$R_S(I_S)$ and dependent on Miller-effect magnification of the collector-base capacitance of Q_{N1}.[5]

The rise time for $v_0(t)$ is limited by the comparatively low ($\not> 2$), and current-dependent loop gain of the PTAT generator when in its regenerative mode, and the relatively low f_T

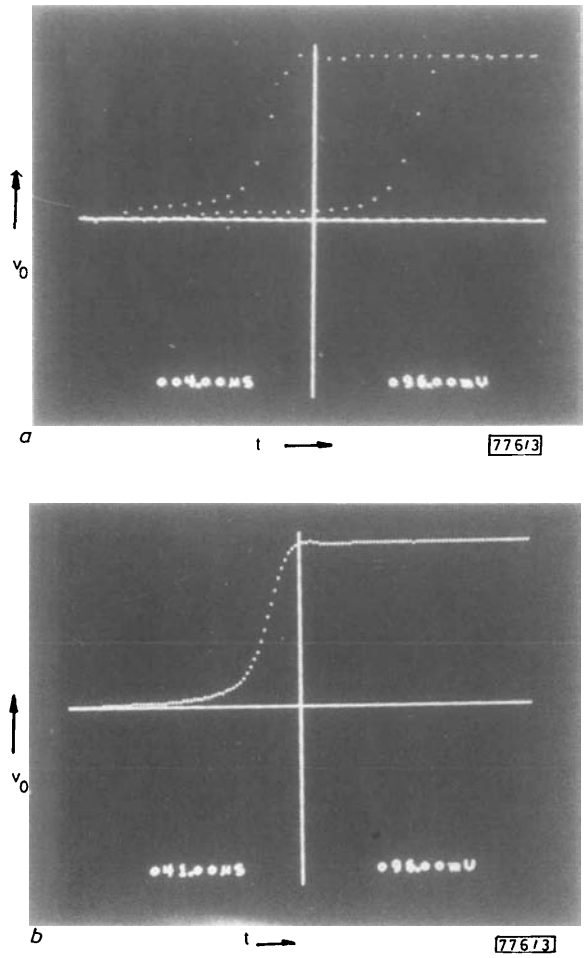

Fig. 3 $v_0(t)$ *for circuit of Fig. 2 when Sw opened (at* $t = 0$*)*

a $v_0(t)$ for $R_S = 13{\cdot}5$ kΩ (left-hand trace) and $R_S = 27$ kΩ (right-hand trace)

b $v_0(t)$ for $R_S = 270$ kΩ

I_S generated by connecting resistor R_S from collector of Q_{N1} to V_{cc}
Horizontal cursor line corresponds to $v_0 = 0$ V
Vertical cursor line corresponds to time at which DC design value of v_0 is reached after Sw opens

(~ 5 MHz) of the *pnp* devices used. The factors affecting the rise time will be discussed more fully in a future publication. In a fully integrated scheme, a low value of I_S could be obtained without a high value of R_S by using a low-current *p*-channel JFET (see, for example, Reference 6) operating with $V_{GS} = 0$, its source connected to V_{cc} and its drain to the collector of Q_{N1}.

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B. L. HART

School of Electrical & Electronic Engineering
North East London Polytechnic
Longbridge Road, Dagenham, Essex RM8 2AS, England

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TURN-ON DELAY FOR JOSEPHSON LOGIC DEVICES WITH HIGH DAMPING

Indexing terms: Logic and logic design, Josephson junctions

Josephson logic devices exhibit, before switching from superconducting to voltage state, a turn-on delay which depends on current overdrive and damping coefficient. A novel expression describing turn-on delay for heavily damped circuits is proposed. A comparison with numerical calculation is made. As an example of application for this expression, the turn-on delay appearing in the simulation of a damped logic gate switching is discussed.

Introduction: Josephson-junction devices are known as very interesting switching elements for high-speed-logic applications. During the last few years, many solutions have been proposed for the assembly of Josephson junctions in logic gate structures.[1,2] In all the cases, the switching time of an elementary gate from the superconducting state to the voltage state can be roughly divided into two parts: a turn-on delay during which the voltage remains almost zero and a rise time where the voltage increases rapidly.

Under certain conditions,[3] it is possible to represent a Josephson junction by a simple electrical model (Fig. 1), known as the RSJC-model. In such a circuit, the rise time is proportional to the product RC_j and depends on the overdrive of

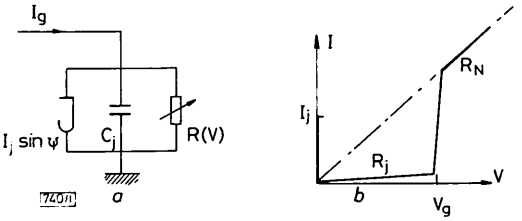

Fig. 1

a Schematic representation of Josephson junction (RSJC model)
b Current/voltage characteristic for this junction without external load

the maximum Josephson current I_j; the turn-on delay also depends on the current overdrive but in a different manner. An analysis of this phenomenon has been made in the case of instantaneous overdrives of I_j,[4,5] and also for some finite ramp rates[6] but always for light-damped junctions. In logic gates recently proposed,[7–9] the presence of some resistors smaller than the subgap junction resistance R_j gives circuits with higher damping, and so the previous analytic formulas describing turn-on delay become invalid. In this letter, we propose an expression for heavily damped circuits; its interest emerges from the simulation of a logic gate switching where large turn-on delay appears.

Analytical expressions: Let us consider the circuit illustrated in Fig. 1, which gives the electrical scheme valid for a Josephson junction with small sizes. This circuit is described by the following equations:

$$C_j \frac{dV}{dt} + \frac{V}{R} + I_j \sin\psi = I_g \qquad (1)$$

and

$$V = \frac{\phi_0}{2\pi}\dot{\psi} \tag{2}$$

where C_j is the junction capacitance, R the total circuit resistance, I_j the maximum Josephson current, ψ the quantum phase across the junction, V the junction voltage and ϕ_0 the flux quantum ($\phi_0 = 2{\cdot}07 \times 10^{-15}$ Wb).

The voltage state is obtained when $I_g > I_j$, since there are no more solutions for eqn. 1 with $\dot{\psi} = 0$. McCumber[10] has given the dimensionless form of eqn. 1 by

$$\beta\ddot{\theta} + \dot{\theta} + \sin\theta = \gamma \tag{3}$$

with $\gamma = I_g/I_j$, $\ddot{\theta} = d^2\psi/d\tau^2$, $\dot{\theta} = d\psi/d\tau$, where $\tau = \omega_j t$ ($\omega j = 2\pi(RI_j/\phi_0)$ is the Josephson frequency), and

$$\beta = 2\pi\frac{R^2 C_j I_j}{\phi_0} = \left(\frac{\omega_j}{\omega_p}\right)^2$$

($\omega_p = \sqrt{[(2\pi I_j)/(\phi_0 C_j)]}$ is the plasma frequency).

If one looks at the hypothetical case where the current across the junction is just equal to I_j (i.e. $\psi = \pi/2$) at $t = 0$ and such that $I_g = \gamma I_j$ ($\gamma > 1$) as soon as $t > 0$, the turn-on delay can be defined as the time required for the phase ψ to increase from $\pi/2$ to $(\pi/2) + \frac{1}{2}$.[4] In the case of lightly damped circuits (i.e. $\beta \gg 1$) we can neglect the V/R term in eqn. 1; thus, eqn. 3 becomes

$$\beta\ddot{\theta} + \sin\theta = \gamma \qquad (\text{for } \beta \gg 1) \tag{4}$$

which gives, if taken between $\pi/2$ and $(\pi/2) + \frac{1}{2}$,

$$\tau'_d = (\omega_j t'_d) = \sqrt{\frac{\beta}{(\gamma - 1)}} \tag{5}$$

For heavily damped circuits (i.e. for $\beta < 1$), eqn. 5 is not valid. If $\beta < 1$ ($\omega_j < \omega_p$), $\dot{\theta}$ then becomes the most important term in eqn. 3.

Neglecting the $\ddot{\theta}$ term, we can write

$$\dot{\theta} + \sin\theta = \gamma \qquad (\text{for } \beta < 1) \tag{6}$$

from which we obtain, on the same phase interval as before,

$$\tau''_d = (\omega_j t''_d)$$

$$= \frac{2}{\sqrt{(\gamma^2 - 1)}}\left[\tan^{-1}\left(\frac{\gamma\tan(\theta/2) - 1}{\sqrt{(\gamma^2 - 1)}}\right)\right]_{\pi/2}^{(\pi/2)+1/2} \tag{7}$$

The choice of $[\pi/2, (\pi/2) + \frac{1}{2}]$ as an integration interval is arbitrary. It comes from the fact that a simple formulation is obtainable in the case of light damping. However, in numerical simulations of junction switching, $\psi = (\pi/2) + \frac{1}{2}$ always appears to be a good approximation of the value from which the voltage increases significantly for both low and high damping coefficient β.

In Fig. 2, we give the exact value of τ_d, obtained by solving the complete eqn. 3 numerically for θ between $\pi/2$ and $(\pi/2) + \frac{1}{2}$, against the McCumber coefficient β, for several values of overdrive $(1 - \gamma)$. The dashed lines represent the two asymptotic forms: eqn. 5 and eqn. 7. As foreseen, a good agreement with eqn. 5 is obtained in the high β domain, and with eqn. 7 for β less than unity.

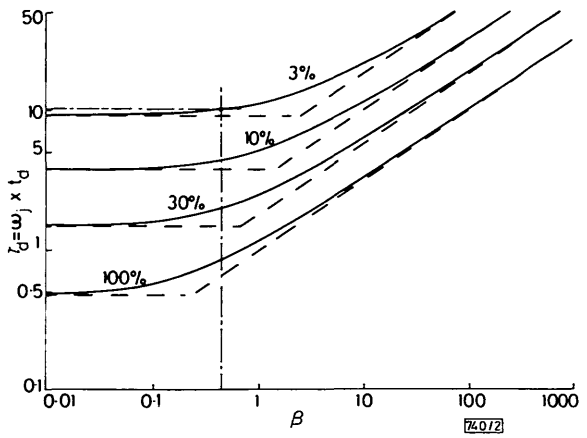

Fig. 2 *Turn-on delay τ_d against McCumber coefficient obtained by solving eqn. 3, for different values of current overdrive $(1 - \gamma)$*

Simulation of a heavily damped circuit: For an illustration of the interest in studying the value of the turn-on delay in the low β domain, Fig. 3 shows the switching behaviour of a logic gate named direct coupled isolator (DCI), as described by eqn. 7.

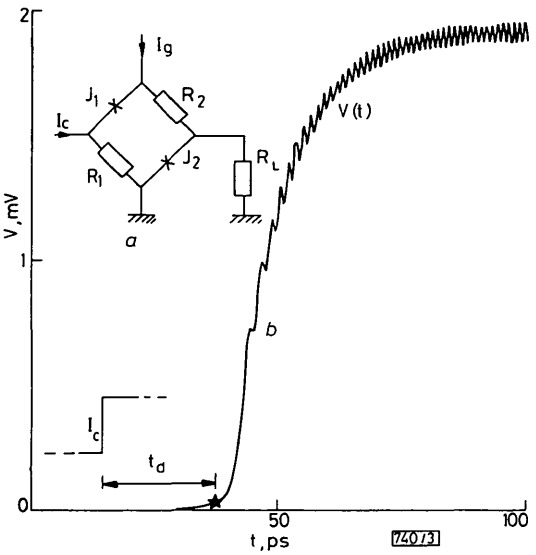

Fig. 3

a DCI gate as described by eqn. 7 comprising two Josephson junctions ($I_j = 100$ μA, $C_j = 0{\cdot}5$ pF and $R_j = 100$ Ω), two resistors: $R_1 = R_2 = 1$ Ω and a load resistor: $R_L = 12$ Ω

b Switching curve for a gate current: $I_g = 2I_j$ and a control current: $I_c = 6$ μA appearing after 15 ps. (The star represents the time for which the phase of junction J_2 has reached the value: $(\pi/2) + \frac{1}{2}$)

Such a gate is usually driven first by a gate current I_g equal to about 75% of the maximum Josephson current ($2I_j$). When a control current I_c is subsequently applied, the gate reaches the voltage state and the gate current is steered to the load branch. Resistors R_1 and R_2 are included to ensure a good input-output isolation.

For the circuit simulation of Fig. 3, the original gate current is 200 μA (i.e. the hypothetic case where $I_g = 2I_j$). After a 15 ps delay, a 6 μA control current is abruptly applied, providing the transition to the voltage state after a turn-on delay of about 20 ps.

Since the control current is added to the gate current in junction J_2 (see Fig. 3*a*) and is subtracted from it in junction J_1, the DCI gate can be seen during the turn-on delay just as junction J_2 is damped by the resistor $(R_1 + R_2)/R_L$, and for which the overdrive $(1 - \gamma)$ is equal to half the total overdrive (coming from the equality: $R_1 = R_2$ in our example).

With the parameters of Fig. 3, the McCumber coefficient β of junction J_2 is equal to 0·43 when including circuit resistors, and the Josephson frequency ω_j is equal to $5{\cdot}11 \times 10^{11}$ rad/s. For these values, the curve ($\gamma = 1{\cdot}03$) in Fig. 2 gives $t_d = 19{\cdot}7$ ps. In the circuit simulation, the phase ψ_2 [$= (\pi/2) + \frac{1}{2}$] was reached at 37·8 ps, corresponding to $t_d = 22{\cdot}8$ ps. The asymptotic value obtained from eqn. 7 is $t''_d = 17{\cdot}9$ ps.

The most important aspect of the behaviour of turn-on delay for low-β devices is the fact that no significant reduction of its value may be expected by circuit miniaturisation. The set of parameters used in the DCI gate simulation corresponds roughly to a Pb/Pb technology.[2] In this circuit, if one supposes, for example, that the junction capacitance C_j could be reduced by a factor of 2, the turn-on delay will drop from $t_d = 22{\cdot}8$ ps to $t_d = 20{\cdot}4$ ps. In that case, only the rise time could be successfully reduced, leading to a total switching time reduction of only 27%.

P. MIGNY
B. PLACAIS

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Laboratoire d'Electronique et de Technologie de l'Informatique
Commissariat à l'Energie Atomique
85X-38041 Grenoble, France

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DEPOSITION MECHANISM OF FINE GLASS PARTICLES AND HIGH-RATE PRODUCTION OF FIBRE PREFORMS IN THE VAD PROCESS

Indexing terms: Optical fibres, Vapour deposition

In order to achieve the high-rate production of fibre preforms, the deposition mechanism in the VAD process has been investigated. The particle deposition rate was found to depend on the Reynolds number of the flame stream. The high-rate preform production of 4·5 g/min was attained by applying this result to the preform fabrication technique.

Introduction: Since the attainment of the ultimate values in both fibre transmission loss and bandwidth,[1] the emphasis of major research efforts has shifted toward achieving high-rate production of high silica fibre preforms and the resultant mass production.[2–4] Energetic efforts have been exerted to achieve high-rate production using the VAD method, and a deposition speed of 1·7 g/min or more has been attained.[5] However, the deposition mechanism of fine glass particles important for achieving high-rate production with the VAD method has not yet been fully clarified because of the complicated deposition behaviour.

The purpose of this letter is to investigate the deposition mechanism of fine glass particles in the VAD method. Emphasis is placed on clarifying the particle-diffusion effect in the flame stream and on applying such effects to the practical fabrication process. A preform-production rate of 4·5 g/min has been achieved in the actual VAD process.

Experiments and discussion: Fig. 1 shows a schematic diagram of the experimental set-up used to investigate the deposition mechanism. In this set-up an actual porous preform is replaced by a quasi-preform made of silica glass with a hemispherical bottom.[6] Fine SiO_2 glass particles (0·05–0·2 μm in particle diameter) synthesised in the oxyhydrogen flame stream from the torch reach near the quasi-preform surface and are deposited onto it. In Fig. 1, the particle velocity designated by U represents the average parallel to the quasi-preform surface, and the particle velocity designated by V represents the average perpendicular to the quasi-preform surface. In this experiment, the flame speed was varied by changing only the oxygen gas speed in order to control the average velocity U. Fine SiO_2 particles were deposited on the quasi-preform surface under different oxygen gas speeds ranging from 0·2 m/s to 1·7 m/s, and the weight of the SiO_2 particles deposited was measured with a chemical balance. Special attention was paid to maintaining a constant surface temperature of the quasi-preform during deposition.

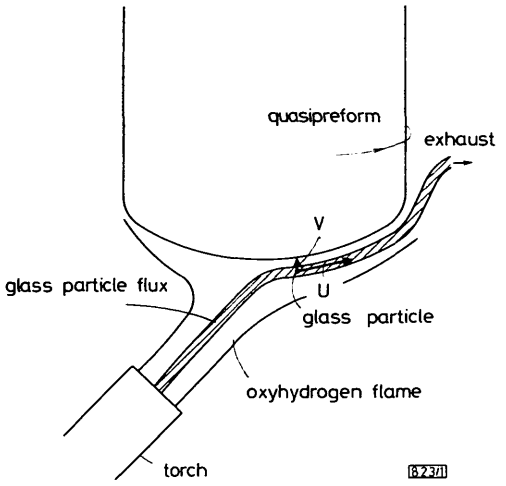

Fig. 1 *Experimental set-up to investigate deposition mechanism*

Fig. 2 shows the dependence of the particle deposition rate on the Reynolds number of the flame stream; the Reynolds numbers are calculated from the oxygen gas speed at the end of the torch. The curves shown in Fig. 2 represent particle deposition rates obtained when the relative $SiCl_4$ feed rates were 1, 2, 3, 4 and 6, respectively. It is found from these results that particle deposition rates depend largely on the Reynolds number and reach a maximum value of around 30. It can also be seen in Fig. 2 that the deposition rates show a sharper dependence on the Reynolds number as the $SiCl_4$ feed rate increases.

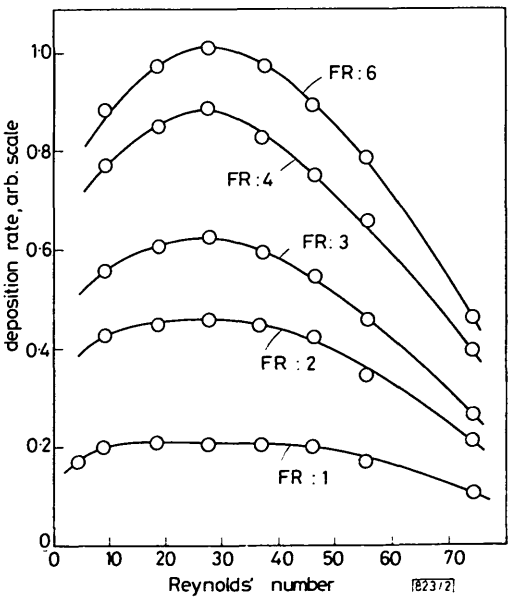

Fig. 2 *Dependence of particle deposition rate on Reynolds number*
FR represents relative $SiCl_4$ feed rate

The experimental results shown in Fig. 2 can be explained in terms of the diffusion effect of fine glass particles in the flame stream. First, the particle deposition onto the quasi-preform, closely related to the velocity V shown in Fig. 1, is caused by two kinds of particle-diffusion effects: one is molecular diffusion and the other is diffusion due to eddying in