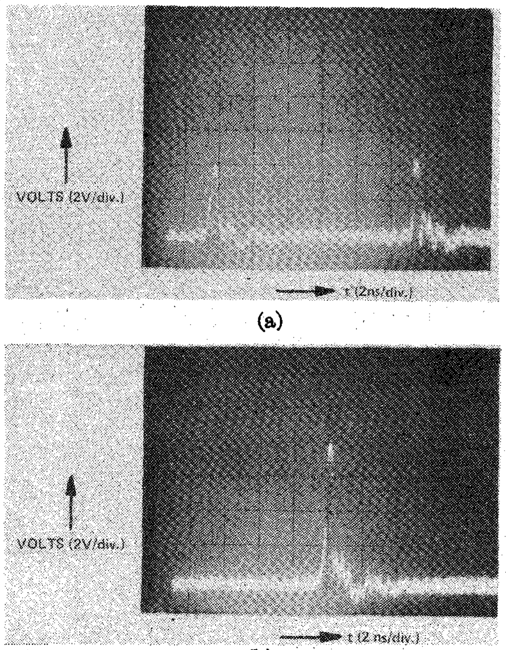

Fig. 6. Waveforms observed at a tap.

to the next increment each fifth transmitted pulse. In this manner, the entire range sector is scanned once every 50 transmitted pulses, a 200-Hz range-scan rate for a pulse-repetition frequency (PRF) of 10 kHz.

A sampling oscilloscope may be placed at any tap position and the resulting waveform may be observed as shown in Fig. 6. In Fig. 6(a) we observe the reconstituted baseband pulse return from a target located at an improper coarse range; the time scale is 2 ns/div and the ordinate is 2 V/div. At the appropriate coarse range and vernier tap, the two pulses coalesce as shown in Fig. 6(b) and exceed the threshold voltage of the avalanche transistor set at 6 V. The avalanche transistor is a monostable device which automatically resets a prescribed time after it discharges awaiting another trigger.

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A Transferred-Electron Frequency Memorizer

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***Abstract*—Transferred-electron oscillators capable of single-frequency operation at any of as many as 20 closely spaced frequencies have been constructed for microwave-frequency-memory applications around 11 GHz. Switching between different frequency states has been achieved with a single RF pulse as short as 0.1 μs.**

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INTRODUCTION

In many microwave signal-processing systems, such as ECM systems, it is desirable to acquire an external input signal and to retain it for a long period of time. One technique for producing time delay is called the "loop" memory system; it consists of an amplifier with a delay line in the feedback path. A second method is to construct a multiposition frequency memory or register that will continue to oscillate at any one of a large number of assigned frequencies until shifted to another by a new input signal. Edson [1] has described the general properties of both systems in a classic article. He showed that the loop memory system is also a form of frequency register where the frequency separation is equal to the reciprocal of the loop time delay. Many of Edson's conclusions (e.g., system behavior in the presence of multifrequency signals, the number of modes possible in practice for each type of frequency register, etc.) appear to be valid at microwave frequencies.

The purpose of the present study is to investigate the feasibility of a frequency-memory register constructed at microwave frequencies using conventional transferred-electron devices (TED's). The TED frequency memorizer utilizes a multiresonant RF circuit to enable oscillation at as many as 20 RF frequencies. A range of over 2 GHz has been achieved with mode spacing of about 132 MHz. Memorizers with smaller mode spacing and the power requirements for switching with pulsed RF input have been studied. Magarshack [2] has previously demonstrated one type of TED frequency-memory oscillator. He points out that such devices may also have application in the field of telecommunications for switching between channels.

RF PERFORMANCE

Fig. 1 shows the equipment layout used for evaluating each frequency memorizer. The TED was operated with dc bias, and a pulsed RF input signal was used for switching. Tests were usually conducted with pulse repetition rates of 1 kHz and pulsewidths of 0.1–1.0 μs. Provision was made so that a single pulse of RF could be produced after setting the RF source to a new frequency. By this means it was verified that switching always occurred during the first pulse of the input RF signal.

Each memorizer tested was found to have a set of stable frequency states. A state was deemed stable if, after switching, the memorizer would continue to oscillate in that state when the input signal was removed. Some states exist only with the presence of additional signals at other states. These states have multiple frequency output.

The number of stable frequency states was affected by the bias voltage of the TED as well as by circuit tuning. The RF frequency and RF power output for each stable state was measured for fixed bias value and circuit tuning condition. This measurement shows the number, range, and separation of the frequency states instantaneously available for an input signal.

Figs. 2 and 3 show the frequency states measured for two experi-

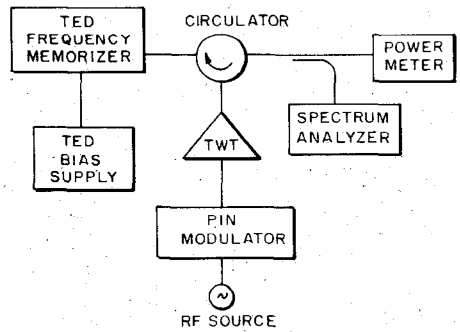

Fig. 1. Equipment layout for switching tests of a TED frequency memorizer.

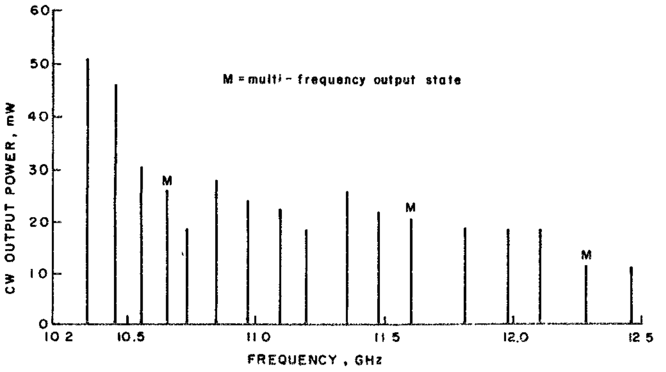

Fig. 2. Frequency states of a frequency memorizer constructed with an alumina microstrip circuit. The TED is operated with 7.73 V and 0.43 A.

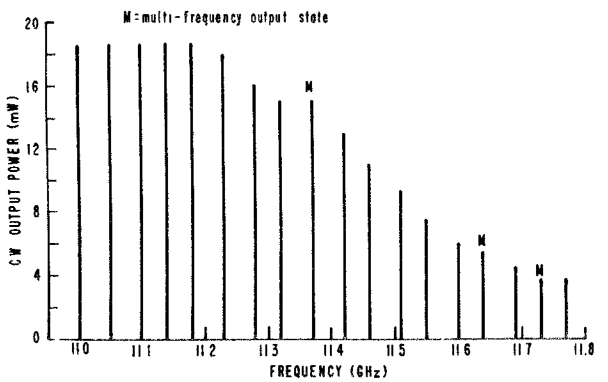

Fig. 3. Frequency states of the frequency memorizer constructed with 0.141-in semirigid coaxial line. The TED is operated at 11.95 V and 0.32 A.

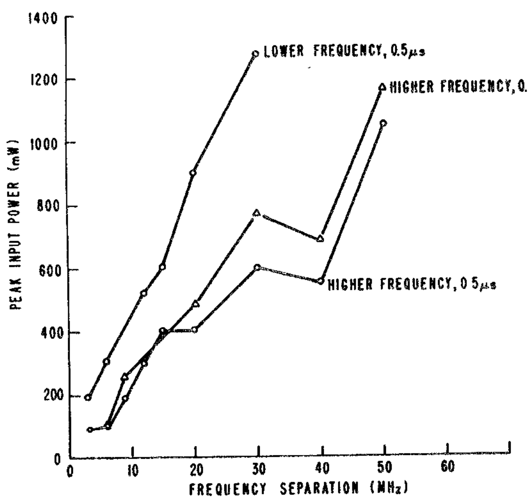

Fig. 4. Peak power required for external source to switch on frequency state at 11.47 GHz as a function of frequency separation between the state and the input signal. The memorizer under test is the same as tested in Fig. 2. The next higher frequency state is separated by 130 MHz and the next lower frequency state is separated by 115 MHz. This state has $Q_{ex} \approx 1510$.

mental memorizers. In both cases, switching occurs even for a single pulse of RF signal of width 0.1 μs if the RF input power is above a threshold value. The minimum input power increases with increase of the frequency separation between the input signal and the frequency state. Use of inadequate input power sometimes causes switching to a state far removed from the input frequency.

Fig. 4 shows typical data for the minimum input power required

TABLE I
COMPARISON OF PROPERTIES OF FOUR DIFFERENT TED FREQUENCY MEMORIZERS

RF Circuit	Average Mode Spacing (MHz)	Freq. Range (MHz)	No. of Missing Modes	No. of States	CW Output Power (mW)
Microstrip on 2" x 2" x .025 " alumina	132	2120	4	17	10-50
5 ft. of WR-90 waveguide	71	1070	0	16	10-70
7 ft. of 0.141" diameter semirigid coaxial line	45	770	0	13	4-20
15 ft. of 0.25" diameter semirigid coaxial line	22.4	425	0	20	25-50

for proper switching as a function of frequency separation between the input signal and the *closest* frequency state. The power requirements do not depend upon the operating frequency existing before switching occurs. Thus these data are the same if the memorizer is one or ten frequency states above or below 11.47 GHz. Therefore, the behavior is significantly different from an injection-locked oscillator.

The performance characteristics for four different memorizers are listed in Table I. The multimode circuits can be fabricated from coaxial line, waveguide, or alumina microstrip. The switching characteristics were generally similar; however, longer input pulses (about 0.5 μs) were required to switch the memorizer with 22.4-MHz mode separation. About 200-mW input power was adequate to switch any of the memorizers if the input signal was within several megahertz of the frequency state.

DISCUSSION

The RF circuit design for the memorizers whose data appear in Table I is shown in Fig. 5. TED's of 100-mW capability are connected across an open- or short-circuited transmission line (waveguide, coaxial, or microstrip) and an output microstrip transformer couples the device to the input/output transmission line. R_L values between 50 and 100 Ω were used.

For low-loss transmission lines, the mode separation, ΔF, can be calculated approximately assuming an integral number of half-wavelengths for each mode. The line length L is then

$$L = \frac{n\lambda_n}{2} = \frac{(n-1)\lambda_{n-1}}{2} = \text{etc.}$$

where

n the number of half-wavelengths for the nth resonance;
λ_n the transmission-line wavelength for the nth resonance.

It is easily shown that

$$\Delta F = \frac{v_g}{2L} = \frac{1}{\tau}$$

where v_g is the group velocity at λ_n and τ is the round-trip time delay of the transmission line. Thus a 10-ns delay line (i.e., 1.5-m-length TEM air line) is required for 100-MHz frequency spacing.

In the design of a frequency memorizer it is important to maintain the stability as uniform as possible over the operating band. If this is not achieved, there is a strong tendency for the memorizer

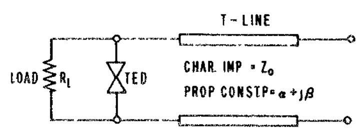

Fig. 5. TED frequency-memorizer circuit.

to jump to the most stable frequency state during switching. Such a state may be well removed from the input frequency.

Best stability is achieved when the circuit's RF impedance line (as a function of frequency) and the TED's load-impedance characteristic (as a function of RF voltage) intersect orthogonally. Large differences in external Q (or load coupling) across the operating frequency band will cause large differences in stability between states. Therefore, it is important to design the output transformer to produce uniform loading. Experiments verified that the erratic switching effects of several states were due to large differences in external Q values between states.

Fig. 6 shows the load-impedance characteristics of one TED used in this study, and Fig. 7 shows the calculated circuit impedance for each mode for two of the experimental circuits. The microstrip circuit has $\Delta F = 108$ MHz, is shunt loaded by 100 Ω, and is fabricated on a piece of $2 \times 2 \times 0.025$-in alumina. The waveguide circuit has $\Delta F = 80$ MHz, consists of 5 ft of WR-90 waveguide, has a waveguide to 50-Ω transformer, and $R_L = 100$ Ω at the device. The number of frequency states achieved is determined by the number of circuit modes which intersect device lines at common frequencies.

The frequency separation between modes may not be decreased indefinitely by using longer and longer transmission lines. The

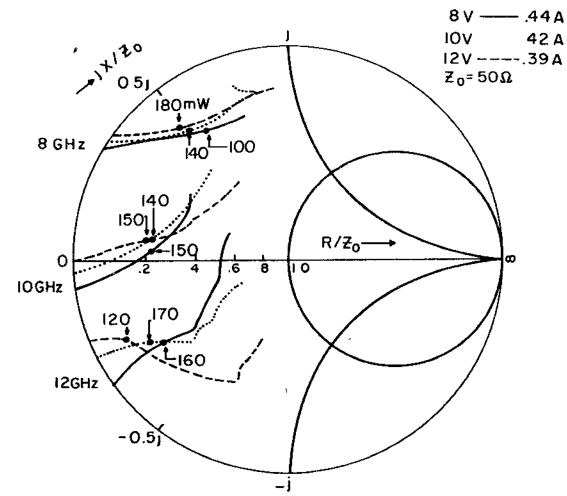

Fig. 6. Smith chart display of measured load-impedance characteristics for a packaged TED. RF output power values are shown.

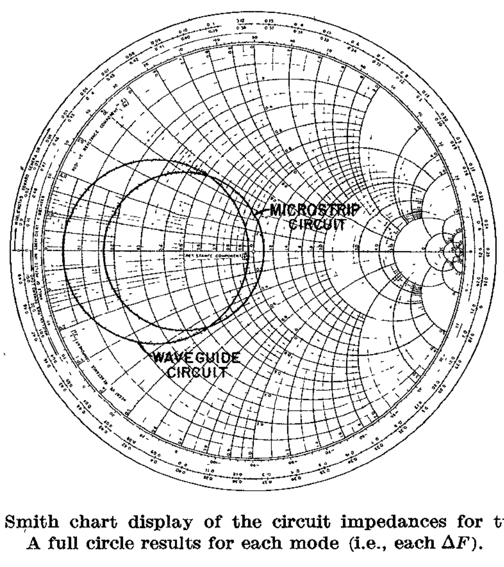

Fig. 7. Smith chart display of the circuit impedances for two cases. A full circle results for each mode (i.e., each ΔF).

TABLE II
CALCULATED CIRCUIT QUALITY FACTOR AT 10 GHz ASSUMING NO LOAD COUPLING

RF Circuit	Z_0 (Ω)	Q	2f/Q (MHz)
.015" thickness alumina microstrip	34	290	70
.025" thickness alumina microstrip	34	466	43
WR-90 waveguide	--	6150	3.2
0.25" diameter semirigid coaxial line	50	1300	15.4

minimum mode separation is limited to about twice the value of f/Q, where f is the RF frequency and Q is the quality factor of the transmission line due to losses. Table II presents calculations of Q and $2f/Q$ values for various types of transmission lines at 10 GHz. Mode spacings of 50 MHz can be easily achieved. However, mode spacings of 10 MHz require a waveguide circuit or larger diameter coaxial line.

Study was made of the switching mechanism and switching RF power requirements. A memorizer's output spectra were observed while the pulsed RF input signal was moved slowly from one frequency state (the initial CW output state) to an adjacent state. Pulsed third- and fifth-order intermodulation signals were clearly observable as well as reflection gain when the input signal approached the second state. Simultaneous with reflection gain, the third-order intermodulation signal was observed to increase an equal distance on the other side of the initial CW state. In addition, pulsed signals exactly at the adjacent frequency states in the memorizer are observed. If the pulsed RF input power is sufficient, the desired state is switched on; otherwise, the state on the other side of the initial state may be switched on.

Phase-coherency measurements between input and output signals showed that when the input power requirements are met, the memorizer phase locks to the input (pulsed) signal in less than 50 ns. Sufficient power is required so that switching to states near intermodulation signals does not occur.

CONCLUSIONS

It has been demonstrated that a multiposition frequency register with as many as 20 frequency states can be constructed and operated near 11 GHz using conventional TED's and a low-loss transmission line. The transmission line can be made from coaxial line, waveguide, or alumina microstrip. Pulsed RF input signals cause switching to the nearest frequency state within 50 ns, and this state is maintained indefinitely or until a new input signal occurs. The RF power required for switching states increases as the frequency separation from the closest state is increased. The minimum state separation achieved was 22.4 MHz.

ACKNOWLEDGMENT

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