ON BAD CIRCUIT MODELLING

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ABSTRACT

Traditional circuit modelling methods typically assume ideal circuit components. Real world audio circuits exhibit variations in behavior due to non-ideal factors including component tolerances, operating temperature, and aging. We present an brief discussion of each of these non-ideal factors for resistors, capacitors, and operational amplifiers (op-amps), and show how they each individually affect the behavior of a circuit model. We present a model of a Sallen-Key lowpass filter circuit that incorporates all of the non-ideal factors together.

1. INTRODUCTION

Audio effect circuits and circuit models are a vital part of modern audio signal processing. Circuit modelling in particular has seen a risein popularity in recent, particularly in the form of audio plugins that model circuits from vintage audio effects, amplifiers, and synthesizers. Many engineers and musicians prefer these software emulations over the original hardware units because of the lower cost, portability, and convenience. However, some users have noticed that the software emulations do not recreate the unit-to-unit variation in these effects. For example, if two engineers buy the same hardware compressor unit, the resulting hardware units will sound similar, but not identical, due to minor variations in the components that comprise each unit. Modern circuit models do not attempt to recreate this unit-to-unit variation, nor do they consider the non-ideal conditions that create this variation.

In this writing, we examine these non-ideal conditions, and show how existing modelling methods can be expanded to include this behavior. In §2 we examine the effects of component tolerances of resistors and capacitors. §3 discusses the effects of aging capacitors and resistors. Op-amp aging and temperature considerations are discussed in §4. Finally, in §5 we show how the above factors can be implemented into existing circuit models using nodal analysis and wave digital filters as examples.

2. COMPONENT TOLERANCES

All resistors and capacitors are labelled with both a component value (e.g. $1k\Omega$ resistor, $1\mu F$ capacitor), and a tolerance rating (i.e. $\pm 5\%$), as shown in fig. 1. We propose adjusting the component values used in a circuit model to a random value within the tolerance range of the component.

When a manufacturer makes a batch of resistors or capacitors the component values of the batch follows a roughly Gaussian distribution centered at the ideal component value. The manufacturer then extracts the worst components that can still satisfy a certain tolerance rating and sells them at that rating [1]. For example, if a manufacturer sells resistors at $\pm 5\%$ and $\pm 10\%$ tolerance the $\pm 10\%$ components will be distributed in a sort of "truncated Gaussian" distribution, comprised of the original Gaussian distribution truncated between 5 and 10 % (see fig. 2). To show how component tolerances can affect the behavior of an audio effect circuit, fig. 3 shows the frequency response of 1000 Sallen-Key lowpass filters made with components that have $\pm 10\%$ tolerance ratings.

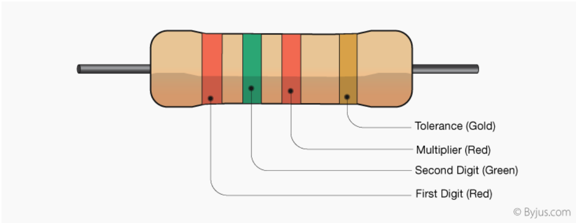

Figure 1: *Resistor labelling. Adapted from* `https://byjus.com/physics/resistor-colour-codes/`.

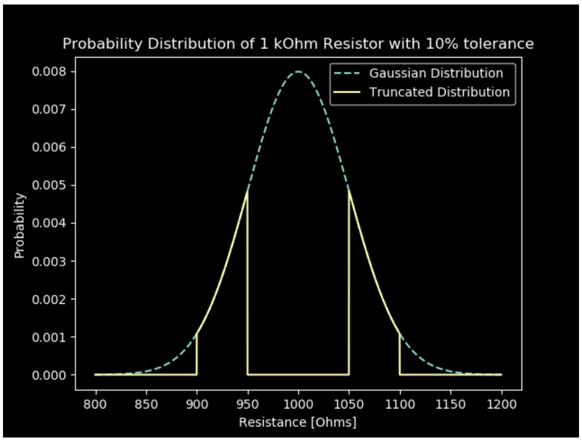

Figure 2: *Probability distribution for the value of a* $10k\Omega$ *resistor with* $\pm 10\%$ *tolerance. Note the "truncated Gaussian" distribution.*

3. COMPONENT AGING

Stuff...

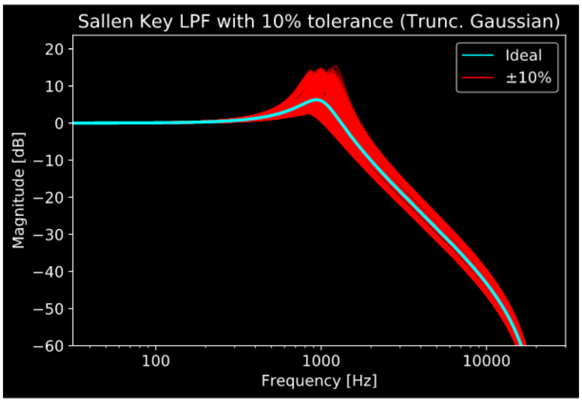

Figure 3: *Frequency response of Sallen-Key lowpass filters made with components with* $\pm 10\%$ *tolerance.*

4. OP-AMP AGING

Stuff

5. IMPLEMENTATION

The structures developed in this study have been implemented as a series of audio plugins using JUCE/C++. The plugins and their source code are freely available on GitHub [1].

6. CONCLUSION

In this paper...

7. ACKNOWLEDGMENTS

Ack

8. REFERENCES

[1] Howard Johnson, "7% solution," `https://www.edn.com/7-solution/`, 2010.

[1] `https://github.com/jatinchowdhury18/Bad-Circuit-Modelling`