Frequency Measurement with

Ways To Improve Accuracy

The LM frequency meter, and its Signal-Corps counterpart, the BC-221, are very ruggedly constructed and, when properly used, are quite accurate instruments. However, they do have certain limitations, and an understanding of these limitations is necessary if errors are to be minimized.

General Construction

These meters have three tubes, sometimes varying in type from model to model, but not in function. One of these tubes is in a calibrated v.f.o. circuit covering the dual fundamental frequency ranges of 125 to 250 kc. (195 to 400 kc. in models prior to LM-10), and 2000 to 4000 kc., as determined by the position of a band switch. By using harmonics of the fundamental ranges, continuous coverage from 125 to 20,000 kc. or higher is available. (The calibration book supplied with the frequency meter stops at 20 Mc., but higher harmonics produce signals of usable strength up to as high as 144 Mc.) There are individual screwdriver-adjusted trimmer capacitors for each of the two fundamental ranges, and a third trimmer common to both ranges. The latter has a panel control marked CORRECTOR.

The second tube performs the functions of detector and a 1000-kc. crystal oscillator, the latter used primarily as a reference for the v.f.o. calibration. Most models have a trimmer across the crystal for accurate setting against WWV.

Both oscillators are coupled to a common output terminal (in some models through an attenuator), and both are also coupled to the detector. The output terminal is also the input terminal for external signals whose frequencies are to be measured. In most models, the v.f.o. and crystal oscillators may be switched on or off independently.

Audio output from the detector (as a result of an audio beat between two signals fed to the detector) is amplified in the third tube which feeds a headphone (low-impedance) output jack. In some models, this audio stage may be switched to function as an audio oscillator for modulation purposes.

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Dial Mechanism

The v.f.o. dial mechanism includes a drum numbered from 0 to 50, and a worm-driven dial numbered from 0 to 100 through 360 degrees. One complete revolution of the dial causes the drum to advance one division. This combination results in an equivalent of 50 × 100 = 5000 dial divisions for each of the two v.f.o. tuning ranges (plus a small overlap at each end). However, the dial has a vernier readout that gives direct readings in tenths of a dial division, making the total virtually 50,000 dial divisions. Each of these 0.1 divisions is equivalent to about 3 cycles over the low-frequency fundamental range, and about 50 cycles over the high-frequency range.

General Operation

These instruments may be used to transmit a signal on some selected frequency, or to measure the frequency of an external signal. The process involved in setting up the frequency meter to emit a signal at some desired frequency is a simple one. First, tune in one of the WWV standard-frequency signals on a communications receiver. The higher this frequency is, the greater the accuracy will be. Couple the frequency meter to the receiver and turn on the crystal oscillator. The crystal signal should be found at zero beat with WWV, or very close to it. If necessary, adjust the crystal trimmer for exact zero beat.

By referring to the calibration book, determine the v.f.o. dial setting for the desired frequency and, on the same page, find the nearest crystal check point. Set the dial accurately to the reading specified for this check point. With headphones, plugged into the frequency-meter jack, turn on the v.f.o., and the v.f.o. signal should be found at or close to, zero beat with the 1000-kc. crystal fundamental signal, or one of its harmonics. If necessary adjust the v.f.o. CORRECTOR control for an exact zero beat. Turn off the crystal oscillator, set the v.f.o. dial to the desired frequency, and the emitted signal will be on that frequency (subject to possible errors discussed later).

Measurement of the frequency of an external signal is simply a matter of matching the v.f.o.

the LM/BC-221

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frequency to that of the external signal, and reading the v.f.o. dial to determine the frequency. If the external signal is sufficiently strong, such as from a local oscillator, or the station transmitter, measurement may be made by feeding the external signal into the input terminal, and listening on the frequency meter itself.

Determine the approximate frequency of the external signal from the receiver calibration or other source. Set up the frequency meter for this approximate frequency, following the same procedure as before. Then adjust the v.f.o. very carefully until the v.f.o. and the external signal are at zero beat. Read the v.f.o. dial, and determine the frequency from the calibration book.

If the external signal is too weak to be heard reliably on the frequency meter, both the signal and the frequency meter should be coupled into a receiver. With the signal tuned in on the receiver, (receiver b.f.o. off) measurement is made in the same manner by adjusting the v.f.o. signal to zero beat. Coupling between the receiver and the frequency meter should be the smallest that will produce satisfactory beat-note strength. Receiver gain and/or the frequency meter attenuator should be adjusted to avoid any possibility of receiver overload. The strongest beat note will be obtained when the external signal and the frequency-meter signal are of the same strength.

Check Points

A "crystal check point" occurs whenever the v.f.o. fundamental, or a harmonic, coincides with the fundamental, or a harmonic, of the crystal oscillator. As examples, the 4th harmonic of 250 kc. (v.f.o.) coincides with the fundamental of the crystal oscillator (1000 kc.); the fundamental at 2000 kc. (v.f.o.) coincides with the 2nd harmonic of 1000 kc. (crystal); the 4th harmonic of 2750 kc. (v.f.o.) coincides with the 11th harmonic of 1000 kc. (crystal). If the v.f.o. dial is set to the reading corresponding to one of these v.f.o. frequencies, and the reading is accurate, then the crystal and v.f.o. signals should be at zero beat when listening on the frequency meter. If they are not, the v.f.o. corrector knob should be adjusted until they are at zero beat. Then, we know that the calibration is accurate *at this point* on the v.f.o. dial. However, the tuning rate on the v.f.o. may not be exactly linear between one check point and the next, so measurements made in between check points may not be as accurate as those made close to the check points. The calibration book lists only a few of the many possible check points. Additional check points may be determined following the procedure described by W4HH in an earlier issue.[1]

Scale Readability

When using harmonics of the v.f.o., the scale-reading accuracy diminishes in inverse proportion to the order of the harmonic. The figure of 3 cycles per 0.1 dial division over the 125–250-kc. range becomes 6 cycles over the 250–500-kc. range of the second harmonic, 9 cycles over the 375–750-kc. range of the third harmonic, and so on. A similar decrease in accuracy prevails when using harmonics of the 2000–4000-kc. range, so that in the 12,000–24,000-kc. range of the sixth harmonic, for example, each 0.1 dial division represents $6 \times 50 = 300$ cycles.

Frequency Conversion

However, there is a method of measuring frequencies higher than the v.f.o. fundamental ranges that can often be used without resorting to harmonics, or at least harmonics higher than the fourth harmonic of the low-frequency v.f.o. range, thus reducing the dial-reading error at the higher frequencies. The method was described by W1JJY several years ago,[2] and touched upon more recently by W6PM[3].

The principle of the method is as follows: when the crystal oscillator and the v.f.o. are fed into the frequency-meter detector simultaneously, the detector will act as a mixer, and frequencies equal to both the sum of, and the difference between, the two input frequencies will be generated in the mixer, as with any heterodyne system. (The principle is the same as that used in a superhet receiver, where the incoming signal and the signal from a local oscillator combine to produce the i.f. frequency in the output of the mixer.) As an example, the fundamental signals

[1] Countryman, "Calibrating the LM Frequency Meter," *QST*, April, 1965

[2] Riley, "Interpolation Frequency Measurements with the BC-221," *QST*, January, 1956.

[3] Robinson, "Extending the Range of the BC-221 Frequency Meter," *QST*, December, 1964.

If you own, or contemplate the acquisition of, an LM or BC-221 surplus frequency meter, this article should be of more than ordinary interest. It covers the various possible sources of error and suggestions for minimizing inaccuracies. Included is a discussion of circuitry and operation of these versatile instruments.

in the low-frequency range of the v.f.o. (125 to 250 kc.) will beat (heterodyne) with the 6th harmonic of the crystal (6000 kc.) to produce signals in the output of the mixer over the *sum* range of 6125 to 6250 kc., and over the *difference* range of 5875 to 5750 kc. If the unknown frequency lies within either of these segments, it can be measured by feeding the unknown frequency and the heterodyne signal from the frequency meter into a receiver, and adjusting the v.f.o. tuning to zero-beat the heterodyne signal with the unknown. (Or, the signal of unknown frequency may be fed into the frequency meter.) The frequency indicated by the frequency meter dial will then be the difference between the unknown frequency and the crystal-harmonic frequency used as a reference. The unknown frequency may then be found by adding the v.f.o. frequency to, or subtracting it from, the crystal-harmonic frequency. If the unknown lies in the range above the crystal-harmonic frequency, the v.f.o. frequency will be added to the crystal frequency; if the unknown lies in the range below the crystal frequency, the v.f.o. frequency will be subtracted. When the unknown frequency lies within the ranges of 125 to 250 kc. above or below any crystal-harmonic frequency, the frequency can be measured in this manner, and the dial-reading accuracy in cycles will be the same as that of the v.f.o. in its fundamental low-frequency range (approximately 3 cycles per 0.1 dial division).

As an example, the receiver indicates that the unknown frequency is approximately 5850 kc. The nearest crystal harmonic is at 6000 kc., and the unknown is obviously on the low-frequency side of this crystal frequency. Also, since it is approximately 150 kc. removed from the crystal harmonic, it should come within the band covered by the 125-to-250 kc. range of the v.f.o.

Both the signal of the unknown frequency, and the frequency meter are fed into the receiver. Both crystal oscillator and v.f.o. are turned on. The v.f.o. is adjusted to approximately 150 kc. (the approximate difference between the unknown and the crystal-harmonic reference), and then tuned carefully to zero beat with the unknown. The dial reading is taken, and the corresponding frequency taken from the calibration book.

Suppose that the frequency read is 150.187 kc. Since we know that the unknown is on the low-frequency side of 6000 kc., we subtract 150.187 from 6000, and the remainder, 5849.813 kc., is the frequency of the unknown.

It will be noticed from the foregoing that the process described does not give continuous frequency coverage. Using the second harmonic of the v.f.o. low-frequency range will increase the coverage to 250–500-kc. either side of the crystal fundamental, or one of its harmonics, with twice the dial-reading error; using the third v.f.o. harmonic, these ranges become 375 to 750 kc. either side, with three times the dial-reading error at the fundamental. Using the fourth v.f.o. harmonic, the ranges are 500 to 1000 kc. either side, with four times the fundamental dial-reading error. It will be seen that the fourth harmonic gives continuous coverage between adjacent 1000-kc. crystal harmonics, so it should never be necessary to go beyond the fourth v.f.o. harmonic for any measurement.

The fact that the output of both oscillators in the frequency meter are rich in harmonics gives rise to the production of many frequencies other than those of immediate interest in making a given measurement, and distinguishing the wanted beats from the unwanted may require close attention under certain circumstances. Crystal check points resulting from the lower-order harmonics will radiate quite a strong signal on the conversion frequency, and may make it difficult to find the zero point on the signal being measured if it happens to be within a few cycles of the conversion frequency. An example of this is 150 kc. If the meter is coupled fairly closely to the receiver, you can listen on the receiver at 5850 kc. (or any other frequency 150 kc. above or below one of the lower-order crystal harmonics) while you adjust the corrector for zero beat at the 150-kc. crystal check point, and hear the signal as it is zeroed in. If the signal to be measured is only a few cycles removed from the crystal-check conversion frequency, it may be difficult to tell which signal you are measuring. However, with a little practice, you will learn how to separate them. Note that this occurs only at the conversion frequency of a strong crystal check point.

If desired, a separate set of calibration charts can be made up for the heterodyne mode of operation, plotting dial readings against the frequencies that result when the v.f.o. funda-

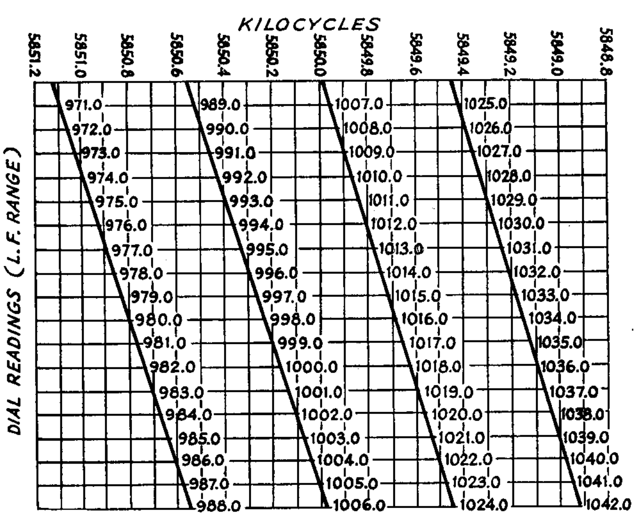

Fig. 1—Sample section of heterodyne calibration covering the range of 5848.8 to 5851.2 kc. Original size is about 9¼ by 7 inches.

mental (or a harmonic) beats against a selected crystal harmonic. The example shown in Fig. 1 is a portion of such a chart, showing the difference frequencies resulting from the combination of the v.f.o. fundamental and the 6th harmonic of the crystal oscillator. To provide good readability, this chart covers only 5851.2 to 5848.8 kc. The actual size of the chart is 9¼ by 7 inches, divided into 1/16-inch squares (standard graph paper). Each square represents 1/5 dial division, or approximately 20 cycles. The chart can easily be read to 1/10 dial division, or 10 cycles, or better.

Circuit Modification

In some models of the LM (but not the BC-221), one section of the crystal-oscillator switch disconnects and grounds the output terminal when the switch is in the "crystal-on" position. If such is the case, this section of the switch must be disconnected and the circuit rewired so as to leave the output terminal connected and ungrounded.

If your model does not have an output attenuator, one can be added, as shown in Fig. 2. This circuit also shows a three-position switch that I have added. In the first position of the switch, the output connection is normal, direct from the attenuator. In the second position, a small series capacitor is inserted to further attenuate the output signal if found desirable. If the third position, a short antenna is added for external-signal pickup.

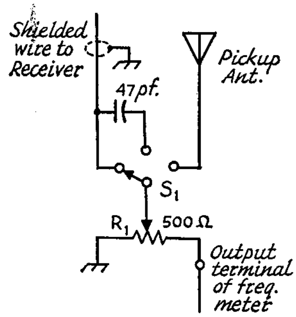

Fig. 2—Added output attenuator and switching system described in the text. S_1 is a 3-position rotary switch. R_1 is a linear control.

Sources of Error

No matter which system of measurement is used, there are certain factors which must be given attention if errors are to be minimized. Most of these sources of error will influence the measurement to a smaller degree if the heterodyne system is used.

Thermal Drift: While more pronounced in the v.f.o. section of the meter, there is also thermal drift in the crystal-oscillator section as the meter warms up. The best way to minimize this drift is to leave the meter turned on continuously, if it is to be used frequently, and make frequency readings as quickly as possible after the crystal-check-point correction has been made.

Voltage Changes: Changes in either plate or heater voltage will also affect the frequency. If an a.c. supply is used, it should be as stable as possible with line-voltage variations, and the plate voltage should be regulated. Some meters have a plate-voltage regulator built in. Be sure that the VR tubes are working. If the line-voltage regulation at your location is poor, increasing the load on the line by turning on the transmitter, for instance, may cause a reduction in heater voltage, resulting in an error in measurement. A small line-voltage regulator (Sola, or similar) may be desirable in such instances.

Dial Backlash: The dial turns a worm gear which engages a spring-loaded gear to turn the v.f.o. variable capacitor. The capacitor shaft should turn freely, with no trace of binding. The worm and gear should be lubricated with a good grade of light oil which will not gum. Be sure that there is lubrication between the two halves of the spring-loaded gear so the two will not stick together. Access may be had by removing the cover from the capacitor compartment.

Nonlinearity: When a meter is new and first calibrated, every crystal check point will fall exactly on the dial reading shown in the calibration book without changing the v.f.o. corrector. But with age, the inductance of the coils, and/or the spacing of the capacitor plates may change, resulting in scale errors. If it is necessary to adjust the corrector knob when moving from one check point to another, there is an error in the calibration between these two points by the amount of correction needed, and a proportionate error at all points in between. For this reason, it is desirable to have a check point as close as possible to the frequency to be measured. QST

Strays

Practically every amateur uses the standard-frequency services from WWV, but only those who go in for frequency measurement in a serious way are likely to realize just how varied those services are. The National Bureau of Standards has just recently issued a new edition of its pamphlet "Standard Frequency and Time Services," describing in detail the transmissions available from WWV, WWVH, WWVB and WWVL, and including a discussion of the accuracy of the various frequencies. The price is 15 cents per copy from the Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. 20402. Ask for Miscellaneous Publication 236.

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