GENERAL STANDARDS

Standardization of electronic components or parts is handled by several cooperating agencies.

In the US, the Electronic Industries Association (EIA)* and the American National Standards Institute (ANSI)† are active in the commercial field. Electron-tube and semiconductor-device standards are handled by the Joint Electron Device Engineering Council (JEDEC), a cooperative effort of EIA and the National Electrical Manufacturers Association (NEMA)‡. Military (MIL) standards are issued by the US Department of Defense or one of its agencies such as the Defense Electronics Supply Center (DESC).

International standardization in the electronics field is carried out by the various Technical Committees of the International Electrotechnical Commission (IEC)§. A list of the available IEC Recommendations is included in the ANSI Index (outside the US, consult the national standardization agency or the IEC). Documents from the IEC may be used directly, or their recommendations may be incorporated in whole or in part in national standards issued by the EIA or ANSI. A few broad areas may be covered by standards issued by the International Standards Organization (ISO).

These organizations establish standards for electronic components or parts (and in some cases, for equipments) to provide interchangeability among different products regarding size, performance, and identification; minimum number of sizes and designs; and uniform testing of products for acceptance. This chapter presents a brief outline of the requirements, characteristics, and designations for the major types of component parts used in electronic equipment. Such standardization offers economic advantages to both the parts user and the parts manufacturer, but is not intended to prevent the manufacture and use of other parts under special conditions.

Color Coding

The color code of Table 1 is used for marking electronic parts.

*EIA Engineering Dept., Washington, D.C. Index of standards is available. EIA was formerly Radio-Electronics-Television Manufacturers' Association (RETMA).

†ANSI, New York, New York. Index of standards is available. ANSI was formerly the USA Standards Institute (USASI).

‡NEMA, New York, New York. Index of standards is available.

§IEC, Central Office; Geneva, Switzerland. The US National Committee for the IEC operates within the ANSI.

Tolerance

The maximum deviation allowed from the specified nominal value is known as the tolerance. It is usually given as a percentage of the nominal value, though for very small capacitors the tolerance may be specified in picofarads (pF). For critical applications it is important to specify the permissible tolerance; where no tolerance is specified, components are likely to vary by ±20 percent from the nominal value.

Do not assume that a given lot of components will have values distributed throughout the acceptable range of values. A lot ordered with a ±20% tolerance may include no parts having values within 5% of the desired nominal value; these may have been sorted out before shipment. The manufacturing process for a given lot may produce parts in a narrow range of values only, not necessarily centered in the acceptable tolerance range.

Preferred Values

To maintain an orderly progression of sizes, preferred numbers are frequently used for the nominal values. A further advantage is that all parts manufactured are salable as one or another of the preferred values. Each preferred value differs from its predecessor by a constant multiplier, and the final result is conveniently rounded to two significant figures.

ANSI Standard 217.1-1973 covers a series of preferred numbers based on $(10)^{1/5}$ and $(10)^{1/10}$ as listed in Table 2. This series has been widely used for fixed wirewound power-type resistors and for time-delay fuses.

Because of the established practice of using ±20-, ±10-, and H-percent tolerances, a series of values based on $(10)^{1/6}$, $(10)^{1/12}$, and $(10)^{1/24}$ has been adopted by the EIA, and is now an ANSI Standard (C83.2-1971) (EIA RS-385). It is widely used for such small electronic components as fixed composition resistors and fixed ceramic, mica, and molded paper capacitors. These values are listed in Table 2. (For series with smaller steps, consult the ANSI or EIA Standard.)

Voltage Rating

Distinction must be made between the breakdown-voltage rating (test volts) and the working-voltage rating. The maximum voltage that may be applied (usually continuously) over a long period of time without causing the part to fail determines the working-voltage rating. Application of the test voltage for more than a very few minutes, or even repeated applications of short duration, may result in permanent damage or failure of the part.

Characteristic

The term "characteristic" is frequently used to include various qualities of a part such as tempera-

TABLE I. STANDARD COLOR CODE OF ELECTRONICS INDUSTRY

Color	Significant Figure	Decimal Multiplier	Tolerance in Percent*	Voltage Rating	Characteristic
Black	0	1	±20 (M)	—	A
Brown	1	10	±1 (F)	100	B
Red	2	100	±2 (G)	200	C
Orange	3	1000	±3	300	D
Yellow	4	10 000	GMV‡	400	E
Green	5	100 000	±5(J)†, (0.50(D))§	500	F
Blue	6	1000000	±6(0.25(C))§	600	G
Violet	7	10 000 000	f12.5, (O.lO(B))§	700	—
Gray	8	0.01†	±30, (0.05(N))§	800	I
White	9	0.1†	±10†	900	J
Gold	—	0.1	±5 (J), (0.50(E))‖	1000	—
Silver	—	0.01	±lO(K)	2000	—
No Color	—	—	±20	500	—

* Tolerance letter symbol as used in type designations has tolerance meaning as shown. ±3, ±6, f12.5, and ±30 percent are tolerances for USA Std 40-, 20-, l0-, and 5-step series, respectively.
† Optional coding where metallic pigments are undesirable.
‡GMV is -0 to +100-percent tolerance or Guaranteed Minimum Value.
§ For some film and other resistors only.
‖ For some capacitors only.

ture coefficient of capacitance or resistance, Q value, maximum permissible operating temperature, stability when subjected to repeated cycles of high and low temperature, and deterioration when it is subjected to moisture either as humidity or water immersion. One or two letters are assigned in EIA or MIL type designations, and the characteristic may be indicated by color coding on the part. An explanation of the characteristics applicable to a component or part will be found in the following sections covering that part.

ENVIRONMENTAL TEST METHODS

Since many component parts and equipments have the same environmental exposure, environmental test methods are becoming standardized. The principal standards follow.

EIA Standard RS-186-E ***(ANSI C83.58-1978):*** Standard Test Methods for Passive Electronic Component Parts.

IEC Publication 68: Basic Environmental Testing Procedures for Electronic Components and Electronic Equipment (published in multiple).

MIL-STD-202F: Military Standard Test Methods for Electronic and Electrical Component Parts.

MIL-STD-750B: Test Method for Semiconductor Device.

Military Standard Environmental Test Methods.

MIL-STD-883B: Test Methods and Procedures for Microelectronics.

MIL-STD-1344A: Test Methods for Electrical Connectors.

ASTM* Standard Test Methods-Primarily applicable to the materials used in electronic component parts.

Wherever the test methods in these standards are reasonably applicable, they should be specified in preference to other methods. This simplifies testing of a wide variety of parts, testing in widely separated locations, and comparison of data.

When selecting destructive environmental tests to determine the probable life of a part, distinguish between the environment prevailing during normal equipment operation and the environment used to accelerate deterioration. During exposure to the latter environment, the item may be out of tolerance with respect to its parameters in its normal operating-environment range. Accelerated tests are most meaningful if some relation between the degree of acceleration and component life is known. Such acceleration factors are known for many insulation systems.

STANDARD AMBIENT CONDITIONS FOR MEASUREMENT

Standard ambient conditions for measurement are listed in Table 3.

*ASTM = American Society for Testing and Materials; Philadelphia, Pa. Index of standards is available.

TABLE 2. PREFERRED VALUES*

Name of Series	USA Standard Z17.1-1973†		USA Standard C83.2-1971 (R 1977)‡		
	"5"	"10"	±20% (E6)	±10% (E12)	±5% (E24)
Percent step size	60	25	≈40	20	10
Step multiplier	$(10)^{1/5}=1.58$	$(10)^{1/10}=1.26$	$(10)^{1/6}=1.46$	$(10)^{1/12}=1.21$	$(10)^{1/24}=1.10$
Values in the series (Use decimal multipliers for smaller or larger values)	10	10	10	10	10
	—	12.5	—	—	11
	—	(12)	—	12	12
	—	—	—	—	13
	—	—	15	15	15
	16	16	—	—	16
	—	—	—	18	18
	—	20	—	—	20
	—	—	22	22	22
	—	—	—	—	24
	25	25	—	—	—
	—	—	—	27	27
	—	31.5	—	—	30
	—	(32)	—	—	—
	—	—	33	33	33
	—	—	—	—	36
	—	—	—	39	39
	40	40	—	—	—
	—	—	—	—	43
	—	—	47	47	47
	—	50	—	—	—
	—	—	—	—	51
	—	—	—	56	56
	—	—	—	—	62
	63	63	—	—	—
	—	—	68	68	68
	—	—	—	—	75
	—	80	—	—	—
	—	—	—	82	82
	—	—	—	—	91
	100	100	100	100	100

* ANSI Standard C83.2-1971 applies to most electronics components. It is the same as EIA Standard RS-385 (formerly GEN-102) and agrees with IEC Publication 63. ANSI Standard Z17.1-1973 covers preferred numbers and agrees with ISO 3 and ISO 497.

† "20" series with 12-percent steps ($(10)^{1/20}$= 1.122 multiplier) and a "40" series with 6-percent steps ($(10)^{1/40}$ =1.059 multiplier) are also standard.

‡ Associate the tolerance ±20%, ±10%, or ±5% only with the values listed in the corresponding column. Thus, 1200 ohms may be either +10 or ±5, but not ±20 percent; 750 ohms may be ±5, but neither ±20 nor ±10 percent.

OTHER STANDARD ENVIRONMENTAL TEST CONDITIONS

Ambient Temperature

Dry heat,°C: + 30, 40, (+ 49), +55, (+ 68), +70, (+ 71), + 85, +100, +125, +155, +200 (values in parentheses not universally used).

Cold, °C: − 10, -25, -40, -55, -65.

Constant-Humidity Tests

40°C 90 to 95% RH; 4, 10, 21, or 56 days.

66°C, ≈ 100% RH: 48, 96, or 240 hours (primarily for small items).

Cycling Humidity Tests

Fig. 1 shows a number of cycling humidity tests. (See applicable chart in standard for full details.) Preconditioning is customary before starting cycle series. RH = relative humidity.

High-Altitude Tests

Information regarding high-altitude tests is given in Table 4.

Vibration Tests

The purposes of vibration tests are:

(A) Search for resonance.

TABLE 3. STANDARD AMBIENT CONDITIONS FOR MEASUREMENT

	Standard	Temperature (°C)	Relative Humidity (%)	Barometric Pressure	
				mm Hg	mbar
Normal range	RS-18 6-D	15-35	45-75	650-800	860-1060
	IEC-68	15-35	45-75	(645-795)	860-1060
	MIL-STD-202E	15-35	45-75	650-800	(8661066)
	MIL-STD-8 10C	13-33	20-80	650-775	(8661033)
Closely controlled range	IEC-68	20±1	65±2	(645-795)	860-1060
	IEC-68	23±l	50±2	(645-795)	860-1060
	MIL-STD-202E	23±l	50±2	650-800	(866-1066)
	MIL-STD-8 10C	23±1.4	50±5	650-775	(866-1033)
	IEC-68	27±l	65±2	(645-795)	860-1060
	RS-186-D	25±2	50±2	650-800	860-1060

Notes:
1. Use the closely controlled range only if the properties are sensitive to temperature or humidity variations, or for referee conditions in case of a dispute. The three temperatures 20°, 23°, and 27°C correspond to normal laboratory conditions in various parts of the world.
2. Rounded **derived values** are shown in parentheses ( ).
3. 25±2°C, 20 to 50% relative humidity (RH) has been widely used as a closely controlled ambient for testing electronics components.

(B) Determination of endurance (life) at resonance (or at specific frequencies).

(C) Determination of deterioration resulting from long exposure to swept frequency (or random vibration).

Recommended Frequency Ranges for Tests- Hertz: 1 to 10, 5 to 35, 10 to 55, 10 to 150, 10 to 500, 10 to 2000 , 10 to 5000.

Recommended Combinations of Amplitude and Freque - IEC Publication 68 recommends testing at constant amplitude below and constant acceleration above the crossover frequency (57 to 62 hertz). MIL-STD.202 and MIL-STD-8 10 also follow this principle but use different crossover points and low-frequency severities. The choice of frequency range and vibration amplitude or acceleration should bear some relation to the. actual service environment. Successful completion' of 10^7 vibration cycles indicates a high probability! of no failures in a similar service environment: Resonances may make the equipment output unusable, although the mechanical life may be adequate.

COMPONENT VALUE CODING

Axial-lead and some other components are often color coded by circumferential bands to indicate

TABLE 4. HIGH-ALTITUDE TESTS

Pressure			Approximate Corresponding Altitude		Standard
mbar	mm Hg	in. Hg	feet	meters	
700	525	20.67	7 218	2200	IEC
600	450	17.72	11 483	3 500	IEC
533	400	15.74	I4 108	4300	IEC
586	439	17.3	15000	4 572	MIL-202
466	349	13.75	20 000	6 096	RS-186
300	22s	8.86	27 900	8 500	IEC
300	226	8.88	30 000	9 144	MIL-202, RS-186
116	87.0	3.44	50 000	15 240	MIL-202, RS-186
85	63.8	2.51	52 500	16000	IEC
44	33.0	1.30	65 600	20 000	IEC
44.4	33.0	1.31	70 000	21 336	MIL-202
20	17.2	0.677	85 300	26 000	IEC
10.6	8.00	0.315	100000	30 480	MIL-202
I.28	1.09	-0.043	150000	45 720	MIL-202
3.18×10^{-6}	2.40×10^{-6}	9.44×10^{-8}	656 000	200000	MIL-202

Notes:
1. The inconsistency in the pressure-altitude relation arises from the use of different model atmospheres. For testing purposes always specify the desired pressure rather than an elevation in feet or meters.
2. Values in italics are derived from the values specified in the associated standard.

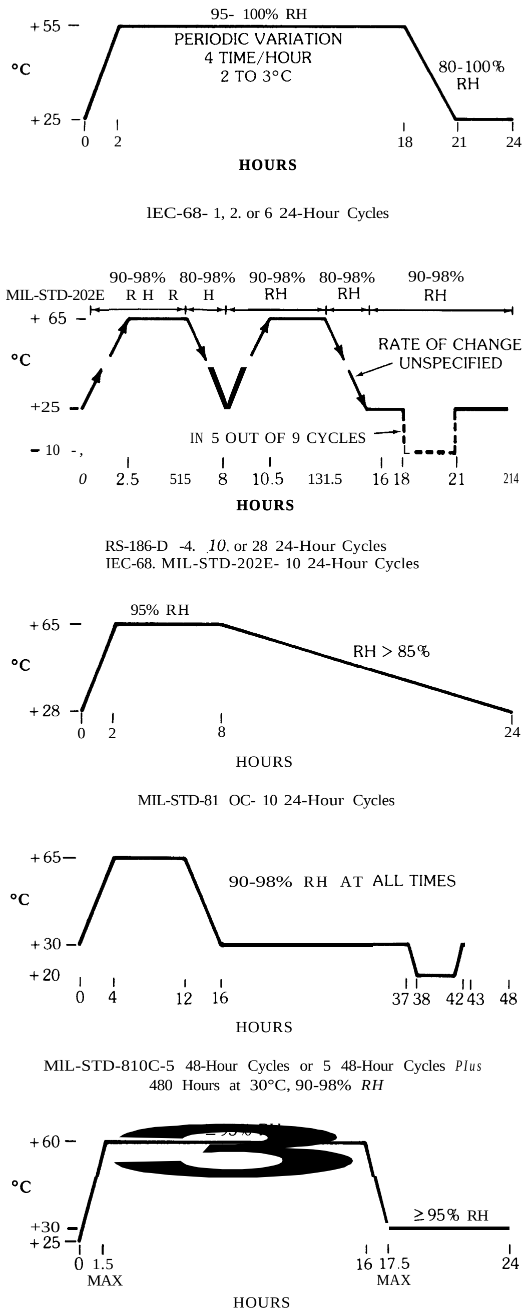


Fig. 1. Cycling humidity tests. Relative humidity for RS-186-D is 90-95% but may be uncontrolled during temperature changes.

the resistance, capacitance, or inductance value and its tolerance. Usually the value may be decoded as indicated in Fig 2 and Table 1.

Sometimes, instead of circumferential bands, colored dots are used as shown in Fig. 3 and Table 5.

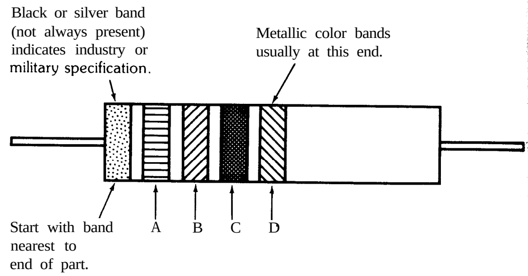


Fig. 2. Component value coding. The code of Table 1 determines values. Band A color = First significant figure of value in ohms, picofarads, or microhenries. Band B color = Second significant figure of value. Band C color = Decimal multiplier for significant figures. Band D color = Tolerance in % (if omitted, the broadest tolerance series of the part applies).

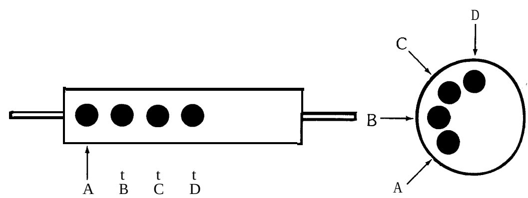


Fig. 3. Alternative methods of component value coding.

TABLE 5. **COLOR-CODE EXAMPLES**

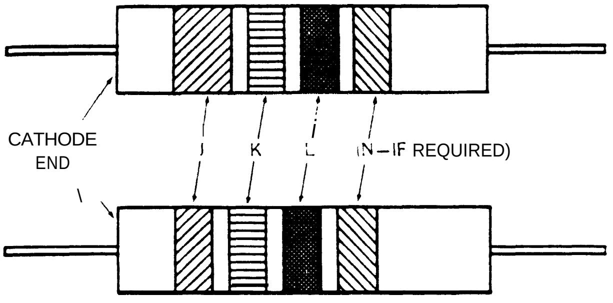
Component Value	Band or Dot Color			
	A	B	C	D
3300±20%	Orange	Orange	Red	Black or omitted
5. 1±10%	Green	Brown	Gold or white	Silver
1.8 megohms ±5% (as applied to a resistor)	Brown	Gray	Green	Gold

Semiconductor-Diode Type-Number Coding

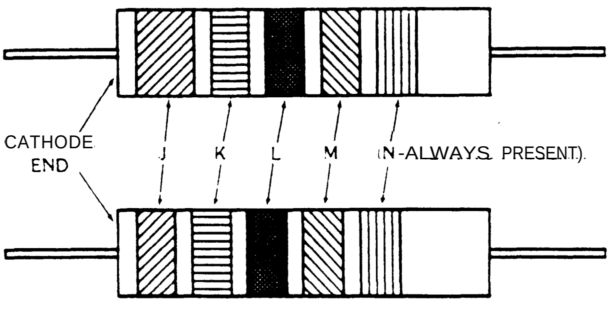
The sequential number portion (following the "1N" of the assigned industry type number) may be indicated by color bands* as shown in Fig. 4. Colors have the numerical significance given in Table 1.

Bands J, K, L, M represent the digits in the sequential number (for two-digit numbers, band J

*EIA Standard RS-236-B.



(A) **2- or 3-digit sequentiai number.**



(8) 4-digit sequential number.

Fig. **4.** Semiconductordiode value coding.

is black). Band N is used to designate the suffix letter as shown in Table 6. Band N may be omitted

TABLE 6. DIODE COLOR CODE

Color	Suffix Letter	Number
Black	—	0
Brown	A	I
Red	B	2
Orange	C	3
Yellow	D	4
Green	E	5
Blue	F	6
Violet	G	7
Gray	H	8
White	J	9

in two- or three-digit number coding if not required, but it will always be present in 4digit number coding (black if no suffix letter is required). See Table 7 for examples.

A single band indicates the cathode end of a diode or rectifier.

RESISTORS-DEFINITIONS

Wattage Rating: The maximum power that the resistor can dissipate, assuming (A) a specific life, (B) a standard ambient temperature, and (C) a stated long-term drift from its no-load value. Increasing the ambient temperature or reducing the allowable deviation from the initial value (more-stable resistance value) requires derating the allowable dissipation. With few exceptions, resistors are derated linearly from full wattage at rated temperature to zero wattage at the maximum temperature.

TABLE 7. EXAMPLES OF DIODE COLOR CODING

Band	Band Color		
J	Red	Red	Orange
K	Green	Green	Blue
L	Yellow	Yellow	Violet
M	—		Red
N	—	Red	Black
	1 N254	1 N254B	1 N3672

Temperature Coefficient (Resistance- Temperature Characteristic): The magnitude of change in resistance due to temperature, usually expressed in percent per degree Celsius or parts per million per degree Celsius ppm/°C). If the changes are linear over the operating temperature range, the parameter is known as "temperature coefficient"; if nonlinear, the parameter is known as "resistance-temperature characteristic." A large temperature coefficient and a high hot-spot temperature cause a large deviation from the nominal condition; e.g., 500 ppm/°C and result in a resistance change of over 12 percent.

Maximum Working Voltage: The maximum voltage that may be applied across the resistor (maximum working voltage) is a function of (A) the materials used, (B) the allowable resistance deviation from the low-voltage value, and (C) the physical configuration of the resistor. Carbon composition resistors are more voltage-sensitive than other types.

Noise: An unwanted voltage fluctuation generated within the resistor. Total noise of a resistor always includes Johnson noise, which depends only on resistance value and the temperature of the resistance element. Depending on type of element and construction, total noise may also include noise caused by current and noise caused by cracked bodies and loose end caps or leads. For adjustable resistors, noise may also be caused by jumping of the contact over turns of wire and by imperfect electrical path between contact and resistance element.

Hot-Spot Temperature: The maximum temperature measured on the resistor due to both heating and the ambient operating temperature. The allowable maximum hot-spot temperature is predicated on thermal limits of the materials and the design. Since the maximum hot-spot temperature may not be exceeded under normal operating conditions, the wattage rating of the resistor must be lowered if it is operated at an ambient temperature higher than that at which the wattage rating was established. At zero dissipation, the maximum ambient around the resistor may be at its maximum hot-spot temperature. The ambient temperature for a resistor is affected by surrounding heat-producing devices; resistors stacked together do not experience the ambient surrounding the stack except under forced cooling.

Critical Resistance Value: A resistor of specified power and voltage ratings has a critical resistance value above which the allowable voltage limits the permissible power dissipation. Below the critical resistance value, the maximum permitted voltage across the resistor is never reached at rated power.

Inductance and Other Frequency Effects: For other than wirewound resistors, the best high-frequency performance is secured if (A) the ratio of resistor length to cross section is a maximum, and (B) dielectric losses are kept low in the base material and a minimum of dielectric binder is used in composition types.

Carbon composition types exhibit little change in effective dc resistance up to frequencies of about 100 kHz. Resistance values above 0.3 megohm start to decrease in resistance at approximately 100 kHz. Above 1 MHz, all resistance values decrease.

Wirewound types have inductive and capacitive effects and are unsuited for use above 50 kHz, even when specially wound to reduce the inductance and capacitance. Wirewound resistors usually exhibit an increase in resistance at high frequencies because of "skin" effect.

Film types have the best high-frequency performance. The effective dc resistance for most resistance values remains fairly constant up to 100 MHz and decreases at higher frequencies. In general, the higher the resistance value the greater the effect of frequency.

Established-Reliability Resistors: Some resistor styles can be purchased with maximum-failure-rate guarantees. Standard-failure-rate levels are:

%/ 1000 hours-1.0; 0.1; 0.01; 0.001.

Resistance Value and Tolerance Choice: A calculated circuit-resistance nominal value should be checked to determine the allowable deviation in that value under the most unfavorable circuit, ambient, and life conditions. A resistor type, resistance value, and tolerance should be selected considering (A) standard resistance values (specials are uneconomical in most cases), (B) purchase tolerance, (C) resistance value changes caused by temperature, humidity, voltage, etc., and (D) long-term drift.

RESISTORS-FIXED COMPOSITION

Color Code

EIA-standard and MIL-specification requirements for color coding of fixed composition resistors are identical (see Fig. 2). The exterior body color of insulated axial-lead composition resistors is usually tan, but other colors (except black) are permitted. Noninsulated axial-lead composition resistors have a black body color.

If three significant figures are required, Fig. 5 shows the resistor markings (EIA Std RS-279).

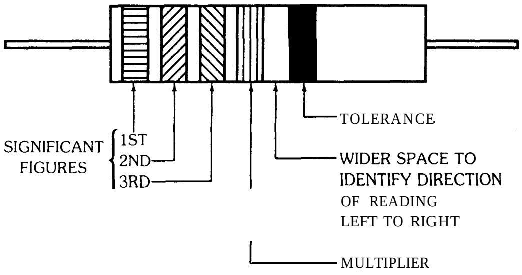


Fig. 5. Resistor value color code for three significant figures. Colors of Table 1 determine values.

Another form of resistor color coding (MIL-STD-1285A) is shown in Fig. 6. Colors have the significance shown in Table 8 for the fifth band.

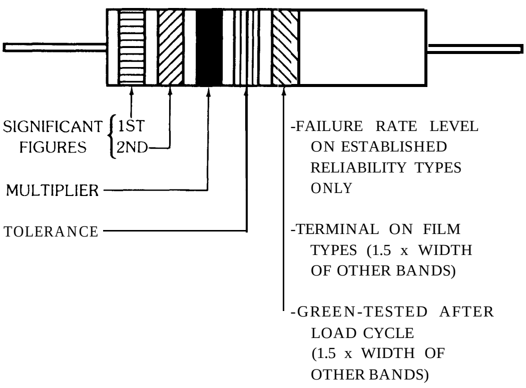


Fig. 6. Resistor color code per MIL-STD-1285A.

Tolerance

Standard resistors are furnished in ±20-, or ±10-, and ±5-percent tolerances, and in the preferred-value series of Table 2. "Even" values, such as 50000 ohms, may be found in old equipment, but they are seldom used in new designs.

RF Effects

The end-to-end shunted capacitance effect may be noticeable because of the short resistor bodies and small internal distance between the ends. Operation at vhf or higher frequencies reduces the effective resistance because of dielectric losses (Boella effect).

Good Design Practice

Operate at one-half the allowable wattage dissipation for the expected ambient temperature. Provide an adequate heat sink. Mount no other heat-dissipating parts within one diameter. Use only in applications where a 15% change from the installed value is permissible or where the environment is controlled to reduce the resistance-value change.

RESISTORS-FIXED WIREWOUND

Fixed wirewound resistors are available as low-power insulated types, precision types, and power types.

EIA Low-Power Insulated Resistors†

These resistors are furnished with power ratings from 1 watt through 15 watts, in tolerances of ±5 and ±10 percent, and in resistance values from 0.1 ohm to 30 000 ohms in the preferred-value series of Table 2. They may be color coded as described in Fig. 2, but band A will be twice the width of the other bands. They may also be typographically marked in accordance with the EIA Standard.

The stability of these resistors is somewhat better than that of composition resistors, and they may be preferred except where a noninductive resistor is required.

EIA Precision Resistors‡

These resistors are furnished in ±1.0-, ±0.5-, ±0.25-, ±0.1-, and ±0.05-percent tolerances and in any value from 1.0 ohm to 1.0 megohm in the preferred-value series of Table 2. Power ratings range from 0.1 watt to 0.5 watt. The maximum ambient temperature for full wattage rating is 125°C. If the resistor is mounted in a confined area or may be required to operate in higher ambient temperature (145°C maximum), the allowable dissipation must be reduced in accordance with the EIA Standard.

These resistors have an inherently low noise level, approaching the thermal agitation level, and their stability is excellent-the typical change in resistance for the lifetime of the resistor will not exceed 50 percent of the initial resistance tolerance when used within the specified design limits of the EIA Standard.

The temperature coefficient of resistance over the range −55°C to +145°C, referred to 25°C, may have maximums as follows:

Value	EIA Standard
Above 10 ohms	±0.002% °C
5 ohms to 10 ohms	±0.006% °C
Below 5 ohms	±0.010% °C

Where required, temperature coefficients of less than ±20 ppm/°C can be obtained by special selection of the resistance wire. Temperature coefficients of ±10 ppm/°C may be obtained by limiting the range of temperatures for testing from -40°C to +105°C. The application of temperature coefficient to resistors should be limited, where possible, to the actual temperatures at which the equipment will operate.

EIA Power Resistors*

These resistors are furnished in 3 styles (strip; tubular, open end; and axial lead) and 24 power ratings ranging from 1 watt to 210 watts in tolerances of ±1.0 percent and ±5 percent. Resistance values range from 1.0 ohm to 182 kilohms in the preferred-value series of Table 2.

Axial-lead types are available in two general inductance classifications-inductive winding and noninductive winding. The noninductive styles have a maximum resistance value of 1/2 the maximum resistance of inductive styles because of the special manner in which they are wound. The inductance of noninductive styles must not exceed 0.5 microhenry when measured at a test frequency of 1.0 megahertz ±5%. However, these resistors should not be used in very-high-frequency circuits where the inductance may affect circuit operation.

The maximum ambient temperature for full wattage rating for these resistors is 25°C. When the resistors are operated at ambient temperatures above the wattage dissipation must be reduced in accordance with the EIA Standard.

RESISTORS-FIXED FILM

Film-type resistors use a thin layer of resistive material deposited on an insulating core. The low-power types are more stable than the usual composition resistors. Except for very high-precision requirements, film-type resistors are a good alternative to accurate wirewound resistors, being both

†EIA Standard RS-344.

‡EIA Standard RS-229-A.

*EIA Standard RS-155-B.

smaller and less expensive and having excellent noise characteristics.

The power types are similar in size and performance to conventional wirewound power resistors. While their 200°C maximum operating temperature limits the power rating, the maximum resistance value available for a given physical size is much higher than that of the corresponding wirewound resistor.

Construction

For low resistance values, a continuous film is applied to the core, a range of values being obtained by varying the film thickness. Higher resistances are achieved by the use of a spiral pattern, a coarse spiral for intermediate values and a fine spiral for high resistance. Thus, the inductance is greater in high values, but it is likely to be far less than in wirewound resistors. Special high-frequency units having greatly reduced inductance are available.

Resistive Films

Resistive-material films presently used are microcrystalline carbon, boron-carbon, and various metallic oxides or precious metals.

Deposited-carbon resistors have a negative temperature coefficient of 0.01 to 0.05 percent/° C for low resistance values and somewhat larger for higher values. Cumulative permanent resistance changes of 1 to 5 percent may result from soldering, overload, low-temperature exposure, and aging. Additional changes up to 5 percent are possible from moisture penetration and temperature cycling.

The introduction of a small percentage of boron into the deposited-carbon film results in a more stable unit. A negative temperature coefficient of 0.005 to 0.02 percent/°C is typical. Similarly, a metallic dispersion in the carbon film provides a negative coefficient of 0.015 to 0.03 percent/°C. In other respects, these materials are similar to standard deposited carbon. Carbon and boron-carbon resistive elements have the highest random noise of the film-type resistors.

Metallic-oxide and precious-metal-alloy films permit higher operating temperatures. Their noise characteristics are excellent. Temperature coefficients are predominantly positive, varying from 0.03 to as little as 0.0025 percent/°C.

Applications

Power ratings of film resistors are based on continuous direct-current operation or on root-mean-square operation. Power derating is necessary for operation at ambient temperatures above the rated temperature. In pulse applications, the power dissipated during each pulse and the pulse duration are more significant than average power conditions. Short high-power pulses may cause instantaneous local heating sufficient to alter or destroy the film. Excessive peak voltages may result in flashover between turns of the film element. Derating under these conditions must be determined experimentally.

Film resistors are fairly stable up to about 10 megahertz. Because of the extremely thin resistive film, skin effect is small. At frequencies above 10 megahertz, it is advisable to use only unspiraled units if inductive effects are to be minimized (these are available in low resistance values only).

Under extreme exposure, deposited-carbon resistors deteriorate rapidly unless the element is protected. Encapsulated or hermetically sealed units are preferred for such applications. Open-circuiting in storage as the result of corrosion under the end caps has been reported in all types of film resistors. Silver-plated caps and core ends effectively overcome this problem.

Technical Characteristics

Some technical characteristics of film resistors are given in Tables 11, 12, and 13.

TABLE 11. STABLE EQUIVALENTS FOR COMPOSITION RESISTORS; AXIAL LEADS; DATA FOR MIL "RL" SERIES

Watts	1/4	1/2	1	2
Voltage rating	250	350	500	500
Critical resistance (megohms)	0.25	0.25	0.25	0.12

Maximum temp for full load-70° C; for 0 load-l 50° C

Resistance-temperature characteristic: ±200 ppm/ C maximum

Life-test resistance change: ±2% maximum

Moisture resistance test: ±1.5% maximum change

Resistance values: E24 series, same as composition resistors; tolerances 2% or 5%.

The MIL "RN" series of film resistors is more stable than the "RL" series and is available in a wider range of ratings. Commercial equivalents are also offered. Where stability and reliability are desired, the "RN" series is economically very competitive with the "RC" or "RL" series.

RESISTORS-ADJUSTABLE

Adjustable resistors may be divided into three separate and distinct categories, potentiometers, trimmers, and rheostats.

Potentiometers are control devices that are used