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LOCKED OSCILLATORS IN FREQUENCY STANDARDS AND FREQUENCY MEASUREMENTS

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A locked oscillator may be defined as an oscillator automatically maintained in fixed phase with respect to a reference frequency. The average frequency of the locked oscillator, referred to the reference frequency, is identical with that of the reference source.

Locked oscillators can be applied to systems for multiplication, division, addition and subtraction of frequencies. The fundamental frequency of a locked oscillator may be equal to the reference frequency, may bear a harmonic relationship to it, or may differ from it by a fixed or variable amount. An oscillator locked to one harmonic of a series acts as a filter of high discrimination, reducing unwanted frequency components in the output. The output level of the locked oscillator can be many times higher than that of the reference source.

Methods and Applications

The applicability of locked oscillators to many problems of frequency standardization and measurement is evident. It will be appropriate now to review briefly some of the ways in which an oscillator can be locked and to consider some representative applications.

One of the simplest ways to lock an oscillator[1,2] is to inject a voltage of the reference frequency directly into the oscillator circuit. Generally speaking, for effective locking the voltage of reference frequency appearing at the grid of the oscillator tube must be of the same order of magnitude as the oscillator grid voltage. This frequently requires the reference voltage to be amplified considerably. The simple circuit of Fig. 1 utilizes the oscillator tuned circuit as the plate load of the pentode reference frequency amplifier to obtain high gain.

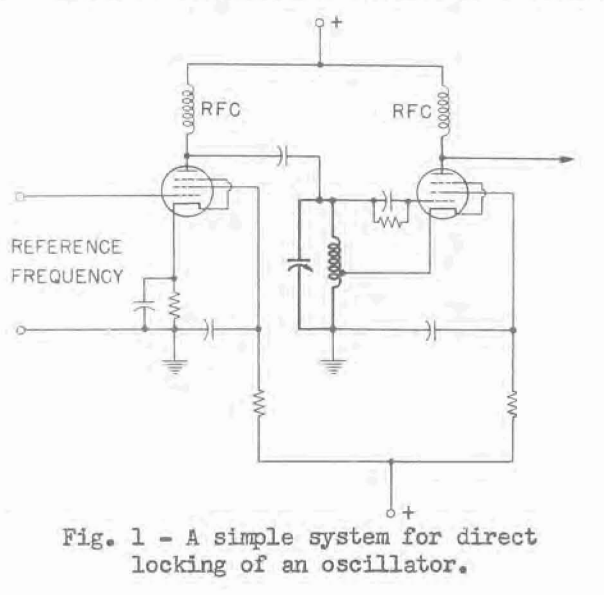


Fig. 1 - A simple system for direct locking of an oscillator.

As is frequently the case, the simplest circuits operate in the most complex manner. In this instance, the oscillator tube acts as an oscillating detector. Consequently, the beat frequency difference of the reference and oscillator frequencies appears in the grid circuit. The grid bias voltage will have an alternating component of this difference frequency. If the frequency difference is made zero, then the varying component of grid bias becomes sensitive to the difference in phase between the reference and oscillator frequencies. If the voltages of these two frequencies are equal, then the phase-sensitive component of bias will have the maximum range in magnitude as the voltages vary from out-of-phase to in-phase. This phase-sensitive bias component produces second order frequency changes in the oscillator such as to maintain the oscillator frequency equal to the reference frequency.

The oscillator will remain in control over a maximum variation in phase of 0 degrees to 180 degrees, with respect to the reference voltage. The range of control, or range of frequency difference between the oscillator and reference frequencies, over which locking will take place, will depend on the magnitudes of oscillator and reference voltages, the frequency stability of the oscillator and reference voltages, the frequency stability of the oscillator and the effectiveness of detecting action of the oscillator circuit. With a highly stable oscillator[3] only a very narrow locking range will be obtained. This is because the oscillator frequency is so nearly independent of the tube voltages that practically no frequency change occurs with bias changes. A stable oscillator can, of course, be readily locked through the use of a voltage-sensitive reactance, as described later.

If, instead of depending on the detecting action of the oscillator, we depend only on the frequency variation with grid bias voltage, a system in which the various functions are separated is readily set up.

Voltages of reference and oscillator frequencies are impressed on a detector through means producing the desired levels. The dc output voltage of the detector is impressed on the oscillator grid simply by connecting in series at the bottom of the grid leak.

An undesired effect, accompanying control by changing the grid bias voltage of the oscillator, is that the oscillator level also changes. If the phase-sensitive bias has unwanted ac components, such as hum, superimposed, then the locked oscillator output will not only vary in magnitude with the magnitude of the control bias, but will be modulated both in phase and magnitude by the ac components. Only a very limited amount of filtering of the dc bias voltage can be used without greatly reducing the locking range of the oscillator. This is because of the time delay, introduced by the filter, between an oscillator change and the correcting change in bias.

Frequency changes produced by a voltage-sensitive reactance can be used to obtain control, instead of the second order frequency changes which are produced by change of oscillator bias. Such

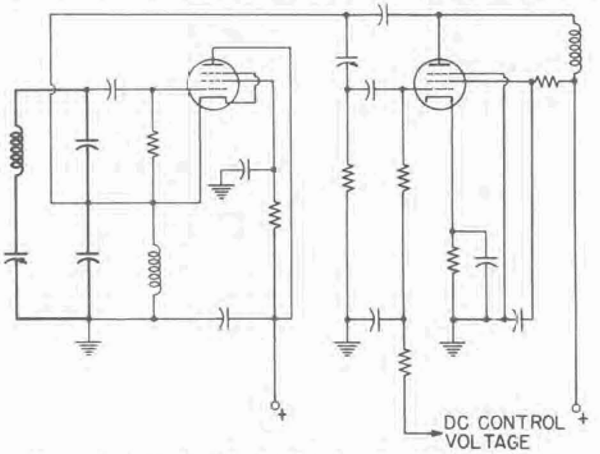


Fig. 2 - A reactance tube locking system.

arrangements are much more reproducible and lend themselves to straight forward design. At frequencies which are not too high, a reactance tube is very effective. Fig. 2 illustrates such a circuit.

At high frequencies it becomes increasingly difficult to make the reactance tube function properly and to avoid excessive shunting of the oscillator circuit. It should be possible to use a ferroelectric capacitor as a control element over a wide range of frequency. A circuit is shown in Fig. 3.

Frequency Multiplication and Division

A locked oscillator can be locked at a multiple of the reference frequency or at a multiple of the oscillator frequency. In the first case, means for generating harmonics of the reference frequency

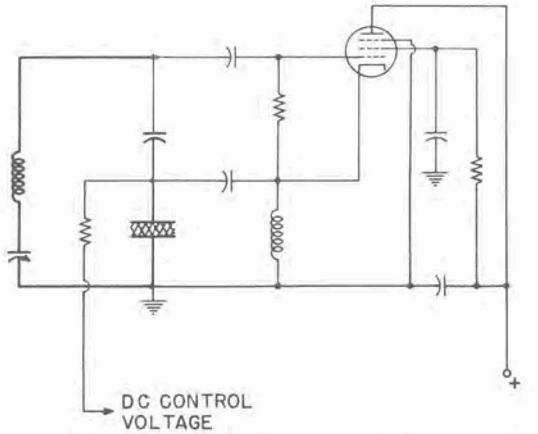


Fig. 3 - The use of a ferroelectric capacitor.

must be provided. The detector and oscillator circuits would be tuned to the required multiple of the reference frequency. This arrangement represents a locked oscillator frequency multiplier (see Fig. 4).

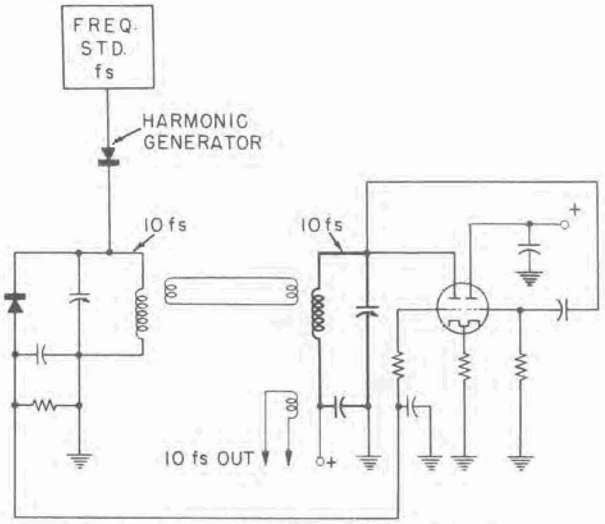


Fig. 4 - A 10:1 multiplier system.

In the second case, means for generating harmonics of the oscillator frequency must be provided. The desired oscillator harmonic would then be at the reference frequency and the detector would be tuned to this frequency. This arrangement represents a locked oscillator frequency divider.

Frequency Addition and Subtraction

In many cases it is possible to lock an oscillator so that a difference in frequency exists between the reference frequency and the oscillator frequency at the frequency of comparison. This difference frequency can be compared with a second, lower, reference frequency and the oscillator locked so as to maintain the original frequency difference at all times equal to the second, lower, reference frequency. The second reference frequency can be either fixed or variable.

An example of the use of a fixed frequency difference is producing a standard frequency which is off-set slightly from true frequency. This is equivalent to adding, or subtracting, a very low frequency to, or from, a much higher frequency. If this is attempted by modulation and side-band selection, the filtering problem is difficult and frequently impracticable of solution.

A 100 kc oscillator can be locked to a 100 kc frequency standard with a fixed frequency difference of ±100 cycles, or ±0.1%. Such an off-set frequency standard is useful in frequency measurements to avoid very low beat frequencies and to identify which harmonic of the frequency standard is being used in a measurement. If the 10th harmonic of the oscillator is locked to the 10th harmonic of the standard, with an off-set of ±100 cycles, the percentage off-set is ±0.01%

An oscillator of extreme frequency stability, which is precisely variable, is required for studying the response of sharply resonant devices such

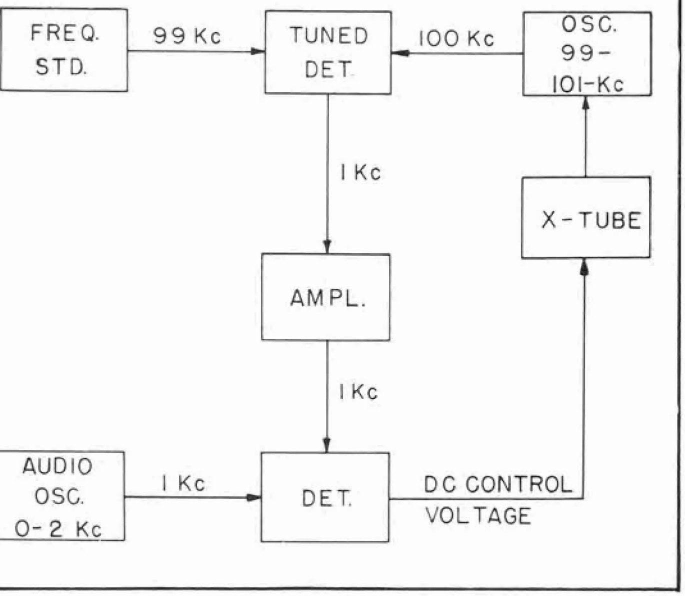


Fig. 5 - An off-set frequency standard.

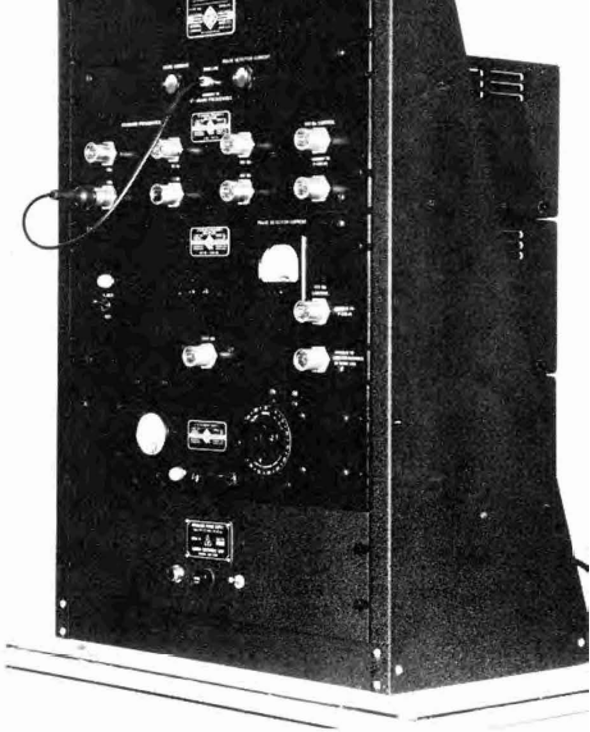
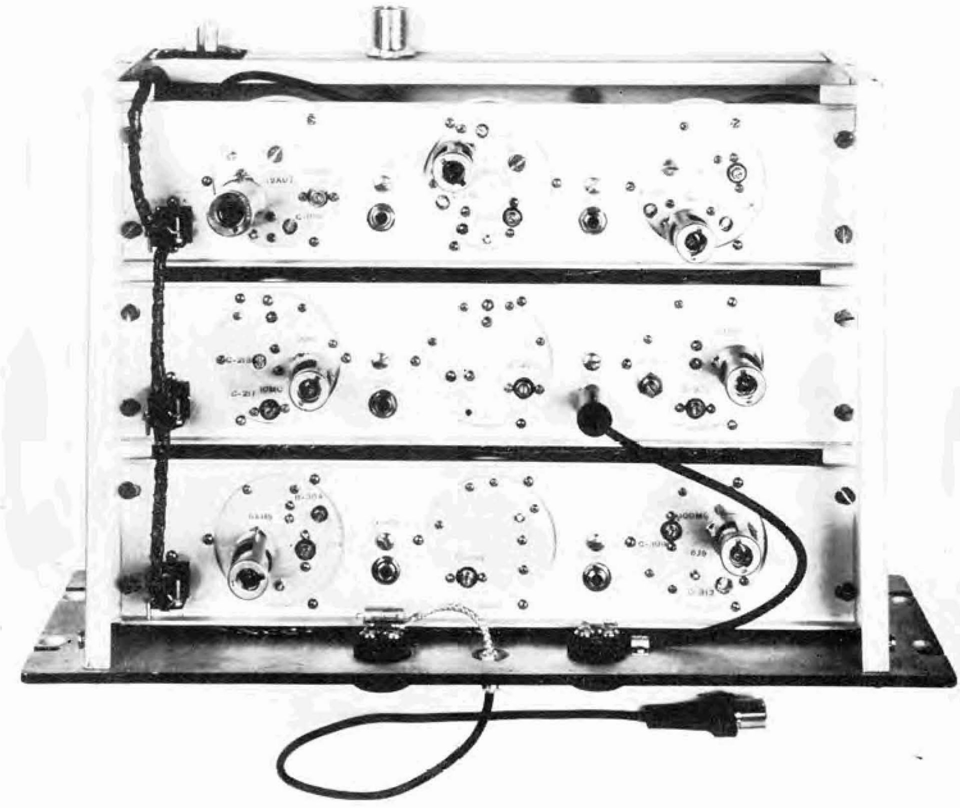


Fig. 6 - Panel view of 10,000:1 multiplie



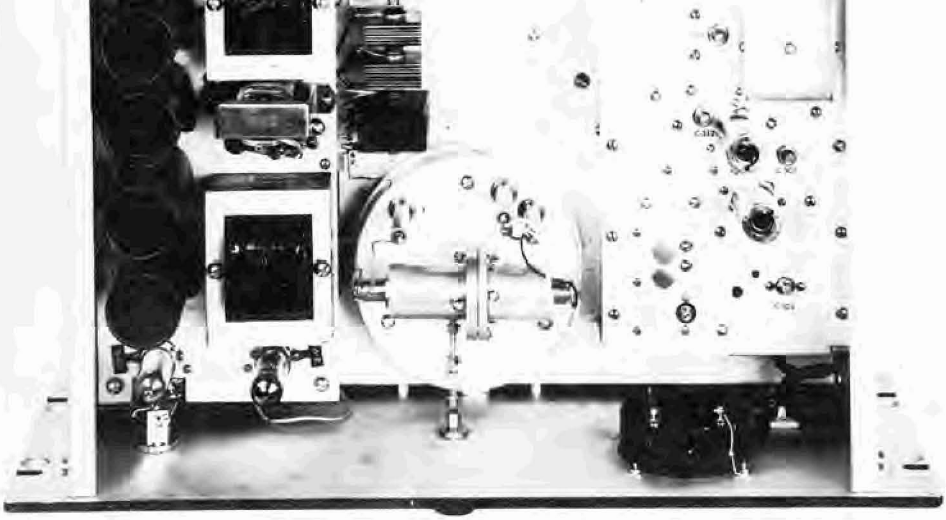


Fig. 8 - Interior view of last stage.

quartz crystal filters.[4] Such a source can be duced by locking an oscillator at a difference quency which is at all times equal to that of a ble, variable, audio frequency oscillator, as wn in Fig. 5.

As an example, an oscillator of approximately kc is beat against 99 kc from a frequency ndard. The difference frequency is compared n an audio frequency interpolation oscillator the 100 kc oscillator is locked so that the audio frequencies are maintained equal. By usting the audio frequency oscillator over the ge from nearly 0 to 2000 cycles, the radio fre- ncy oscillator is adjusted from approximately to 101 kc. The frequency of the radio frequency illator is known to approximately 1 in 10^6. The rt period stability is about 5 in 10^7.

A Particular Application

A standard frequency multiplier was designed, ed on the circuit of Fig. 4. The base frequency 100 kc which was multiplied by 10, in four suc- sive stages, so that the final output frequency 1000 mc. The first three stages were essen- lly as shown in Fig. 2. The final stage was a centric line oscillator using a pencil tube. nge of oscillator bias was by means of a cathode lower amplifier.

The operation of the final stage was based on off-set operation described above. The 100 mc put of the preceding stage was tripled in two cessive germanium diode multipliers, giving an put of 900 mc. This frequency, combined with 1000 mc oscillator frequency in a mixer, re- ts in a mixer output of 100 mc. This 100 mc quency is compared, in a phase detector, with the original 100 mc voltage. The output of the phase detector is used to lock the 100 mc oscillator.

The control ranges of the successive stage were 1.5, 0.5, 0.5, and 0.15 per cent. The rms frequency deviations caused by noise (principal introduced by the input and first stage multipl were less than 2 in 10^7 on all outputs.

Photographs of this equipment are shown in Figs. 6, 7 and 8. The panel view shows the pat ing system for connection of any combination of four output frequencies to the waveguide mixer. The first rear view shows the first three stage made up in strip form, each strip containing a monic multiplier, detector and locked oscillato In each stage the output frequency is ten times the input frequency. The second rear view show the two germanium diode triplers, the mixer and the concentric-line locked oscillator.

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