SET readout using RF reflectometry and kinetic inductance nonlinearity

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Abstract

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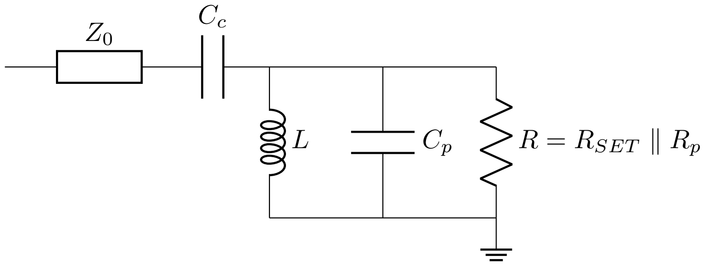

Figure 1: Topology of the resonator that we are going to use. C_p and R_p are a virtual capacitor and resistance used to model losses in the circuit, while R_{SET} is the resistance of the SET in any state. That leaves C_c and L as the degrees of freedom in our system.

3 The parallel RLC resonator

Now that we have a good theoretical context of all the parts of the problem, we will start by analyzing the resonator with a non-kinetic inductance.

3.1 Resonant frequency and effective impedance

Our analysis begins with obtaining expressions for the resonant frequency and the effective impedance of our resonator. It's easy to see that the impedance of our resonator in figure 1 is

$$Z = \frac{1}{j\omega C_p + \frac{1}{j\omega L} + \frac{1}{R}} + \frac{1}{j\omega C_c} \tag{3.1}$$

Which after a little massaging turns into

$$Z = \frac{\omega^2 L^2 R}{R^2(1-\omega^2 C_p L)^2 + \omega^2 L^2} + j\left(\frac{\omega^2 L^2 R}{R^2(1-\omega^2 C_p L)^2 + \omega^2 L^2} - \frac{1}{\omega C_c}\right) \tag{3.2}$$

The resonant frequency ω_r that makes $\operatorname{Im} Z = 0$ is

$$\omega_r^2 = \frac{1}{L(C_c + C_p)}\left(1 + \frac{C_c}{2C_p} - \frac{L}{2R^2 C_p} \pm \sqrt{\left(1 + \frac{C_c}{2C_p} - \frac{L}{2R^2 C_p}\right)^2 - 1 - \frac{C_c}{C_p}}\right) \tag{3.3}$$

Choosing C_c and L such that $\frac{C_c}{C_p}, \frac{L}{R^2 C_p} \ll 1$, leaves us with the approximate expression for the resonant frequency

$$\omega_r \approx \frac{1}{\sqrt{L(C_c + C_p)}} \tag{3.4}$$

Finally, to obtain the effective impedance we use this expression in $\operatorname{Re} Z$

$$Z_{eff} = \operatorname{Re} Z(\omega_r) = \frac{\omega_r^2 L^2 R}{R^2(1-\omega_r^2 C_p L)^2 + \omega_r^2 L^2} \approx \frac{L(C_c+C_p)}{RC_c^2}\left(1+\frac{L(C_c+C_p)}{R^2C_c^2}\right)^{-1} \tag{3.5}$$

And by, again, choosing L and C_c such that $\frac{L(C_c+C_p)}{R^2C_c^2} \ll 1$ we arrive to our expression for the effective impedance

$$Z_{eff} \approx \frac{L(C_c+C_p)}{RC_c^2} \tag{3.6}$$

In future sections we will be using quite a lot of expressions obtained via approximations in non-approximated systems, only to do more approximations with them. Due to this, it is really important to have a clear picture of the regimes we are working in to ensure that our results work in the state-of-the-art technology, and that's why after each result we are going to recontextualize our approximations.

In this case, the approximations to obtain ω_r are clear and straight forward:

$$\frac{C_c}{C_p} \ll 1 \tag{3.7}$$

$$\frac{L}{R^2 C_p} \ll 1 \tag{3.8}$$

But the approximation for Z_{eff} needs a little bit of extra work. If we multiply $(C_c/C_p)^2$ in both sides, it turns into

$$\frac{L}{R^2C_p}\left(1+\frac{C_c}{C_p}\right) \ll \left(\frac{C_c}{C_p}\right)^2 \tag{3.9}$$

And since we used equation 3.4 to arrive here, it must hold the approximation 3.7, turning the previous expression into

$$\frac{L}{R^2C_p} \ll \left(\frac{C_c}{C_p}\right)^2 \tag{3.10}$$

While approximations 3.7 and 3.8 impose a **general condition** in our degrees of freedom, approximation 3.10 imposes a **relative condition** between the previous two.

3.2 Contrast and it's optimization

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4 The parallel kinetic RLC resonator

4.1 Impact of the nonlinearity in the contrast

5 Simulations of the models

6 Conclusions