
N0AX

# HANDS-ON RADIO

## Experiment #56 — Design Sensitivities

Sensitivity is important in ham radio, and in more ways than just the ability to hear signals. When designing an electronic circuit, it's important to know which component values are critical. It might be critical to choose just the right type of component or even change the design to be more tolerant of component variations. In this column, we'll introduce sensitivity and how it's calculated.

### Terms to Learn

*Tolerance* — allowable variation around the nominal value, usually given in percent (%) or parts per million (ppm).

*Nominal value* — the specified value of a component.

*Standard value* — a series of normal production values commonly specified for components.

*Actual value* — the measured value of a component.

*Ideal value* — an exact value resulting from a design calculation.

*Typical value* — a common value exhibited by components of the specified type.

### Component Values

When designing a circuit, a calculator will spit out values with many digits, such as 4.83456 kΩ or 373.29 pF. It would be difficult to order components with these *ideal values*, however. You might use variable components carefully adjusted to those exact values, but what about inductors and transistors? What about measurement errors? Adjustment won't work very well. The usual technique is to use the closest *standard value* and accept any resulting differences in performance.

Where do standard values come from? If you open a catalog or look at a list of available component values, you'll recognize a series of familiar numbers such as those for "5%" components seen in Table 1. The percentage value refers to the component's *tolerance*. Each component's value is centered in a *tolerance window* centered between those of its neighbors. For example, a 12 Ω resistor with a 5% tolerance may have an actual resistance anywhere from 12 – 5% = 11.4 Ω to 12 + 5% = 12.6 Ω. The next lowest neighbor, 11 Ω, has a tolerance window ranging from 10.45 Ω to 11.55 Ω, overlapping the lower edge of the 12 Ω window from 11.4 Ω to 11.55 Ω.

### Exercise Set #1

Use the same procedure as in the preceding paragraph to see if the 36 Ω standard value's tolerance window overlaps with the edges of the 33 Ω and 39 Ω windows. Find the tolerance window for a 68 Ω, 10% resistor. Go to your junk box and find up to 10 resistors with the same value marked on their surface in text or with paint bands. Using a volt-ohm-milliammeter (VOM), measure the value of each resistor and calculate the difference in percent from the marked value. If you have more than one VOM, measure the resistors *again* using the second VOM. (This is a good exercise to perform with a couple of friends, sharing resistors and meters.) Make a histogram of each set of values as shown at **en.wikipedia.org/wiki/Histogram** and compare the results. Not only do resistor values vary, but measurements by different meters vary, too!

### Ideal, Nominal and Actual

The value indicated by those component markings, such as "103" on a ceramic capacitor meaning $1 \times 10^3$ pF = 1 nF = 0.001 µF, is the *nominal* value. It's almost certainly *not* the component's *actual* value because of the allowed tolerance, such as 5% or 10%. As you just saw in Exercise Set #1, there can be a significant amount of variation between components of the same nominal value!

A design calculation produces an *ideal* value, such as 1.0927 MΩ. The closest *standard* value is chosen for the design and that is the nominal value of the component. When the nominal values of each component are used to calculate circuit parameters such as gain or frequency response, the result is the nominal value for that parameter. If measured, the component and parameter will have a third value, the *actual* value. Actual values determine the actual value of circuit parameters — how the circuit actually functions.

Designers have to take into account this progression from ideal to actual, even for transistors and ICs. For example, the dc gain or β of a transistor is specified to have a minimum and maximum acceptable value, along with a *typical* value, representative of how most components will behave.

Because the values of the components vary from component to component, the performance of the circuit in which the component is used will also vary. Sometimes the variations are quite small compared to the amount of change in the component value. In other circuits, small variations can have big effects on performance. Circuit designers must take into account the relationship between component variation and circuit performance. This is called *design sensitivity*.

Calculating design sensitivity for a particular component begins with choosing the design parameter of interest. For example, in an antenna tuner circuit, sensitivity may be calculated with respect to range and not for harmonic rejection or power dissipation.

**Table 1**
**5% and 10% Standard Values**

**5% Standard Series**

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 11 | 12 | 13 | 15 | 16 | 18 | 20 | 22 | 24 | 27 | 30 | 33 | 36 | 39 | 43 | 47 | 51 | 56 | 62 | 68 | 75 | 82 | 91 |

**10% Standard Series**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 12 | 15 | 18 | 22 | 27 | 33 | 39 | 47 | 56 | 68 | 82 |

For 1% standard series see **www.rfcafe.com/references/electrical/resistor_values.htm**.

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Only the value of the component under investigation is changed. Other component values are kept constant so that the calculated sensitivity depends only on changes in the value of the selected component.

Sensitivity is often expressed in % of parameter change per % of component change — % per %. If in the tuner circuit a change in 5% of a capacitor's value results in a 10% change in matching range, the sensitivity of range to capacitor value is 10% / 5% or 2% per %. (Sensitivity can also be expressed in electrical units, such as Ω / pF or V / µH, if that is most useful to the designer.) Amplifier and filter circuits often have sensitivity expressed as dB per % of change.

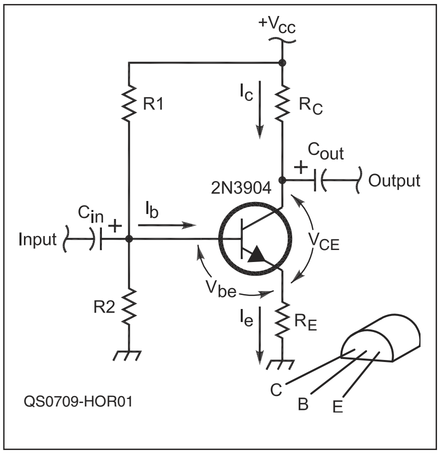

**Figure 1 — The common-emitter amplifier's gain is determined by the ratio of $R_C$ and $R_E$.**

## Exercise Set #2

Read the very first *Hands-On Radio* column (Feb 2003) about the "Common-Emitter Amplifier" shown in Figure 1 and find the equation for voltage gain; $A_V \approx -R_C/R_E$.[1] We'll determine voltage gain sensitivity to both $R_C$ and $R_E$. Assume nominal values for $R_C = 3.9\ k\Omega$ and $R_E = 220\ \Omega$. The nominal value for midband gain is approximately –17.7. What is the actual value of gain if either $R_C$ or $R_E$ vary by 5%? (Either –18.6 or –16.8) The sensitivity of gain to $R_C$ = change in gain / change in $R_C$ value = [(–18.6 –17.7) / –17.7] / 5% = 5.08% / 5% ≈ 1% / %, meaning that for every percent $R_C$ changes, gain will change by the same amount. (The sensitivity for changes in $R_E$ = –1% / % because as $R_E$ increases, the gain is reduced.) Sensitivity to changes in $R_C$ or $R_E$ could also have been expressed in dB / %. A sensitivity of 1% / % = 0.04 dB / %.

## Exercise Set #3

Read the *Hands-On Radio* column on "Notch Filters" from July 2006 and find the equation for center frequency, $f_0$, of the Twin-T circuit shown in Figure 2. Let's assume that all of the Rs and Cs are exactly matched. If this circuit is going to be used in your backpack station, it will probably be subjected to temperature swings. How much will the filter's center frequency change with temperature as the capacitors heat and cool?

Most audio circuits use film capacitors. A common temperature coefficient for film capacitors is –150 ppm / °C. (The capacitor expands, increasing the separation between electrodes and reducing capacitance.) A change of 10 ppm is 0.001%, so the capacitor has a "tempco" of –0.015% / °C.

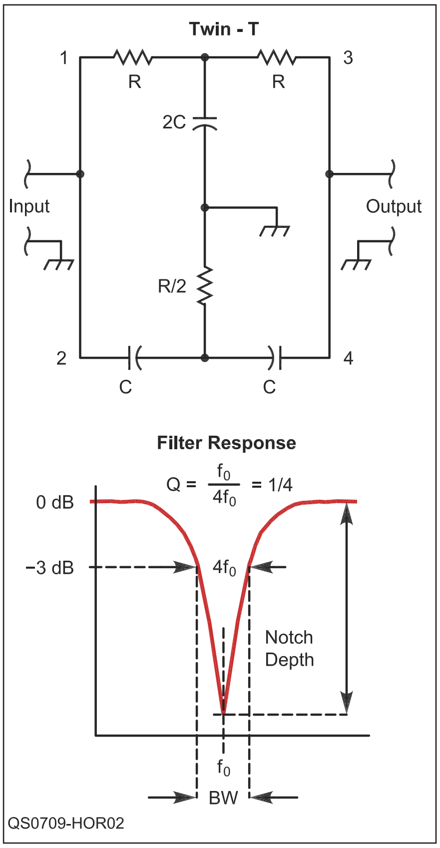

**Figure 2 — Notch frequency and depth depend on careful matching of component values. Temperature changes can upset that balance.**

Start by computing the sensitivity of $f_O$ to the value of C as in the previous Exercise — change the value of C by a few percent and see how much $f_0$ changes as a result. (We're assuming both capacitors change temperature equally and so both can be treated as a single component.) You'll find the sensitivity of $f_0$ to C is –1% / %; as C increases, $f_0$ decreases. For C to change 1%, temperature must change by 1 / 0.015 = 66.6°C, which is equivalent to 1 / 66.6 = 0.015% / °C. So the sensitivity of $f_O$ to temperature is –0.015% / °C. If $f_O$ is 1 kHz at room temperature (23 °C), taking it outside into the hot sun at 35 °C, the change of 12° will result in $f_0$ changing by 0.015% × 12 = 0.18% or 1.8 Hz.

## Worst Case and Monte Carlo

In Exercise #2, what is voltage gain if $R_C$ increases by 5% and $R_E$ decreases by the same amount (–19.6)? Vice versa? (–16.0). The *worst case* values of gain occur when both components vary to the maximum amount allowed and in ways that change the circuit parameter in the same direction. In a complicated circuit, finding the worst-case scenario can be very difficult. As a result, circuit designers use the *Monte Carlo* method in which all significant component values are varied randomly within their specified tolerance windows. The resulting values of the circuit parameter, such as gain, also vary randomly. As more and more component value combinations are tried, gradually the extreme worst case values of gain are found. Obviously, this requires a computer to perform the necessary calculations and display the results.

## Recommended Reading

How about some more practice in computing sensitivities? You can use any of the *Hands-On Radio* circuits that define a parameter in terms of component values. For a slightly trickier calculation, take a look at the August 2004 column on "Current Sources" and determine the sensitivity of load current ($I_{LOAD}$) to transistor gain (β) for the current mirror.

## Next Month

We haven't visited transmission lines in a while, so let's learn some more about stubs and the use of the nearly ubiquitous SWR analyzer instrument. You'll need an oscilloscope to make the necessary adjustments and measurements. If you don't have one, buddy up, or make this one a club project.

# Strays

### MARIANAS CLUB SEEKS DONATIONS

◊ I am writing this as an appeal for help for the hams on Guam and throughout Micronesia. Our club, the Marianas Amateur Radio Club, has been actively recruiting, training and testing people from all over Micronesia and Oceania plus the military personnel passing through. We have been very successful in getting people licensed but now comes the problem: For several reasons, getting equipment to get these folks on the air is a major problem.

I'm asking for donations of your equipment, old or new, broken or not (as long as it may be repairable by robbing parts from one to another, as parts can be another problem.) MARC is a non-profit organization, and a tax deduction may be available to US residents.

I realize shipping may be a problem but we do have some resources for that as we are fortunate enough have a pilot for a major airline who will help line up the shipping. Our Web site is **www.guamham.com**.

Thanks for your time and constructive comments are more than welcome. — *Dick Manns, KH2G, Yigo, Guam*

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[1] ARRL members can download Hands-On Radio columns from **www.arrl.org/tis/info/HTML/Hands-On-Radio**.