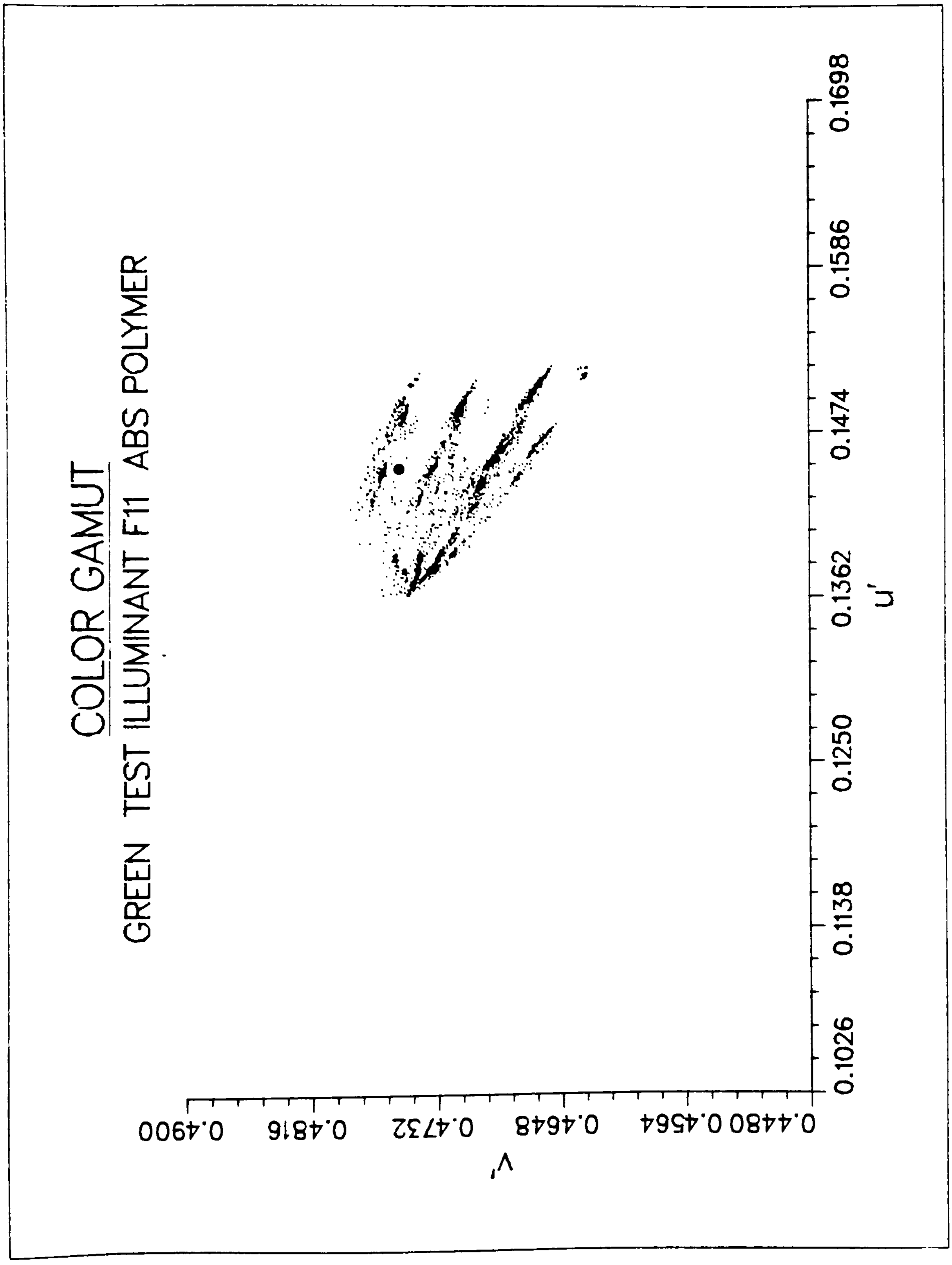
COLOR GAMUT
GREEN TEST ILLUMINANT F11 ABS POLYMER
0.1026
0.1138
0.1250
0.1362
0.1474
0.1586
0.1698
u'
0.4480
0.4564
0.4648
0.4732
0.4816
0.4900
v'

FIGURE 23.

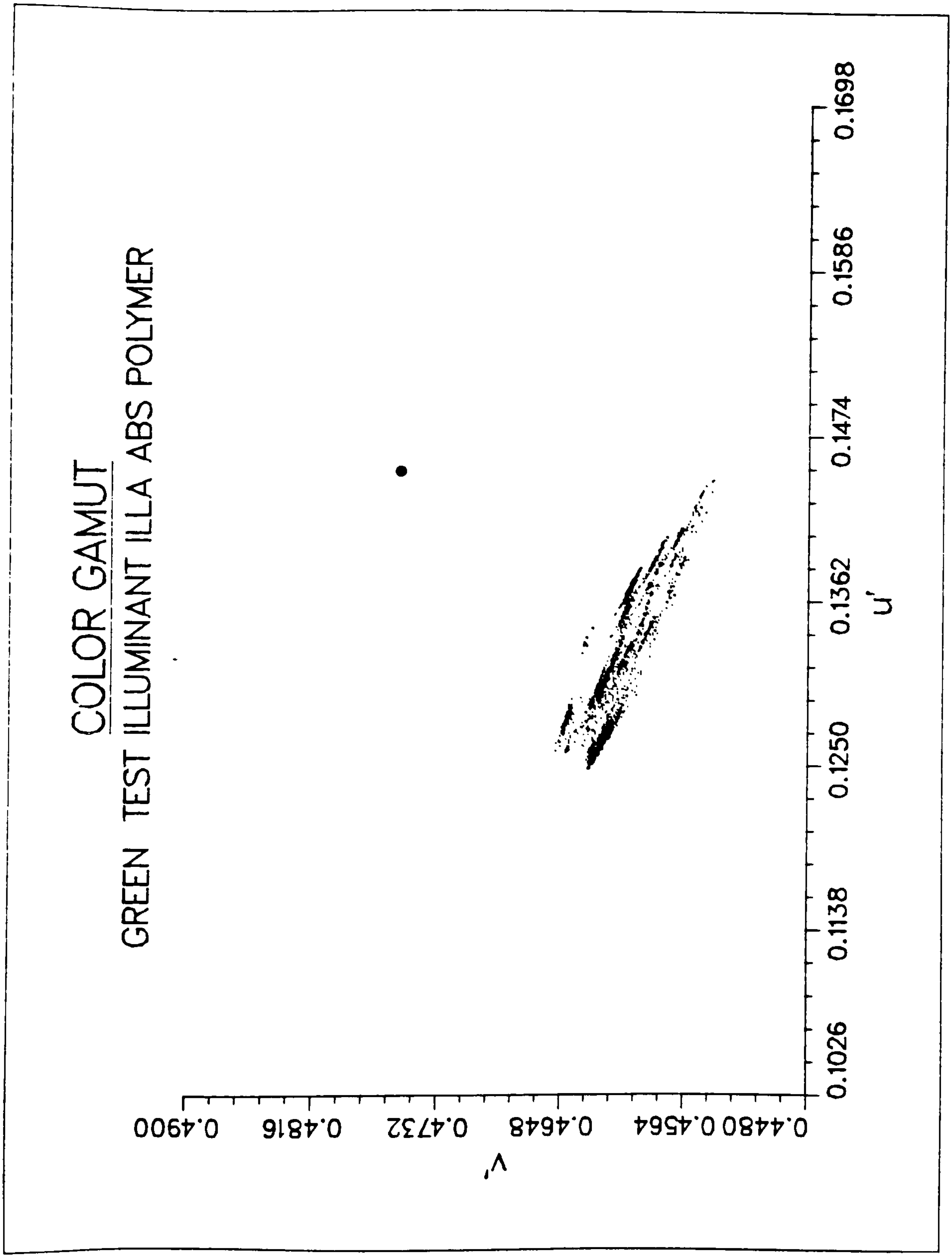
COLOR GAMUT
GREEN TEST ILLUMINANT ILLA ABS POLYMER
u'
0.1026
0.1138
0.1250
0.1362
0.1474
0.1586
0.1698
v'
0.4480
0.4564
0.4648
0.4732
0.4816
0.4900

FIGURE 24.

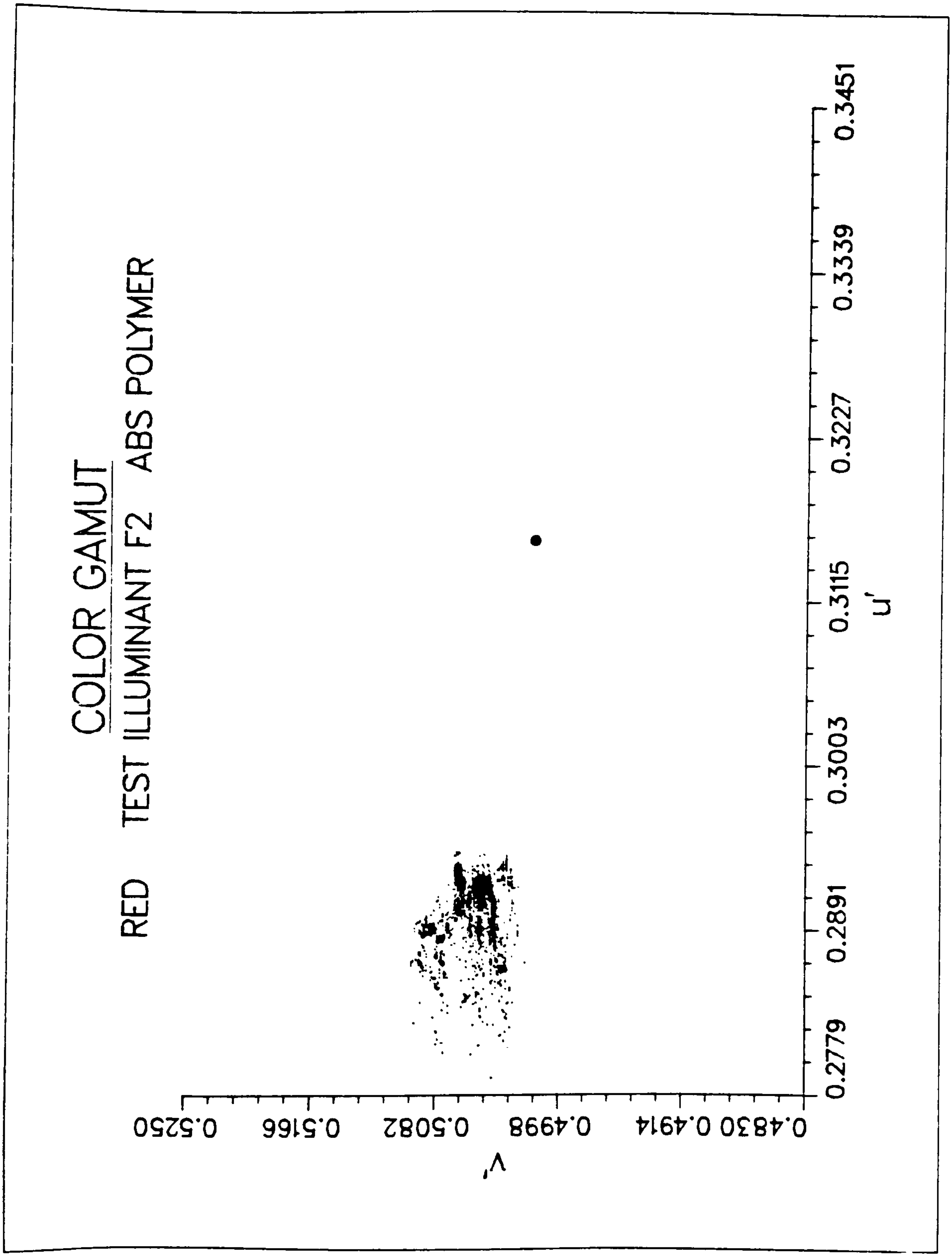
COLOR GAMUT
RED
TEST ILLUMINANT F2
ABS POLYMER
0.2779
0.2891
0.3003
0.3115
0.3227
0.3339
0.3451
u′
0.4830
0.4914
0.4998
0.5082
0.5166
0.5250
v′

FIGURE 25.

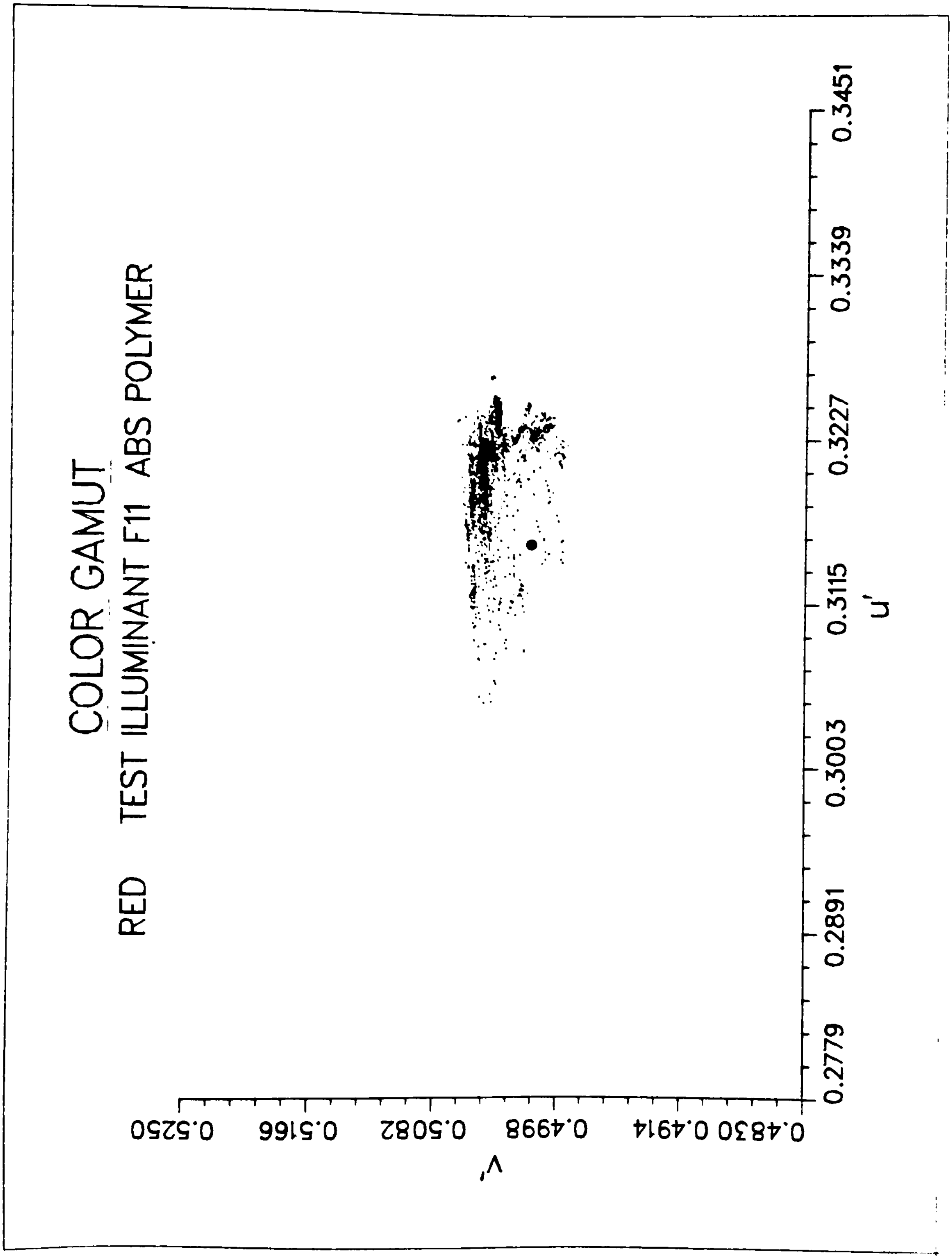
COLOR GAMUT
RED
TEST ILLUMINANT F11 ABS POLYMER
0.2779
0.2891
0.3003
0.3115
0.3227
0.3339
0.3451
u'
0.4830
0.4914
0.4998
0.5082
0.5166
0.5250
v'

FIGURE 26.

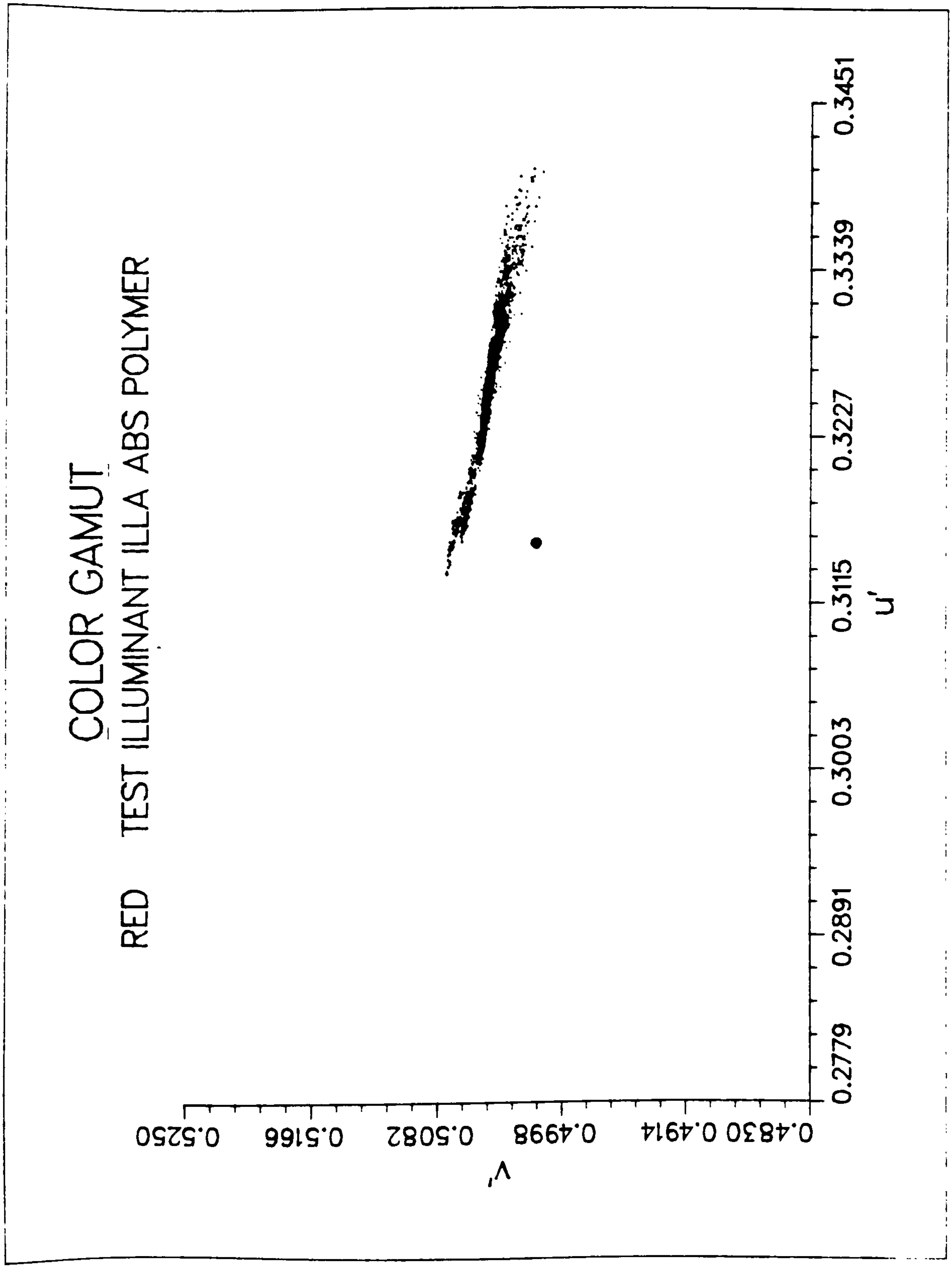
COLOR GAMUT
RED
TEST ILLUMINANT ILLA ABS POLYMER
u'
0.2779
0.2891
0.3003
0.3115
0.3227
0.3339
0.3451
v'
0.4830
0.4914
0.4998
0.5082
0.5166
0.5250

FIGURE 27.

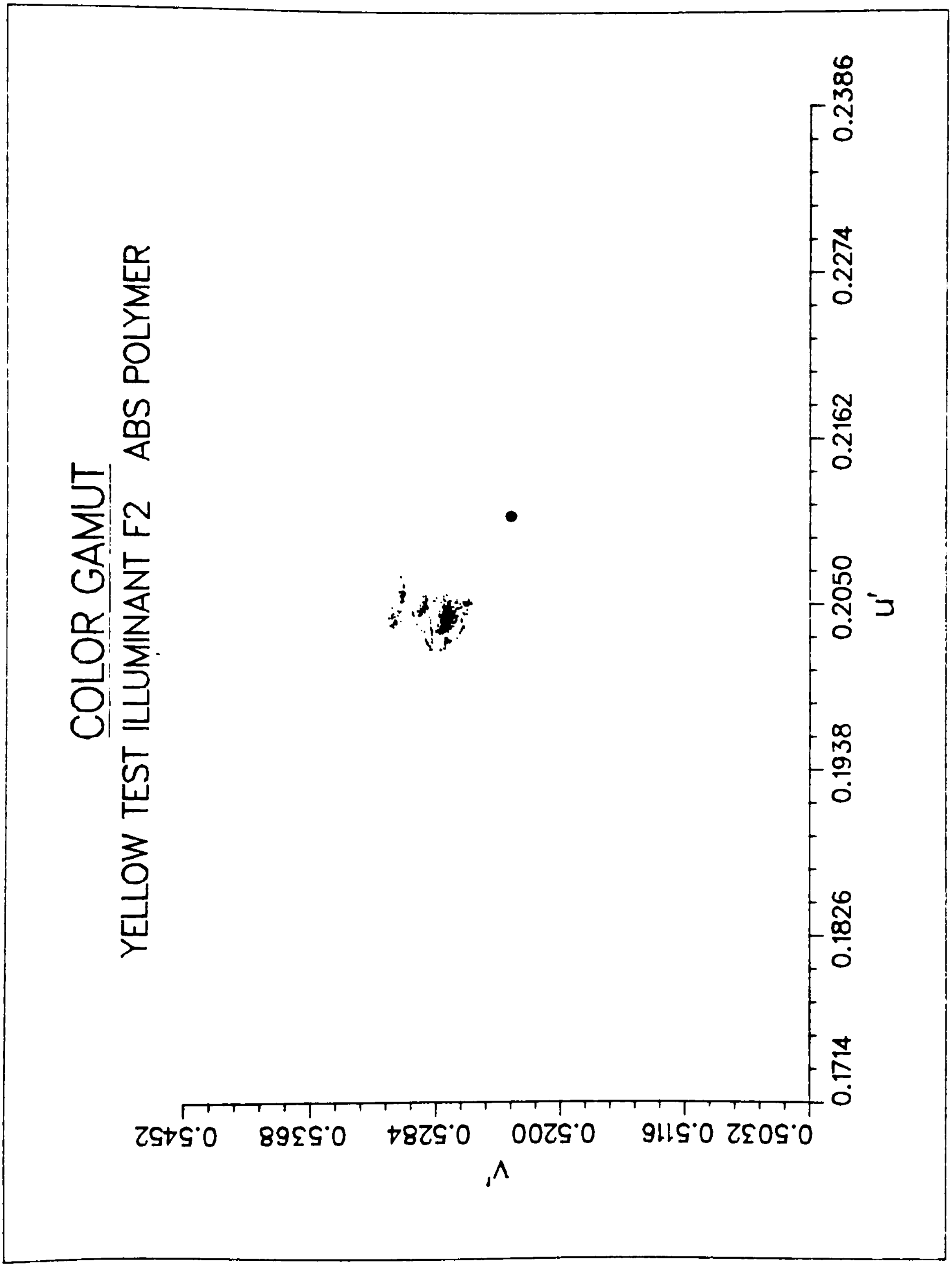
COLOR GAMUT
YELLOW TEST ILLUMINANT F2   ABS POLYMER
u'
0.1714
0.1826
0.1938
0.2050
0.2162
0.2274
0.2386
v'
0.5032
0.5116
0.5200
0.5284
0.5368
0.5452

FIGURE 28.

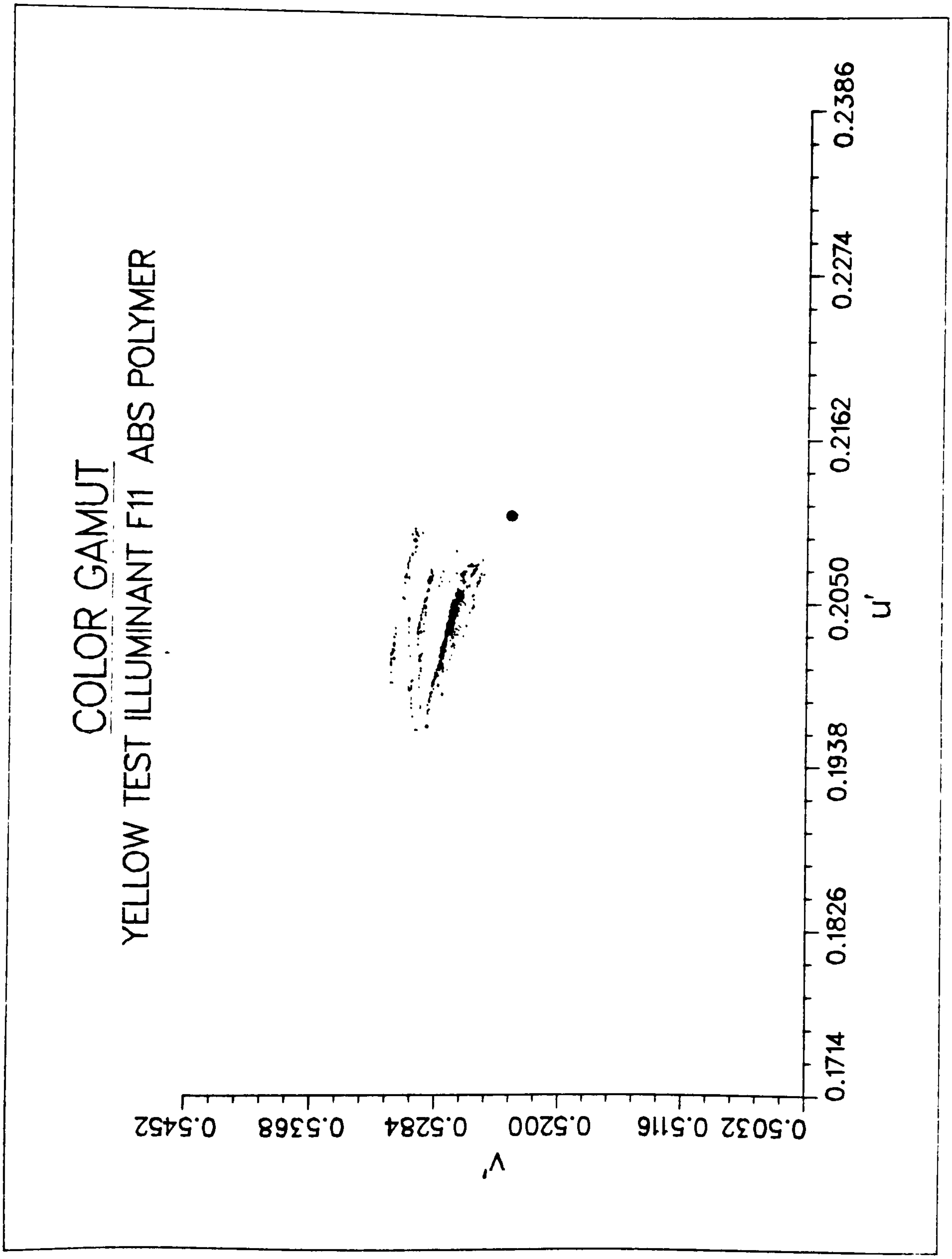
COLOR GAMUT
YELLOW TEST ILLUMINANT F11 ABS POLYMER
u'
0.1714
0.1826
0.1938
0.2050
0.2162
0.2274
0.2386
v'
0.5032
0.5116
0.5200
0.5284
0.5368
0.5452

FIGURE 29.

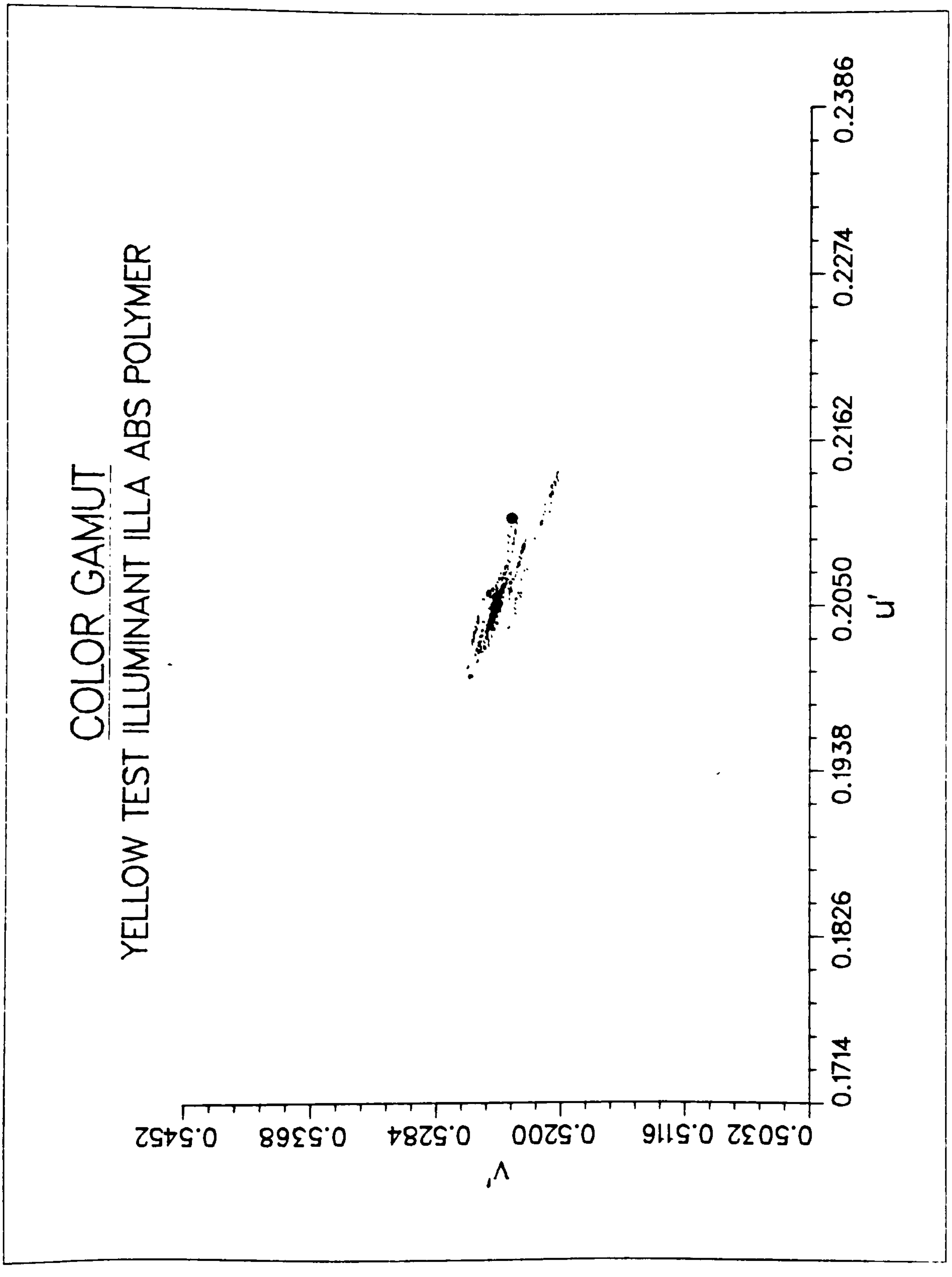
COLOR GAMUT
YELLOW TEST ILLUMINANT ILLA ABS POLYMER
0.1714
0.1826
0.1938
0.2050
0.2162
0.2274
0.2386
u'
0.5452
0.5368
0.5284
0.5200
0.5116
0.5032
v'

FIGURE 30.

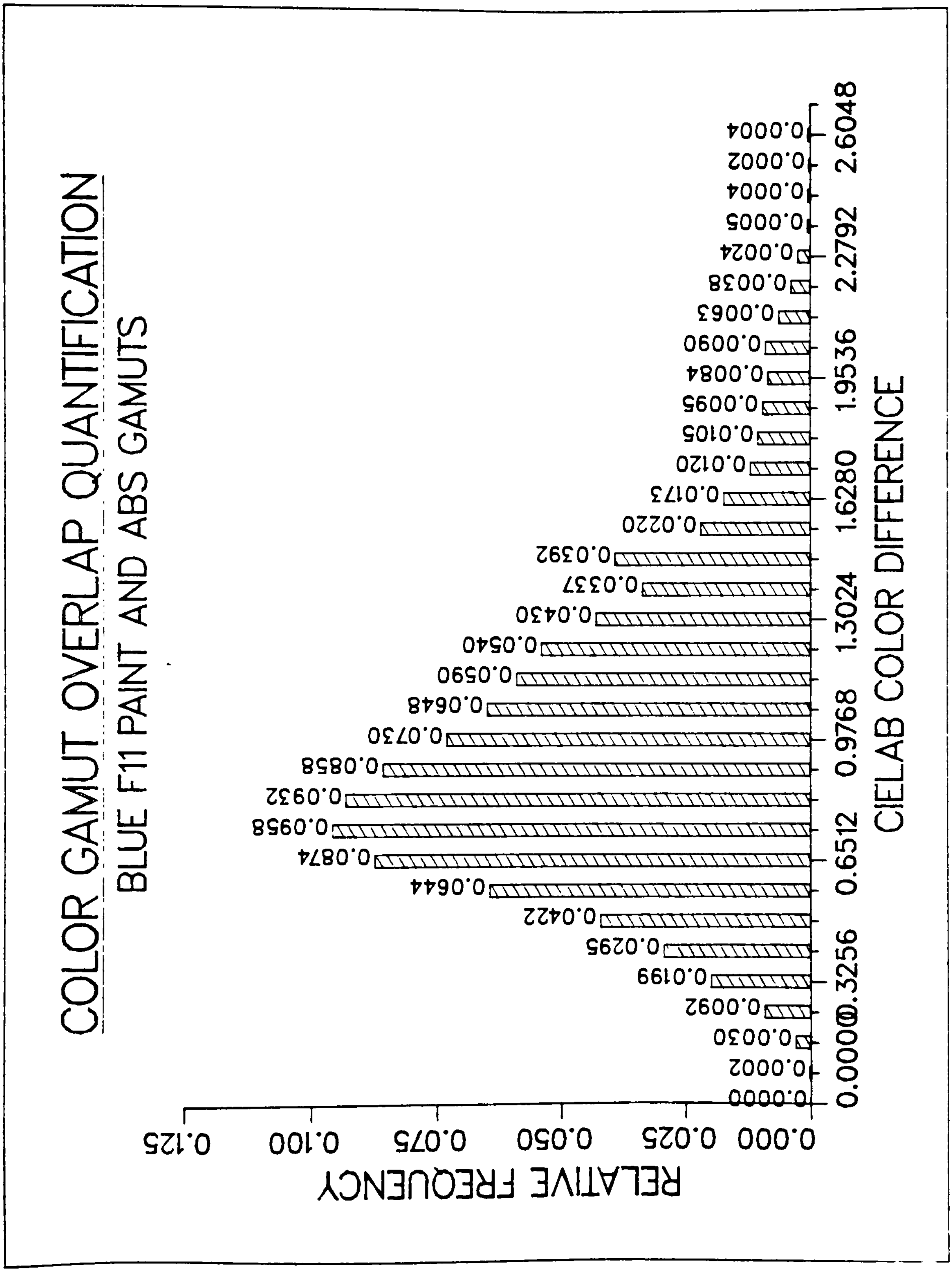
COLOR GAMUT OVERLAP QUANTIFICATION
BLUE F11 PAINT AND ABS GAMUTS
CIELAB COLOR DIFFERENCE
0.0000
0.3256
0.6512
0.9768
1.3024
1.6280
1.9536
2.2792
2.6048
RELATIVE FREQUENCY
0.000
0.025
0.050
0.075
0.100
0.125
0.0000
0.0002
0.0030
0.0092
0.0199
0.0295
0.0422
0.0644
0.0874
0.0958
0.0932
0.0858
0.0730
0.0648
0.0590
0.0540
0.0430
0.0337
0.0392
0.0220
0.0173
0.0120
0.0105
0.0095
0.0084
0.0090
0.0063
0.0038
0.0024
0.0005
0.0004
0.0002
0.0004

FIGURE 31.

IV. Discussion

The gamuts achieved were all confined to narrow ranges of the Y tristimulus value (Table 2 and 3). This is in agreement with the results of the work completed in 1975 by Ohta and Wyszecki. It is expected that this narrow Y range would not have been achievable if CIE Illuminant D65 would have been used as a test illuminant rather than the reference illuminant. The Y ranges for all the trials under F2 and F11 were very close, usually within one unit of each other, while the values obtained under CIE Illuminant A were found to fall several units from the others. The Y values obtained under Illuminant A also presented the smallest range, never greater than .2861 tristimulus units. No pattern was found for the values or ranges of the Y values. It appears that the Y values are strictly dependent on the desired reference stimuli. For the colorant set used here the ranges were very similar when comparisons were made between the two colorant sets.

The color constancy indicies of the formulations showed no trends by test illuminant. The values ranged from less than 1.0000 to approximately 14.0000 for both colorant sets. The range of this index did not appear to be dependent on the number of colorants in the data base either. The only dependence found was once again the desired reference stimuli and the test illuminant chosen. The stimuli corresponding to blue presented the smallest range in both cases. The stimuli corresponding to gray presented the smallest values in both cases. The values obtained under the F2 and F11 test illuminants were found to be vastly different. All the maximum and minimum color constancy index values are listed in tables 4 and 5.

No definite trends were found in the metameric index calculated for each formulation. In all but one case for the blue paint, the results under F2 illuminant yield the best of the maximum index values. Once again the results obtained under F2 and F11 were not similar. The worst case was found for a red paint match under Illuminant A. The maximum and minimum metameric index values are listed in tables 4 and 5.

Figures 1 through 30 illustrate the gamuts, mismatch limits achieved for each case. These plots yield some information about each of the test illuminants. The gamuts calculated under CIE Illuminant A show a compression in the v′ range and an elongation in u′. The gamuts resulting under the two fluorescents appeared more spherical but not similiar. The direction of color constancy resulting under each illuminant was found to be different.

There was a gamut overlap found for each set of data processed under identical reference and test conditions. The quantification of this overlap was performed using a relative frequency histogram. An example of this can be seen in figure 31. The figure shows that the majority of the formulations fall within one CIELAB color difference unit of each other. This represents a satisfactory overlap of the two colorant sets for these conditions.

V. Conclusions

The results of this work strongly suggest that the two illuminants F2 and F11 should be carefully identified and differentiated. This is due to the differences found in the color gamuts size, shape, and locations, along with differences in color constancy. The narrow-band fluorescent source does not perform like the standard cool white fluorescent.

The amount of overlap between the two colorant sets used suggests that matemerism can be easily controlled in this case. This suggests that it is possible to identify and thereby control the extent of metamerism between any two colorant sets in a given situation. This would only require the simultaneous formulation of matches in potentially metameric situations involving different colorant sets.

Further work would involve experimentation with close color matches under the reference illuminant and the resulting color gamuts. Also a comparison of spectral reflectance curves of colorant samples as ranked by both color constancy index and metameric index are in the planning. Additionally, textile colorant sets will also be included.

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Vita

Michael M. Beering was born in Buffalo, New York and was raised in Hamburg, a suburb of Buffalo. He attended and graduated from Hamburg Senior High School. Michael is currently finishing up the requirements for a Bachelor's of Science degree in the Imaging and Photographic Science department at Rochester Institute of Technology