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PARAMETRIC INTERACTIONS IN HIGH-Tc SUPERCONDUCTING STEP EDGE JUNCTIONS AT X BAND

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ABSTRACT

We have fabricated and tested both single junctions and series arrays of YBCO step edge junctions for four photon parametric effects at X band as a first step in developing a parametric amplifier at 60 GHz. The series array of 25 junctions at 10.3 Ghz shows a 10 dB increase in reflected signal power as the pump power is increased, while the single junction at 12.2 GHz indicates a 2 dB change. The reflected power at the characteristic idler frequency of $2\omega_p$-ω_s is evidence of true Josephson junction parametric interaction. We are currently investigating the use of thallium based films at 60 GHz which offer a broader range of operating temperatures than does YBCO. Our design for a parametric amplifier at V band is a combination of microstrip based series arrays of junctions and an antipodal finline transition.

INTRODUCTION

There has been a growing interest in exploiting the nonlinear inductive characteristics of high temperature superconducting (HTS) Josephson junctions for use at microwave and millimeter wave frequencies [1,2]. One of the exciting possibilities is the development of a parametric amplifier (paramp) using all HTS components. Such a device would operate over a broader range of temperatures than the previous low temperature superconducting paramps [3,4] while maintaining the unique capabilities and characteristics of Josephson junction based paramps. Such a device can be monolithically incorporated as a preamplifier for phased array radar at 60 GHz to improve system performance and noise figure. The first step in developing such an amplifier in HTS is the demonstration of parametric interactions due to the nonlinear Josephson junction element.

EXPERIMENTAL DESIGN AND SETUP

The Josephson junctions used in these experiments were microbridges formed by using a step edge junction process [5]. When the junction is irradiated with microwave energy such that the microwaves generate a current less than the junction's critical current, Ic, the characteristic josephson inductance L_j will change according to:

$$L_j = \frac{\Phi_o}{2\pi I_c \sqrt{1-\left(\frac{I}{I_c}\right)^2}} \qquad (1)$$

where I is the applied RF current and Φ_o is the flux quantum =h/2e . If the device is "pumped" at a frequency ω_p and a small signal is applied at ω_s, a transferred power will be observed at a characteristic idler frequency, ω_i . Evidence of this idler response is a strong indication that parametric interactions are ocurring within the junction.

In this experiment a four photon process is the primary process under investigation. This process describes the allocation of the primary frequencies and power distribution such that:

$$2\,\omega_p = \omega_s + \omega_i \qquad (2)$$

$$P_s / \omega_s = P_j / \omega_i \qquad (3)$$

$$P_p / \omega_p + P_s / \omega_s + P_i / \omega_i = 0 \qquad (4)$$

where Pp, Ps, and Pi are the pump power, signal power, and idler power respectively. This process requires no

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initial current biasing of the junction as it takes advantage of the junction's phase symmetry. Because of this, a true DC contact is not required to connect the device with the outside world. This allows the experiment to be relatively easily implemented.

Theoretical analysis of the currents flowing in the junctions at the three primary frequencies of ω_p, ω_s and ω_i indicate signal gain at ω_s when the junction is properly inserted into a circuit. In fact, the circuit will behave as a reflection amplifier. The gain in the signal level at ω_s is shown through the cross-coupling terms in the junction admittance matrix as described in [3].

The junctions were fabricated on 20 mil thick lanthanum aluminate substrates. Step edges were formed by ion milling the substrate to form a long narrow pit. HTS was then deposited across the pit edge to form the microbridge junction. A final silver contact layer was deposited on top of the HTS. The layout of the series array of 25 junctions and the electrical equivalent circuit is shown in figure 1. The term Y/N refers to the admittance matrix associated with the N junctions. The term Gj/N refers to the shunt resistance associated with the RSJ model of microbridge Josephson junctions. Yt includes all additional shunting admittances such as stubs, coupling structures,etc. The shunting λ /12 stubs are used to suppress the 3rd harmonic of the device. Because of the unique nature of the Josephson element, only odd harmonics occur in four photon parametric effects.

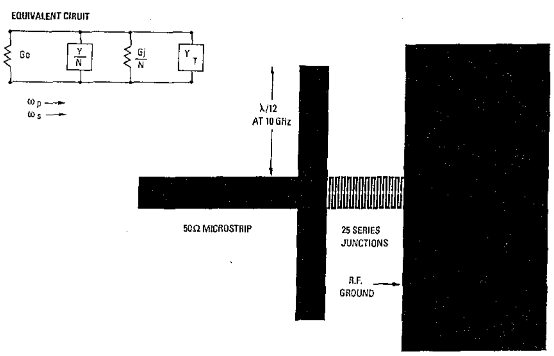

Figure 1. Layout of 25 junction series array and equivalent circuit model.

After the device was fabricated it was mounted in a probe and placed in a dewar containing liquid helium. At no time was the device immersed in the LHE itself. This was done to insure the device temperature to be at or above 10K. The entire experimental setup is illustrated in figure 2. The signal and the pump were generated by two HP8350B sources. The microwave signals were then sent to the device via a circulator. The reflected pump,signal and idler signals were then input to a low noise amplifier before entering the HP8592A spectrum analyzer. A shorting nut replaced the device for calibration purposes.

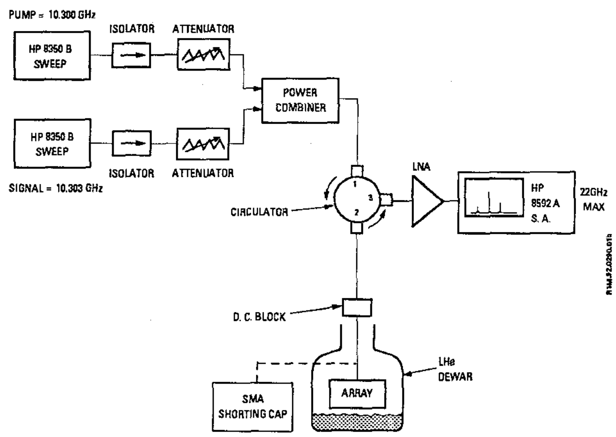

Figure 2. Experimental setup for testing the junction array.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 3 is the reflected power spectrum from the 25 junction series array at 10 K. The incident pump power to the array is -40 dBm while the incident signal power is -50 dBm. The incident power is determined by the observed reflected power from the shorting nut. The parametric interaction within the array is immediately obvious from the observation of the reflected power at the characteristic idler frequency. This reflected idler power arrises due to the changing nonlinear inductance of the array. Notice that the pump and signal reflected power levels differ by only 5 dBm whereas the incident pump and signal powers differ by 10 dBm. This indicates an internal device gain of +5 dBm. The absolute level of

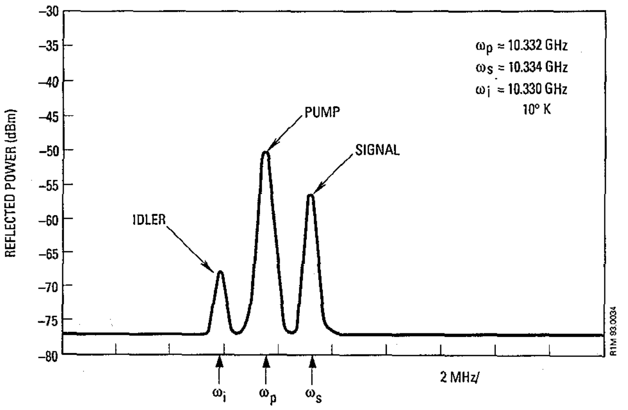

Figure 3. Reflected power spectrum from the 25 junction array at 10 K. The parametric interaction within the array is immediately obvious from the observation of the reflected power at the characteristic idler frequency.

the incident power is higher than that reflected from the array due to internal array losses.

Figure 4 is a plot of the signal and idler power versus the applied pump power. Notice the extremely low level of pump power (-65 dBm) and input signal power (-73 dBm) at which the device exhibits an increase in reflected signal power, i.e. the onset of parametric effects in the series array. The device also exhibited a characteristic decrease in peak reflected signal power as the temperature increased. The device exhibited at least a 3 dB increase in reflected signal power up to as much as 50K.

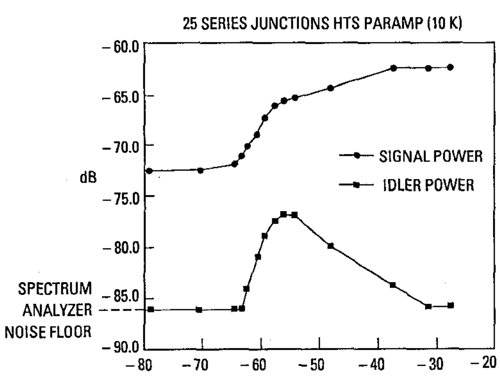

Figure 4. Reflected signal and idler power versus reflected pump power at 10 K.

With the clear indication of parametric effects in our series array, we designed a 60 GHz microstrip based parametric amplifier. The layout of the device is indicated in figure 5. The antipodal finline waveguide to microstrip transition is 3.0 λ long. The microstrip is designed for 50Ω. The microstrip feeds into the series array of junctions which have an open ended λ/4 long microstrip behind them to provide an RF short at 60 GHz. The simple RF chokes both before and after the junction array allow for monitoring of the I-V curve of the array while RF power is applied.

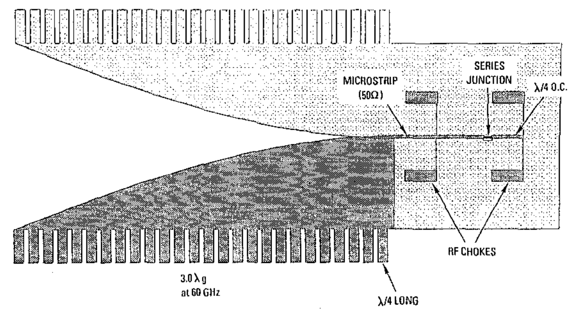

Figure 5. Layout of 60 GHz parametric amplifier using an antipodal finline waveguide to microstrip transition.

CONCLUSION

We have demonstrated parametric interactions in single junction and 25 junction series arrays using HTS step edge devices at X band. The devices exhibit characteristic idler power and idler frequency consistent with a four photon parametric process. The 25 junction array exhibits a 10 dB increase in reflected signal power. Based on these results we have designed a 60 GHz microstrip based parametric amplifier using antipodal finline transitions.

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REFERENCES

[1] J. H. Takemoto-Kobayashi, *et al*., "Monolithic High-Tc Superconducting Phase Shifter at 10 GHz", IEEE MTT-S Symposium 1992, pp. 469-472

[2] C. M. Jackson and D. J. Durand, "10 GHz High Temperature Superconductor Phase Shifter", IEEE MTT-S Symposium 1991, pp. 165-168

[3] M. J. Feldman, P. T. Parrish, and R. Y. Chiao, "Parametric Amplification by Unbiased Josephson Junctions", J. Appl. Phys., Vol. 46, No. 9, Sept 1975, pp. 4031-4042

[4] A. D. Smith, *et al*. "Low Noise Microwave Parametric Amplifier", IEEE Transactions on Magnetics, MAG-21, March 1985, pp. 1022-1028

[5] J. Luine, *et al*. "Characteristics of High Performance YBa2Cu3O7 Step-edge Junctions", Appl. Phys. Lett. 61, No. 9, August 1992, pp. 1128-1130