4-Mc X-cut quartz crystal transducer, *X*, 15 mm in diameter. A drop of oil on the upper surface of the transducer assured mechanical coupling to the transmission plate. The transducer was supported by an adjustable brass holder, *V*, through which it was connected to the electronic apparatus via a slug-tuned coil, *S*, and a length of coaxial cable attached to the base at *U*. The impedance of the coil was adjusted by varying the position of the slug attached to the screw, *Q*. A removable cap, *P*, was screwed down on a gasket (not shown) and prevented leakage of oil into the base of the interferometer.

The interferometer was immersed in an oil bath which was thermostated at 25.000 ± 0.005°C, using the electronic proportional regulator developed by Ransom.[4] The oil bath was surrounded by an insulated wooden box which also enclosed the upper part of the interferometer and the microscope (except for the micrometer eyepiece), thereby increasing the temperature stability of the system.

*Electronic Circuits.*—Our previous interferometer[5] followed the familiar method of using a microammeter to determine the change in reactance of the cell with motion of the reflector. Unfortunately, the maximum galvanometer deflection, corresponding to a standing-wave position, could only be discerned after it had been passed, and the lead screw had enough residual backlash to prevent determination of the exact position by moving the reflector back and forth. A better method of determining standing-wave positions was needed, in which the off-balance is visible at all times and can be reduced to zero by moving the reflector continuously in one direction, thus avoiding backlash. It occurred to us that this might be accomplished by a slight modulation of the oscillator. The signal formerly read on the microammeter could then be applied to the vertical plates of an oscilloscope, while a uniform sweep proportional to the frequency was applied to the horizontal plates. This would give a trace with a peak at the frequency corresponding to a standing-wave system. As the reflector was moved steadily (e.g., away from the transmission plate), the maximum of the trace would move uniformly (in this case,

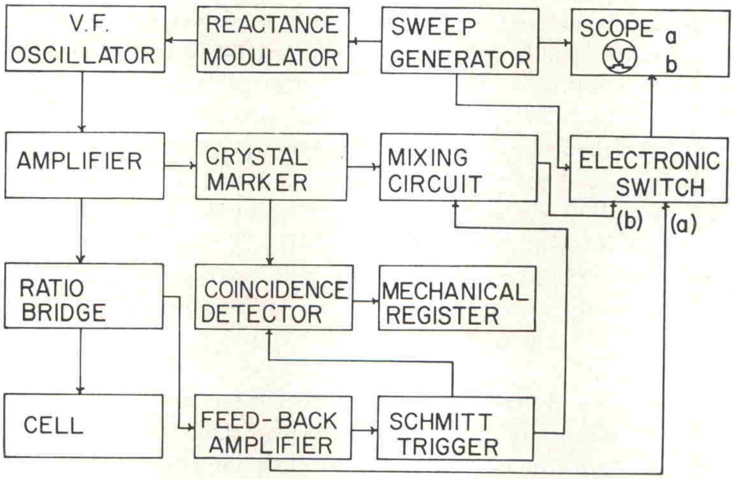

FIG. 2.—Block diagram of FM-interferometer circuits.

toward a lower frequency) until it coincided with a calibrated 4-Mc frequency marker signal. Such an arrangement not only would display the off-balance position at every instant, but also the wave form in the vicinity of a standing-wave position. This idea was discussed with Mr. George F. Siddons, Director of the Indiana University Electronics Department, who designed and supervised the construction of the frequency-modulated interferometer circuits shown in the accompanying block diagram (Fig. 2).

The variable-frequency (VF) oscillator employs a Clapp (series-tuned Colpitts) circuit, with a center frequency adjustable over the range 3.9–4.1 Mc and stable to ±100 cps. Its frequency is varied by a reactance modulator with a band width adjustable from 0 to 24 kc. The modulator is triggered by a sweep generator operated at 60 sweeps per second to give a saw-toothed time-frequency curve.

The oscillator is connected through an amplifier (comprising two buffer stages and a power stage) to a ratio bridge consisting of three 52-ohm resistors with the cell as the fourth arm. The a-c component of the bridge output is passed through a three-stage 50-db feed-back-stabilized amplifier. The amplified signal is divided. One part passes through the electronic switch and a vertical amplifier (not shown) to appear as the upper, *a*, trace on the oscilloscope. Another part of the amplified bridge signal goes through a clipping circuit (not shown), which removes all but the highest peaks and drives a Schmitt trigger circuit which converts the input pulse to a square wave. The output from the Schmitt trigger circuit also is divided, part going to the mixing circuit and part to the coincidence detector.

A crystal marker connected to the amplifier is used to indicate a frequency of 4 Mc. This frequency is calibrated against WWV with a General Radio Type 1213-C Time/Frequency Calibrator and adjusted to 4 Mc (±20 cps) by means of a piston-type trimmer capacitor. When the VF oscillator sweeps through 4 Mc, a crystal in the marker circuit tuned to exactly this frequency presents a low impedance path to a diode rectifier and clipper (not shown) which emits a sharp output pulse.

The output from the crystal marker circuit is divided and part is fed into the mixing circuit, part into the coincidence detector. The combined signals from the Schmitt trigger and crystal marker go from the mixing circuit to the electronic switch and appear as the lower, *b*, trace on the oscilloscope. The electronic switch is operated by the sweep generator, connected through a fly-back amplifier and a "flip-flop" circuit (neither shown). Alternate pulses of the sweep generator reverse the connections of the electronic switch and successively present to the vertical plates of the oscilloscope: (*a*) the amplified bridge signal forming the upper trace and (*b*) the output from the mixing circuit forming the lower trace.

The sweep generator consists of a gas-type discharge tube connected in a relaxation oscillator, with a frequency of 60 or 120 sweeps per second. This is coupled through an amplifier (not shown) to the horizontal plates of the oscilloscope, and also directly to the reactance modulator. Thus the sweep generator controls the electronic switch, the horizontal sweep of the oscilloscope, and the frequency modulation of the oscillator.

The coincidence detector passes a pulse whenever the square wave from the Schmitt trigger coincides with a pulse from the crystal marker circuit. The output passes through a pulse stretcher and amplifier (neither shown) to a mechanical register. A count is registered when the pulse from the Schmitt trigger coincides