ECEN 4013

*Design of Engineering Systems*

# Agenda

NCL Training

New Sprint

Resistors

# Project 1

It is now week 5 in the semester.

Demo is week 8

# NCL Training

What tools are at your disposal?

- CNC Mill
- CNC Lathe
- CNC Router
- Abrasive Water Jet
- Sheet Metal Forming
- Thermal Plastic Bender
- Thermal Plastic Vaccuum Former
- Welding
- Casting
- Powder Coating
- Boss Laser 150 Watt

# NCL Training

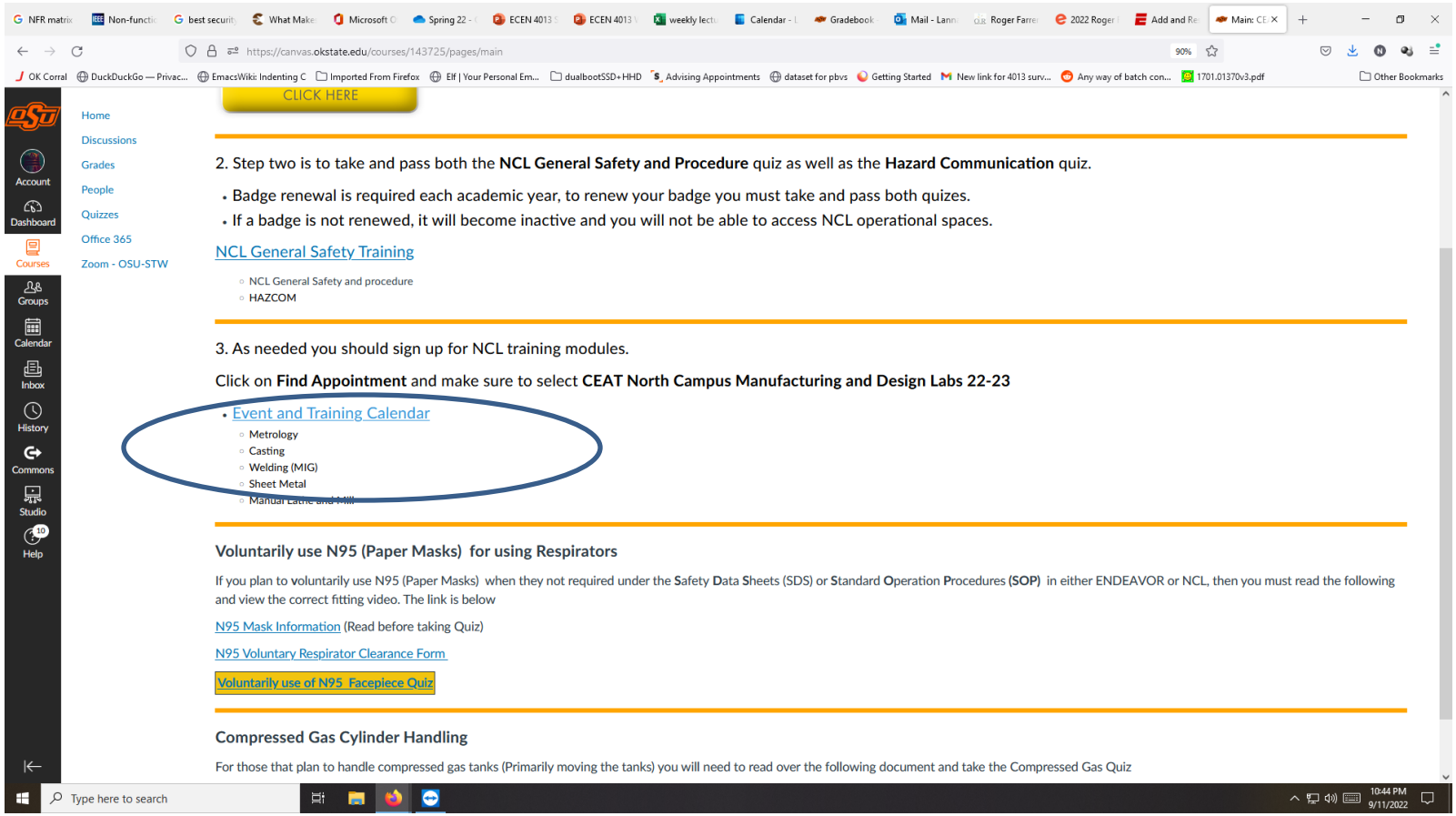
What do you need to do to use these tools?

1. Complete Safety Quizzes and get badge
2. Sign up for training
   - Thermal plastic is a case-by-case training – you can contact CEATNCL@oksate.edu when you have a design or make an appointment for one of the "Design Friday" sessions
3. Attend Training

# NCL Training

## What do you need to do to use these tools?

2. Sign up for training

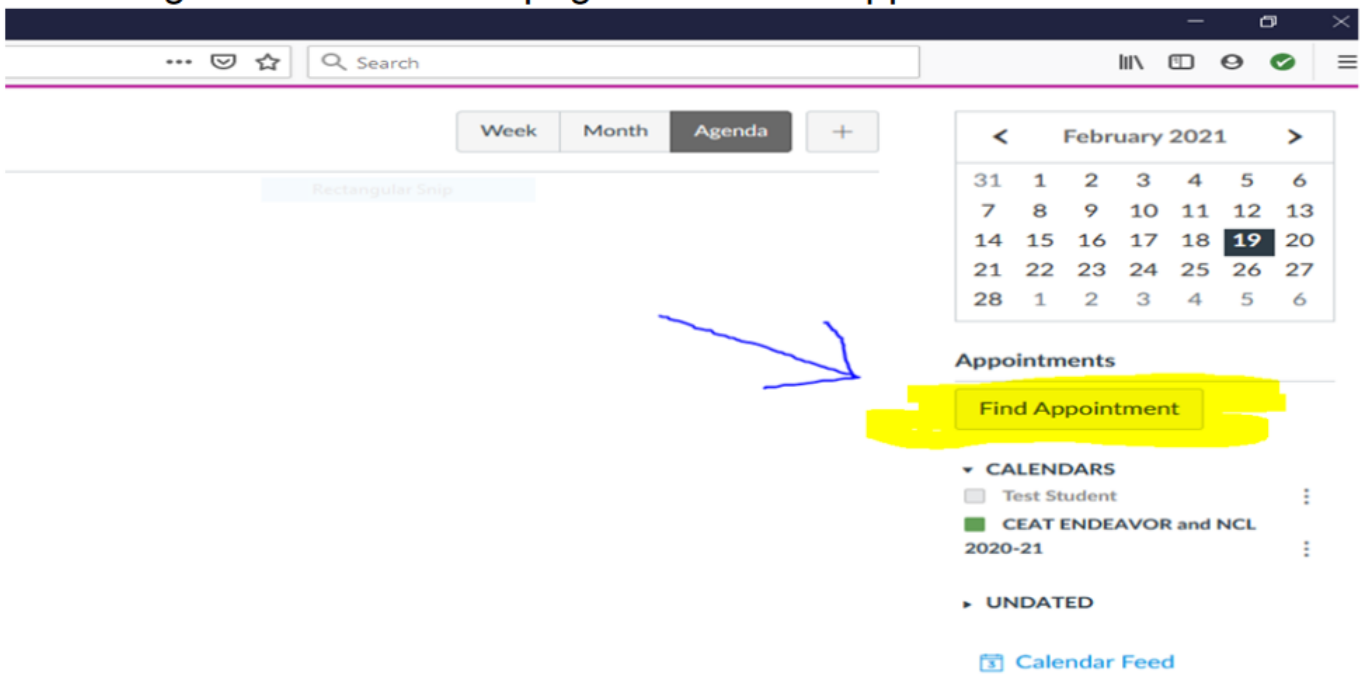


# NCL Training

What do you need to do to use these tools?

2. Sign up for training

On the right side of the next page select Find Appointments.

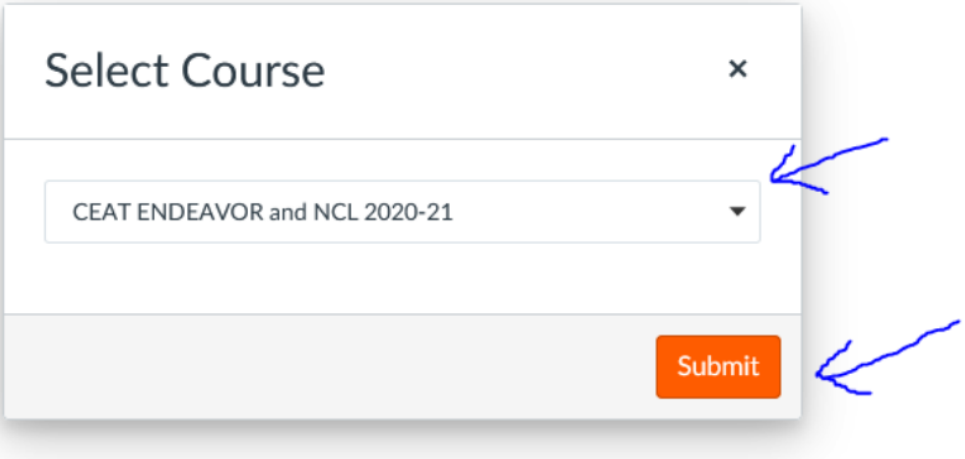


# NCL Training

## What do you need to do to use these tools?

## 2. Sign up for training

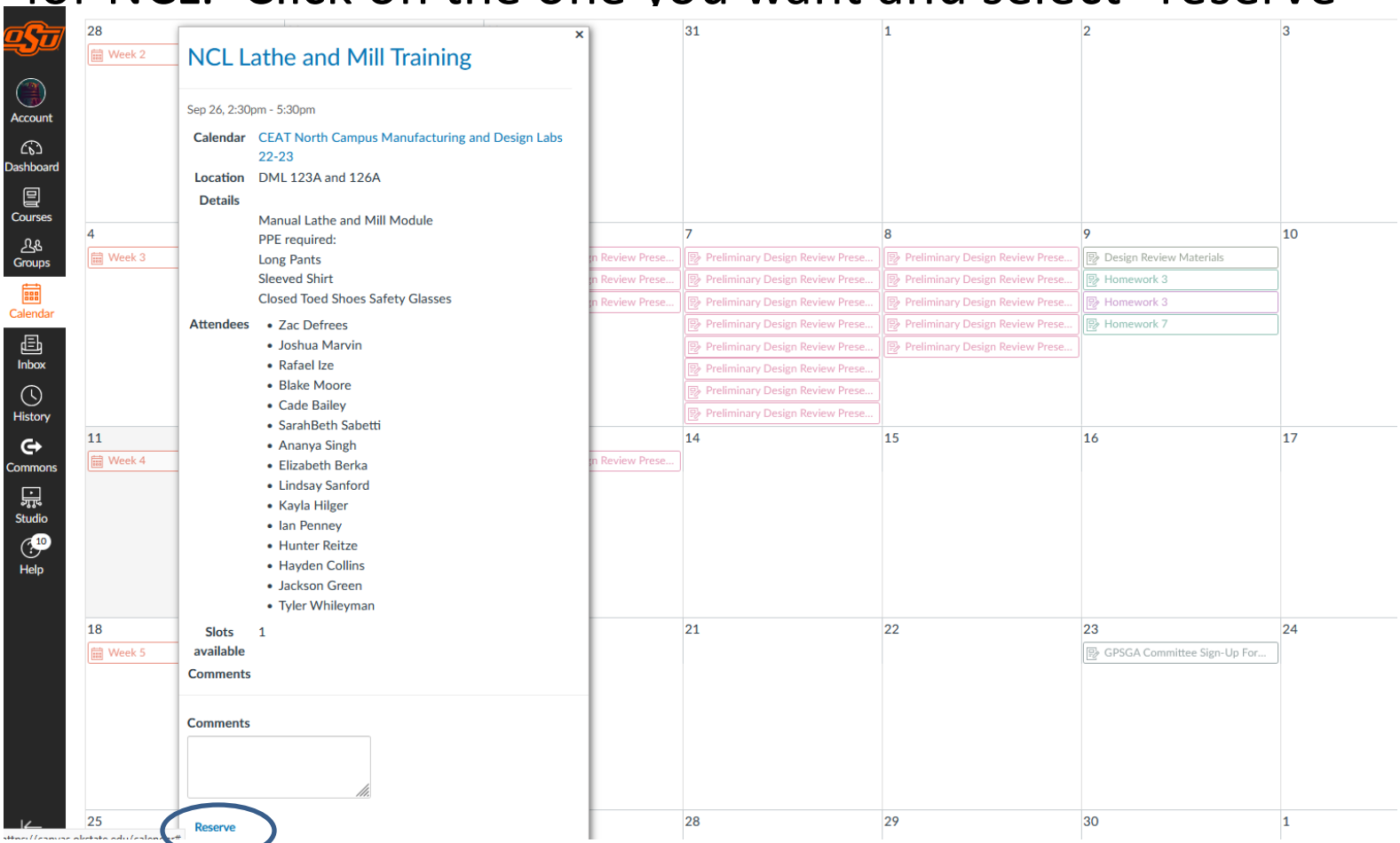
In the pop up window select the current CEAT Endeavor and NCL canvas page. (may have to turn of pop up blocker). Push submit once course is selected.



# NCL Training

What do you need to do to use these tools?

2. Sign up for training – training dates will be highlighted for NCL. Click on the one you want and select "reserve"



# NCL Training

What do you need to do to use these tools?

2. Sign up for training

If your schedule changes and you will not be able to attend a training, return to this page and select un-reserve. It will be in the location that reserve was. This will allow you to enroll in a future training of the same type. If you are unable to do this and need to re-enroll in a training please contact CEATNCL@oksate.edu and we will work to manually enroll you in an open training.

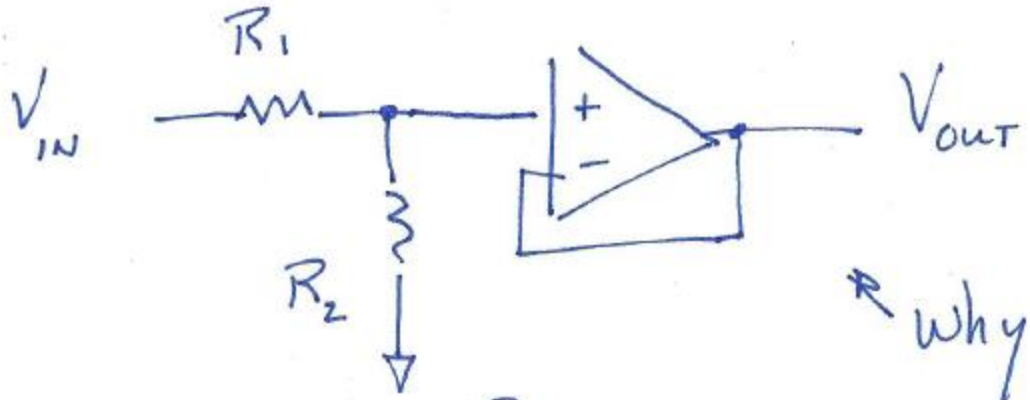
# Basic resistor calculations and resistor tolerances

# Basic resistor calculations and resistor tolerances

Take a few minutes and design a resistive divider (attenuator) to attenuate signal by a factor of 10 (20 dB attenuation) accurate to 1%.

Maximum input voltage is ±10 Volts

# Attenuator – initial sketch




↖ Why use a buffer?

$$H(s) = \frac{R_2}{R_1 + R_2}$$

let $R_1 = 9K$

$R_2 = 1K$

# Attenuator – basic error estimate

$$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$$ Transfer Function

$$\frac{\partial V_{out}}{\partial R_1} = -V_{in}\frac{R2}{(R_1 + R_2)^2}$$ Change due to R1

$$\frac{\partial V_{out}}{\partial R_2} = V_{in}\frac{R1}{(R_1 + R_2)^2}$$ Change due to R2

$$\Delta V_{out} = \pm\left(\left|\frac{\partial V_{out}}{\partial R_1}\Delta R_1\right| + \left|\frac{\partial V_{out}}{\partial R_2}\Delta R_2\right|\right)$$ Maximum Difference in Vout

$$\Delta R_1 = \pm 9000 * 0.01 = \pm 90$$

# Attenuator – basic error estimate

$$\Delta V_{out} = \pm\left(\left|\frac{\partial V_{out}}{\partial R_1}\Delta R_1\right| + \left|\frac{\partial V_{out}}{\partial R_2}\Delta R_2\right|\right)$$

Let Vin = 100v and Vout = 10v
R1 = 9k and R2=1k

$$\Delta V_{out} = \text{ 0.18 V}$$

This is 1.8% of Vout and would therefore be outside of accuracy spec. You would need better than 1% tolerant resistors

# Attenuator – part selection

1 kohm is a standard value resistor

Unfortunately, 9 kohm is not a standard value part.

You will need to know about standard resistor values.

# Attenuator – part selection

That simple resistive divider really isn't all that simple.

Notice we've neglected resistor temperature effects and non-idealities of the operational amplifier.

Designers have to take all these things and more into account.  Good design requires careful attention to all details.

# RESISTORS

- Resistors are basic components and are used almost everywhere in electronics.
- A great many options are available to designers.  This presentation introduces material needed to select and apply them correctly.
- Only types likely to be useful for your project are covered.

# RESISTORS

- Resistors can be fixed or variable.  Most applications use fixed resistors.

- Fixed resistors are readily available in a bewildering range of packages, tolerances, power dissipation ratings, compositions, and other details.

- Selection can be confusing for the new designer. We will consider typical examples.

# CARBON COMPOSITION RESISTORS

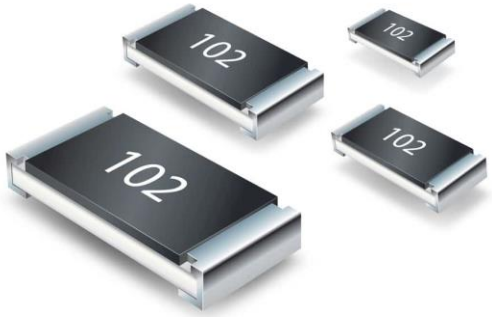
- Carbon composition resistors (rarely used in new work) go back to the earliest days of electronics (but were used well into the 1970s). You can still buy them. They usually are used for restorations or when the customer wants an exact duplicate of an old design.
- They often exhibit “excess noise” due to their construction.

# CARBON FILM RESISTORS

- Carbon film resistors are very common and are a common leaded part used in through-hole applications.  They are robust, versatile, inexpensive, and readily available from many sources.
- Standard values range from fractions of an ohm to 22 Megohm.
- Temperature coefficients are good (usually 200-400 ppm/°C) but not great for large temperature excursion applications.

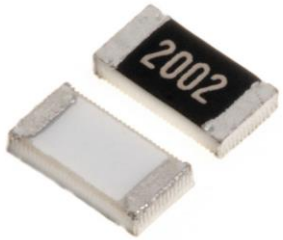
# THICK FILM RESISTORS

- Thick film resistors are made by screening conductive ink onto a ceramic substrate and firing in an oven to fuse the ink particles to each other and to the substrate.
- Widely available as surface-mount and through-hole devices (by attaching lead wires and encapsulating the assembly to look like carbon film).
- Noise and temperature coefficients vary but are usually acceptable.

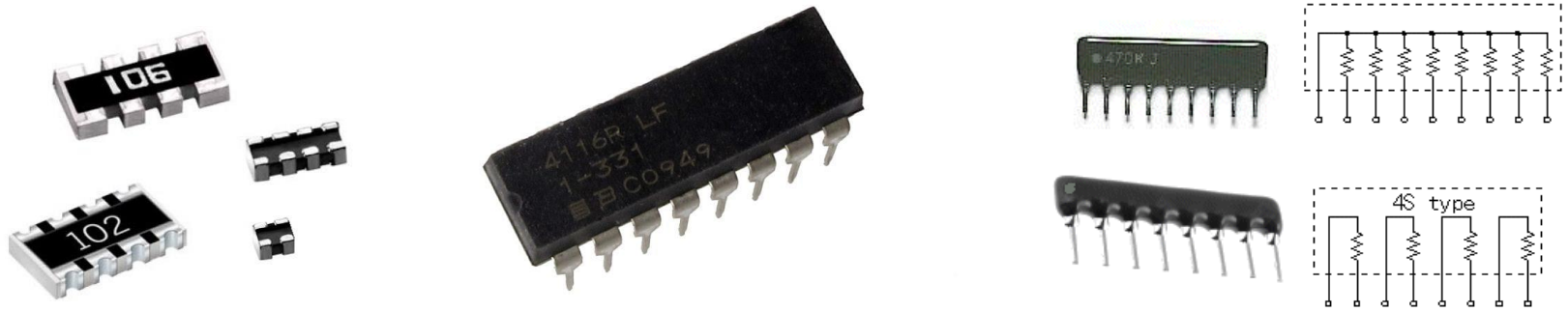

# THIN FILM RESISTORS

- Thin film resistors usually are made by depositing a thin metal layer on a ceramic substrate in various geometries. This construction has no particle boundaries and consequently tends to have lower noise.
- Available as surface-mount and leaded parts.
- Noise and temperature coefficients are usually superior to carbon film and thick film devices.



# RESISTOR NETWORKS AND ARRAYS

- Resistor networks and arrays are widely used as data line terminations, attenuators, gain-setting networks, and as ratio-matched resistor sets for precision amplifiers.
- Thick-film or thin-film constructions are common. Temperature coefficients and noise are typical of the particular construction.
- DMM range selection is typically done using a thick-film resistor array.



# WIREWOUND RESISTORS

- Wirewound resistors are used for applications requiring more than 1 Watt of power dissipation. 2-5 Watt ratings are relatively common. Much higher power ratings are possible.
- Construction involves winding resistive wire or strap around a ceramic core.
- This construction produces a resistor with an inductive component; use is typically limited to low-frequency applications requiring modest or high power dissipation.



# RESISTORS – THE ENGINEERING DETAILS

# ABOUT THE COLOR CODE

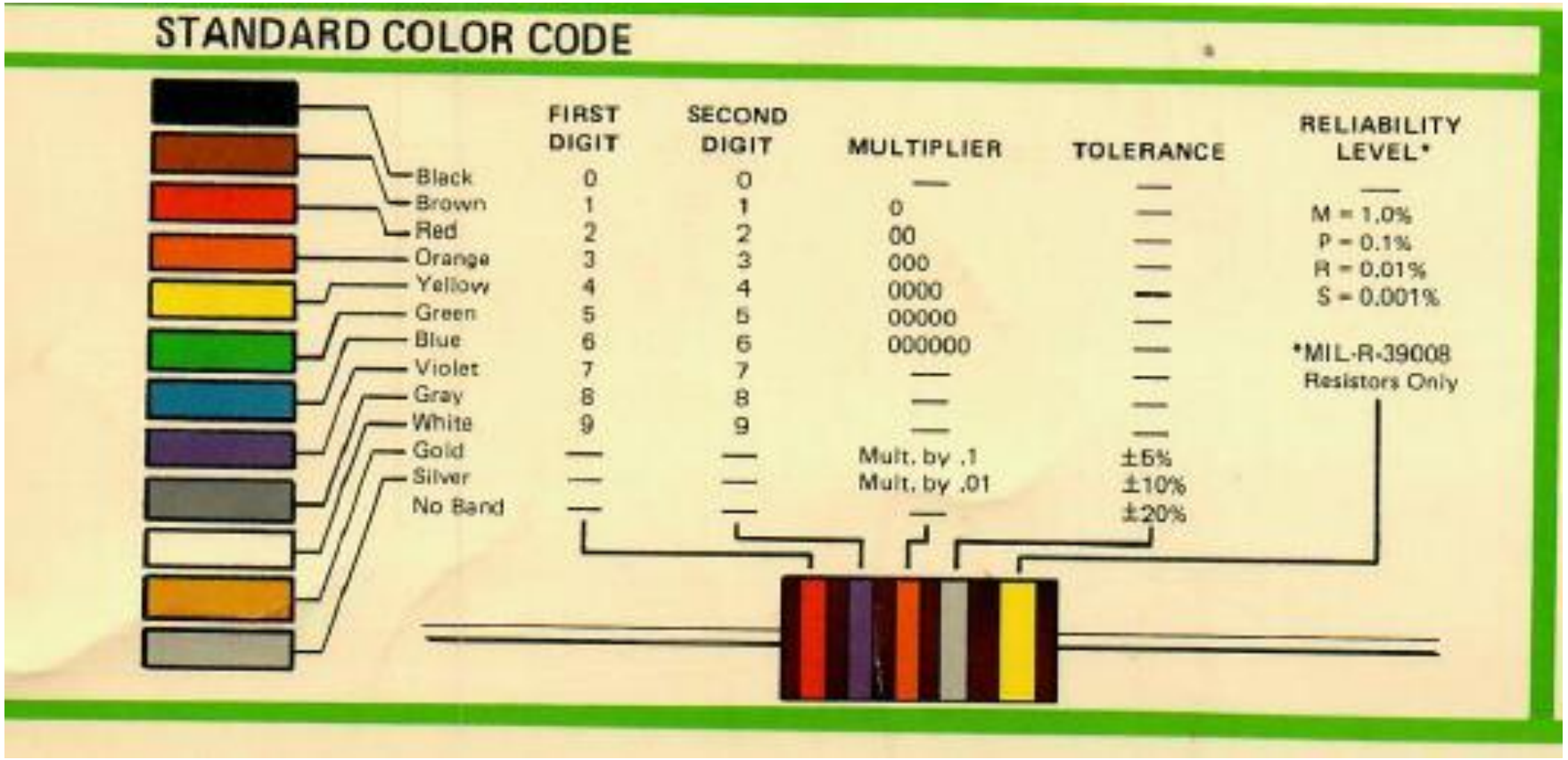
Think of the color code as being similar to color temperatures – from cold (black and brown) through red, orange, yellow, and progressively shorter wavelengths. The analogy isn't 100% accurate, but it helps.

Make your own acronym for the color sequence BBROYGBVGW

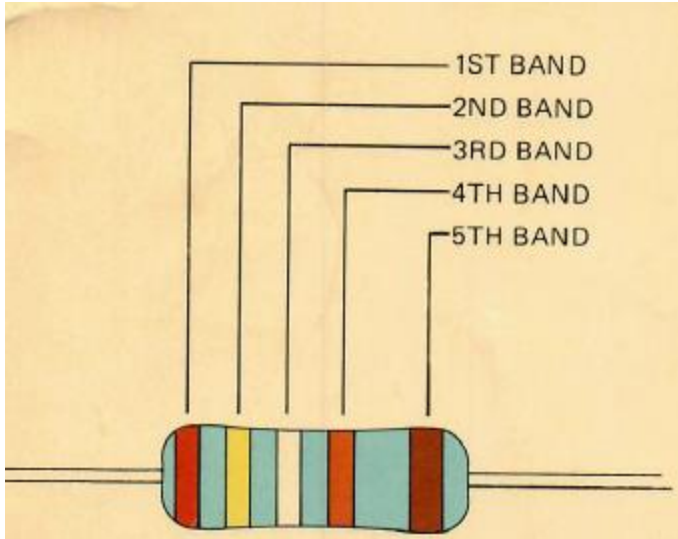
**B**adly **B**urnt **R**esistors **O**n **Y**our **G**round **B**us **V**oid **G**eneral **W**arranty

You all should be able to read/understand the color code

# FIXED RESISTORS – 5% TOLERANCE available in ECE stockroom



# FIXED RESISTORS – 1% TOLERANCE readily available from Mouser




| | PRECISION | GENERAL PURPOSE |
|---|---|---|
| 1ST BAND | NOMINAL | NOMINAL |
| 2ND BAND | NOMINAL | NOMINAL |
| 3RD BAND | NOMINAL | MULTIPLIER |
| 4TH BAND | MULTIPLIER | TOLERANCE |
| 5TH BAND | TOLERANCE | SOLDERABILITY (OPTIONAL) |

| | NOMINAL | MULTIPLIER | TOLERANCE (%) |
|---|---|---|---|
| Black | 0 | 1 | |
| Brown | 1 | 10 | 1 |
| Red | 2 | 100 | 2 |
| Orange | 3 | 1K | |
| Yellow | 4 | 10K | |
| Green | 5 | 100K | 0.5 |
| Blue | 6 | | 0.25 |
| Violet | 7 | | 0.1 |
| Gray | 8 | | |
| White | 9 | | |
| Silver | | 0.01 | |
| Gold | | 0.1 | 5 |

METAL FILM resistors used for general-purpose and semiprecision (RL) applications have two significant-figure bands, a multiplier band, a tolerance band, and a final white band to indicate that leads can be soldered. Precision (RN) and low-resistance units are available with either color bands or alphanumeric printing. If banded, these resistors have three significant-figure bands, a multiplier band, and a tolerance band.

Complete physical, electrical and environmental data available in Bulletin

STACKPOLE
COMPONENTS COMPANY
P. O. BOX 14466, RALEIGH, NC 27620
Phone 919-828-6201 • TWX 510-928-0520

# FIXED RESISTORS – STANDARD VALUES

**STANDARD RESISTANCE VALUES FOR THE 10-TO-100 DECADE**
**(also usable in decade multiples or sub-multiples)**

| RESISTANCE TOLERANCE (±%) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1% 0.25% 0.5% | 1% | 2% 5% | 0.1% 0.25% 0.5% | 1% | 2% 5% | 0.1% 0.25% 0.5% | 1% | 2% 5% | 0.1% 0.25% 0.5% | 1% | 2% 5% | 0.1% 0.25% 0.5% | 1% | 2% 5% | 0.1% 0.25% 0.5% | 1% | 2% 5% |
| 10.0 | 10.0 | 10 | 14.7 | 14.7 | – | 21.5 | 21.5 | – | 31.6 | 31.6 | – | 46.4 | 46.4 | – | 68.1 | 68.1 | 68 |
| 10.1 | – | – | 14.9 | – | – | 21.8 | – | – | 32.0 | – | – | 47.0 | – | 47 | 69.0 | – | – |
| 10.2 | 10.2 | – | 15.0 | 15.0 | 15 | 22.1 | 22.1 | 22 | 32.4 | 32.4 | – | 47.5 | 47.5 | – | 69.8 | 69.8 | – |
| 10.4 | – | – | 15.2 | – | – | 22.3 | – | – | 32.8 | – | – | 48.1 | – | – | 70.6 | – | – |
| 10.5 | 10.5 | – | 15.4 | 15.4 | – | 22.6 | 22.6 | – | 33.2 | 33.2 | 33 | 48.7 | 48.7 | – | 71.5 | 71.5 | – |
| 10.6 | – | – | 15.6 | – | – | 22.9 | – | – | 33.6 | – | – | 49.3 | – | – | 72.3 | – | – |
| 10.7 | 10.7 | – | 15.8 | 15.8 | – | 23.2 | 23.2 | – | 34.0 | 34.0 | – | 49.9 | 49.9 | – | 73.2 | 73.2 | – |
| 10.9 | – | – | 16.0 | – | 16 | 23.4 | – | – | 34.4 | – | – | 50.5 | – | – | 74.1 | – | – |
| 11.0 | 11.0 | 11 | 16.2 | 16.2 | – | 23.7 | 23.7 | – | 34.8 | 34.8 | – | 51.1 | 51.1 | 51 | 75.0 | 75.0 | 75 |
| 11.1 | – | – | 16.4 | – | – | 24.0 | – | 24 | 35.2 | – | – | 51.7 | – | – | 75.9 | – | – |
| 11.3 | 11.3 | – | 16.5 | 16.5 | – | 24.3 | 24.3 | – | 35.7 | 35.7 | – | 52.3 | 52.3 | – | 76.8 | 76.8 | – |
| 11.4 | – | – | 16.7 | – | – | 24.6 | – | – | 36.1 | – | 36 | 53.0 | – | – | 77.7 | – | – |
| 11.5 | 11.5 | – | 16.9 | 16.9 | – | 24.9 | 24.9 | – | 36.5 | 36.5 | – | 53.6 | 53.6 | – | 78.7 | 78.7 | – |
| 11.7 | – | – | 17.2 | – | – | 25.2 | – | – | 37.0 | – | – | 54.2 | – | – | 79.6 | – | – |
| 11.8 | 11.8 | – | 17.4 | 17.4 | – | 25.5 | 25.5 | – | 37.4 | 37.4 | – | 54.9 | 54.9 | – | 80.6 | 80.6 | – |
| 12.0 | – | 12 | 17.6 | – | – | 25.8 | – | – | 37.9 | – | – | 56.6 | – | – | 81.6 | – | – |
| 12.1 | 12.1 | – | 17.8 | 17.8 | – | 26.1 | 26.1 | – | 38.3 | 38.3 | – | 56.2 | 56.2 | 56 | 82.5 | 82.5 | – |
| 12.3 | – | – | 18.0 | – | 18 | 26.4 | – | – | 38.8 | – | – | 56.9 | – | – | 83.5 | – | – |
| 12.4 | 12.4 | – | 18.2 | 18.2 | – | 26.7 | 26.7 | – | 39.2 | 39.2 | – | 57.6 | 57.6 | – | 84.5 | 84.5 | – |
| 12.6 | – | – | 18.4 | – | – | 27.1 | – | 27 | 39.7 | – | – | 58.3 | – | – | 85.6 | – | – |
| 12.7 | 12.7 | – | 18.7 | 18.7 | – | 27.4 | 27.4 | – | 40.2 | 40.2 | – | 59.0 | 59.0 | – | 86.6 | 86.6 | – |
| 12.9 | – | – | 18.9 | – | – | 27.7 | – | – | 40.7 | – | – | 59.7 | – | – | 87.6 | – | – |
| 13.0 | 13.0 | 13 | 19.1 | 19.1 | – | 28.0 | 28.0 | – | 41.2 | 41.2 | – | 60.4 | 60.4 | – | 88.7 | 88.7 | – |
| 13.2 | – | – | 19.3 | – | – | 28.4 | – | – | 41.7 | – | – | 61.2 | – | – | 89.8 | – | – |
| 13.3 | 13.3 | – | 19.6 | 19.6 | – | 28.7 | 28.7 | – | 42.2 | 42.2 | – | 61.9 | 61.9 | 62 | 90.9 | 90.9 | 91 |
| 13.5 | – | – | 19.8 | – | – | 29.1 | – | – | 42.7 | – | – | 62.6 | – | – | 92.0 | – | – |
| 13.7 | 13.7 | – | 20.0 | 20.0 | 20 | 29.4 | 29.4 | – | 43.2 | 43.2 | 43 | 63.4 | 63.4 | – | 93.1 | 93.1 | – |
| 13.8 | – | – | 20.3 | – | – | 29.8 | – | – | 43.7 | – | – | 64.2 | – | – | 94.2 | – | – |
| 14.0 | 14.0 | – | 20.5 | 20.5 | – | 30.1 | 30.1 | 30 | 44.2 | 44.2 | – | 64.9 | 64.9 | – | 95.3 | 95.3 | – |
| 14.2 | – | – | 20.8 | – | – | 30.5 | – | – | 44.8 | – | – | 65.7 | – | – | 96.5 | – | – |
| 14.3 | 14.3 | – | 21.0 | 21.0 | – | 30.9 | 30.9 | – | 45.3 | 45.3 | – | 66.5 | 66.5 | – | 97.6 | 97.6 | – |
| 14.5 | – | – | 21.3 | – | – | 31.2 | – | – | 45.9 | – | – | 67.3 | – | – | 98.8 | – | – |

# ABOUT TOLERANCE AND AVAILABLE VALUES

Resistor tolerance and standard values are related. The coarser values (2% and 5% tolerances) overlap the older composition resistor values.

1% tolerance resistors are readily available at little or no price penalty relative to the 2% and 5% values. 1% values are probably the most widely used.

Tolerances to 0.1% are standard parts available for a higher price.

Our examples will assume 5% tolerance parts.

# 5% COLOR CODE EXAMPLES

Yellow-Violet-Red

Yellow = first digit = 4

Violet = second digit = 7

Red = multiplier => add two zeros

Yellow-Violet-Red = 4700 = 4.7k

# 5% COLOR CODE EXAMPLES

Brown-Black-Orange

Brown = first digit = 1

Black = second digit = 0

Orange => add three zeros

Brown-Black-Orange = 10000 = 10.0k

# 5% COLOR CODE EXAMPLES

Red-Black-Brown

Red = first digit = 2

Black = second digit = 0

Brown => add one zero

Red-Black-Brown = 200 = 200 ohm

# ABOUT THE PART NUMBERS

Manufacturer part numbers for these simple parts are lengthy. They vary from manufacturer to manufacturer, although the information they represent are generally the same.

This is necessary because of the wide variety of types available.

# ABOUT THE PART NUMBERS

STACKPOLE Example:

CF12GT10K2

CF = Standard carbon film

12 = 1/2 Watt

G = 2% tolerance

T = Tape and Reel packaging

10K2 = 10.2 kohm resistance

# OTHER ENGINEER STUFF

Resistance varies with temperature (tempco) and also varies by type, power rating, and manufacturer series.

The Stackpole part in previous slide has guaranteed tempco between 0 and -500 ppm/°C, where

ppm = parts per million

# OTHER ENGINEER STUFF

Power ratings, voltage limits, mechanical dimensions, packaging information, and other important design information are found in the spec sheets.

Power dissipation capability must be de-rated at high ambient temperatures, typically beginning at 70°C.

# FIXED RESISTORS – SURFACE MOUNT DEVICES

- Standard resistors are available in surface-mount packages. These are widely used, especially in high production volumes or when small physical size is important.
- Automated machinery makes manufacturing fast, efficient, and low cost.
- Resistance codes are numerical and printed on the part.

# FIXED RESISTORS – SURFACE MOUNT DEVICES

- Surface-mount devices require a circuit board with proper solder pads. This makes sense in a manufacturing environment but may not be the best option for prototyping on a short-term project.

- Be careful to avoid devices that are too small – the tiniest devices are very difficult to install by hand.

# SURFACE MOUNT DEVICES

# OTHER RESISTORS OF INTEREST


Other resistor elements are available to provide functions related to variable resistance. Potentiometers are well known devices of this type. Potentiometers are commonly available, but often suffer from mechanical instability, fragility, tempco issues, and physical size. Digital potentiometers pack many resistor values in one small IC.

# Questions?