TUNNEL DIODE SUPER-REGENERATIVE AMPLIFICATION

By

A. H. ABOU EL ELA, A. B. EL-BAILY and TH. AMH

Physics Department, National Research Centre

University College for Women, Ain Shams University

ABSTRACT

Superregenerative tunnel diode amplification was studied using an approximation of the i — u characteristics in the form of 11th degree polynom. The effect of tunnel diode nonlineraities on the gain in linear and lograitimic modes was investigated. Experiments confirms the existance of superregenerative amplification in the linear and logarithmic modes.

The limit of gain in an ordinary regenerative amplifiers is reached when positive feed back is incrased to a point where the circuit oscillates. Super-regeneration extends operation into the region of oscillation by allowing the circuit to oscillate for a fraction of time. Therefore, voltage gain of over a million can be obtained. There are two modes of operation defined for superregeneration. The linear mode : which results when the positive quench period is so short that the oscillations do not have time to build to full saturation amplitude. The logaritimic mode : which occurs when the period is sufficiently long to allow oscillations to build to full amplitude before the end of the positive quench period.

Tunnel diode superregenerative amplifiers (TDSRA) were only qualitatively considered (1,2). Simplified analysis using cubic approximation for the current-voltage characteristics was reported (3,4) It was suggedted (4) that the simple expressions for the gain of superregenerative amplifier (4,5) could be used for tunnel diode. However, these expressions are approximate and does not account for the high nonlinearity of tunnel diode. Therefore, the real characteristics of the superregenerative amplifier will differ considerably from the values obtained using approximate expressions (4,5).

The aim of the present contribution is to clarify how the real values of the gain (considering tunnel diode nonlineraity) will differ from the values obtained from approximate expressions (6).

Supper-regenerative Amplification

Tunnel diode characteristics could be approximated in the form of a polynom (6,7) 11th degree,

$$i = \sum_{n=0}^{11} a_n u^n \qquad (1)$$

which is very suitable approximation for the nonlinear characteristics of tunnel diode. The values of the constants are,

$a_0 = 0$, $a_1 = 0.07172$ Amapere/Volt, $a_2 = -0.20463$ A/V^2,
$a_3 = -29.964$ A/V^3, $a_4 = 593.063$ A/V^4, $a_5 = -5626.1$ A/V^5,
$a^6 = 32292.26$ A/V^6, $a_7 = -119527.9$ A/V^7, $a_8 = 288142.1$ A/V^8,
$a_9 = -437936.5$ A/V^9, $a_{01} = 381595.9$ A/V^{10}, $a_{11} = -145439.35$ A/V^{11}.

In the case of a resonant load of the amplifier with a high Q value and a resonant frequency w , the resonator can be replaced by a parallel equivalent circuit LCR. When the condition $1 \gg \frac{1}{Q}$ is satisfied the voltage on the tunnel diode could be expressed in the form

$$u = U_o + V \sin wt \qquad (2)$$

Substituting eq. (2) in (1) one could obtain the average value (I_{av}) and the first harmonic (I_1) current components of the fourier analysis of the current (1). Hence, the tunnel diode average conductance $G_{av} = \frac{I_1}{V}$ is calculated. Fig. 1 shows the dependence of $|G_{av}|$ on the signal amplitude (V) at different d.c bias voltages.

Linear Mode

Since the I—V characteristics of tunnel diode are highly nonlinear, linear mode could only observed at very small signal amplitudes. Simple analysis (5) shows that the gain of superregenerative amplifier in linear mode is iven by

$$\alpha = e^{\left(\frac{R_t}{2L}\right) T_o} = e^{\frac{d}{2} W_o T_o}$$

where R_T is the total resistance of the circuit, T_o is the period in which the total circuit decrement is neative (quench period) and d is the modulus of circuit decrement $d = \rho |G_{av}| - \frac{1}{Q}$ where ρ is

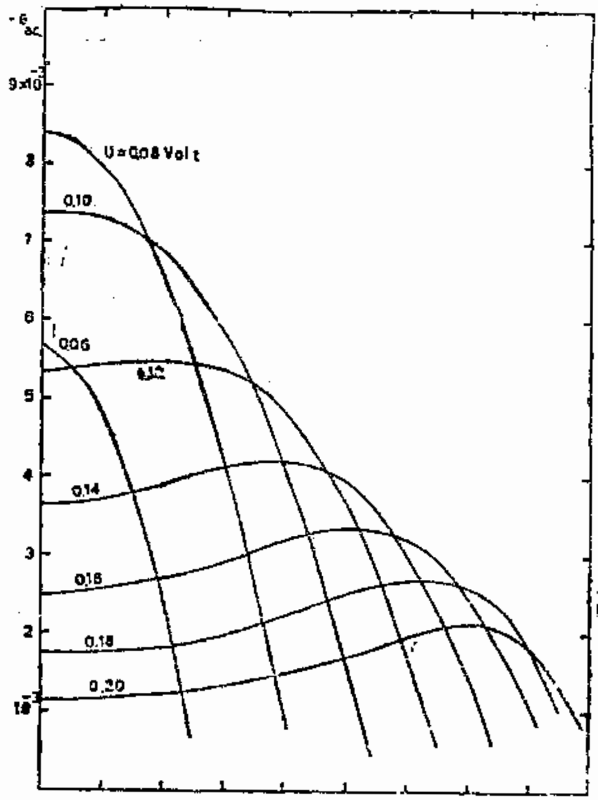

Fig. 1 — The dependence of negative conductance on the bias voltage U for different signal amplitudes V.

the characteristic resistance of the tank circuit. Let $|G_{uv}| = G_o - g(V)$, therefore $d = d_o - \rho\, g(V)$ where $d_o = \rho\,|G_o| - \frac{1}{Q}$ is the modulus of the modulus of the negative decrement for V = O (when the tunnel diode nonlineraity is neglected). The exact expression for the gain will be

$$\alpha = e^{\frac{d_o}{2} W_o T_o}\, e^{-\frac{1}{2}\rho\, g(V)\, W_o T_o} = K_1\, \xi_1 \quad \ldots\ldots \quad (3)$$

The factor $e^{-\frac{1}{2}\rho\, g(V)\, W_o T_o} = \xi_1$ represents a correction factor accounting for the nonlinear dependence of the gain on the signal amplitude. Using Fig. 1 and equation (3) the dependence of ξ_1 on V for $U_o = 0.1$ is plotted in Fig. 2 for different K_1 values and for $\frac{1}{\rho Q} = 0.1$ G . It is clear that, for $U_o = 0.1$ V, on increasing

K_1 and V the factor monotonically decreases. There fore, calculation of the gain in linear mode of SRA by the approximate, expression (4) gives values differs largely from the real values.

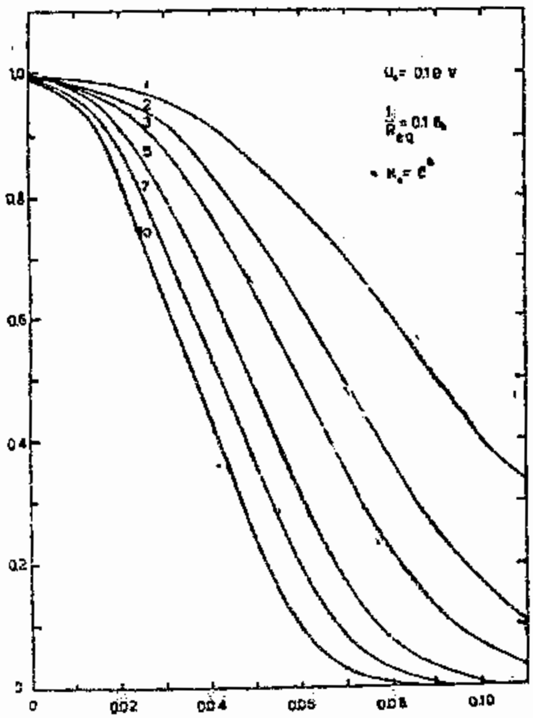

Fig. 2 V_{signal} (V)

Fig. 2 — The dependence of the nonlinearity factor on the signal amplitude at different K_1 values.

Logarithmic mode

In the logarithmic mode the output signal is determined by the variation of the area of the oscillation burst with the level of the received signal (ε). This variation depends on the law of the growth of the oscillation amplitudeg, which could be expressed, for a linear system, as

$$V = \in e^{\frac{d}{2} W_0 t} = \in \rho^{1/2 W_0 [d_0 - \rho g (V)] t} \quad \dots (4)$$

for different values of the parameter g (V) = constant. Curves of V (t), for linear systems with different d values, could be plotted (Fig. 3). Therefore, nonlinear system could be considered as a linear one for a small time interval Δ t. Transitions from one of Δ t values to another are accompanied by jumpwise variation of d values,

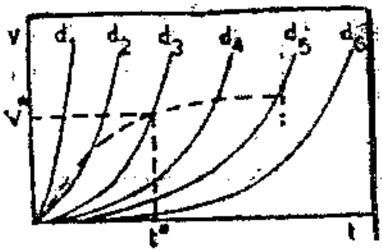

Fig. 3

Fig. 3 — Growth of oscillations for inear and logarithmic modes for different d values.

therefore, the dynamic characteristics V (t) for nonlinear system could be expressed in the form

$$t^* = L_n \left(\frac{V}{\epsilon}\right)^* \cdot [\,{}^1/_2\, W_o (\,d_o - \rho\, g\, (V)^*\,)]^{-1} \quad \cdots\cdots (5)$$

and the variation of the area of the oscillations burst

$$\Delta S = \int_o^{V_{st}} [\, t\,(V^*, \epsilon^1) - t^*\,(V^*, \epsilon_2\,)\,]\, dv^* \quad \cdots\cdots (6)$$

Substituting (5) is (6) and integrate we get

$$\Delta S = \frac{2}{w_o\, d_o} v_{st}\, \xi_2\, l_n \frac{\epsilon_2}{\epsilon_1} = \frac{2}{w_o\, d_o} v_{st}\, \xi_2\, l_n \left(1 + \frac{\Delta\epsilon}{\epsilon}\right) \text{where}$$

$$\xi_2 = \frac{1}{\Lambda_{st}} \int_o^{V_{st}} \left(I - \frac{g\,(V^*)}{|G_o| - \frac{1}{\rho Q}}\right)^{-1} dv^*$$

The voltage output of the amplifier iwll be

$$\Delta V = F_q\, K_o\, \Delta S \quad \cdots\cdots\cdot (7)$$

where F_q is the quench frequency and K_o is the transmission factor of the circuit. The logarithmic S R A output voltage when g (V) zero is given by (5)

$$\Delta V = F_q\, K\, V_{st} \frac{2}{W_o d_o}\, l_n \left(1 + \frac{\Delta\epsilon}{\epsilon}\right) \quad \cdots\cdots\cdot (8)$$

By comparing (7) and (8) we obtain the relation

$$\alpha_1 = \alpha_1\, (\,V = O\,)\, \xi_2$$

i.e. the real gain in the logarithmic mode of tunnel diode S R A α_1 is highr than the simplified expression α_1 (V=O). The variation of δ_2 with bias voltage is shown in Fig. 4 it is clear that $\delta_2 > 1$ for voltags less than 100 mV.

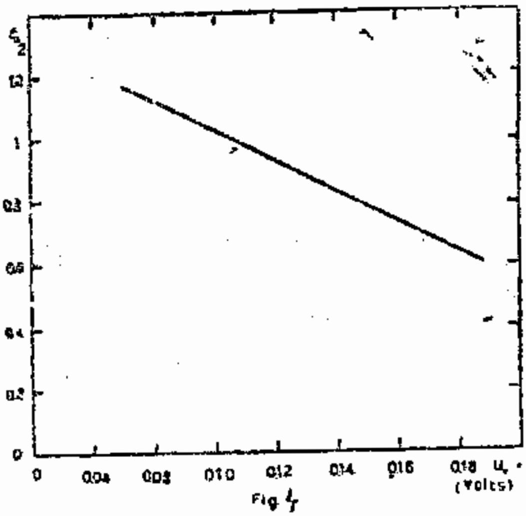

Fig. 4 — The dependence of the nonlinearity factor on the bias voltage for the logarithmic mode.

Experimental

The experimental circuit used to investigate superregenerative amplification is represented in Fig. 5. A high frequency oscillator

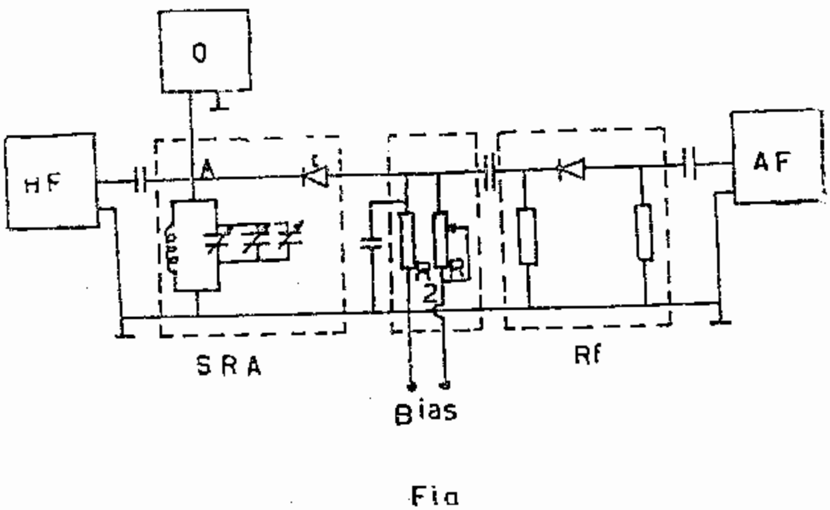

Fig. 5 — Experimental Circuit for superregenerative amplification.

(HF) is used as a signal source and a half wave diode rectifier is used to quench the tunnel diode, the quench frequency is determined by the audio-frequency oscillator (AF). The S R A is consisted from a Ga As tunnel diode connected in parallel with a tank circuit of resonant frequency $\simeq$ 2.5 Mc/s. The oscillations burst is observed on an oscilloscope. Experiments were carried out at signal frequency 2 Mc/s and quench frequency of 20 to 300 c/s. Experimental observations confirms the occurence of superregenerative amplification in the linear and nonlinear modes. However, linear mode occurs in a very narrow voltage value (because of tunnel diode nonlineraities. As the quench period and the signal amplitude increases the area of the oscillation (5) burst increases and the logarithmic mode takes place. The shape of the oscillation bursts are shown in Fig. 6 in linear mode (Fig. 6 a) and logarithmic (Fig. 6 b). Experimental observations shows that the logarithmic mode is highly stable than the linear mode. On increasing the quench frquency (rom 20 c/s to 250 c/s) transition from linear mode to logarithmic mode occurs.

(a)

(b)

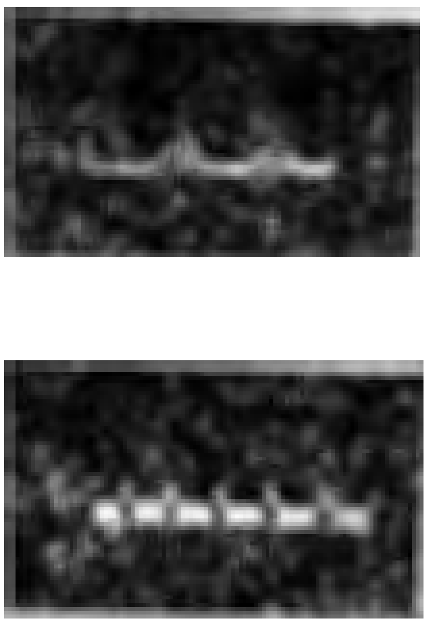

Fig. 6 — Superregenerative amplifier output.

References

1. Skalskii J. and Kapaservic A., Proc. IRE No. 2. (1962).

2. Reindel J., Proc. IEEE No. 11, (1963).

3. Jordan A. G., Elco R., J. Electron and Control No. 1, (1961).

4. Akchqrin E.A. and Berectnev B.D. Radioengineering (Soviet Journal) No. 8 (1963).

5. Van Voothis S.N. Microwave Receivers, and M.I.T., McGraw-Hill Book Co. Inc. (1948).

6. Woo F. Chow, Principles of Tunnel Diode Circuits, John Wiley Inc. New York (1964).

7. Akchyrin E.A., Semiconductor Devices. Soviet Radio (1966).