PARAMETERS OF A JOSEPHSON TUNNEL JUNCTION ARRAY PARAMETRIC AMPLIFIER

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Résumé.- L'amplification paramétrique d'un réseau de jonctions est commandée par un champ magnétique. Les paramètres expérimentaux sont en accord avec les estimations théoriques.

Abstract.- The parametric amplification in arrays of small tunnel junctions was turned via a magnetic field. The experimental parameters agree well with theoretical estimates.

The non-linear inductance of a Josephson junction makes it suitable as the active element in a high frequency parametric amplifier. Advantages are the low pump power needed and the low noise temperature expected. This work utilizes arrays of small Josephson tunnel junctions packed close together in a microstrip configuration. They were run in an unbiased, doubly degenerate mode, i.e. with the pump and signal frequencies being almost equal. We found it possible to tune the amplifiers to stable, high gain by a magnetic flux,ϕ. Hence they could be optimized and their parameters evaluated. We will concentrate upon the latter aspect and make comparisons with the theoretical model for the SUPARAMP (Superconducting Unbiased PARametric AMPlifier) developed by Feldman, Parrish and Chiao (FPC) /1/.

The FPC theory utilizes a simplified, voltage clamped circuit model, reasonable for a tunnel junction with its high capacitance,C. The main concept is the so called ING curve in the g-ξ plane defined in figure 1.

Experiments were done with arrays of 1, 10, 30, or 40 Pb tunnel junctions /2/. Pump and signal frequencies (8-12 GHz) were applied via a circulator and the reflected powers detected by a spectrum analyzer or a superheterodyne receiver. Different values of I_J(0.1-10 A/(mm)^2) were obtained by varying the oxidation temperature. In an array, the I_J's of the individual tunnel junctions varied less than about 20 %.

The parameters I_J, R_N (the mean tunnel resistance), C, g, ξ, ζ,(the cos ϕ amplitude), N(the number of coherent junctions), Z_0(the line impedance) and R_J (the rf resistance) were determined by several methods (figure 1), namely (i) the I-V characteristic, (ii) the power reflection vs $\beta=\sin(2\pi e\phi/h)/(2\pi e\phi/h)$, (iii) the powerwidth, i.e. the range of pump power, P_0^+, for a signal gain, Γ_s, within 3 dB of the max gain, and (iv) P_0^+ for max Γ_s as a function of I_J. The fact that several of the parameters were evaluated by more than one method gave a valuable cross-check.

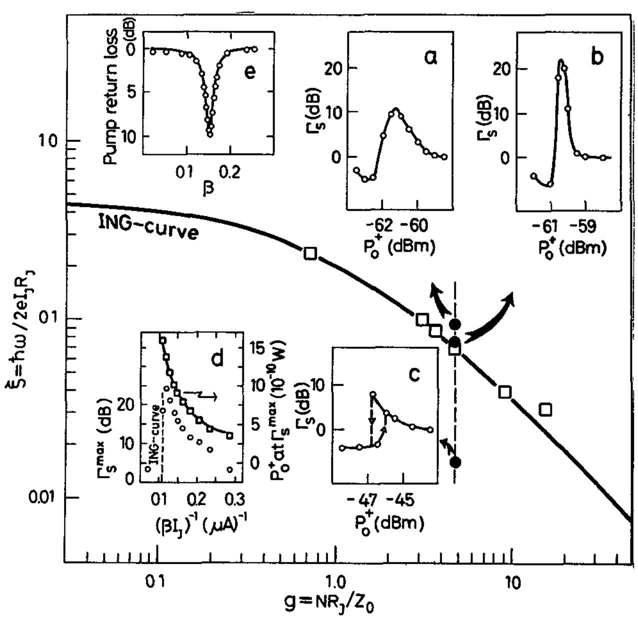

Fig. 1 : The behaviour of a SUPARAMP is characterized by the two normalized parameters g and ξ . The curve of Infinite Non-reentrant Gain (ING) divides the (g,ξ) plane in two regions. Above the curve, the gain, Γ_s, has a smooth maximum as a function of pump power, P_0^+, inset (a). As the ING curve is approached, the gain increases at the expense of the powerwidth, inset (b). Below the curve, Γ_s is a reentrant function of P_0^+, and the amplifier is unstable (c). A (g,ξ) point slightly above the ING curve should be chosen to give high, stable gain. Inset (d) shows the change of the peak gain along a path with g = 3.6 and ξ varying from 0.05 to 0.22. The SUPARAMP parameters, like g and ξ can be evaluated by determining the pump power at peak gain as a function of the magnetic field (d), the power reflection (e), and the powerwidth, (a) and (b), the curves in (d) an (e) are theoretical fits. The squares represent experimental ING values of six of our samples.

Results of Γ_s vs P_0^+ agree qualitatively with the FPC theory. As predicted, relatively low pump power (about 10^{-10} to 10^{-8} W) was needed for gain while the power width, ΔP, was 0.1-1 dB. We could determine the (g,ξ) value of the different operating points, and in particular we could fix their values at infinite gain. The experimental $(g,\xi)_{ING}$ values are given in figure 1. The excellent agreement with the theoretical curve confirms the concept of the ING curve and strongly supports the FPC theory.

50-90 % of the tunnel junctions were coherent, i.e. participated in the amplification process. The values of R_J and R_N almost coincided and C agreed well with calculated values at 4.2 K.

Saturation is a serious problem, increasing the fluctuation noise temperature and limiting the band width. A strong monochromatic signal can saturate the device, but this is no severe limitation as we noted a linear gain with output signals up to 15 dB below the pump level. More serious is the saturation due to the broadband room temperature noise. The output noise power near the signal frequency is plotted against the input noise temperature in Figure 2.

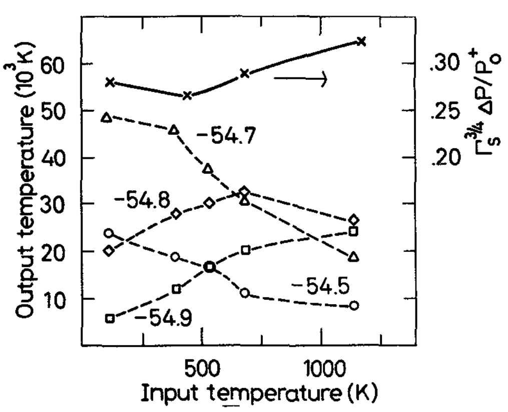

Fig. 2 : Output vs input noise temperature for different gains obtained by pump power variations (the pump levels are given in dBm for each set). The data were taken for a g value of 0.7 at 4.2 K. The crosses show that $\Gamma_s^{3/4}\,\Delta P_0^+$ is independent of saturation.

Above a certain pump power, the output noise temperature decreases with increasing input noise temperature instead of approaching a maximally saturated output (or brightness) temperature T' as predicted by Feldman /3/. If we calculated T' with our experimental values of the gain-bandwidth product (which disagree with theory) and the gain-power width (agreeing, cf figure 2) we get a striking agreement with the observed maximum output temperatures as shown in table I.

Table I

Parameters of saturated SUPARAMP's

g	P_0^+(dBm)	Γ_s(dB)	$\Gamma_s^{1/2}\Delta\omega/\omega$	T_N(K)	T'_{exp}(K)	T'_{th}(K)
4.8	-59.2	23	0.00021	2.1×10^5	2.6×10^7	2.4×10^7
3.6	-56.7	25	0.0012	5.8×10^4	1.9×10^6	2.2×10^6
15	-64.1	24	0.0013	$4\ \times10^4$	$>9.7\times10^6$	6.9×10^6
0.7	-49.2	22	0.0020	2.2×10^4	2.0×10^6	2.1×10^6
15	-69.5	8.9	0.017	2.5×10^3	2.3×10^4	4.8×10^4
3	-54	20	>0.030	<50	2.3×10^4	

As the gain depends on the input noise level a conventional noise figure measurement on a saturated SUPARAMP will give an erroneous result. Instead we have estimated T_N by measuring the signal to noise ratio /4/. Generally, we found very high values of T_N, the higher the more saturated the amplifier was, see table I. A larger N gives less saturation and a lower T_N. Only in an amplifier where the bandwidth was limited to about 60 MHz, we could avoid noise limiting and estimated a T_N of 30±20 K.

References

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