

Tunnel Diode-Transistor Binary Scaler

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This paper describes a new type of tunnel diode-transistor binary scaler which is very simple in concept and in design. It is capable of operating reliably at input pulse repetition rates in excess of 200 MHz. A significant feature of the scaler is that there is no maximum input pulse width restriction. Input and output circuits which allow the scaler to operate over a wide range of input driving conditions and to be cascaded directly with similar scalars are also presented.

INTRODUCTION

SCALERS capable of operating with input pulse repetition rates greater than 100 MHz are common but most require input pulses of width less than a specified maximum. A simple scaler which operates reliably with no maximum input pulse width restriction is described in this paper. The basic arrangement of the scaler is shown in Fig. 1. Essentially it consists of a long-tailed pair with regenerative feedback from the collectors to the opposite bases *via* level-shifting Zener diodes. The tunnel diodes in the emitter leads provide the necessary memory elements of the binary. This circuit technique was originally devised by K. L. Tan¹ and employed by him in a binary scaler of somewhat similar circuit configuration but completely different design philosophy and mode of operation.

PRINCIPLE OF OPERATION

In the two steady-state conditions either T_1 or T_2 is conducting. Assuming that initially T_1 is ON, then TD1 is biased in the low voltage state A by the current I_b flowing through it (see Fig. 2). The collector potentials V_{c1} and V_{c2} are $(I_z + I_b)R$ and $I_z R$, respectively.² When an input current ΔI_{in} is supplied to the long-tailed pair it raises V_{c1} , and consequently V_{b2} , by $\Delta I_{in} R$. If ΔI_{in} is large enough, TD1 switches to the high voltage state B

and V_{e2} rises by about 0.5 V (V_f for Ge tunnel diodes). By selecting the value of R such that

$$V_{e2} < V_{b2} + V_t$$

when ΔI_{in} switches TD1 to state B and

$$V_{e2} > V_{b2} + V_t$$

when ΔI_{in} is removed and TD1 is in state C, T_2 is forced to remain OFF until ΔI_{in} is removed. V_t is the emitter-base voltage³ when T_2 commences to conduct. On removal of ΔI_{in} , T_2 starts to conduct and I_b is transferred from T_1 to T_2 , the process of transfer being assisted by the regenerative feedback loops. Tunnel diode TD1 reverse switches when its current falls below I_v . In the other condition T_1 is OFF and T_2 is ON and TD2 is biased in the low voltage state A. The next input pulse will return the scaler to its initial condition of T_1 ON and T_2 OFF.

From the above description it is evident that there is no maximum input pulse width restriction. The minimum width is that necessary to ensure the switching of the tunnel diodes. Figure 3 shows the variation of V_{c1} and V_{c2} when input pulses are applied to the scaler. Either collector potential change can serve as an output for the scaler.

DESIGN CONSIDERATIONS

In any scaling circuit there are two sets of design conditions, one set necessary for proper operation and the other set desirable for optimum performance. With reference to the notation of Figs. 1 and 2, the necessary design conditions for the scaler are as follows:

- (1) The input current ΔI_{in} must be sufficient to switch

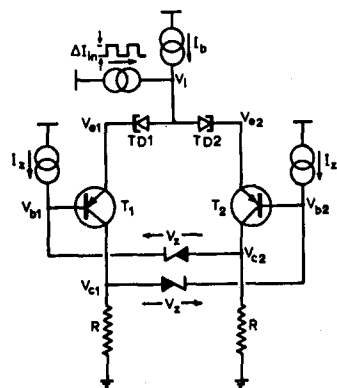


FIG. 1. Basic arrangement of scaler.

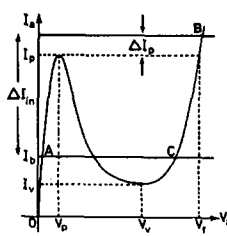


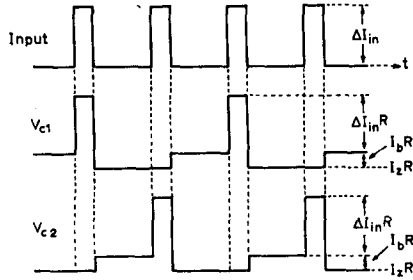
FIG. 2. Static characteristic diagram of tunnel diode.

¹ K. L. Tan, "High speed transistor regenerative switching circuits," Thesis submitted for Ph.D. in Elec. Eng., Univ. of Canterbury, New Zealand, July 1967.

² To avoid unnecessary complexity the α 's of the transistors are assumed to be equal to unity.

³ This voltage is assumed to be 0.3 V below V_{eb} , the emitter-base 'knee' voltage. For Ge transistors $V_t = 0$ and for Si transistors $V_t = 0.5$ V.

FIG. 3. Theoretical collector potential variations.



either TD1 or TD2, depending on which is biased by the current I_b , i.e.,

$$(I_b + \Delta I_{in}) > I_{p \max}$$

(2) The off-transistor must remain non-conducting when ΔI_{in} is present and commence conducting when it is removed, i.e.,

$$(I_z + I_b + \Delta I_{in})R + V_z + V_t > V_i > (I_z + I_b)R + V_z + V_t,$$

which, on substitution of $(I_z R + V_z + V_{eb} + V_f)$ for V_i , reduces to

$$(I_b + \Delta I_{in})R + V_t > V_{eb} + V_f > I_b R + V_t$$

and since $(I_b + \Delta I_{in})$ must be greater than $I_{p \max}$,

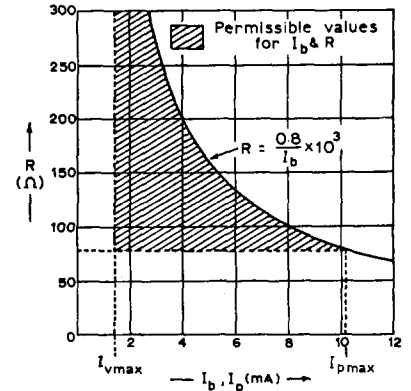
$$I_{p \max} R + V_t > V_{eb} + V_f > I_b R + V_t.$$

(3) When ΔI_{in} is removed, the switched tunnel diode must remain in the high voltage state to allow the off-transistor to conduct and establish a complete transfer of the current I_b in the long-tailed pair, i.e.,

$$I_b > I_{v \max}$$

(4) For fast rise input pulses the switching time (i.e., delay time + rise time) of the on-transistor must be greater than that of the switching tunnel diode to ensure that the off-transistor does not start to conduct when ΔI_{in} is applied.

Conditions (1), (2), and (3) can be satisfied by the choice of values for I_b , ΔI_{in} and R . Figure 4 summarizes

FIG. 4. Design conditions for I_b and R .

conditions (2) and (3) by graphically showing permissible values for R and I_b (shaded region) for a scaler employing Ge transistors and tunnel diodes. Typical values of 0.3 V and 0.5 V are assumed for V_{eb} and V_f respectively. V_t in this case is zero. Condition (4) can be met by appropriate selection of transistor and tunnel diode types.

The following are desirable for optimum performance:

(1) High speed transistors and tunnel diodes should be used for maximum speed of operation.

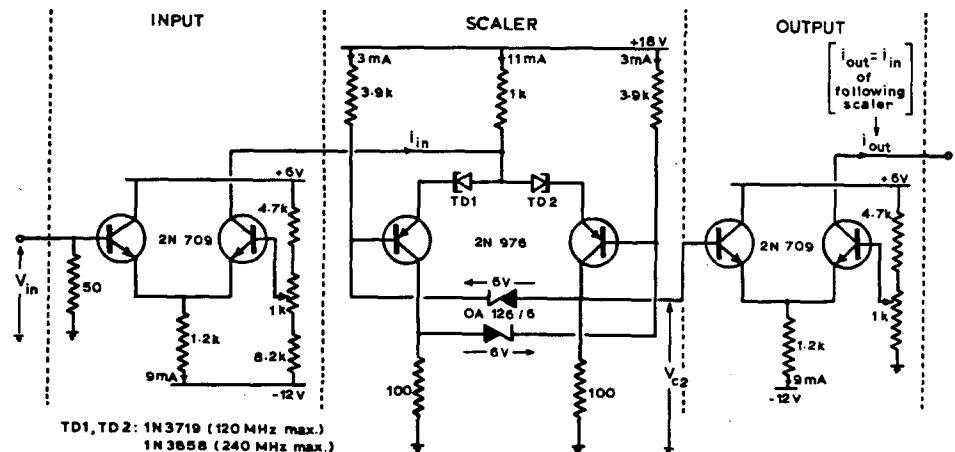
(2) Voltage swings should be kept small to minimize the effects of circuit capacitances. It is desirable therefore for ΔI_{in} and R to be small.

(3) The current switched in the long-tailed pair is I_b so that a small value of I_b improves the speed of the current transfer and also reduces delay in reverse switching the tunnel diodes.

(4) Zener diodes with equal V_z 's should be used. However, if matched Zener diodes are not available, one of the I_z 's may be varied to achieve the necessary equalization of the minimum levels of V_{b1} and V_{b2} .

PRACTICAL CIRCUIT

The practical circuit of the scaler is shown in Fig. 5. An examination of Fig. 4 indicates that a 10 mA tunnel diode is a reasonable choice, as a 5 mA type tends to

FIG. 5. Practical scaling circuit ($I_b = 2$ mA, $\Delta I_{in} = 9$ mA, $R = 100\Omega$).

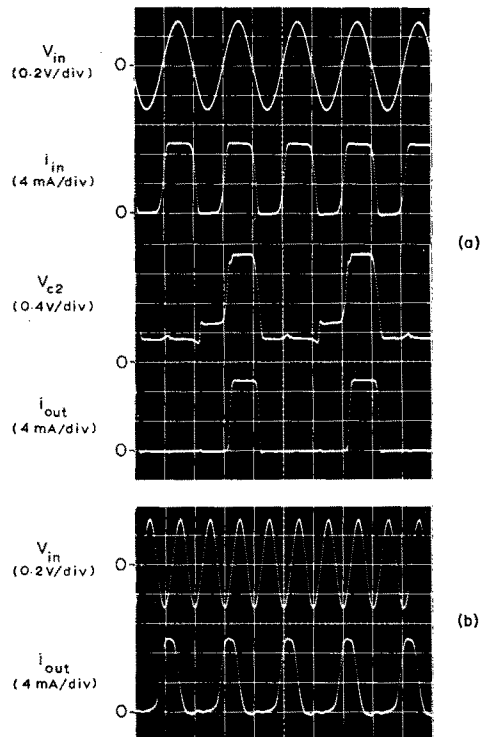


FIG. 6. Experimental waveforms (GE 1N3719 tunnel diodes). (a) Operation at 10 MHz (hor: 50 nsec/div.). (b) Operation at 100 MHz (hor: 10 nsec/div.).

dictate a rather high value of R , and a 20 mA type demands large input and bias currents. The practical values of I_b , ΔI_{in} , R , etc. are selected in accordance with the stipulated conditions. It should be noted that although pnp transistors are used in the long-tailed pair, npn types, with appropriate bias changes, will serve just as well. When the latter type transistors are used, negative input pulses are necessary. Ancillary long-tailed pairs are employed as input and output coupling circuits. The use of npn transistors in these circuits eliminates any level-coupling problems, thus allowing direct connections to be made. The final output is a current pulse capable of driving another scaler directly.

PERFORMANCE

With GE 1N3719 tunnel diodes, the scaler operates very reliably up to a maximum input repetition frequency of about 120 MHz. It is insensitive to changes ($\pm 10\%$) of power supply levels. Practical waveforms showing the scaler operating at input repetition rates of 10 and 100 MHz are shown in Figs. 6(a) and 6(b), respectively. If reference is made to the notations used in the practical circuit these figures are self-explanatory.

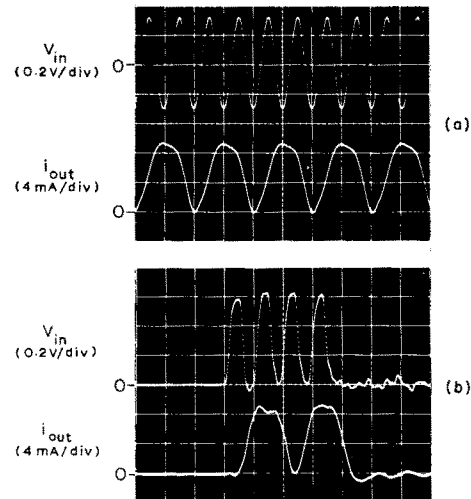


FIG. 7. Experimental waveforms (RCA 1N3858 tunnel diodes). (a) Operation with 200 MHz sinusoidal signal (hor: 5 nsec/div.). (b) Operation with 220 MHz pulses (hor: 5 nsec/div.).

The maximum speed of operation of the scaler will, to a very large extent, depend on the speed of the transistors and tunnel diodes used. Using the same transistors,⁴ the substitution of a much faster tunnel diode type (RCA 1N3858) increased the maximum operating frequency to about 240 MHz. Figure 7 shows the input and output waveforms of the scaler operating at 200 MHz. In Fig. 7(a) it is scaling down a 200 MHz sinusoidal input signal and Fig. 7(b) shows it functioning at an input repetition rate of 220 MHz with input pulses from an HP 10451A multipulser driven by an HP 215A pulse generator. It should be pointed out that the substituted tunnel diodes are too fast for the transistors used. The tendency for the scaler to multivibrate when the amplitude of ΔI_{in} is increased indicates that the scaler is relying mainly on the delay-time of the tunnel diode to satisfy the necessary condition (4). For small values of overdrive ΔI_p (see Fig. 2), this delay time depends significantly on ΔI_p . It is reasonable to assume that with faster transistors the scaler should operate with input repetition rates in excess of 200 MHz with a much higher degree of reliability.

ACKNOWLEDGMENTS

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⁴The 2N976's used were the fastest switching transistors locally available at the time of the scaler's development.