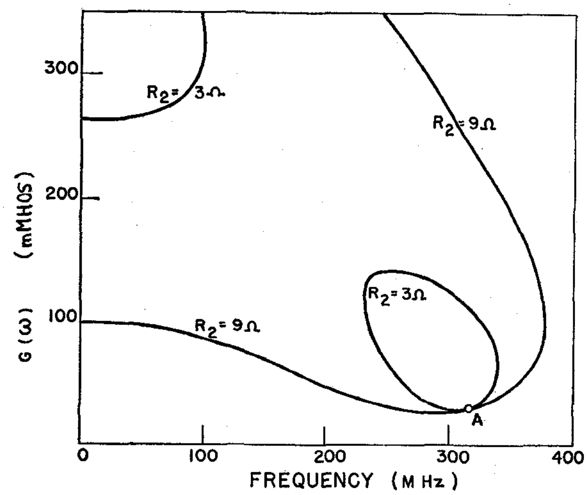

Fig. 2. Required tunnel diode negative conductance versus frequency of oscillation for R_1 = 0.8 ohm, L = 2.8 nH, C = 90 pF, and for two values of R_2.

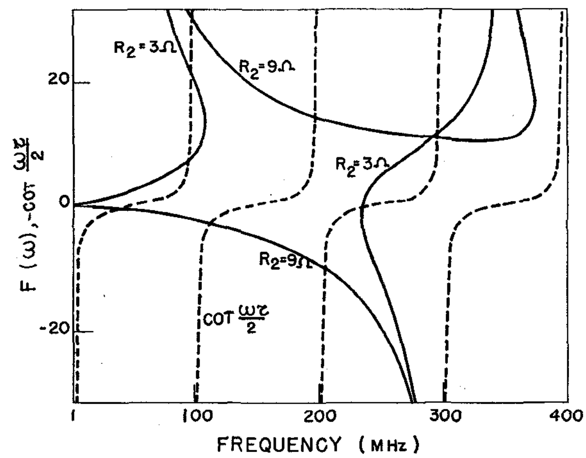

Fig. 3. $F(\omega)$ for two values of R_2 and $-\cot \omega\tau/2$ for $\tau = 10^{-8}$ second versus frequency. The intersections indicate possible oscillation modes.

a period of one day is easily obtained. Operation in the low-frequency branch corresponds to a relaxation oscillation as indicated by Jaskolski and Ishii [2].

The stability depends on the variation of the transmission line length with temperature and the variation of g with temperature and with bias. Regulation of the bias supply to 1 percent regulates the frequency to 0.001 percent at constant temperature. It is necessary to control the temperature to approximately 1°C for this frequency stability. It is thought that with better temperature control, or using tunnel diodes whose characteristics are temperature insensitive, appreciably better stability can be obtained.

Because of the nonlinearity of the I–V characteristic, the third harmonic is large in amplitude, often of the order of the fundamental. Thus, the third harmonic can also be used as a highly stable frequency.

If the operation is below the maximum frequency, the bias affects the oscillation frequency. There exists a range of bias where the frequency varies approximately linearly with voltage. Operation in this region can be used for frequency modulation.

Because of the nonlinear properties of the oscillator, it can be synchronized to a standard. We have been able to synchronize such a diode to an oscillator having a stability of one part in 10^{10}. The output voltage of the tunnel diode was 100 mV rms for a synchronization signal of 2 mV. If it were mounted in an antenna, it would be expected that it could be used to amplify small signals from standard stations.

Acknowledgment

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Invariant of A Noisy Two-Port

***Abstract*—A recent paper [2] is extended to show the existence of a quantity associated with a noisy two-port that is invariant under lossless transformation. The transforming network may be reciprocal or nonreciprocal.**

In linear noisy two-ports, the spot noise figure is known to depend on the admittance Y_s of its input termination in the manner expressed by the relation [1]

$$F(Y_s) = F_{op} + \frac{R_n}{\mathrm{Re}\,(Y_s)}\,|Y_s - Y_{op}|^2 \tag{1}$$

where $F(Y_s)$ is the noise figure for the source admittance Y_s, F_{op} is the minimum noise figure, Y_{op} is the optimum source admittance for which the optimum noise figure F_{op} is realized, and R_n is a positive constant which characterizes the rapidity with which the noise figure deteriorates from the minimum value as Y_s departs from Y_{op}.

The parameters F_{op}, Y_{op}, and R_n characterize the noise properties of a device. F_{op} is invariant under lossless transformation, and Y_{op} transforms like any ordinary admittance. However, R_n varies in a complicated manner. It is suggested [2] that R_n be written as

$$R_n = \frac{N}{\mathrm{Re}\,[Y_{op}]}, \tag{2}$$

where N is a new quantity; then (1) is of the form

$$F(Y_s) = F_{op} + \frac{N \cdot |Y_s - Y_{op}|^2}{\mathrm{Re}\,[Y_{op}]\,\mathrm{Re}\,[Y_s]}. \tag{3}$$

It has been found that[1] in automatic noise figure measurements the OFF–ON impedance of the noise lamps are not the same and, since device gain in some cases is dependent on the generator impedance, an isolator is required for accurate measurements. A generalization to include invariance of the parameter N under transformation by *lossless nonreciprocal* networks is given as follows.

Consider a noisy two-port preceded by a nonreciprocal network represented by the matrix $[Y]$ as shown in Fig. 1.

The matrix $[Y]$ for a nonreciprocal lossless network can be written as

$$Y = \begin{bmatrix} jB_{11} & jB_{12} \\ jB_{21} & jB_{22} \end{bmatrix} \tag{4}$$

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[1] The authors gratefully acknowledge comments by the referees and Editor on this point.

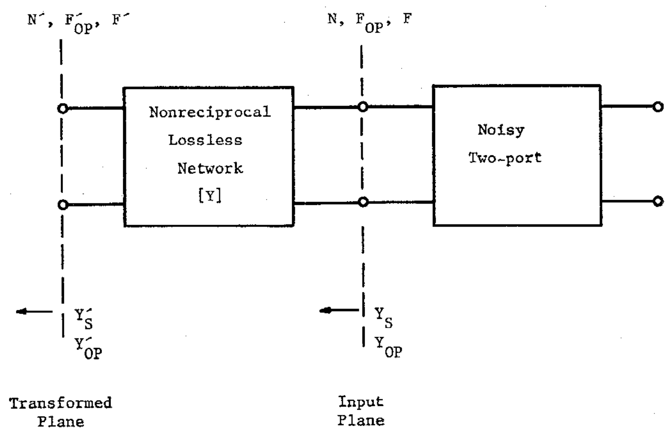

Fig. 1. Noise parameters at input and transformed planes.

where B_{11}, B_{12}, B_{21}, and B_{22} are real. The noise parameters designated by the unprimed quantities in Fig. 1 represent those of the noisy two-port without lossless transformation, and the noise parameters designated by the primed quantities represent those of the noisy two-port under lossless transformation. Thus as far as the noise performance is concerned, a source admittance Y_s' terminating the input of the nonreciprocal network at the transformed plane is equivalent to a source admittance Y_s terminating the input of the noisy two-port at the input plane without the lossless network. Y_s' may be expressed in terms of Y_s and the B_{ij}.

In Lange's original paper, $B_{12} = B_{21}$. If in his calculations, B_{12}^2 is replaced by $B_{12}B_{21}$ everywhere, his equations carry through to yield

$$\frac{|Y_s' - Y_{op}'|^2}{\mathrm{Re}\,(Y_s')\ \mathrm{Re}\,(Y_{op}')} = \frac{|Y_s - Y_{op}|^2}{\mathrm{Re}\,(Y_s)\ \mathrm{Re}\,(Y_{op})}. \tag{5}$$

Therefore, the quantity $|Y_s - Y_{op}|^2/\mathrm{Re}\,(Y_s)\ \mathrm{Re}\,(Y_{op})$ is invariant under nonreciprocal lossless transformation, and since $F_{op}' = F_{op}$ and $F'(Y_s') = F(Y_s)$, it follows from (3) that

$$N' = N. \tag{6}$$

This completes the proof that N is invariant.

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Tunnel-Diode-Pair Unidirectional Pulse Regenerating Circuits

***Abstract*—A method of constructing unidirectional pulse regenerating circuits with a pair of two-terminal active devices, such as tunnel diodes, is described.**

Pulse regenerating circuits of a pair of tunnel diodes that regenerate the pulse into the output port but not into the input port are described.

The basic circuit is shown in Fig. 1, where the tunnel diodes

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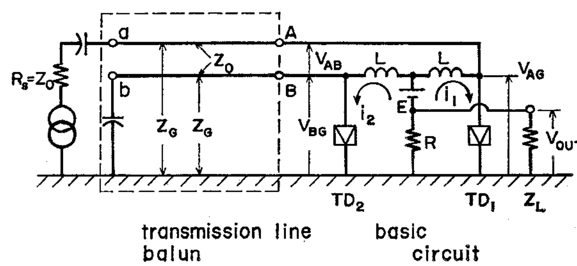

Fig. 1. Tunnel-diode-pair unidirectional pulse regenerating circuit with a transmission line balun.

TD_1 and TD_2 are dc biased at a stable point just below the peak current point of the i–v curve. Thus, the circuit can be regarded as consisting of a pair of identical monostable trigger circuits coupled through the common resistance R. The input trigger pulse is applied to the port AB, and the regenerated output pulse is obtained across R, which is shunted with the load impedance Z_L (output transmission line impedance). The operation of the circuit can be explained as follows.

When an input trigger pulse of an appropriate magnitude in the polarity shown in Fig. 1 is applied, the TD_1 monostable circuit is triggered and i_1 suddenly reduces. Due to this reduction of i_1, the voltage drop across R reduces, and the voltage across TD_2 increases. Thus, the TD_2 monostable circuit is triggered. Since the time delay between these successive triggerings is a small fraction of the risetime of the regenerated pulses, the regenerated pulses are added at the output port and subtracted at the input port, thus resulting in a unidirectional pulse regenerating circuit.

The circuit can be triggered by an input trigger pulse in either polarity. However, the polarity of the output pulse is determined by the polarity of the diodes in the circuit regardless of the input pulse polarities.

The circuit can also be triggered by a pulse of proper magnitude and polarity applied to the output port, although this is undesirable. In this mode of operation, the circuit operates as a conventional two-terminal pulse regenerating circuit, i.e., it regenerates no pulse at the port AB.

The fact that the input and output ports of the basic circuit do not have a common "ground" terminal presents difficulties in practical applications. The difficulties can be circumvented by the use of a transformer, either of the conventional type (electromagnetic induction type) or of the transmission-line type. For low-speed applications (say, pulse repetition rate below 100 MHz), the conventional transformer can be conveniently used. Such a circuit has been described by Taki *et al.* [1]. However, when the speed of operation increases, the inductance of the transformer windings will become the dominant factor that limits the speed. For such high-speed applications, the transmission-line transformer [2] can be used.

Such an arrangement is shown in Fig. 1, where a pair of parallel wires above the ground plane form a transformer or a balun. The parallel wires aA and bB form a transmission line (impedance Z_0) which supports the "primary wave" while each wire (aA or bB) and the ground plane form transmission lines (impedance Z_G) which support the "secondary wave," where the structure is made to satisfy the condition $Z_0 \ll Z_G$.

A pulse applied to the port ab excites two waves, i.e., the primary wave and secondary wave between the wire aA and the ground. However, since $Z_0 \ll Z_G$, most of the pulse energy is carried by the primary wave that propagates to the port AB, where it is terminated by the impedance consisting of the two diodes connected in series and the shunt inductance $2L$. Since most of the pulse energy must be absorbed by the diodes for efficient triggering, Z_0 should be roughly equal to the dynamic resistance of the series diodes at around the dc bias point.

At the port AB, the primary wave voltage V_{AB} is divided