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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A HETERODYNE FREQUENCY METER FOR 10 TO 3,000 MEGACYCLES

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● TO MEASURE FREQUENCIES, power from an unknown source can be absorbed in a calibrated resonant circuit and made to operate an indicator. The indicator can be an incandescent lamp, a glow tube or a galvanometer preceded by a detector. This simple and straightforward method requires appreciable power and is limited to frequencies for which resonant circuits are available.

In a heterodyne frequency meter, the power required from the unknown source to produce beat notes with a calibrated oscillator is smaller by several orders of magnitude, and the frequency range that can be covered with a single oscillator, spanning a two to one range, extends continuously over several decades.

If the unknown frequency is lower than the lowest frequency of the heterodyne oscillator, harmonics of the unknown are used to produce beats with the oscillator fundamental. If the unknown is higher than the highest frequency of the heterodyne oscillator, harmonics of the oscillator are used. In either case the harmonics are produced in a non-linear element of the heterodyne frequency meter.

Experience has shown that harmonics up to the twentieth order can be used in an instrument of this type with a corresponding spacing of 5% between frequencies which

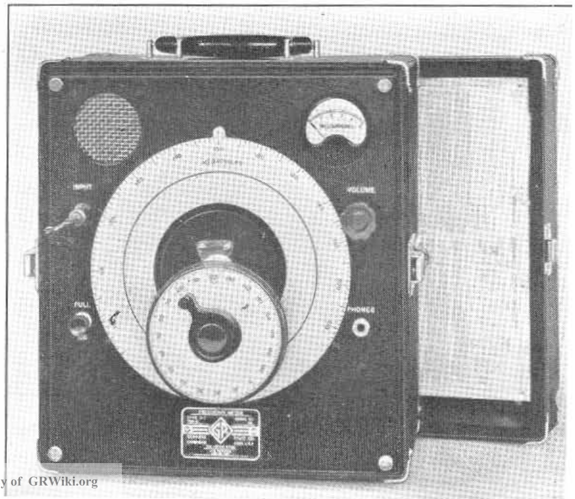

Figure 1. View of the Type 720-A Heterodyne Frequency Meter with cover removed.

produce adjacent beats. It follows that the calibrated oscillator should have a range of approximately 100 to 200 megacycles if unknown frequencies up to 3,000 megacycles are to be measured.

The chief obstacle to producing a heterodyne frequency meter for this range has been the erratic performance of oscillators using conventional tuned circuits. Sliding contacts produce erratic variations in frequency and amplitude, while changes in tubes and supply voltages have much greater effects than at lower frequencies. The newly developed Butterfly Circuit,* however, has made it possible to avoid most of these difficulties. With the new Type 720-A Heterodyne Frequency Meter, which uses the Butterfly Circuit, a frequency of 3000 Mc can be measured as conveniently and as accurately as those in the broadcast range. The low-frequency limit for normal use is about 10 Mc, but lower frequencies can be measured if more than 1 volt at the unknown frequency is available at the detector input.

The Type 720-A Heterodyne Frequency Meter is a portable battery-operated instrument of small size and light weight, with unusually high sensitivity. The panel view of the new instrument is shown in Figure 1. A complete set of operating instructions is mounted in the removable cover. The functional elements of the instrument are a calibrated oscillator, a detector, and an audio amplifier as shown in the schematic diagram of Figure 2. An internal view of the instrument is shown in Figure 3.

Oscillator

The frequency of the heterodyne oscillator is continuously variable between 100 and 200 megacycles. The frequency-determining element is a tuned circuit of the butterfly type, with rotor plates shaped to give an approximately logarithmic frequency distribution. The rotor is mounted in ball bearings. No sliding contacts are used, and no current flows through the bearings. Smooth adjustment of frequency and stability of calibration are therefore assured.

The main dial of the frequency meter is calibrated directly in megacycles. The scale is 15″ long and approximately logarithmic. The gear ratio between the tuned circuit and the vernier dial is over 200 : 1. Over most of the frequency range one-half turn of the vernier dial corresponds to 1% variation in frequency, and one division of the vernier dial to a frequency change of 100 parts per million. Unknown frequencies are measured by producing beats with the calibrated heterodyne oscillator. Beats may be produced between the fundamentals of the unknown source and the

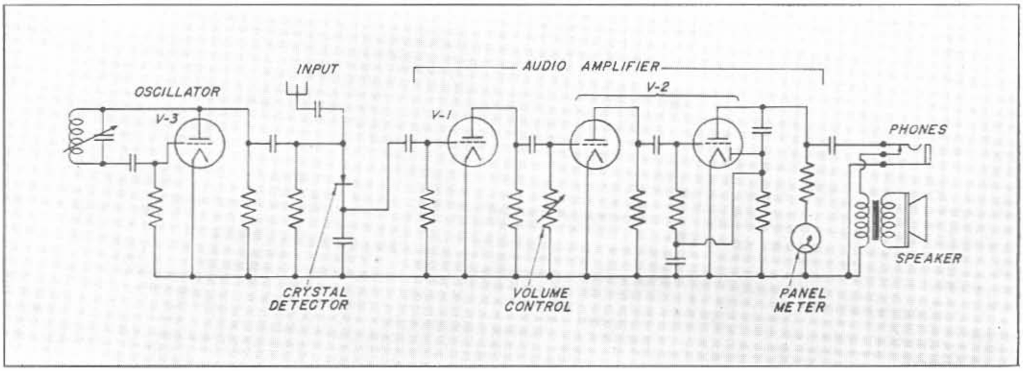

Figure 2. Schematic circuit diagram of the heterodyne frequency meter.

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*E. Karplus, "The Butterfly Circuit," General Radio *Experimenter*, Volume XIX, No. 5, October, 1944.

heterodyne oscillator, between harmonics of the unknown frequency and the heterodyne fundamental, between the unknown fundamental and harmonics of the heterodyne oscillator, or between harmonics of both the unknown source and the heterodyne oscillator.

Detector

The detector, in which the harmonics of the known and unknown frequencies and their beats or difference frequencies are produced, is a standard 1N21B-type crystal detector, consisting of a silicon crystal and a tungsten wire, mounted in a small ceramic cartridge. The detector cartridge is located near the antenna input terminal and is held in place by a ring-shaped spring. A spare detector is furnished with the instrument, but, since the cartridge used has standard dimensions, different makes and types of detectors can be substituted.

Adequate input to the detector is usually obtained if the instrument is placed in the vicinity of the oscillator whose frequency is to be measured. An input antenna of adjustable length is permanently mounted on the front panel. This adjustment is used to improve signal strength when working with frequencies above 1000 Mc. For frequencies below 100 Mc, it may be necessary to connect an additional wire to the "input" terminal.

Amplifier

The three-stage audio amplifier has an effective band width of 50 kc and is connected to produce a deflection of the panel meter when a strong signal is impressed on the detector. This feature is particularly useful when the frequency under measurement is not sufficiently stable to produce a steady audible beat. Audible beats are simultaneously heard in the small dynamic speaker mounted on the front panel. Weak beat notes are best observed with a pair of headphones plugged into the PHONES jack.

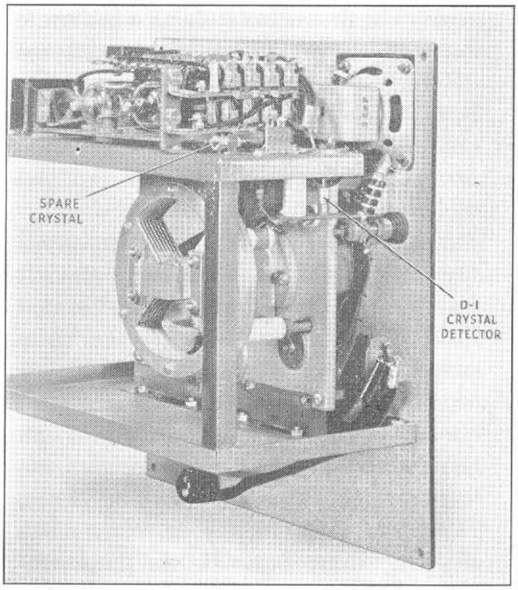

FIGURE 3. Interior view showing the butterfly-type tuned circuit and the location of the working and spare crystals.

Power Supply

One Burgess TYPE 6TA60 Battery is used to supply 90 volts to the plates and 1.5 volts to the filaments of the three vacuum tubes used. All necessary connections are made by a battery plug attached to a short cable. The filament and plate loads are well balanced, and the battery will give long service in intermittent use. Since the heating up time of the tubes is very short, the instrument can be turned off if appreciable time elapses between measurements. The instrument can also be operated from a rectifier power supply, and a compact a-c power unit to fit the battery compartment will be available later.

Making Frequency Measurements

The process of making frequency measurements by the heterodyne method consists fundamentally of three

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steps. The first is to establish a beat note between the unknown source and the heterodyne oscillator. The second step is to determine the order of the beat observed, and the third step is to determine the frequency of the heterodyne oscillator.

With the Type 720-A Heterodyne Frequency Meter the last step consists merely in reading the directly-calibrated main dial of the instrument. The accuracy thus obtained is 0.1%. If higher accuracies are desired, the true frequency of the heterodyne oscillator can be measured in terms of a more accurate low-frequency standard. The Type 720-A then is merely a convenient stepping stone between the high unknown frequency and the low standard frequency, which are too far apart to produce beat notes by themselves. The best procedure to establish beat notes and to determine their order depends on whether the unknown frequency is in the range of the fundamental oscillator frequency or above or below. In general, if the "unknown" frequency is known approximately, a single beat is sufficient to determine the frequency accurately. On the other hand, if the approximate value is not known, it will be necessary to note successive beats until their pattern can be determined.

Frequencies between 100 and 200 Mc. When the frequency to be measured lies within the fundamental range of the Type 720-A Heterodyne Frequency Meter, the unknown frequency is read directly from the main dial when a strong beat is obtained. In addition to this beat note, other weaker beat notes may be heard. For example, if a fundamental frequency of 150 Mc is measured, a strong beat will be obtained at a dial setting of 150.0 Mc, and weaker beats may be heard at dial settings of 100 and 112.5 Mc. These weaker beats are produced between the 2d and 3d harmonics of the unknown frequency and the 3d and 4th harmonics of the Type 720-A Oscillator, respectively; 2 × 150 Mc = 3 × 100 Mc and 3 × 150 Mc = 4 × 112.5 Mc.

Frequencies over 200 Mc. For frequencies which lie above 200 Mc the procedure is to start at the high end of the frequency range and to note the successive settings of strong harmonic beats as the frequency of the heterodyne oscillator is progressively reduced. If the frequency at which one beat occurs is divided by the frequency difference between it and a successive beat, the result must be an integer and is the harmonic number of the successive beat. *Example:* A high frequency is measured and strong beats are obtained at 200.0 and 160.0 Mc. Subtracting the second beat from the first gives 200.0 — 160.0 = 40.0. Dividing the first beat by this difference gives 200.0/40.0 = 5, which is the harmonic number of the second

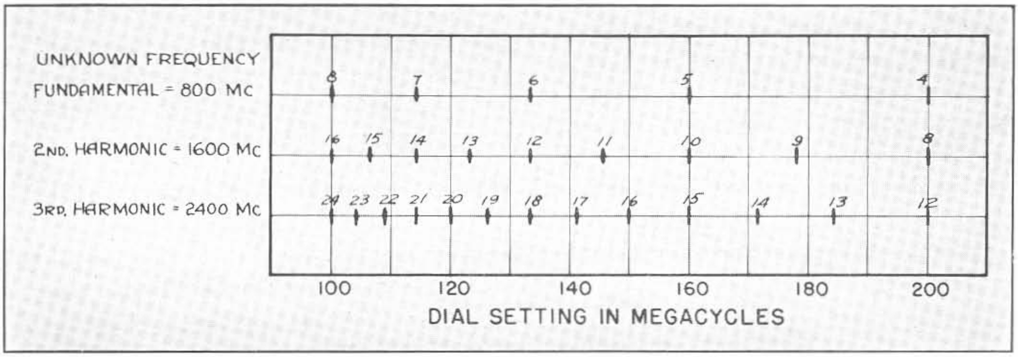

Figure 4. Chart showing pattern of harmonic beats for an unknown frequency of 800 megacycles.

beat. Hence, the unknown frequency is $5 \times 160.0 = 800.0$ Mc.

In many cases it will be possible to produce beats between harmonics of the unknown frequency and harmonics of the heterodyne oscillator. These beats will usually be much weaker than the beats produced between the unknown fundamental and the heterodyne harmonics. The chart of Figure 4 gives the possible beats up to the 3d harmonic of the unknown used in the example above.

Frequencies under 100 Mc. For frequencies which lie below 100 Mc, the procedure is to start at the low end of the frequency range and to note the successive settings of beats as the frequency of the heterodyne oscillator is progressively increased. The frequency difference between two successive beat settings is equal to the unknown frequency. *Example:* A low frequency is measured and beats are observed at 105.0, 120.0 and 135.0 Mc. The frequency difference between successive beats is 15.0 Mc, which is the frequency being measured.

Wavelength. The wavelength in centimeters is obtained with sufficient accuracy by dividing 3×10^{10} by frequency. In most applications electromagnetic waves are characterized by their frequency, but in some problems the use of wavelength may be more convenient. It has been shown in the paragraph entitled "Frequencies over 200 Mc" above, for instance, how an unknown frequency over 200 Mc can be determined from the two frequencies of the heterodyne oscillator which produce successive beat notes. If all frequencies are converted into wavelength, the wavelength of the unknown is simply the difference between the two wavelengths which produced the successive beat notes. *Example:* 160 and 200 Mc in the example above correspond to 187.5 and 150 cm. The difference of 37.5 cm corresponds to 800 Mc.

— EDUARD KARPLUS

SPECIFICATIONS

Frequency Range: The fundamental frequency range is from 100 to 200 Mc. This range is covered in a single band with approximately logarithmic frequency distribution. By harmonic methods, frequencies between 10 Mc and 3000 Mc can be measured.

Calibration: The main dial is calibrated in frequency, each division corresponding to 1 Mc. The vernier dial is geared to the tuning unit to make one-half turn of the dial correspond to 1% change in frequency over the major part of the tuning range. The vernier dial carries 200 uniform divisions.

Accuracy: The overall accuracy of measurement is 0.1%. Changes in tubes or battery voltages and variations of temperature and humidity over the range of laboratory conditions normally encountered do not affect the accuracy of the instrument.

Detector: One cartridge-type crystal detector (1N21-B) is used and is supplied with the instrument.

Vacuum Tubes: The following tubes are used and are supplied with the instrument:

1 — TYPE 1N5GT
1 — TYPE 1D8GT
1 — TYPE 958

Battery: A single-block Burgess TYPE 6TA60 Battery is used and is supplied with the instrument. The power required is approximately 80 volts, 6 ma and 1.4 volts, 250 ma.

Case: The TYPE 720-A Heterodyne Frequency Meter is mounted in a shielded carrying case of durable airplane luggage construction.

Spare Parts: One 1N21-B-type detector is supplied as a spare in addition to the one in the instrument.

Accessories: Headphones which can be plugged in on the front panel and stored in the cover of the instrument are recommended.

Dimensions: Overall, (width) 12½″ × (height) 13½″ × (depth) 10½″. Panel, (width) 10¾″ × (height) 11¾″.

Net Weight: Including battery, 27¾ pounds.

Type		*Code Word*	*Price*
720-A	Heterodyne Frequency Meter	FANCY	$250.00

This instrument is manufactured and sold under (1) patents of the American Telephone and Telegraph Company, and (2) U. S. Patent No. 2,367,681.