Fig. 2. Display operated in the reflection mode between crossed polarizers with 1.3-V rms 50-Hz square-wave excitation.

ordering, the wall-induced alignment of the molecules in the boundary layers close to the electrodes has to be as unidirectional as possible. The photograph of a multidigit display shown in Fig. 2 was taken from a cell containing the compound M I. It was operated in the reflection mode between crossed linear polarizers. Behind the display a white background was provided. The display was illuminated with an incandescent lamp on the observer side of the cell. The display segments were driven in parallel by a square-wave voltage of 50-Hz frequency and 1.3-V amplitude. An even better contrast than shown in Fig. 2 has been obtained for the transmission mode of operation.

The display devices described here operate with voltages lower by nearly an order of magnitude than the voltages required in comparable displays based on the dynamic scattering effect. In addition contrast degradation due to the reflected image of the illumination source can be avoided more easily. At present no extensive life-time evaluation data for the mixtures M I and M II are available.

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Comments on "Noise Effect in Oscillators Using Multiple Active Devices Connected in Series or in Parallel"

Introduction

In the above letter,[1] Saito, Takagi, and Mano have stated that when a multiple-device oscillator is constructed with N diodes, a series connection of diodes improves the noise performance of the oscillator N^3 times, while a parallel connection deteriorates it N times. More appropriate assumptions discussed here show that the noise performance (FM noise power to carrier power ratio) improves N times for both series and parallel connections.

The $I-V$ characteristic of the devices used is nonlinear and is assumed to be of the form

$$i(v) = \alpha_0 - \alpha_1 v - \alpha_2 v^2 + \alpha_3 v^3, \qquad \text{all } \alpha > 0. \quad (1)$$

Saito *et al.* have used the ratio of normalized FM noise power spectra for comparing the single-device and multiple-device oscillators, obtaining

$$K = \frac{(P_n/Q^2P_0)_{N\text{-device}}}{(P_n/Q^2P_0)_{1\text{-device}}}. \quad (2)$$

P_0 is the maximum signal power output of the oscillator [maximized by choosing the optimum load conductance G for a fixed device conductance g, i.e., for a given operating point, the power being independent of all other parameters by virtue of the assumptions implied in (1)]. P_n is the FM noise power output of the oscillator (other contributions to noise are disregarded implying that the ratio K being defined is useful only in those applications where FM noise alone is of concern). Q is the Q factor of the resonant circuit at the frequency of oscillation.

In using this ratio K for comparing single-device and multiple-device oscillators, it is important to state the parameters that are being held constant in the two oscillators. To emphasize this point, different parameters are explicitly defined in the next section.

Parallel Connection

For parallel connected diodes, the power output of the N-device oscillator is given by eq. (4) of Saito *et al.*[1] as

$$P_N = \frac{2}{3\alpha_3} G \left(g - \frac{G}{N}\right) \quad (3)$$

where G is the real part of the circuit admittance and g is the device conductance at its operating point.

Single-Device Oscillator

The resonant circuit parameters are G_s, C_s, and L_s; the device conductance at its operating point is $-g_s$; the mean-square noise current at this operating point is $(\overline{i_n^2})_s$; and the frequency of oscillation is ω_s. Therefore,

$$\omega_s = [L_s(C_s + C_0)]^{-1/2}$$
$$Q = \omega_s(C_s + C_0)/G_s$$
$$P_0 = \frac{2G_s^2}{3\alpha_3}$$

attained by making $G_s = (1/2)g_s$;

$$P_n = \frac{2(\overline{i_n^2})_s}{g_s}$$

when $G_s = (1/2)g_s$; and

$$\frac{P_0Q^2}{P_n} = \frac{g_s\omega_s^2(C_s + C_0)^2}{3\alpha_3(\overline{i_n^2})_s}. \quad (4)$$

Multiple-Device Oscillator

The resonant circuit parameters are G_N, C_N, and L_N; the device conductance of each device at its operating point is $-g_N$; the mean-square noise current of each diode at this operating point is $(\overline{i_n^2})_N$; and the frequency of oscillation is ω_N. Therefore,

$$\omega_N = [L_N(C_N + NC_0)]^{-1/2}$$
$$Q = \omega_N(C_N + NC_0)/G_N$$
$$P_0 = \frac{2G_N^2}{3N\alpha_3}$$

attained by making $G_N = (N/2)g_N$;

$$P_n = \frac{2(\overline{i_n^2})_N}{g_N}$$

when $G_N = (N/2)g_N$; and

$$\frac{P_0Q^2}{P_n} = \frac{g_N\omega_N^2(C_N + NC_0)^2}{3N\alpha_3(\overline{i_n^2})_N}. \quad (5)$$

To compare the two oscillators directly it is further assumed that the operating point of the devices is the same in both cases, i.e., $g_s = g_N$ and $(\overline{i_n^2})_s = (\overline{i_n^2})_N$. Then

$$K = \frac{\omega_s^2(C_s + C_0)^2N}{\omega_N^2(C_N + NC_0)^2}. \quad (6)$$

It is clear from (6) that K is dependent upon the resonant circuit parameters, and different results can be found by imposing different conditions. Saito *et al.* have not stated which circuit parameters were held constant to obtain their result $K = N$. It can be obtained, for example, by setting $L_N = NL_s$ and $C_N = NC_s$. Then the frequency of oscillation of the two oscillators differs by N times. A more reasonable assumption would be to hold the frequency and Q constant for the two oscillators. This gives

$$K = \frac{1}{N} \quad (7)$$

which is in agreement with the results of Kurokawa.[2] Still other assumptions may be used to give different results. It is not worthwhile to use (6) to optimize the circuit parameters in an attempt to minimize noise because of the limiting assumptions involved. Further, the diodes can be operated at different operating points in the two oscillators in practice, and the mean-square noise currents will then depend upon the operating point.

Series Connection

It should be pointed out that eq. (1) of Saito *et al.*[1] is a valid description of their fig. 1(a) only when the noise voltage is small; however, this is a reasonable assumption. Carrying out the analysis as for the parallel connection gives

$$K = \frac{\omega_s^2(C_s + C_0)^2}{N^3\omega_N^2[C_N + (C_0/N)]^2}. \quad (8)$$

Again, one of the ways in which the result $K = 1/N^3$ of Saito *et al.* can be found is to set $L_N = L_s/N$ and $C_N = C_s/N$, which makes

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[1] T. Saito, T. Takagi, and K. Mano, *Proc. IEEE* (Lett.), vol. 60, pp. 126–127, Jan. 1972.

[2] K. Kurokawa, "The single-cavity multiple-device oscillator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 793–801, Oct. 1971.

the frequency of the N-device oscillator N times smaller. If both the frequency and the Q were kept identical,

$$K = \frac{1}{N}. \qquad (9)$$

The experimental results quoted,[1] which have been taken at a fixed frequency, are more in accordance with the $1/N$ improvement than with the $1/N^3$ result.[1]

Conclusions

In conclusion, the results and limitations may be summarized as follows.

1) The noise improvement in going from a single-device to a multiple-device oscillator would depend upon the circuit conditions, and a variety of results can be found by holding different parameters constant.

2) The noise power P_n has not been calculated as $G\overline{v^2}$ from eqs. (1) and (2) of Saito *et al.*[1] but rather from the equivalent circuit where the device has been replaced by a conductance $g=-f'(E)$ or $-f'(E/N)$ which is independent of signal level. This is equivalent to the assumption that the signal level as well as the noise level is very small. At the same time, the oscillator is operated at maximum power output, requiring the signal level to be large. The two conditions can therefore be contradictory.

3) The assumption of the instantaneous $I-V$ characteristic of (1) cannot be rigorously justified for avalanche transit-time or transferred-electron devices. The representation of the diode by an admittance consisting of a nonlinear conductance g in parallel with a constant frequency-independent capacitor C_0 is a very crude approximation.

4) Only the FM noise power has been considered, and the ratio K is defined at the maximum power output point. The results are therefore not useful for those applications where FM noise is not of primary concern, or where power requirements do not make it necessary to operate the device at the maximum output operating point.

5) The expressions for K in (6) and (8) are found under the assumption that the device operating point is the same in single- and multiple-device oscillators, so that $g_s=g_N$ and $(\overline{i_n^2})_s=(\overline{i_n^2})_N$. In practice, the diodes could be operated at different operating points in the two oscillators and then K would depend upon the relationship between the operating point and the mean-square noise current.

In view of these conditions, the applicability of the method and results is severely limited.

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Authors' Reply[3]

In their comment, M. S. Gupta and R. J. Lomax describe the influence of the shunt capacitances of the active devices on the noise properties and the variety of the results due to circuit conditions. In our case, we assumed that the effect of these parasitic parameters is not so great and the oscillation frequency and Q can be determined mainly by external resonant circuit.

The difference between the conclusion presented in our letter and that given by Gupta and Lomax stems from the difference of assumption. Gupta and Lomax have obtained the result $K=1/N$ under the assumption of Q constant. But in our letter, the difference in Q between the single- and the N-device oscillator is very important in determining the noise performance K, because the load conductance at the maximum power is not the same for both oscillators.

If Q can be held constant, the result of $K=1/N$ for both parallel and series connections can be obtained straightforwardly from eq. (7) in our letter[1] because the injected noise power P_n is the same for both cases under the maximum available power condition. We doubt whether it is reasonable or realistic to hold Q constant from the practical point of view.

Of course, the model used in our consideration involves the limiting assumption, especially for the avalanche transit-time or transferred-electron device; however, the precise circuit model of these devices including the noise properties for nonlinear analysis has not been sufficiently developed, so that we considered the macroscopic view of the noise performance in the complex oscillators by using the most fundamental model.

Our reason for considering the FM or PM noise power and the ratio K at the maximum output is that the FM and PM components are much more strongly distorted by noise than the AM component, and FM or PM noise becomes a very important factor in the communication systems, and the purpose of the N-device oscillator is to increase the power capability.

The experimental results shown[1] were obtained at a fixed frequency and different Q, but only about $1/N$ improvement was achieved. We think it is reasonable to attribute this to the other factors that could not be taken into account.

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[3] Manuscript received May 17, 1972.

Two-Frequency Microwave Holographic Interferometry

***Abstract*—Some experimental results on two-frequency microwave holographic interferometry are reported. This technique, well known in optics, has been extended to microwaves associated with the optical reconstruction of the interference pattern. Two different procedures were used to perform the superposition of the two microwave holograms on the same plate. Possible applications are suggested.**

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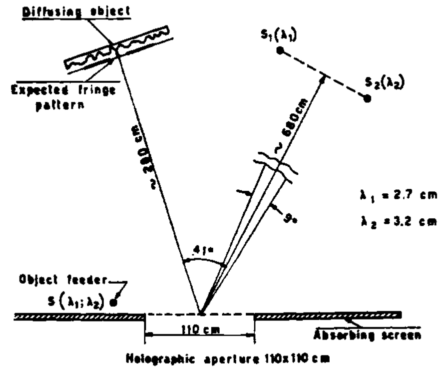

Fig. 1. Diagram of the microwave recording setup. A cross section of the expected fringe pattern is drawn near the diffusing object.

The first experimental result on holographic microwave interferometry has been previously reported [1] and the visible image of a deformed object crossed by fringes due to microwave interference has been shown. The possibility of extending to nonoptical wavelengths the two-frequency interferometry, already applied in optical holography [2]–[4], has been considered [4]. Microwave two-frequency interferometry, associated with optical reconstruction has been suggested in order to obtain precise information on the longitudinal size of large objects [1]. In particular the map of a terrain with superimposed constant level contours could be obtained with this technique.

Here we report some experimental results we obtained on two-frequency microwave holographic interferometry. The method consists of recording, whether simultaneously or not, two holograms at two slightly different microwave frequencies. The holograms are superposed on the same plate and scaled down in size. In the optical reconstruction two images are obtained that interfere with each other to form a fringe pattern. The fringes represent constant range contours on the object's surface with respect to the recording aperture [3]. The range separation r corresponding to successive fringes turns out to be

$$r = \lambda_1 \cdot \lambda_2 / 2\Delta\lambda \qquad (1)$$

where λ_1 and λ_2 are the two wavelengths used in the recording and $\Delta\lambda$ is their difference. Provided that the range between the holographic aperture and the object is sufficiently long, the fringes represent constant depth contours on the object's surface.

Constant depth fringes could also be obtained by means of two monochromatic sources [3] at the same frequency illuminating the object at different angles. This technique seems to be generally less convenient at low frequencies where large objects are assumed to be illuminated by a source which is also used as scanning detector (technique of the synthetic apertures [5], [6]).

The two-frequency method has been tested in the laboratory by using the record-