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RESPONSE OF SUPERCONDUCTING POINT CONTACTS TO HIGH-FREQUENCY RADIATION

Prepared by H. KANTER and F. L. VERNON, Jr.
Electronics Research Laboratory

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Laboratory Operations
THE AEROSPACE CORPORATION

Prepared for SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
Los Angeles, California

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The high-frequency response predicted by a perturbation approach for a highly damped current driven Josephson junction agrees in its parameter dependence remarkably well with observations on point contacts used as video type detectors of microwave radiation.

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FOREWORD

This report is published by The Aerospace Corporation, El Segundo, California, under Air Force Contract No. F04701-71-C-0172.

This report, which documents research carried out from July to December 1970, was submitted 6 October 1971 to Lieutenant William E. Belote, SYAE, for review and approval.

Approved

A. H. Silver, Director
Electronics Research Laboratory

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

W. E. Belote
William E. Belote
1st Lt., United States Air Force
Project Officer

CONTENTS

RESPONSE OF SUPERCONDUCTING POINT CONTACTS TO HIGH-FREQUENCY RADIATION

For a current driven Josephson junction small enough to have uniform current density across the contact area the equation of motion is (see inset of Fig. 1)

$$\frac{V}{R} + I_C \sin\left(2e\int^t V(\tau)\, d\tau/\hbar\right) = I_B + I_S \sin \omega t \qquad (1)$$

where R is the resistive portion of the contact, and I_C its critical supercurrent. Contact capacity and inductances have been neglected. The righthand side consists of a d-c battery current superposed with an ac current of amplitude $I_S \ll I_B$. For $I_S = 0$, Eq. (1) has been solved by Aslamazov and Larkin [1]. Accordingly (for $I_B > I_C$), $V(t) = R\left(I_B^2 - I_C^2\right)/(I_B + I_C \sin \omega_o t)$, with $\bar{V} = R\left(I_B^2 - I_C^2\right)^{1/2}$ being the average voltage measured across the contact and $\omega_o = 2e\,\bar{V}/\hbar$ the Josephson frequency. Using a second-order perturbation approach for $I_S \ll I_B$ in which we replaced I_B with $I_B + I_S \sin \omega t$ in the expression for V(t) and allowed the phase of the $I_C \sin \omega_o t$ term to adjust to satisfy Eq. (1), we calculated the change of the average contact voltage with I_S. The result is

$$\Delta\bar{V} = \frac{I_S^2}{4}\, R\, \frac{I_C^2}{\left(I_B^2 - I_C^2\right)^{3/2}}\, \frac{\omega_o^2}{\omega^2 - \omega_o^2} \qquad (2)$$

In the limits $\omega_o \lessgtr \omega$, the solution can be expressed in terms of the first and second derivative of the V-I characteristic. Expanding V(t) to first order in $I_S \sin \omega t$, we find that for $\omega_o \ll \omega$ the impedance $Z(\omega) \rightarrow R$, and we obtain

$$\Delta\bar{V}_{\omega_o \ll \omega} = P\left(\frac{2e}{\hbar\omega}\right)^2 \frac{RI_C}{2} \left(\frac{I_C}{I_B}\right) \frac{d\bar{V}}{dI_B} \qquad (3)$$

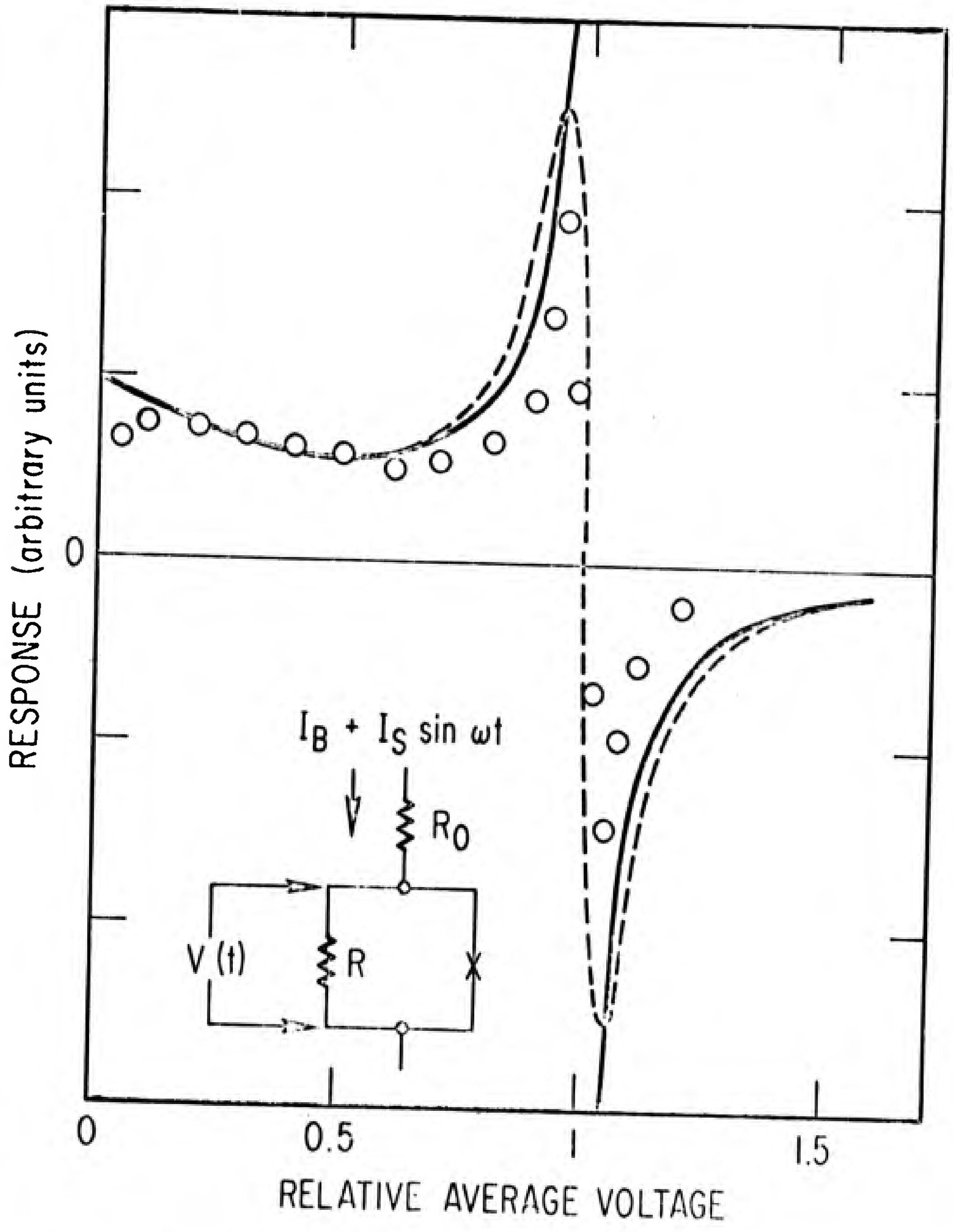

Figure 1. Calculated dc-Current Response to Currents of High Frequency ω as a Function of Bias Voltage in Units of $\hbar\omega/2e$ (Solid)

Bias fluctuations broaden and reduce the resonance response as indicated by the dashed line. Data points are experimental.

where P refers to the high-frequency power in the circuit [2]. For $\omega_o \gg \omega$, Eq. (2) predicts the "classical" result that the response is proportional to the curvature of the static V-I characteristic, for $\omega_o \sim \omega$ resonance behavior with sign reversal. While the regions $\omega_o \gtrless \omega$ are relatively insensitive to the specific ω_o, i.e., bias voltage (broad band response), for $\omega_o \sim \omega$ critical dependence on voltage fluctuations and, thus, the bandwidth of ω_o is expected (narrow band). The solid line in Fig. 1 represents the current response from Eq. (2), $2\Delta\overline{V}/(I_S^2 \cdot R \cdot d\overline{V}/dI_B)$; the effect of fluctuations, which smear out the resonance, is indicated by the dashed line. We note that in contrast to the model used by Richards and Sterling [3, 4], the resonance here is not principally dependent on an external circuit.

Experimental results obtained on niobium point contact junctions situated across an E-band waveguide and illuminated with 90 GHz Klystron radiation are in qualitative agreement with the results of the analysis, although the d-c V-I characteristics only approximately represented the ideal form. We find: (1) for the entire bias voltage range, the response is proportional to input power, (2) the predicted resonance behavior is clearly observed, (3) for $\omega_o < \omega$, the voltage response is proportional to $d\overline{V}/dI_B$, (4) for $\omega_o > \omega$, the response is proportional to curvature, (5) no significant dependence on either I_C or R was observed for our junctions for which the product $I_C \cdot R$ was nearly constant. Data points for a typical junction are shown in Fig. 1. The detailed comparison of the parameter dependences is left to a separate publication. Of practical interest is the result that the "zero voltage" response for $\omega_o \ll \omega$ decreases with the inverse square of the frequency, while the resonance response appears to be independent of ω. Thus, the latter might be more suitable for higher frequency detection.

The minimum detectable power (or noise equivalent power, NEP) for our model was evaluated by relating the current response per unit signal power from Eq. (3) to the minimum noise current fluctuations previously [5] measured for $eV \ll kT$ on our junctions: $< i^2 > \sim 4\,kT(I_B/\overline{V})$. Accordingly, we would expect NEP ~ 8.10^{-16} watt/$Hz^{1/2}$ for our junctions, with $I_C \sim 10^{-5}$ A, R ~40Ω and T ~ 4.2°K. This compares with our best measured value of NEP ~ 5.10^{-15} watt/$Hz^{1/2}$. The remaining discrepancy indicates that at 90 GHz operation, the contact capacity cannot be considered negligible and needs to be included in analysis for performance estimates.

REFERENCES

1. L. G. Aslmazov and A. I. Larkin, JETP Lett. 9, 87 (1969).
2. H. Kanter and F. L. Vernon, Jr., "Low Temperature Physics LTR" (to be published). The current response as given in this reference and obtained by a more approximate analysis is identical to the voltage response as given by Eq. (3) divided by the incremental impedance dV/dI_B if $I_B \sim I_C$, which is true for near-zero bias-voltage.
3. P. L. Richards and S. A. Sterling, Appl. Phys. Letters 14, 394 (1969).
4. N. R. Werthamer and S. Shapiro, Phys. Rev. 164, 523 (1967).
5. H. Kanter and F. L. Vernon, Jr., Phys. Rev. Letters 25, 588 (1970).