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Color Codes of Optical Fiber and Color Shade Measurement Standards in Optical Fiber Cables

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Abstract
This application note describes color identification scheme of Optical Fibers in a Sterlite Fiber Optic Cable and most common ways to measure color in fiber optic industry. Munsell color system, L/C/H system, and Delta E system of color identification are described and their equivalence presented.

Keywords
Color optical fiber, color code, Munsell color chart, Hue, Chroma, Lightness, Delta E

Optical Fiber Colors and Color Codes

Like electrical wires, optical fibers are color coded for field recognition during cable installation. In a fiber optic cable buffer tube containing multiple fibers, each fiber needs to be distinguished from others by means of color coding. During splicing/ joining of two fiber ends, like color fibers are spliced to ensure continuity in an optical fiber network.TIA/EIA-598 is the most widely used color coding standard in fiber optic industry. This standard defines recommended identification scheme for individual fibers, buffered fibers, fiber units within a fiber optic cable both for premises and outdoor applications. Table 1 shows the color codes used for optical fibers in a Sterlite fiber optic cable. Color codes may be customized based on specific customer requirement.

Table 1 Sterlite optical fiber color code in cable

Fiber Number	Base color and Ring marking	Abbreviation
1	Blue	BL
2	Orange	OR
3	Green	GR
4	Brown	BR
5	Slate (Grey)	SL
6	White	WH
7	Red	RD
8	Black	BK
9	Yellow	YL
10	Violet	VI
11	Pink	PK
12	Aqua	AQ
13	Blue with Black Rinq mark	-B-L-
14	Orange with Black Ring mark	-e-R-
15	Green with Black Ring mark	GR
16	Brown with Black Ring mark	BR
17	Slate with Black Ring mark	-¬
18	White with Black Rinq mark	WH
19	Red with Black Ring mark	RD
20	Natural (no color) or Natural with Black Ring mark	NT /-1,4-
21	Yellow with Black Ring mark	-'T'L--
22	Violet with Black Ring mark	--VI-
23	Pink with Black Ring mark	PK
24	Aqua with Black Ring mark	AQ

Color Control Systems

Due to the variability in the manufacturing process, a visual color standard is required to ensure that the base color codes are manufactured within a reasonable tolerance to the exact color. So there is a need for color standard that helps to ensure consistent color between color fiber lots and therefore, safe and easy identification of color fibers during cable installation and testing. There are three main ways to measure and control optical fiber color shades practiced in fiber optic industry.

1. Munsell color system or H/C/V system
2. L/C/H system
3. Color difference or Colortolerance or Delta E (AE)

1. Munsell Color System

Munsell color system is a qualitative way to measure and control color shades and is accepted in both TIA/EIA-598 and EIA-359 standards.[1,2] Munsell worked with the Electrical Industries Association (EIA) to develop color standards that correlate to the color coding system for telecom and fiber optics industries3. Each Munsell color coding standard includes a 'best match' or centroid color plate and acceptable visual variations away from the centroid color. The color of the centroid and other acceptable color plates are specified by Hue (H), Value (V) and Chroma (C).

Hue (H) is the quality by which we distinguish one color from other like blue, green, red, etc. Munsell Hue color circle as shown in Fig. 1, is divided into 10 equal regions by five main hues like Red (R), Yellow (Y), Green (G), Blue (B), Purple (P) and five intermediate hues like Yellow-Red (YR), Green-Yellow (GY), Blue-Green (BG), Purple- Blue (PB) and Red-Purple (RP). The colors are placed around a color circle at equal points and the colors in between these points are a mixture of the two, in favor of the nearer point/color as shown in Fig.1. For example, "2.5R", to represent the hue two-and-a-half steps around the circle from Red while moving clockwise.

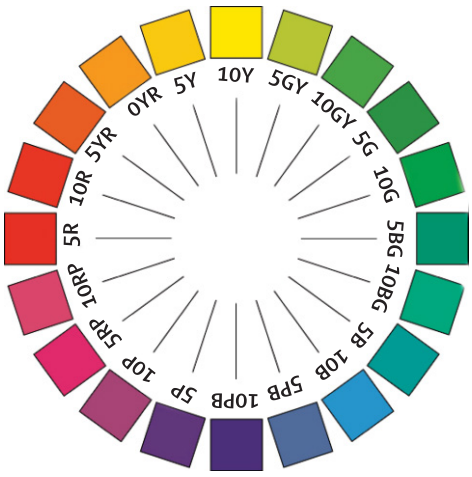

Fig.1 Munsell Hue Circle

Chroma (C) (also known as Saturation) is defined as strength or dominance of the hue. It is also stands for intensity or purity of a color. On the outer edge of the hue wheel are the intensely saturated hues. Towards the center of the color wheel, no hue dominates and they become less and less saturated. In Munsell standard, the scale of chroma extends from 0 at the center of the circle, which is completely unsaturated (neutral grey) to 10, 12, 14 or further, depending upon the strength (saturation) of the color. In Fig. 2 chroma of purple-blue color is varied from 0 atthe centerto 12 at the outer edge.

Value (V) describes overall intensity or how light or dark a color is. Value in Munsell standard it is expressed as numbers from 0 to 10 in a vertical scale as shown in Fig. 2. Zero stands for no lightness (i.e. completely black) and 10 stands for maximum lightness (i.e. completely white).

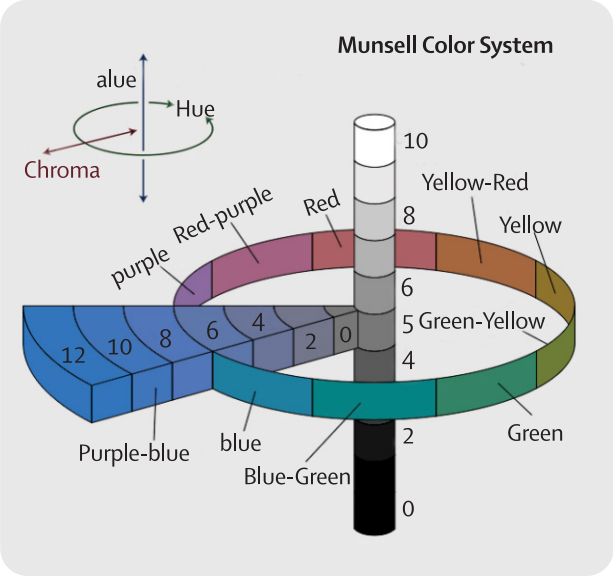

Fig.2 Munsell color system

2. L/C/H system

Munsell color standard plates are widely used qualitative methods to verify color of optical fibers. Color shades can also be measured quantitatively by spectrophotometer or colorimeter. Some organizations like British Telecom prefer quantitative representation and control of color shades. Most common ways to represent spectro-photometer output are using L/C/H and AE methods. L/C/H is slightly different compare to H/C/V terms used in Munsell color system. Value in the Munsell method is known as Lightness (L) in L/C/H system. The othertwo metrics, Hue and Chroma have the same nomenclature.

Value (V) in Munsell standard is expressed as numbers from 0 to 10, whereas Lightness (L) is measured in percentage from 0% - 100%, that means L is 10 times of V. Zero stands for no lightness (i.e. completely black) and 100 stands for maximum lightness (i.e. completely white). Fig 3 shows how lightness varies from zero (black) and 100 (white) in a vertical scale. In L/C/H system, Hues are expressed as an angle from 0 to 360° as shown in Fig 3,where Red hue is traditionally at zero degree and that makes Green at -1200, Blue at 240° and so on. In L/C/H system Chroma scale is 0 to 100 or more and the numbers are approximately 5 times the C in Munsell system.

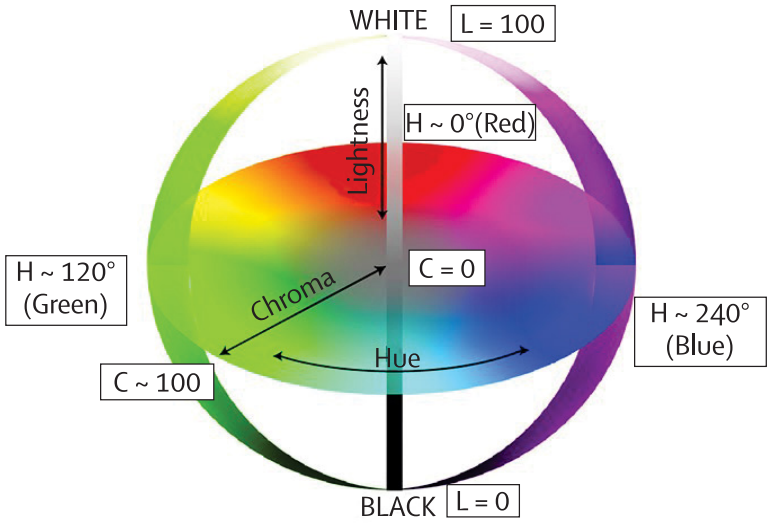

Fig. 3 Three coordinate color circle according to L/C/H system

3. Color difference or Color tolerance or Delta E (△E)

Another quantitative way to represent color shades is to calculate difference between two samples where one sample is the reference sample or industry standard and the other is the manufacturing sample. The calculated number is called the "△E" (Delta E) or "color difference" or "color tolerance". △E displays the difference as a single number for hue, chroma, and value/lightness. △E is calculated by comparing the measurements, taken with a spectrophotometer, of a manufacturing fiber sample (the output) to the data of a known color (the specification or input value).

Different studies proposed different formula to calculate △E. Two formulas are well practiced in fiber optic industry.

a) The formula as shown in equation 1, proposed by International Commission of Illumination (CIE) in 1976 is referred in TIA/EIA-598 standard for controlling cable jacket / sheath color and it is symbolized as △Eab.

$\Delta E_{ab} = V(\Delta Hue)^2 + (\Delta Value)^2 + (\Delta Chroma)^2$ .....Eq (1)

b) Color Measurement Committee (CMC) in 1984 proposed a different formula to calculate rE and it is symbolized as Δ^{CMC4}. Some organizations like France Telecom prefer r^{ECMC} measurement to control fiber color shades. Target L/C/H values as specified by the buyer, are taken as the input parameter of the spectrophotometer and L/C/H of the manufacturing sample is measured. Both target and measured L/C/H values are used to calculate ΔE_{CMC} of a manufacturing sample.

Lower the △E value, closer is the manufacturing sample to the specifications or reference sample. △E values of 4 and over will normally be visible to the average person, while those between 2 and 4 will be visible to an experienced observer. In TIA/EIA-598 standard, ΔE_{ab} value less than 6 is acceptable for cable jacket / sheath. ΔE_{cmc} value less than 8 are acceptable for most of the optical fiber colors in other industry standards.

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