COUPLING OPTIMIZATION OF POINT CONTACT DETECTORS AND MIXERS

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One shows that, for a given IR power, the angular width of an illuminating focused laser beam can be adjusted to optimize the electromagnetic coupling. The predicted conditions have been checked experimentally for various devices (Schottky, MIM, Josephson) at 337, 70 and 10.6 µm.

In the IR range, point contact structures provide good performances until wavelengths of few microns. The coupling to external fields occurs in the free-space, the point contact structure being used alone or in conjunction with mirrors of various shapes (corners, parabolic cylinders...). The external fields consist of focused or parallel laser beams.

The coupling problem is to deliver to the junction located at the tip of the point contact structure the largest possible part of the power carried by the incident beams. For a few years ago, this problem has been considered as an antenna problem [1] [2] [3]. This point of view has allowed to determine the incidence angle providing an efficient coupling. A more complete electromagnetic treatment [4] [5] includes more details on the illumination conditions and it is then possible to predict quantitatively the effect of various parameters of practical interest such as focusing angle, defocusing..

The consideration of the point contact structure as an antenna leads us to characterize it by its radiation pattern $\vec{F}(\vec{u})$ in the direction $\vec{u}$ and its input impedance Z_i in the emitting situation. Characterizing a laser beam by its angular spectrum of spherical waves has proved to be very convenient, especially for focused beams [5]. The particular case of a parallel beam can also be considered. The angular spectrum $\vec{E}^+(\vec{u})$ associated to the incoming spherical wave of the beam is a quantity describing the angular variations of the field distribution in the cross section of the laser beam. Similarly $\vec{F}(\vec{u})$ describes the angular variations of the far field which would be radiated by the structure in emitting situation.

It has been shown that the power coupling factor ρ, defined as the ratio of the power delivered to the junction-characterized by its equivalent impédance Z_j- to the incident power, is given by [4]:

$$\rho = \rho_L \rho_E \tag{1}$$

$$\rho_L = 1 - \left| \frac{Z_j - Z_i^*}{Z_j + Z_i} \right|^2 \tag{2}$$

$$\rho_E = \frac{\left| \int_{4\pi} \vec{E}^+(\vec{u}) \cdot \vec{F}(\vec{u})\, d\varpi(\vec{u}) \right|^2}{\int_{4\pi} E'^{+2}(\vec{u}) d\varpi(\vec{u}) \cdot \int_{4\pi} F'^2(\vec{u}) d\varpi(\vec{u})} \tag{3}$$

where $d\omega(\vec{u})$ denotes the elementary solid angle in the direction $\vec{u}$, and A'^2 is the local hermitian norm of a vector $\vec{A}$.

The load factor ρ_L and the electromagnetic factor ρ_E vary between 0 and 1. The value 1 is reached under the following conditions :

$$Z_j = Z_i^* \tag{4}$$

$$\vec{E}^+(\vec{u}) = \vec{F}^*(\vec{u}) \quad ; \forall \vec{u} \tag{5}$$

The first condition is well known from classical circuit theory, the second one indicates that the angular distributions of $\vec{E}^+$ and $\vec{F}$ are identical and that the corresponding vectors describe conjugate ellipses (polarization match). When both conditions (4) and (5) are verified, the power transfer from the beam to the junction is total. In practice, it is difficult to satisfy exactly these conditions, but it is always to use (1-3) to compute ρ for any given configuration. This has been done for Josephson junctions at 337 µm and predicted values are in close agreement with experimental results.

Relating $\vec{F}$ and $\vec{E}^+$ to the practical parameters of the structure allows to point out their influence on ρ_E. An idealized situation is illustrated in Fig. 1. Assuming that $\vec{F}$ and $\vec{E}^+$ can be approximated by pulse-type functions (constant in a given angular interval and zero outside) and there is a perfect polarization match, one obtains when $\Theta_i = \Theta_S$.

$$\rho_E = \frac{\Delta\phi_i}{2\pi} \; \frac{\widetilde{\Delta\Theta}^2}{\Delta\Theta_i \; \Delta\Theta_s} \tag{6}$$

With

$$\widetilde{\Delta\Theta} = \mathrm{Min}\{\Delta\Theta_i, \Delta\Theta_s\}$$

Where $\Delta\Theta_i$, $\Delta\phi_i$, $\Delta\Theta_S, \Theta_i$ and Θ_S are indicated in Fig. 1. For instance, for long thin wire structures of length ℓ at wavelength λ : $\Delta\Theta_S \simeq \sqrt{\frac{\lambda}{\ell}}$

For laser beams focused by lenses of aperature D and focal length f : $\Delta\Theta_i \simeq \frac{D}{2f}$

Clearly, concerning the azimuthal aspect, the factor ρ_E is maximum for $\Delta\Theta_i = \Delta\Theta_S$ (Fig. 2). This condition defines the optimal coupling.

$$\rho_{E,opt.} = \frac{\Delta\phi_i}{2\pi} \qquad (7)$$

The previous formula shows the interest of distroying the rotationnal symmetry of the structure pattern by means of mirrors [6]. In that case the factor 2π is replaced by the azimutal angular width of the structure pattern.

The existence of such optimal illuminations have been successfully cheked experimentally with MIM and Schottky diodes at 10.6 µm, 70 µm and 337 µm [7][8]. Fig. 3 shows a typical variation of the coupling factor versus beam angular width obtained by using lenses of different focal length. This result corresponds to a Schottky diode whose radiation pattern at 337 µm is given in Fig. 4.

It can be easily taken into account the defocalization effects by means of the translation theorem. If $\vec{\delta}$ is the translation vector relaying the tip of the structure to the beam focus, the pattern $\vec{F}$ has to be changed in formula (3) for the translated pattern $\vec{F}_\delta$ such that :

In any case, expressions (1-3) appear to be very usefull in order to calculate the power coupling factor as long as the radiation pattern of the structure and its input impedance are known.

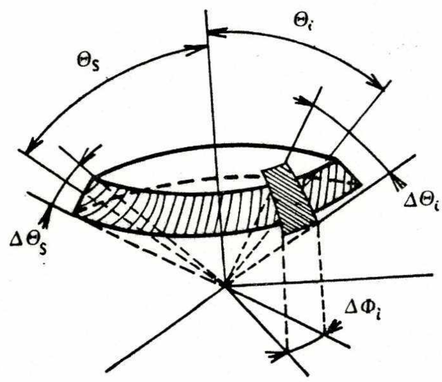

FIGURE 1 : Idealized characterization of a structure by its pattern and of a laser beam by its cross section

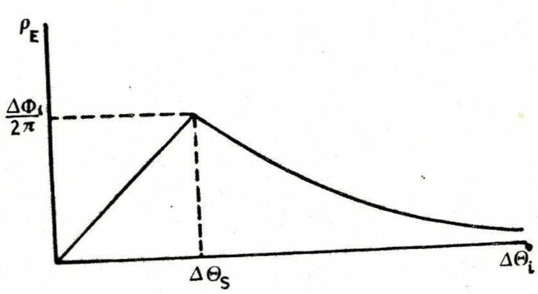

FIGURE 2 : Idealized variation of the coupling coefficient versus angular beam width $-(\theta_i = \theta_S)$.

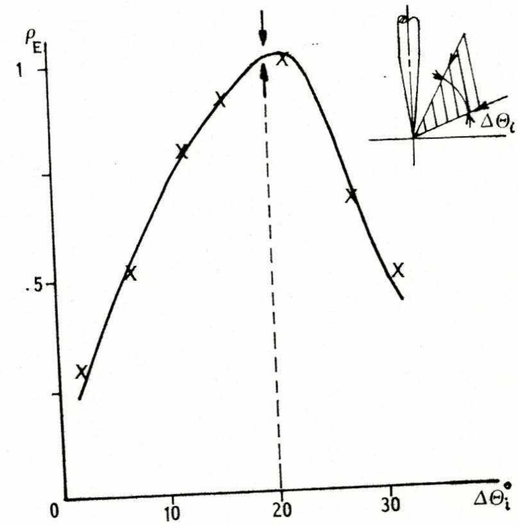

FIGURE 3 : Coupling factor variation (in arbitrary units - $\theta_i = \theta_S$) versus beam angular width. The arrow indicate the predicted theoretical angle of optimal coupling ($\Delta\theta_i = \Delta\theta_S$).

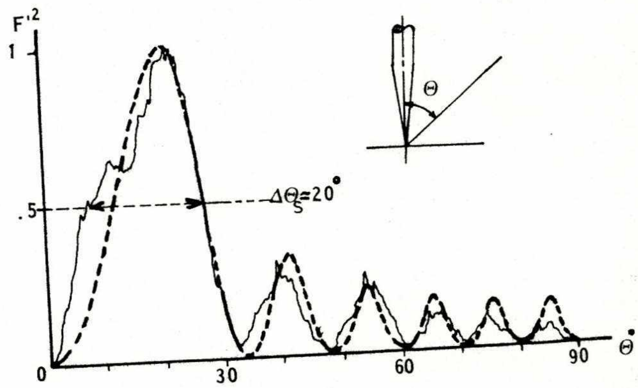

FIGURE 4 : Normalized radiation pattern of a Schottky diode at 337 µm.

——— experimental

----- theoretical (using current travelling wave approximation [1])

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