Engineering Josephson Oscillators

Personnel

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As the telecommunications revolution pushes for denser utilization of the spectrum, there is a need to develop inexpensive sources and detectors that operate in the 100 GHz to several THz range. It is precisely in this range that Josephson junctions provide an almost ideal solid state, current controllable source.

Arrays of junctions provide for relatively large power but due to non-linearities they can exhibit diverse complex spatiotemporal patterns. Experiments, simulations, and analysis were per-formed on a broad range of discrete arrays of Josephson-junction oscillators in order to understand their ability to produce coherent radiation. Networks ranging from single square and triangular plaquettes to one- and two-dimensional arrays were studied. In each array, the junctions are iden-tical, and the arrays are driven by dc bias currents. Although few analytical results are known for these systems, we study the technically interesting solutions which can be represented as traveling waves. It is in this mode that the devices can be used as submillimeter wave sources.

Using the mathematical technique of harmonic balance it is possible to create an equivalent linear circuit of a Josephson network that is operating in a traveling wave mode. Though the non-linearity of the system allows for mixing of all the harmonics, in underdamped systems we find that the first harmonic is orders of magnitude stronger than the rest. In general, any variable can be decomposed in terms of its dc and ac spectrum. If we further restrict the ac component to a single frequency as suggested by our simulations, then the branch current and voltage across a junction can be written as:

$$
\begin{aligned}
I &= I_{DC} + i_{ac} e^{j\omega t} \\
V &= V_{DC} + v_{ac} e^{j\omega t} \\
I_c &= e^{jk}, \\
I_M &= \frac{v_{ac}}{j\omega} \frac{e^{-jk}}{2}.
\end{aligned}
\qquad (3)
$$

Our equivalent circuit then consists of a dc bias circuit and a mixing circuit that creates the first harmonic. Figure 8 depicts the equivalent circuit. Here k represents the phase difference between the first harmonic and the rotating part of the Josephson oscillation, and the mixing current, IM, represents the nonlinear interaction between them. This equivalent circuit makes it possible to use powerful circuit theoretic tools to understand a Joseph-son network.

This model has been used to design a matched load detector. A Josephson junction can be used to detect and measure power, and designing a detector to match the impedance of an array allows us to measure the power produced by the array. As shown in Figure 9, exper-iments measuring the power which an array of 54 overdamped junctions delivers to an impedance match load attest to the usefulness of our model, giving a strong qualitative correlation between the predicted and measured power for varying magnetic flux (measured in units of frustration, the number of flux quantum per unit cell).

Currently, much of our oscillator work is designed to drive quantum circuits, such as the qubit and the quantum ratchet. The oscillators designed for this work are less focused on maximum power than minimum decoherence, meaning that designs may benefit from deliberately unmatched impedances. The exacting requirements of this application further test the accuracy of our model in a challenging regime.

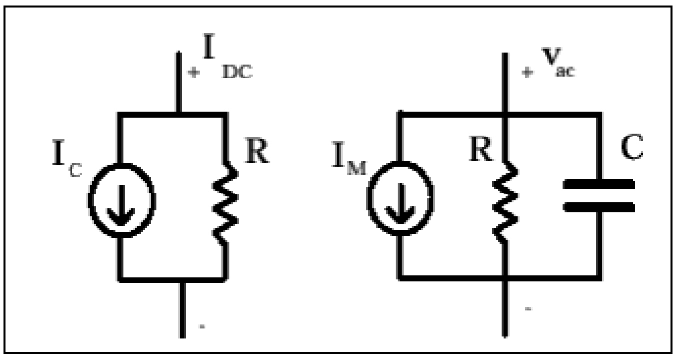

Fig. 8: Equivalent circuit for a Josephson junction in a voltage state and with a single harmonic. Non-linearity is captured by I_M which is a mixing current that describes the interaction between the rotating Josephson phase and its first harmonic.

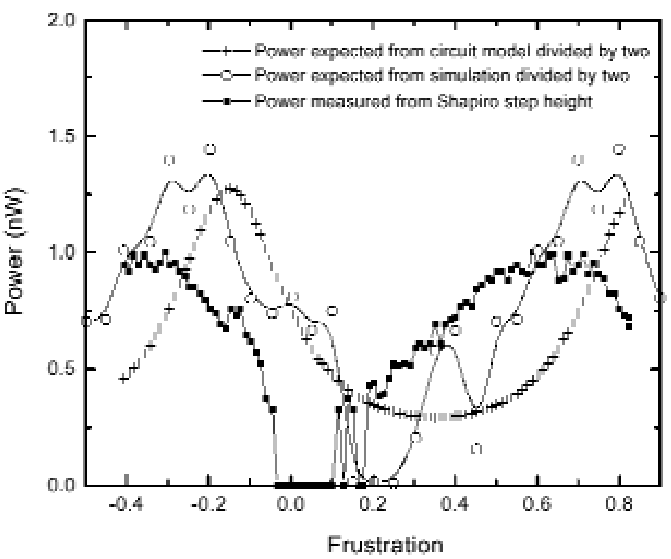

Fig. 9: The power produced by the array, experimental measurements compared to nonlinear simulation and linear circuit model predictions. The array is biased at V_{arr} = 0.1035 mV.