WHIPPING . . . *(Continued from page 8)*

perimental data obtained by Model Basin personnel on *Essex* were used by BuShips to verify the bow immersion effect on whipping stresses and to provide a check point on the need for the structural modifications incorporated in ShipAlt 1171.

Besides providing back-up data for structural repairs to these carriers, the information obtained during the voyage by *Essex* around Cape Horn contributed materially to the long-range program to improve methods for the design of the ship's girder and to improve the seaworthiness of ships.

In a subsequent article, a statistical method will be presented for determining ship stresses, bending moments, and motions based upon experimental data obtained at sea on *Essex* and other ships.

---

# Development of Frequency Synthesizers

**By Walter A. Schultz**
*Transmitter Equipment Section*
*Bureau of Ships*

During and subsequent to World War II, the requirements for crystals were sharply increased. Dependence on limited quartz-supply sources stimulated instrumentation for crystal-saving devices. Although prompted by crystal-saving, this development also made possible substantially smaller equipments, with multichannel features; and furnished a means of obtaining increased stabilities.

During the past few years, emphasis in crystal-synthesis development has shifted from crystal-saving capability to precision-frequency generation. For example, in electronic systems under development today, a synthesizer is used in generating frequencies from a single crystal, internally available or externally supplied. Phase coherence is a prerequisite of performance.

A synthesizer should contain a reference frequency with a maximum stability-versus-volume factor, and a means of translating the reference frequency to the required output frequencies. How well this task is accomplished is determined by the ability of the synthesizer to be the "equivalent black box" of the reference at the translated frequency. In terms of equivalence, extraneous noises; spurious outputs; and, in some cases, harmonic content are considered. In terms of basic function, a crystal synthesizer is the electronic counterpart of a high-quality filter. It may be considered as an instrument dedicated to performance, not as a crystal-saver but as a crystal-filter-saver.

A comparison of the techniques of synthesis may be likened to a choice of one of the methods of achieving filtering, such as the use of LC, crystals, or mechanical filters.

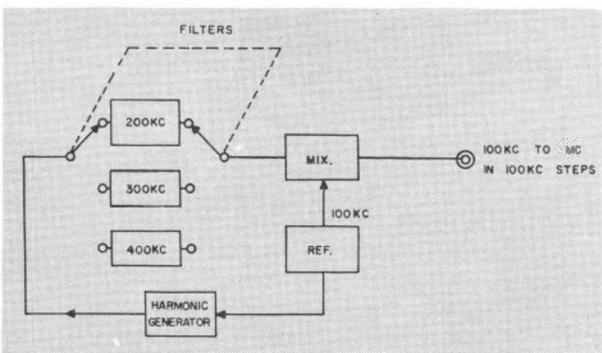



Figure 1. Direct synthesis.

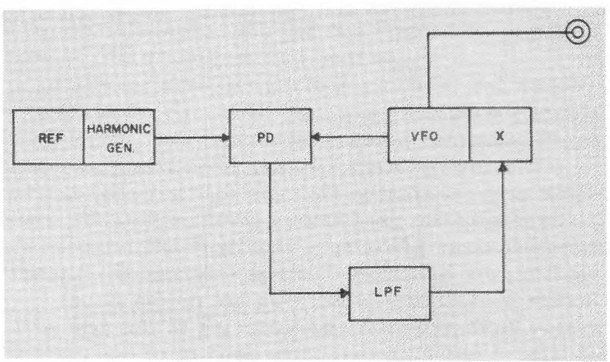



Figure 2. Indirect synthesis.

### Ideal Performance

It may be well to consider what a synthesizer should contain to achieve ideal performance (that is, to deliver one frequency at a time with no spurious output whatsoever). An ideal synthesizer should not contain elements such as oscillators, mixers, and multipliers. Amplification alone should be permissible; and amplifier linearity should be absolute. Under these ideal conditions, the synthesizer quality should approach optimum. In reality, the mathematical functions of addition, subtraction, multiplication, and division must be performed in the translation of frequencies.

Two systems for performing these functions are available to the engineer. The first and most obvious technique is the use of mixers in a decade-type device in which the output frequency represents a summation or subtraction process. (One mixer with 10 oscillators per decade is shown in figure 1.) This system, analogous to a chain, is known as the Direct Method of Synthesis.

In the second method, a synthesizer and an oscillator are disciplined to a reference frequency, via a feedback loop, as shown in figure 2. In this configuration, the output oscillator delivers energy which was internally generated under the conditions of the disciplining. This method is known as the Indirect Method of Synthesis. Combinations of the two methods may be employed.

Evaluation of the performance capabilities of the systems shown in figures 1 and 2 may be stated in terms of the extent to which they approach the capability of an ideal synthesizer. In the Direct Method, the use of mixers must be kept to a minimum in order to minimize undesired frequencies being generated by the mixer products.

In the Indirect Method, the oscillator should be disciplined so that it is operating at the output frequency of the equipment. Circuitry arrangements which provide decoupling from the power supply and from extraneous proximity effects must be maintained, because they effectively shunt the performance of the filter arrangement shown in figure 2. In particular, no frequencies should be generated that fall within pass-characteristics of the low-pass filter. The interposition of functions between the VFO and the output jack may include amplification, but it should not include mixers and multipliers because their use lowers the quality of the output signal.

**Radio-Frequency Synthesizer**

The successful application of the principles outlined above is represented in Bureau of Ships Model O-464 Radio-Frequency Synthesizer, 2 to 34 mc. (1-kc. steps from 16 to 34 mc.; 125-cycle steps between 2 and 4 mc.). The method of indirect synthesis has been employed throughout and has resulted in a quality signal in which the signal-to-spurious level for any one of 66,000 frequencies lies between 80 and 100 db with respect to desired output-frequency. (See spectrum analysis, figure 3.)

To avoid the generation of frequencies within the bandpass of the low-pass filter, only one spectrum frequency (at 100 kc.) has been developed in the instrument. Ten-kc. and 1-kc. steps have been achieved by division circuitry. Multioctave frequency coverage (16 to 34, 8 to 16, 4 to 8, and 2 to 4) has likewise been achieved by frequency division.

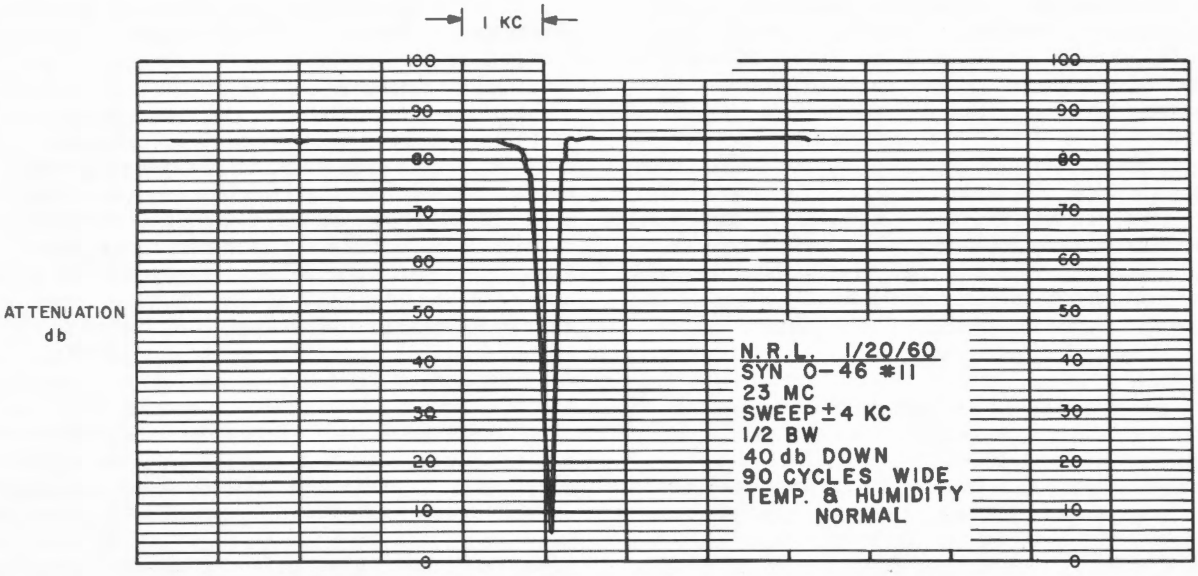
Frequency division has been used, instead of multiplication, because improvement of filtering is a normal result in division. For example: assume that 2 mc. and 16 mc. are required to be generated; that, in one case, a 16-mc. signal is available and that energy is required at 2 mc.; and that, in the other case, a 2-mc. signal is available when it is necessary to generate 16 mc.

When a 2-mc. signal must be generated from a 16-mc. signal, and a frequency division of 8 is employed, the frequencies developed are harmonically related to the output. However, the multiplication of a 2-mc. signal by 8 results in a 16-mc. signal with sideband energies at 14 and 18 mc., in the second case. Multioctave coverage is obtained by division in the Model O-464 Synthesizer.

For convenience in frequency presentation, figure 4 shows an in-line counter-readout for all octaves. The type of frequency presentation and the method of turning are closely related to the specifications of the free-running stability of the disciplined VFO.

Referring again to figure 2, if the stability in the VFO is equivalent to that of the reference, the feedback loop may be considered open because it is not contributing to output-frequency stability. However, as the feedback loop is called upon to discipline a relatively unstable oscillator, more and more dependence on feedback characteristics is incurred.

Figure 3. Spectrum analysis graph.






575737 O - 60 - 3

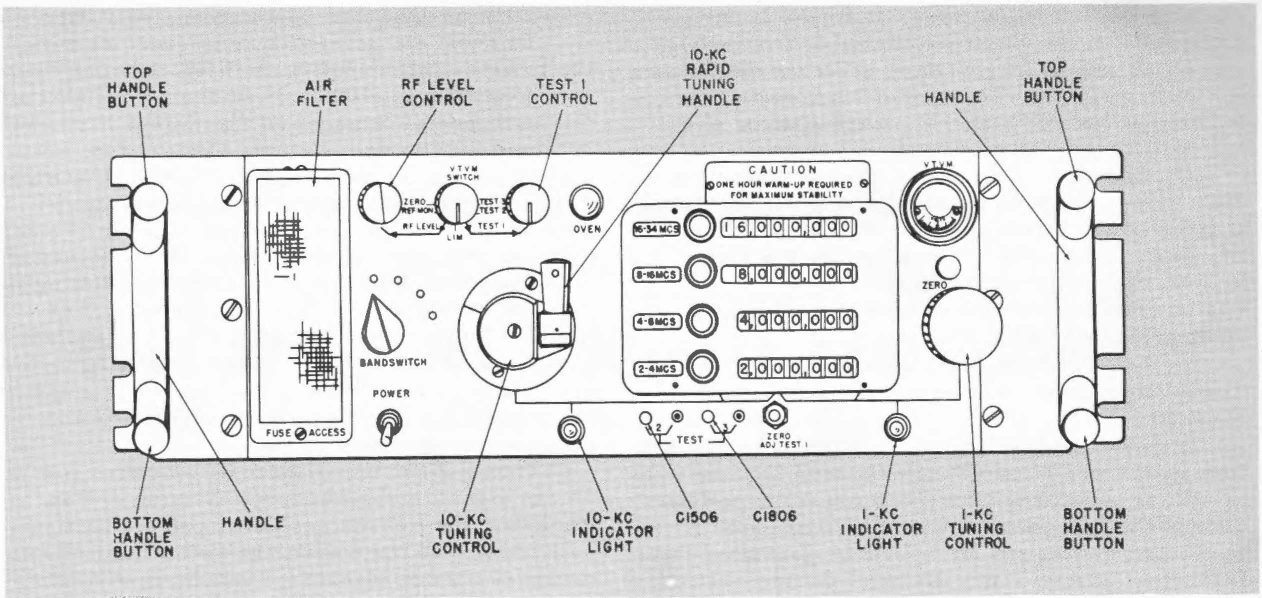



Figure 4. Front panel of synthesizer.

**VFO Stability**

The stability of the main VFO of the Model O-464 Synthesizer has been reduced to 0.02 percent with time, temperature, and tracking.

This oscillator is the hub about which synthesis is developed (see figure 5). The details of the Synthesizer system are shown in figure 6. Three loops are used for obtaining steps of 100 kc., 10 kc., and 1 kc., respectively. Jitter-free performance requires careful attention to the means of generating the spectrum. The achievement of optimum performance requires the use of a sharp, high-amplitude pulse delivered to a low-impedance terminal.

In the equipment under discussion, a saturable reactor is employed. High-level sinusoidal amplification from the reference frequency is used to drive the saturable reactor. High-frequency energy distribution is obtained from a computer-type ferrite toroid, 30/1000 inch in diameter.

The circuitry and the toroid are shown in figure 7. The high-quality pulse obtained is used to lock up three disciplined VFO's operating to deliver 1-kc., 10-kc., and 100-kc. steps in the system via the main loop, the 10-kc. loop, and the 1-kc. loop. The 100-kc. pulse delivers energy to phase detectors and successfully locks the 10-kc. and 1-kc. VFO to the 400th harmonic of the pulse. The phase detector used to accomplish this multiplication is shown in figure 8.

**Division Advantages**

The advantages of division over multiplication have been discussed previously. The use of the 1-kc., 10-kc., and 100-kc. loops locks the VFO's in the normal manner. The details of frequency generation will not be discussed. In the system discussed in this article, the 10-kc. VFO must move in 10 steps, of 10 kc. each, from 3,910 mc. to 4 mc. The

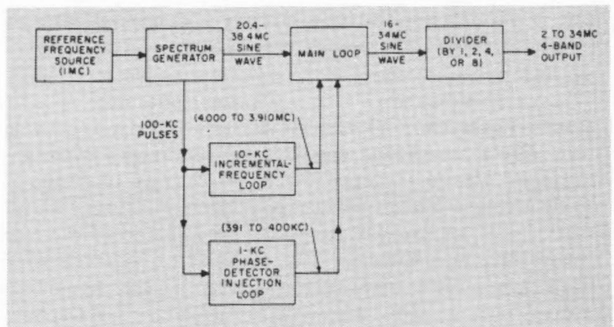



Figure 5. Simplified block diagram.

1-kc. VFO must move from 391 to 400 kc., in 10 steps of 1 kc. each. These oscillators are directly disciplined at the required output-frequency; that is, no multipliers, mixers, or processes other than amplification and division are employed after the disciplined oscillator.

Ten-kc. steps could easily be obtained from a 100-kc. spectrum divided by 10. However, the use of 10-kc. energy developed in the synthesizer clashes with the ideal approach previously outlined. No mention of a 1-kc. spectrum is considered necessary, since no frequency in or close to passband characteristics in the feedback loop should be generated. As an aside, it should be noted that the objective of the passband filter should not be maximum filtering but rather the widest frequency response obtainable which is consistent with the degenerative performance of the feedback loops.

The determination of the filter characteristics hinges on the basic free-running stability of the oscillator. As previously stated, if the oscillator stability were equivalent to the reference, the feedback loop could be opened. The filter characteristic would then have infinite bandwidth, because

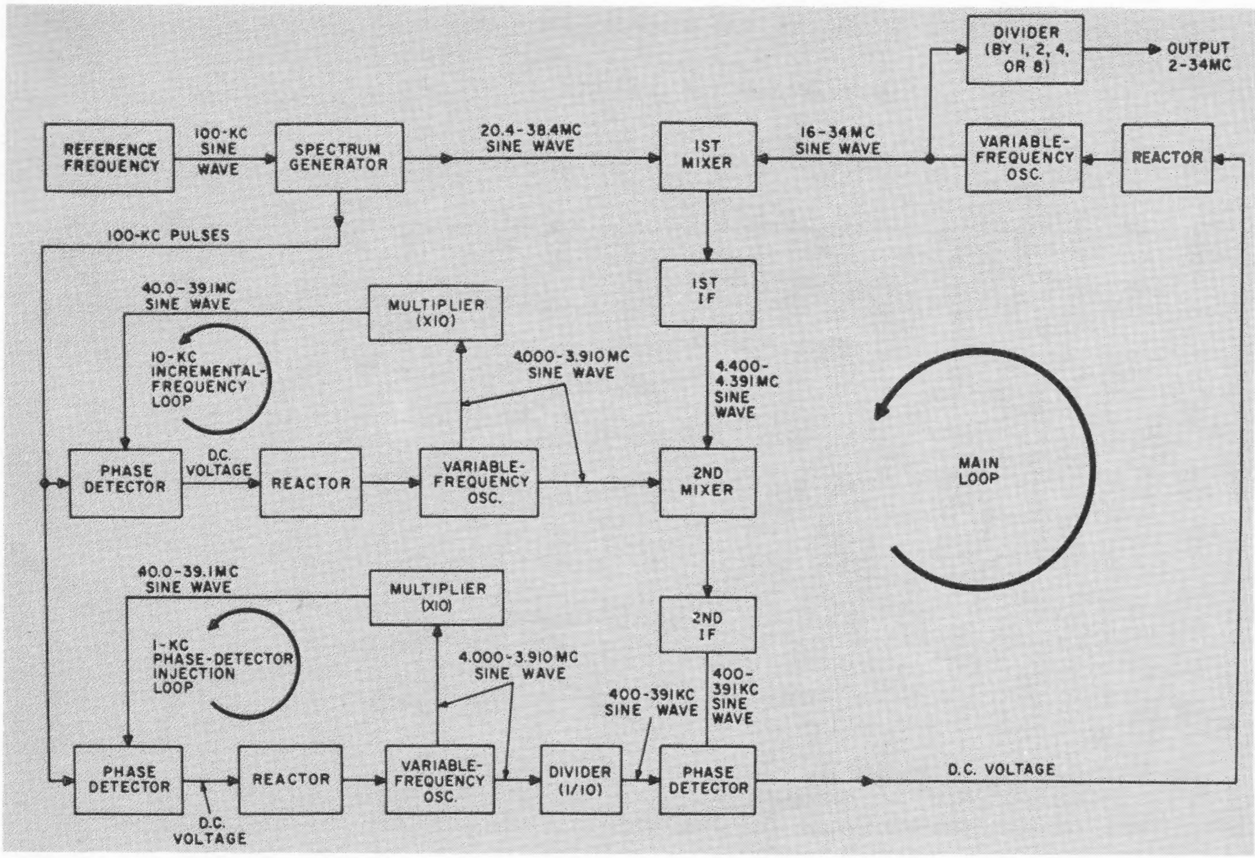



Figure 6. Detailed block diagram.

no feedback gain would be required. However, as the VFO stability departs from that of the reference stability, more and more gain and more and more filtering are required from the feedback system to achieve reliable phase-lock performance.

Optimum bandwidths successfully degenerate microphonic tendencies and extraneous power-line intrusions other than those appearing on the reference. Therefore, conflicting requirements are imposed in the filter characteristic—the greater the bandwidth, the poorer the filtering capability, and the greater the filtering capability, the less the degenerative effects due to such causes as microphonics of the VFO. In any system, therefore, the loop bandwidth should be design-limited by the VFO stability rather than by the spurious frequencies generated in the synthesizer. For this reason, no frequency lower than 100 kc. is generated in the synthesizer under discussion.

Ten-kc. steps have been achieved through division techniques. A 4-mc. VFO is multiplied by 10 and compared, in a phase detector, to a 100-kc. pulse. At phase coincidence of the X 10 harmonic of the 4-mc. oscillator and the 400th harmonic of the 100-kc. pulse, a phase-sensing voltage from the phase detector disciplines the VFO. Moving the oscillator in 10-kc. steps successfully locks it to the 400th, 399th, and down to the 390th harmonic of 100 kc. as required, so that the VFO now moves in 10-kc. steps, as required for the frequency-generation evolution of the system under discussion.

**Redundant Circuit**

A completely redundant circuit is the same as that described above, plus an added divider which steps down the 4-mc. frequencies to 400 kc. and 399 kc., as required, so that the 1-kc. steps are obtained. The disciplined VFO appears as an injection into the main loop of the phase detector, with only division serving as the post-operation on the phase-locked VFO. Maximum freedom from spurious frequencies may then be anticipated. In this manner, 1-kc. spectrums and 10-kc. spectrums are totally avoided.

It has been shown that the low-frequency spectrums are not consonant with the idealized requirements of synthesizers, in terms of loop bandwidth. It is also obvious that extreme difficulties may be anticipated in obtaining circuit-decoupling which is adequate to prevent the generation of 1-kc.- and 10-kc.-order spectrums.

The main VFO of the Model O-464 Synthesizer covers a single octave, from 16 to 34 mc., in 1-kc. steps. The additional three octaves are obtained by division. Preliminary work has been done; and further division (by simple, untuned, binary methods) to cover frequency ranges down to 2 kc. and even lower is feasible. Units using similar techniques

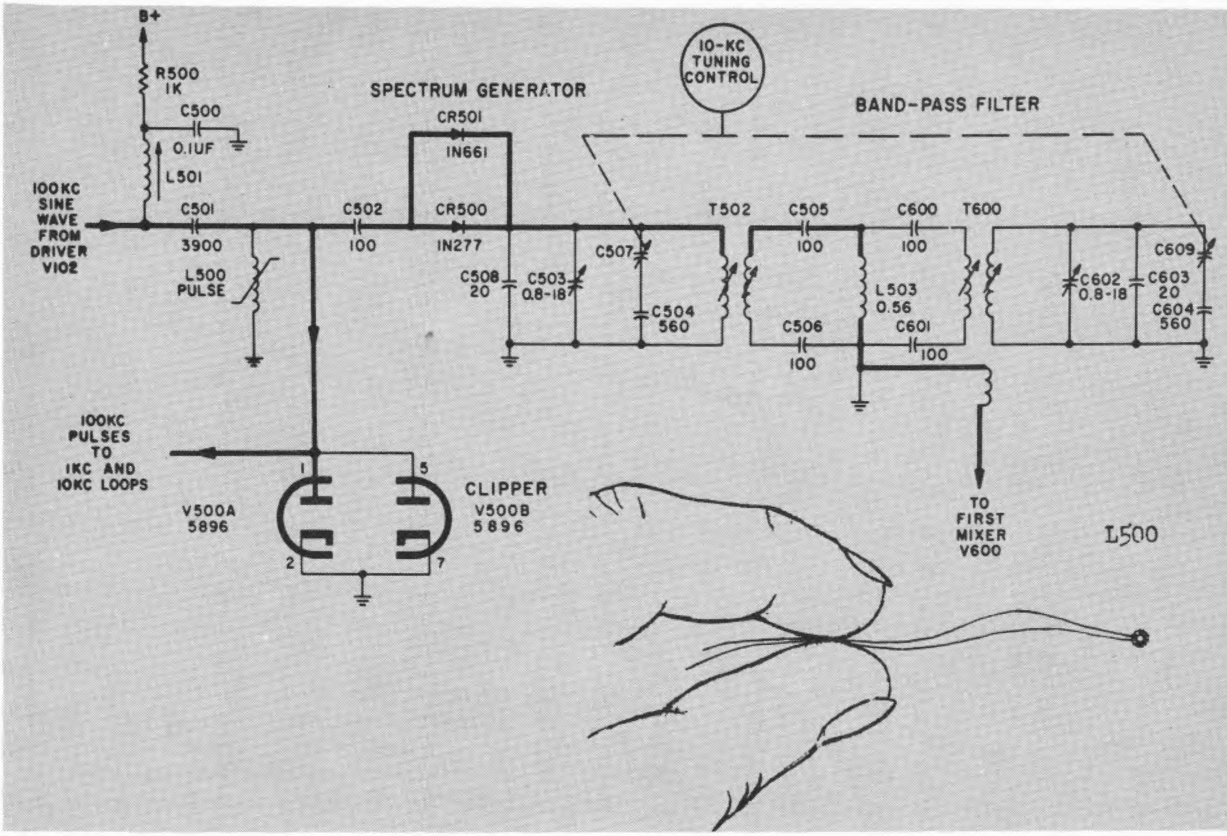
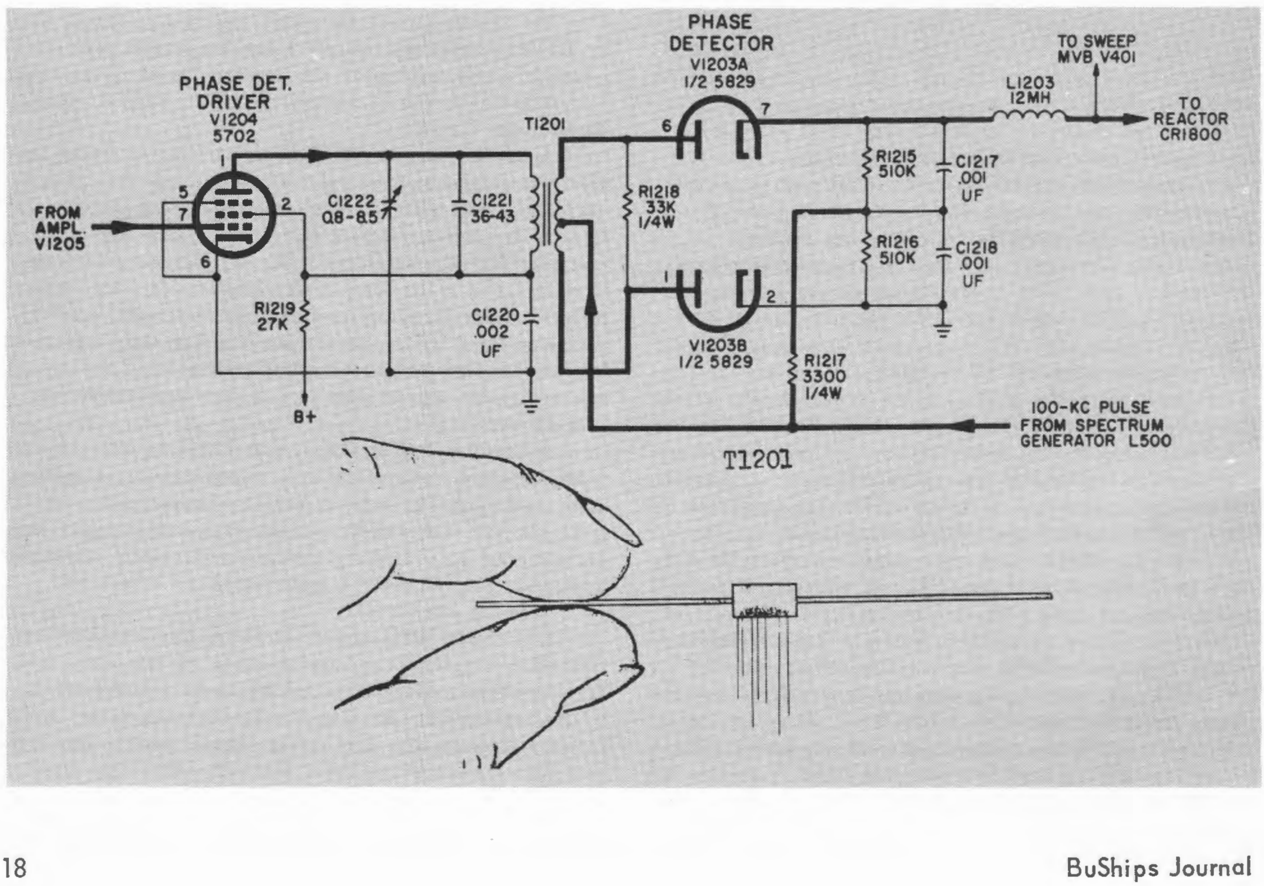



Figure 7 (above). Pulse generator.

Figure 8 (below). Phase detector.



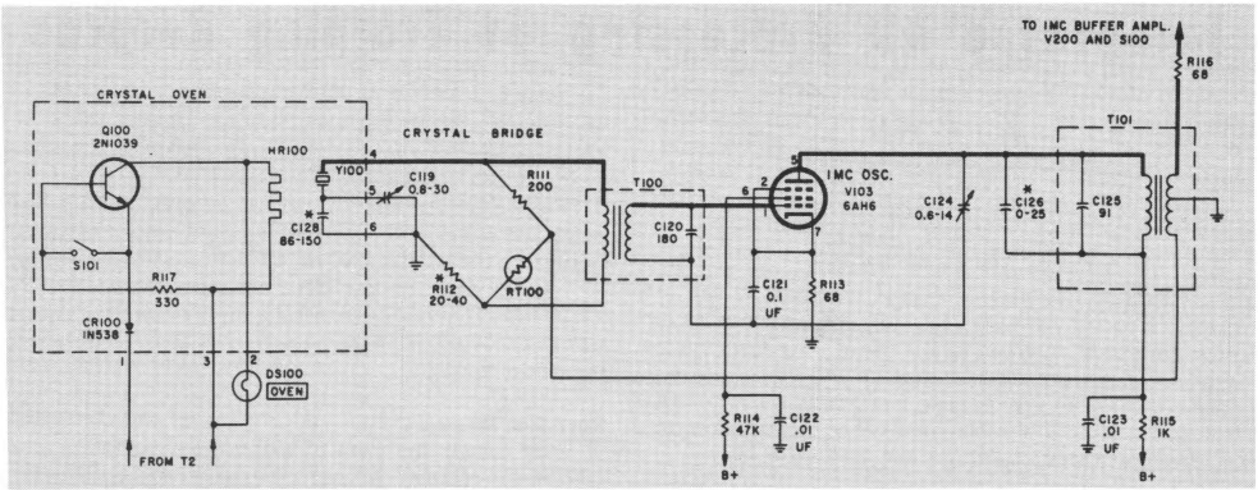



**Figure 9. Meacham oscillator schematic.**

to cover the higher frequencies are in the advanced stage of development.

Stabilities obtainable in the reference approach 2 to 3 parts in $10^9$ per day. An HC6-AT crystal with a single-stage, high-gain, Meacham bridge circuit is used (see figure 9). Especially-developed toroids, crystals, and ovens enhance the performance which is respectable in terms of the volume-versus-space factor.

### Mercury Oven-Switch

Oven performance makes use of a mercury switch which permits operation with an ageless temperature-versus-time setting. Storage temperature and shock and vibration deficiencies of the normal, mercury oven-switch have been surmounted without loss of the desirable characteristics of a mercury controller. The oven can survive the −65° C. storage-temperature specification of Mil-E-16400. Vibration and shock effects have been minimized by appropriate mounting and by the use of a pressurized-mercury column. Because of the latter, separation of the mercury is avoided, even under conditions of 125G shock-impact tests of Air Force Specification Mil-S-4456.

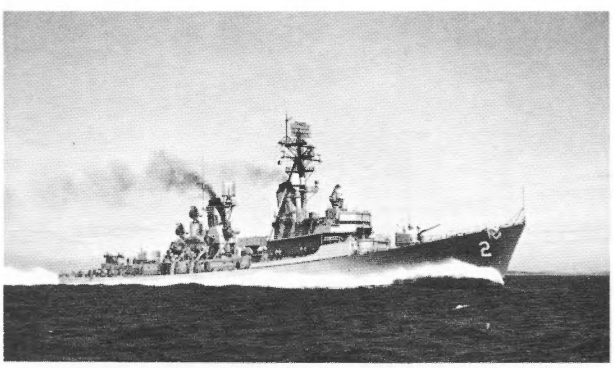
A transistor switch, activated by less than 1-milliampere mercury current, controls the power flowing to the heater winding. Oven efficiency permits operation with less than 0.6 of a watt for 25° C. room ambient. Use of a Dewar flask enhances this capability.

Temperature cycling, normally accompanied by incremental control, is minimized by techniques which can be used with ovens which have symmetrical thermal gradients. Crystal position in the oven is accurately located for maximum immunity to external ambients and internal cycling. Sine-wave cycling, due to incremental control may be reduced to 1 to 2 parts in $10^{10}$ with no interference spectra from 14 kc. to 1 kilomegacycle when searched in accordance with Mil-E-16400 Interference Test.

Long experience with the crystal employed permits the use of predicted-aging techniques. Aging rates under clock correction may be reduced considerably, with 5 parts in $10^8$ per annum after 6 months of run-in as a practical requirement.

---

## USS Charles F. Adams Joins Fleet



The guided-missile destroyer USS *Charles F. Adams* (DDG-2), named for the former Secretary of the Navy, has joined the Fleet. She is the first ship to be built from the keel up as a guided-missile destroyer.

The 437-foot ship, launched at Bath Iron Works, Bath, Maine, in September 1959, was commissioned at Boston Naval Shipyard on 10 September 1960. She has a standard displacement of 3,370 tons. The design of the ship incorporates the most recent improvements in habitability, including air-conditioning of all living quarters. Her armament consists of the Navy's newest and smallest surface-to-air guided missile, TARTAR; 5-inch, 54-caliber rapid-fire guns; and the latest antisubmarine weapons, including ASROC. Her complement is 24 officers and 330 enlisted men.