L-29

OBSERVATION OF MICROWAVE COMB GENERATION WITH A JOSEPHSON JUNCTION ARRAY

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Abstract **- We report high harmonic content sideband generation with a Josephson junction array as center conductor of a 50 Ohm coplanar line. The line was fed with a low level microwave signal and an ac bias current with a dc offset. Over 100 harmonics of the ac signal were observed in the mixing spectrum at rf frequencies up to 20 GHz. The shape of the spectrum changed with magnetic field and dc bias point.**

I. INTRODUCTION

Tunneling of Cooper pairs from one superconductor to another is associated with a number of interesting effects. One of the results of the pair tunneling is a hysteretic, nonlinear I-V-curve. Figure 1 illustrates this with the characteristic of a Nb-AlOx-Nb thin film tunnel junction driven by a swept current source.

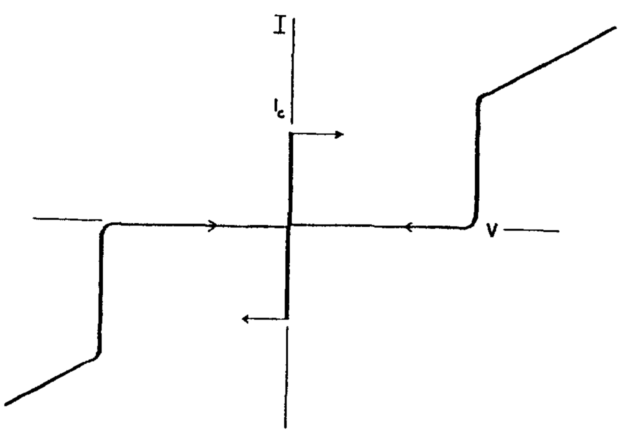

Figure 1. General Josephson Tunnel Junction IV Curve

This planar two terminal device has associated with it voltage levels of about 3 mV, current levels in the mA range and 40 fF/μm^2 capacitance. Applications in 50 Ohm systems are difficult at these low signal and impedance levels. Hence, series arrays have been used to boost amplitude and impedance. Thin film junction arrays have been used as SIS mixers (1), voltage standards (2), parametric amplifiers (3) and wideband oscillators (4), for example. An excellent overview of this area with many references is given in (5).

II. DEVICE LAYOUT AND FABRICATION

We focus here on the mixing behavior of a series array in which the individual Josephson junctions do not experience significant rf coupling between each other. This means that an rf signal generated by a junction via the ac Josephson effect does not affect any other junction. This situation existed in the chosen circuit layout where 1000 relatively large and hence high capacitance junctions formed the center conductor of a 50 Ohm coplanar line as shown in Fig.2. A junction size of 40 μm x 40 μm resulted in a junction capacitance of about 64 pF per device, substantially above the capacitance of the coplanar line over the length of that device section. The Nb-Pb junctions were fabricated via standard thin film deposition and process techniques. The base layer for junctions, coplanar line, groundplane and connections was a dc magnetron deposited Nb thinfilm with about 300 nm thickness. Nb-NbOx-Pb

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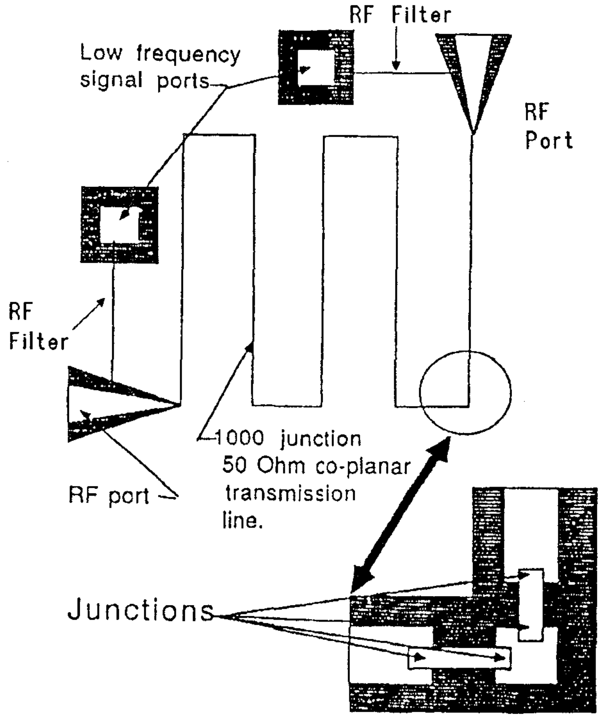

Figure 2. Layout of the array

junctions were formed via rf oxidation and Pb evaporation. Their current density was approximately 200 A/cm^2. A fixture with coaxial connections was used for device evaluation. Rf and bias signals were supplied by bias Tees located outside the liquid helium test dewar for cooling of the circuit (Fig.3).

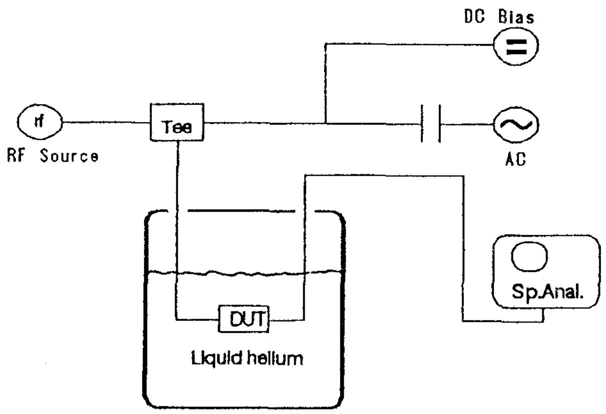

Figure 3. Test Setup

Figure 4 shows a typical series array I-V-curve. As opposed to the characteristic of a single device, multiple small discontinuities appear as a result of fabrication non-uniformities (Fig. 5).

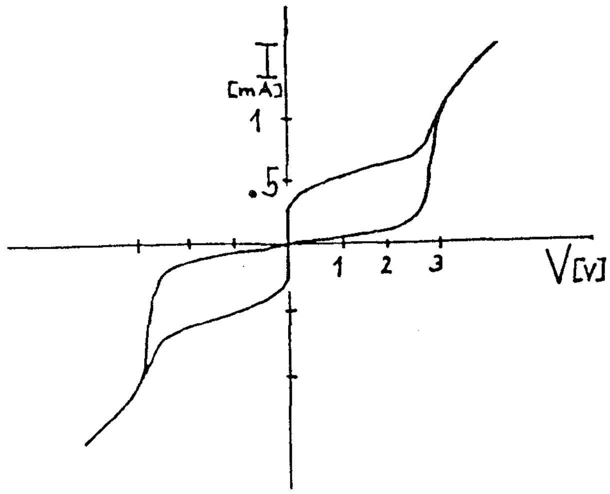

Figure 4. Typical array IV Characteristic

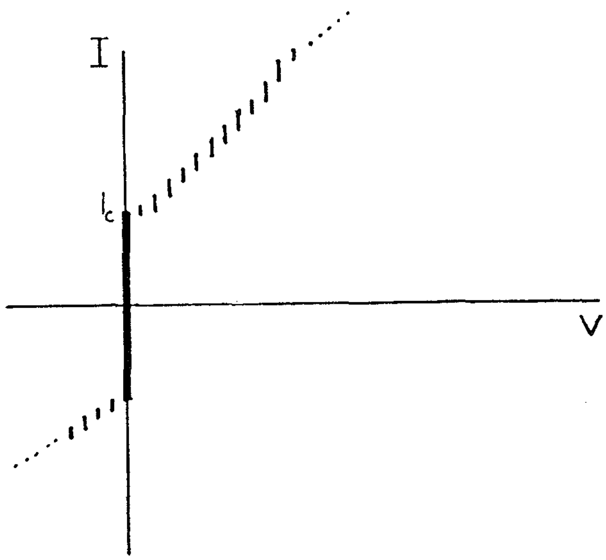

Figure 5. Detail of IV Curve near origin

III. MIXING

We explored the mixing properties of arrays with nonuniform critical current distributions and found sidebands with many harmonics in the output spectrum. For example, a 2 GHz rf signal with an amplitude of -30 dBm was supplied to the circuit. The Josephson junctions were biased with a 5 kHz signal. It swept the I-V-curve symmetrically up to the so-called gap voltage of ±2.7 V (see Fig. 4). The resulting modulation spectrum contained more than 100 harmonics of this frequency as demonstrated in Figure 6. Similar results were achieved at an operating frequency of 20 GHz with a 200 Hz modulation signal (Fig. 7).

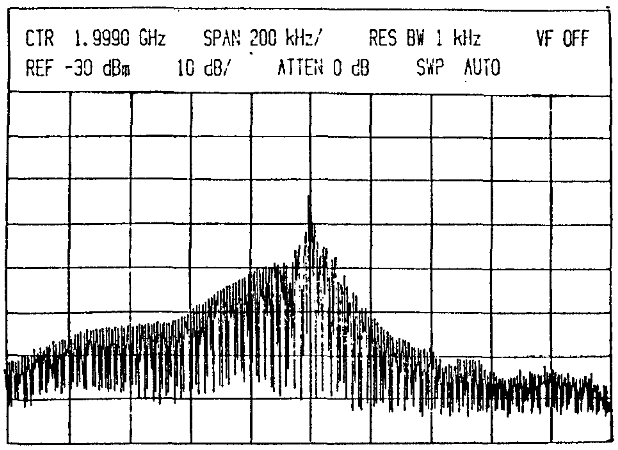

Figure 6. Output Spectrum with 2GHz LO & 5KHz Modulation

With a symmetric bias sweep and the anti-symmetric I-V-curve of the array even harmonics in the spectrum had a high level, odd harmonics were suppressed (Fig. 8). An asymmetric bias condition was achieved by dc biasing to about 1.5 V. The low frequency signal amplitude was reduced to sweep only the positive half of the I-V-curve. Now odd harmonics of the ac signal appeared in the output spectrum in addition to the even ones. An explanation was found by examining the power series representation of the I-V-characteristic. If it is anti-symmetric (see Fig. 1) even powers will represent it. From mixing theory, even harmonics will dominate the output spectrum.

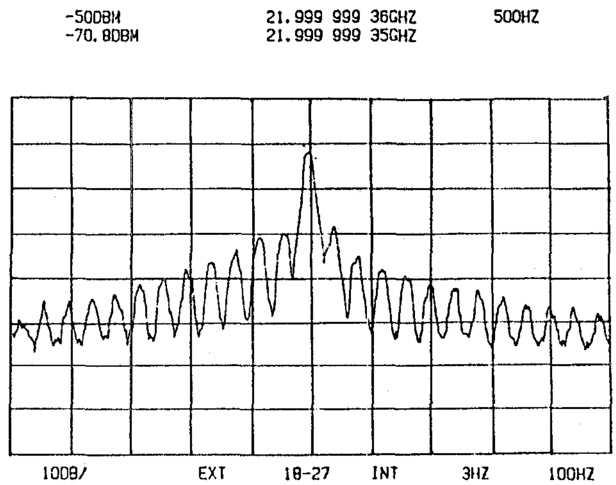

Figure 7. Output Spectrum with 22GHz LO & 200Hz Modulation

For a bias into the first quadrant of the I-V-curve, for example, all harmonics will be found after mixing since the series expansion now contains even and odd powers. The observed spectral content thus changes as a function of voltage bias conditions.

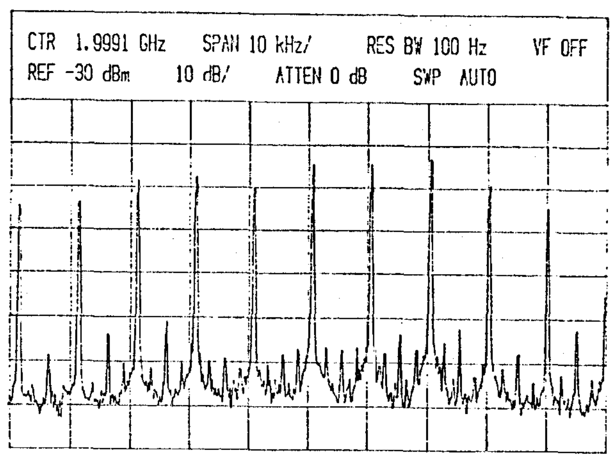

Figure 8. Suppression of Odd Harmonics with Symmetric Bias

The shape of the resultant spectrum also depended on the level of magnetic field applied to the circuit. It caused a reduction of critical current I_c of individual Josephson junctions. The envelope of the mixing spectrum without magnetic field application appears to follow a 1/n behavior as expected from square wave modulation. The presence of a magnetic field resulted in considerable distortion of this shape and ultimately suppression of harmonic generation.

IV. CONCLUSION

While not pursuing a specific application with this device, we have found some interesting properties of Josephson junction series arrays used as a modulator. Harmonic content of the mixing spectrum was manipulated by dc biasing. Magnetic field application altered the envelope of the spectrum. Despite the typically low impedance and signal level environment of individual Josephson junctions, the array functioned in a 50 Ohm system at mW signal levels.

V.REFERENCES

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