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A Cryogenic Oscillator

Two superconducting oscillators have been reported in the patent literature. F. E. Steele* of the Northrup Aircraft Corporation developed an oscillator based on a superconducting tank circuit. The device is characterized by high stability and low-energy outputs. Another oscillator was developed by E. A. Ericsson† of Sweden. This device also uses a tuned circuit but it is somewhat more complicated in design. The oscillator described in this communication, however, is much simpler in design than either of these and is based on a relaxation process in the transition between the superconducting and conducting phases of a Pb film.

Oscillator configuration

The working models of the oscillator in Fig. 1a have been made of an evaporated Pb conductor shunted with a piece of #42 Cu wire. The Pb line is 6 milli-inches wide and approximately 1000 angstroms thick. With this parallel combination of conductors, the resistance of the Pb when it switches to the normal phase becomes much greater than the resistance of the Cu wire. One set of leads is used to supply a direct current to the device and another to monitor the voltage waveform across it. The Pb line is evaporated on a glass substrate (2" by 3/4") which is mounted on a phenolic holder and lowered into a liquid-helium Dewar flask.

Principle of operation

The principle of operation is that of a relaxation oscillator. At liquid-helium temperature, with a constant current supplied to the device, the current flowing from A to A' will divide in the Cu and Pb legs according to the inverse portion of the inductances of the two paths. Eventually all the current will switch to the superconducting path because of its zero resistance. If the supply current exceeds I_{cr} of the Pb film, resistance will be restored in the superconductor with an accompanying temperature rise of the Pb due to I^2R heating. Therefore, since the Cu wire has much less resistance than the Pb, most of the applied current switches to the Cu wire when the Pb switches to normal conductance and continues to flow in the Cu until the Pb can cool sufficiently to return to the superconducting state. When the Pb does go superconducting, the current will return to that path until the critical value is reached. The current again switches to the Cu path, repeating the cycle.

*Stable Resonant Circuit, U. S. Patent 2,704,431 (March 22, 1955).

†Oscillation Circuit with Superconductor, U. S. Patent 2,725,474 (November 29, 1955).

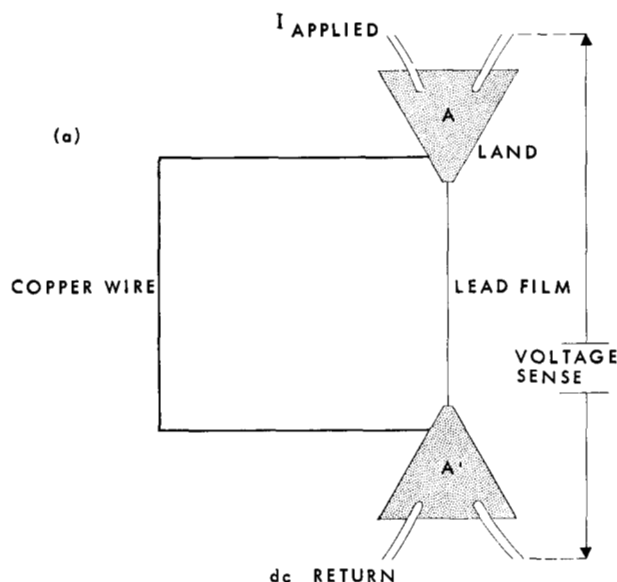
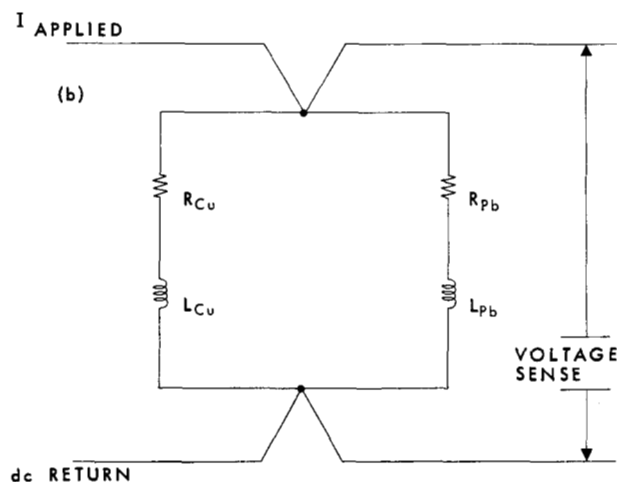


Figure 1a Configuration of experimental cryogenic oscillator.

Figure 1b Equivalent circuit of experimental cryogenic oscillator.



Current and voltage waveforms

The observed voltage developed across the device and the deduced current distribution are shown in Fig. 2. The critical current value is reached in the Pb at time t_1 , causing the Pb to go resistive and to heat up. Most of the current will switch to the Cu leg, with the switching time a function of $(L_{Cu} + L_{Pb}) / (R_{Cu} + R_{Pb})$. The voltage spike in Fig. 2 is due to the value of $L(di/dt)$ caused by this rapidly switching current. Since the rate of change of current is maximum at t_1 , the peak voltage appears at this time. The voltage falls as $V \exp(-tR/L)$ where $R/L = (R_{Cu} + R_{Pb}) / (L_{Cu} + L_{Pb})$ and where R_{Pb} is a function of the varying temperature of the Pb. The voltage step between t_2 and t_3 is $I_{applied} [(R_{Cu} \times R_{Pb}) / (R_{Cu} + R_{Pb})]$, where the current through the Pb is small enough to allow the Pb to cool off. The period between t_2 and t_3 appears to be a thermal delay which is a function of the heat flow away from the Pb less the $I^2 R_{Pb}$ heat which is continually generated.

At t_3 the Pb returns to the superconducting state, causing the current to switch back to that leg. This switching time is a function of $(L_{Cu} + L_{Pb}) / R_{Cu}$, which is much larger than the first time constant since $R_{Pb} > R_{Cu}$. Therefore time t_3 to t'_1 will always be much longer than t_1 to t_2 .

Since the frequency of oscillation is primarily dependent on the time period $t_3 - t'_1$, we can vary the frequency by varying this time period. This change in $t_3 - t'_1$ can be accomplished most readily by varying the applied current. The current rise in the Pb will always be exponential. When the applied current is varied the critical current value of the Pb is reached at different points on the exponential curve.

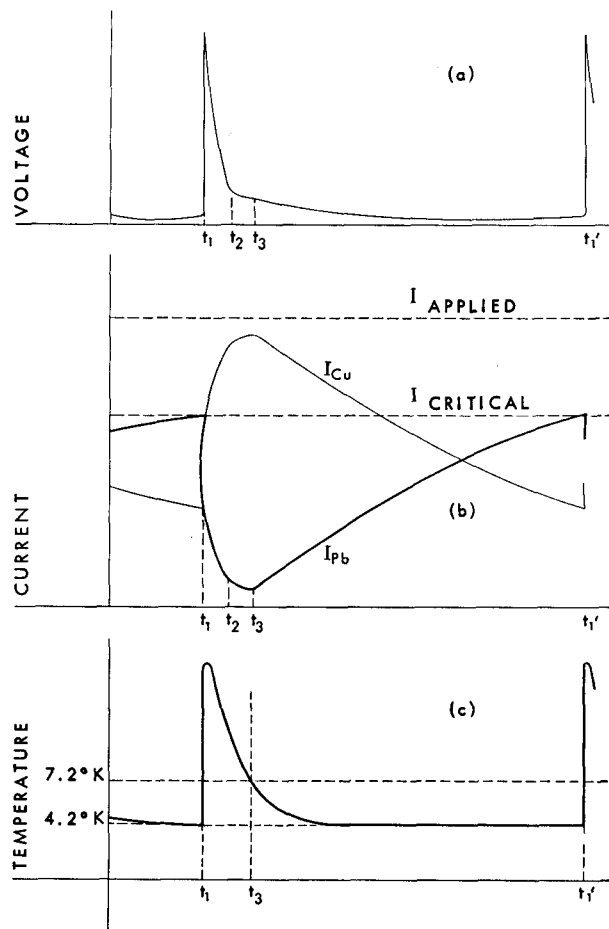
The chart below shows how the frequency varies with applied current for one oscillator tested:

$I_{applied}$	Frequency
920 ma	77 kc
1000	100
1140	143
1520	212

The lower frequency limit is determined by the critical current of the Pb line while the upper frequency limit is determined by the heat generated. When the heat generated by the device is sufficient to keep the temperature above the critical temperature of the Pb, the Pb remains in the normal conducting state. In summary, the voltage output can be expressed as follows for the time intervals specified:

$$t_1 < t < t_2 \quad v = V_1 \exp[-t(R_{Cu} + R_{Pb})/L],$$

Figure 2 a) Observed voltage waveform across AA' of Fig. 1a.
b) Deduced approximate current division in cryogenic oscillator.
c) Hypothetical curve of temperature/time function.



where V_1 is the voltage at t_1 and L is $L_{Cu} + L_{Pb}$.

$$t_2 < t < t_3 \quad v = I \frac{R_{Cu} \times R_{Pb}}{R_{Cu} + R_{Pb}},$$

where I is the applied current.

$$t_3 < t < t'_1 \quad v = V_2 \exp(-tR_{Cu}/L),$$

where V_2 is the voltage at t_3 .

The oscillator may prove to be valuable as a means of investigating several parameters of cryogenic circuits.

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