A band-gap engineered Travelling Wave Parametric Amplifier

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Josephson Parametric Amplifiers (JPA) are key to research fields involving microwave signals in the quantum regime, such as superconducting quantum bits or nano electromechanical systems. Their elementary building block, the Josephson junction, is at the the same time strongly non-linear and non-dissipative. Therefore they provide both large gain [1,2] and noise performances close to the quantum limit [3,4]. To obtain reasonable gain (typically $20\,\mathrm{dB}$), the interaction time between the weak signal, the strong pump and the non-linear medium must be maximized. Up to now, this interaction time was increased by coupling the Josephson element to a resonant cavity, but at the expense of a reduced bandwidth. Despite continuous improvement[5,6,7], these resonant amplifiers still display a bandwidth below $1\,\mathrm{GHz}$.

Increasing this interaction time is also possible using distributed non-linear media, similar to non-linear optical fibers, thus overriding the difficulties created by resonant cavities. Such devices are called Traveling Wave Parametric Amplifier (TWPA) and require arrays of at least one thousand Josephson junctions to obtain more than $10\,\mathrm{dB}$ gain over more than $1\,\mathrm{GHz}$ bandwidth. Fabricating such amplifiers is now technically possible [8]. However, these travelling-wave amplifiers raise new issues.

TWPA must be perfectly impedance matched with the rest of the setup, which is typically $50\,\Omega$, to transmit the amplified signal without spurious reflection. Josephson junctions are very inductive elements ($450\,\mathrm{pH/sq}$), thus junction arrays usually show characteristic impedance far above $50\,\Omega$. We will present the fabrication process we developed to match such arrays with the rest of the setup. However, fabricating a perfectly matched array is not enough and leads to $10\,\mathrm{dB}/12\,\mathrm{dB}$ maximum gain over a band of $1.5\,\mathrm{GHz}$.

In a second part we will show that an imperative condition to increase the maximum gain and the bandwidth of the TWPA is to phase match the strong pump and the weak signal, which is not trivial in a non-linear medium. We have chosen to engineer band-gap in the dispersion relation of the array to compensate the different phase velocities. We will show gain greater than $12\,\mathrm{dB}$ while having bandwidth larger than $3\,\mathrm{GHz}$.

[1] B. Yurke *et al.*, Applied Physics Letters 69, 3078 (1996).
[2] M. J. Feldman *et al.*, Journal of Applied Physics 46, 4031 (1975)
[3] M. A. Castellanos-Beltran *et al.*, Nature Physics 4, 928 (2008)
[4] C. M. Caves, Physical Review D 26, 8 (1982)
[5] T. Roy *et al.*, Applied Physics Letters 107, 262601 (2015)
[6] X. Zhou *et al.* Physical Review D 89, 214517 (2014)
[7] J. Y. Mutus *et al.* Applied Physics Letters 104, 263513 (2014).
[8] C. Macklin *et al.* Science 350, 6258 (2015)