

power must be absorbed by adequate loads. The sign of $W_{1,0}$ is not proof *per se* of the instability of most parametric amplifiers. Indeed, electronic parametric amplifiers are stable.

In the case of the up-converter, the Manley-Rowe equations yield:

$$\frac{W_{1,0}^*}{f_0} + \frac{W_{1,1}}{f_1 + f_0} = 0 \quad (11)$$

$$\frac{W_{0,1}}{f_1} + \frac{W_{1,1}}{f_1 + f_0} = 0. \quad (12)$$

The output energy $W_{1,1}$ is absorbed by the load. Both signal energy $W_{1,0}$ and pump energy $W_{0,1}$ are generated by power sources. The sign of $W_{1,0}$ tells that the output is at a different frequency from the input. It also tells that an input signal generator is necessary. Eqs. (11) and (12) are proof *per se* of the stability of the up-converter.

P. A. CLAVER
Westinghouse Elec. Corp.
Electronic Tube Div.
Elmira, N. Y.

Short-Time Stability of a Quartz-Crystal Oscillator as Measured with an Ammonia Maser*

There are many applications, such as that required with atomic standards, where the very short time (second-to-second) stability of a quartz oscillator is important. Work at the National Bureau of Standards Boulder Laboratories on a high-precision oscillator, operated with the quartz crystal immersed in liquid helium, gave the results shown in Fig. 2. This may be compared with the short-time stability (Fig. 1) of another quartz oscillator with the crystal at about 40°C.

Temperature variations of the quartz crystal immersed in the liquid helium are reduced by controlling the pressure of the helium gas above the liquid. Apparently—compare Figs. 2 and 3—the regulator is adversely affecting the short-time stability of the oscillator. The pressure regulator, however, does provide satisfactory long-time stability.

About one hour trace was taken like that of Fig. 2, and about four hours like that of Fig. 3. The results were very consistent. The first run was made with the pressure regulator in operation for a period of over two hours and showed a drift of less than ~ 2 parts in 10^{11} . The following day, a trace was made without the pressure regulator. After about one hour of this recording, the pressure regulator was activated and the transition from the stability illustrated by Fig. 2 to that in Fig. 3 was observed.

The larger frequency fluctuations when the pressure regulator is used may be attributed to either the temperature change associated with pressure fluctuations or to

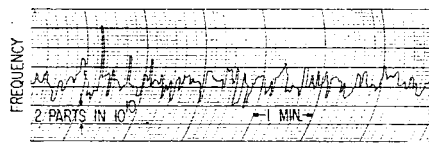


Fig. 1—Oscillator vs maser (approx. 40°C).

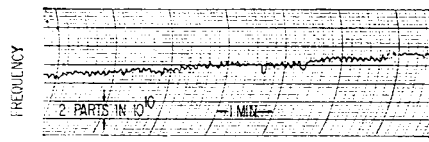


Fig. 2—Helium oscillator vs maser (no pressure control).

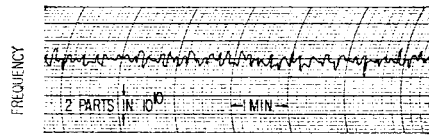


Fig. 3—Helium oscillator vs maser (pressure control).

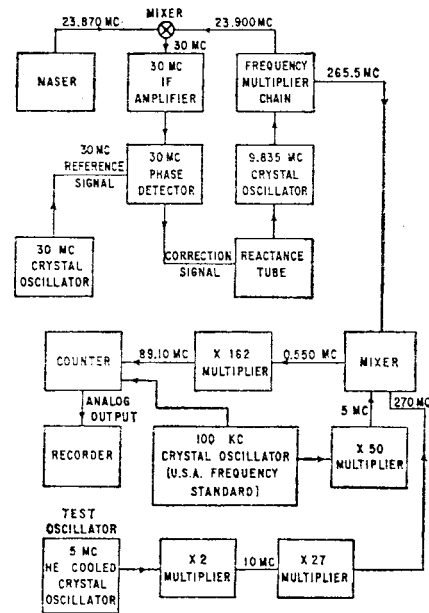


Fig. 4—Maser stabilized frequency-multiplier chain (all frequencies are nominal).

mechanical vibrations introduced by the regulator—crystals at very low temperatures are rather microphonic.

The quartz crystal was enclosed in an evacuated glass bulb and this was placed inside a brass cylinder. Liquid helium was in direct contact with the outside of the cylinder. A double dewar was used, with liquid nitrogen in the outer jacket and the helium in the inner container. In this system the pressure was regulated at about 650 mm of mercury.

The scheme used in comparing the helium-cooled oscillator with a maser-stabilized multiplier chain is shown in Fig. 4. The traces, of which Figs. 2 and 3 are samples, were derived from the analog output of the counter. The counter was set to count for one second and display for one second. Fluctuations at shorter time inter-

vals—to 0.001 second¹—could be observed with this maser apparatus with a somewhat different scheme of comparison. The minimum time interval in the above experiment was limited to one second by the electronic counter.

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A. H. MORGAN
J. A. BARNES
National Bureau of Standards
Boulder, Colo.

¹ 0.001 second is the time constant of the maser servo-system.

Phase Considerations in Degenerate Parametric Amplifier Circuits*

A previous paper¹ has given an expression for the negative resistance introduced into the signaling circuit of a degenerate parametric amplifier employing a quadratic nonlinearity of the magnetic type. It is the purpose of my paper to examine this resistance as a function of the phase angle between the pump and signal voltages. Bloom and Chang consider only signal voltages which pass through zero at alternate zeros of the pump.

We will write the signal and pump voltages as

$$V_1 \cos \omega_1 t$$

and

$$V_2 \cos (2\omega_1 t + \theta),$$

respectively. Their analysis¹ is for the special case $\theta = 0$. The inductance is assumed to have its flux ϕ and its current i related by

$$\phi = L_0 i - \mathcal{L} i^2.$$

The inductance, the series resonant signal circuit, and the series resonant pump circuit are all connected in parallel as in Bloom and Chang. Small signal analysis gives the ratio of the resistance, R , inserted into the signal circuit by the action of the pump, to the resistance R_T of the signal circuit as

$$\frac{R}{R_T} = \beta \left[\frac{(1 + \beta^2) \sin \theta - 2\beta}{1 + \beta^2 - 2\beta \sin \theta} \right] \quad (1)$$

where β is defined by

$$\beta = \frac{\omega_1 \mathcal{L} V_2}{R_T R_2}$$

R_2 is the resistance in the pump circuit.

For a nonlinear capacitance, having charge q and voltage v related by

$$v = S_0 q - S_2 q^2$$

connected in parallel with the series resonant

* Received by the IRE, March 18, 1959.

¹ S. Bloom and K. K. N. Chang, "Theory of parametric amplification using non-linear reactances," *RCA Rev.*, vol. 18, pp. 578-593; December, 1957.

* Received by the IRE, April 9, 1959.