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mfm

LAMPKIN

Micrometer Frequency Meter

ENGINEERING DATA SHEETS

SECOND EDITION

Type 103-B — OPERATING INSTRUCTIONS — Type 105-B

The following accessories are required with the Micrometer Frequency Meter, or MFM: a pair of headphones with cord and plug, magnetic type of 2000-ohm or higher impedance, or crystal type; an antenna wire for RF pickup; and a small screwdriver to adjust the trimmer. In addition, the Type 103-B unit requires a radio receiver for reception of standard-frequency signals from station WWV, Washington, D. C.

Connect the MFM to a source of power, as specified on the nameplate. Turn the POWER and PLATE switches on and allow the MFM to warm up for one hour, resting in the position in which it is to be used. Due to anode heating in the oscillator tube, there is a thermal frequency drift associated with the PLATE switch; the drift amounts to two or three divisions and requires ten to twenty minutes to stabilize; for this reason the PLATE switch should be on at least 20 minutes prior to making measurements.

Dial readings generally will be in five figures; the first two figures are read from the left-hand wheels of the Veeder counter, and the last three from the dial scale, estimating by eye to the nearest tenth of a dial division. ALWAYS make any dial setting by coming just to the correct point, from a reading at least 100 divisions lower, in order to eliminate the effect of backlash.

The calibration of the MFM must be standardized just prior to measurements, and every 10 or 15 minutes while measurements are in process. To standardize the calibration of the Type 105-B MFM against the internal crystal, set the selector switch on CALIB., then adjust the dial to the point indicated by the panel thermometer. Plug headphones into the PHONES jack. Turn the trimmer screw above the nameplate till the tone heard in the headphones is reduced to a slow flutter of less than one or two per second.

To standardize the calibration of the Type 103-B MFM (or the Type 105-B) against emissions from radio station WWV, set the MFM selector switch on XMTR. With a short-wave receiver pick up the tone-modulated signal from WWV on 2.5, 5, 10, 15 megacycles or higher, listening to a loudspeaker or headphones at the receiver output. Adjust the MFM dial 5 to 15 divisions away from the reading for 2500 kc. as given in the Standard Calibration Table, and connect a few feet of wire to the RF tip jack. This will generate a beat note on WWV. Try different methods of antenna pickup on the receiver, and various degrees of coupling to the MFM wire, until the beat note is loudest. Adjust the dial of the MFM exactly to the setting for 2500 kc. With the screwdriver turn the trimmer screw above the nameplate so that the beat note is reduced to zero during a period of no modulation from WWV, and then to a slow flutter during the tone modulation.

After standardizing the calibration, the MFM is ready for transmitter measurements. Have the selector switch on XMTR. With headphones in the MFM, rotate the dial to the region indicated on the Deviation Calibration chart for the transmitter frequency in question. Try various antenna lengths from 0 to 100 feet on the MFM, vertical or horizontal polarization, and various couplings to the transmitter or its antenna, for loudest beat note in the headphones. Then adjust the MFM dial for zero beat on the transmitter, take the reading, and refer to the chart to determine the deviation, plus or minus. If zero beat is weak, or several divisions wide, locate the setting midway between tones of equal pitch on either side. For transmission on other frequencies, repeat the process, moving the dial to the region given on the chart for the particular frequency.

For further details, see the Engineering Data Sheets inside this booklet. Receiver alignment is covered in Sec. 4.11.

LAMPKIN LABORATORIES, INC., BRADENTON, FLA.

This booklet is a complete rewrite based on the "B" models of the Micrometer Frequency Meter. A previous booklet has gone through two printings and two revisions during the more than fourteen years that the MFM has been in production. Over that period the original, fundamental design of the MFM has remained unchanged, but there have been improvements in detail to follow the continuing trend to higher transmitter frequencies and closer channel spacing.

Earlier MFM type numbers were as follows:

	Power Supply	Frequency Range	Crystal Calibrator
Type 103	AC-DC	100 kc./56 mc.	no
Type 105	AC-DC	100 kc./56 mc.	yes
Type 103-A	transformer	100 kc./175 mc.	no
Type 105-A	transformer	100 kc./175 mc.	yes

There were two versions of the "A" design, the first with power transformer at the end of a resistance line cord, and series tube filaments; the later version with parallel tube filaments, the power transformer mounted on the instrument case, and the latter isolated from the AC line.

The two present MFM models, Type 103-B and Type 105-B, supersede all other designs.

Several types of information pertinent to the Micrometer Frequency Meter are presented here. The information is divided as follows:

Operating Instructions, on the front cover—brief, condensed details telling how to use the MFM.

Transmitter Chart, on the back cover—for ready reference to frequency and calibration figures on one or several transmitters.

Specifications—on page 2, for the two types of MFM—reprinted from the descriptive bulletin.

Engineering Data Sheets, text in the body of the booklet—details about the design, construction, operation, and performance of the MFM.

Tables 1, 2, and 3, on pages 17 to 24—numerical tables to aid in calculation of dial readings and frequencies up to 175 mc.

Standard Calibration Table, inside the back cover—typed individually for each MFM, giving dial readings for each 10 kc. of fundamental frequency.

Deviation Calibration chart, supplied separately for one or more specified transmitter frequencies—a graph sheet showing percentage deviation versus MFM dial reading.

This booklet applies to meters as produced in 1952 and later. There will of course be apparent in older models differences from the description. Some of the differences lie in the details and materials of construction rather than in performance or operating characteristics. Allowing for such variations, the information presented herein may be found useful with any Micrometer Frequency Meter.

Our instruments are useful only to the extent that they meet your needs. They are designed to do certain jobs, but only through continuing customer suggestions and criticisms can we keep up with such needs. Please write, wire, or phone whenever you need cooperation.

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LAMPKIN LABORATORIES, INC., BRADENTON, FLA., U.S

ENGINEERING DATA SHEETS

Type 103-B and Type 105-B Micrometer Frequency Meter

TABLE OF CONTENTS

SPECIFICATIONS

MICROMETER FREQUENCY METER — TYPE 103-B AND TYPE 105-B

FREQUENCY RANGE—The fundamental-frequency range, stamped on the nameplate, averages from 2330 to 2670 kc., or a spread of 1.14 to 1. By means of harmonics and their combinations, nearby transmitters can be monitored in a continuous range from 100 kc. to 175 mc. Signals picked up on a radio receiver may be measured if they come within the fundamental range of the MFM, or within one of the harmonic ranges; likewise, a radio receiver responsive in any of these ranges can be aligned using the MFM as an unmodulated signal source. The harmonic ranges of the MFM begin to overlap at approximately 20 mc.

CALIBRATION—The Standard Calibration Table is typed individually for each MFM; it shows the MFM dial reading to 0.1 of a division, for every 10 kc. of fundamental frequency throughout the range; and also the Dial Difference, or increment between successive calibration points for use in interpolation. A Deviation Calibration Chart will be supplied with each meter, if the transmitter or operating frequencies are specified. This chart carries a graph line for each frequency, showing MFM dial reading versus percentage deviation from assigned frequency. No extra charge is made for up to five such graphs with original shipment; a nominal charge is applied to additional, or later, graphs.

CONTROLS—The variable frequency is controlled by a 4-inch circular dial having 200 divisions around its circumference and a total travel of 40 turns. This amounts to 8,000 divisions spread out over 42 feet of scale length, and yields a reset accuracy of better than 0.0005%. The dial reading is taken directly from the dial scale and the Veeder counter alongside. The dial is coupled to the spindle of a machinist's micrometer; the spindle carries a conically-tapered rotor in and out of an insulated tubular stator, all forming a uniquely stable and accurate tuning condenser. Other controls starting from the lower left of the panel, are an RF coupling jack, a function-selector switch, a plate-voltage switch, a pilot light, an AC power switch, a jack for headphones, and a panel fuse holder. A trimmer screw above the MFM nameplate is provided for resetting the calibration. The pilot light and AC fuse are replacable from the front of the panel. The phone jack is shockproof.

CRYSTAL CALIBRATOR—Only the Type 105-B meter has a crystal calibrator. The frequency of the crystal is approximately 7500 kc., to which the third harmonic of the MFM is adjusted. The panel thermometer indicates the correct calibration point for ambient temperatures from 20° to 120°F. The overall stability of the calibrator is better than 0.0005% and this can be checked in the field against WWV. The crystal standardizes one point near the mid-range of the MFM dial.

WWV STANDARD FREQUENCIES—By definition of the FCC, the primary standard of frequency maintained by the U. S. Bureau of Standards is the final authority for frequency measurements in the U. S. A. From this standard, by means of round-the-clock transmissions through radio station WWV, near Washington, D. C., standard frequencies can be heard anywhere in the U.S.A. and many places in the world, accurate to 0.00001% or better. Practically any type of short-wave receiver will pick up one or more of the transmissions on 2.5, 5, 10, 15, 20, 25, 30 or 35 mc. To check the dial calibration on either the Type 103-B or the Type 105-B MFM, the dial simply is set to a calibrated point, and the panel trimmer screw is adjusted for zero beat on the WWV signal heard in the receiver.

ACCURACY—The MFM accuracy conservatively is guaranteed better than 0.0025%. This accuracy holds for fundamental frequencies within 50 kc. of the dial check point. For fundamental frequencies 50 to 100 kc. removed from the check point, the accuracy is guaranteed better than 0.005%. Because of harmonic relations, all transmitter frequencies above 70 mc. and approximately half of the frequencies below can be measured within the 0.0025% guarantee.

TUBES—A type 6J7 ratio-coupled oscillator, a type 7F7 untuned detector, and a type 6SN7 twin-triode as audio amplifier and plate-voltage rectifier, are supplied with the MFM. In the Type 105-B model, the second triode section of the 7F7 tube is a crystal oscillator.

POWER SUPPLY—The power supply is 115 volts, 50/400 cycles AC, 25 watts. A small power transformer is mounted externally at the right of the MFM case, with a 5-foot cord. The case is insulated from the power source.

DIMENSIONS—The MFM assembly is mounted on a vertical panel 5" high by 10" wide, and is housed in a metal case 6" deep; the external surfaces are black-crackle finished, with white lettering on the panel. The controls extend a maximum of 2⅞" from the panel face; the transformer extends 2⅝" to the right of the MFM case, and itself is 3" deep by 3" high. Net weight of the MFM is 12.5 pounds, and the shipping weight averages 18 pounds.

GUARANTEE—Lampkin equipment is guaranteed to give complete satisfaction or your money will be refunded. The equipment is honestly described and we will give the best possible service long after the sale. Materials and workmanship are guaranteed against defects for one year from date of sale.

TYPE 105-B FRONT PANEL, WITH CONTROLS IDENTIFIED

Trimmer Screw

Name Plate

Crystal Thermometer

Power Transformer

RF Tip Jack — Selector Switch — Plate Switch — Pilot Light — Power Switch — Veeder Counter and Tuning Dial — Headphone Jack — Power Fuse

The Type 103-B MFM does not have the crystal thermometer, nor the CALIB. position on the selector switch; otherwise, it is the same as above.

1.0 DESCRIPTION

The Micrometer Frequency Meter, or MFM, is an instrument for measuring frequencies of radio transmitters or oscillators over a wide range, and for use as a precision, unmodulated signal generator. The Type 103-B MFM comprises a radio-frequency oscillator, a diode harmonic generator, an untuned detector, an audio amplifier, and a rectifier-filter power supply; in addition, the 105-B model has a crystal oscillator. The block diagram in Fig. 1 illustrates the components.

The heart of the instrument is a highly-stable oscillator, whose frequency is continuously variable over a relatively narrow range approximating 1.14-to-1 ratio, maximum-to-minimum. The frequency is controlled by a precision dial and condenser and is calibrated at numerous points in terms of dial reading. The output of the variable-frequency oscillator and a portion of the output from the transmitter whose frequency is to be measured are impressed on the untuned detector.

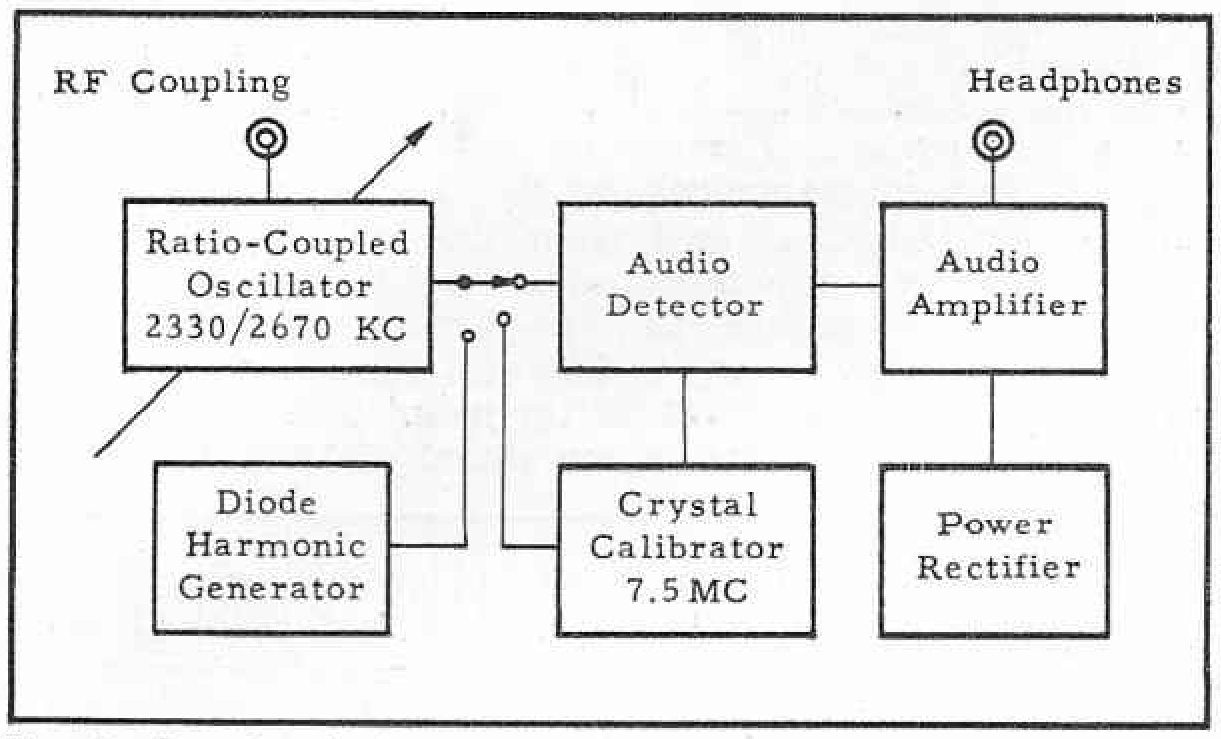


Fig. 1. Functional diagram of the MFM. The crystal calibrator is omitted in the 103-B model.

The measurement is made by adjusting the variable frequency of the MFM, or a harmonic thereof, to coincidence with the transmitter frequency, or a harmonic thereof, utilizing heterodyne reception and aural indication with headphones. The transmitter frequency is determined by referring the MFM dial reading to a table or chart.

The accuracy of the calibration of the MFM oscillator is maintained at one point by reference to a standard frequency, the source of which is external for the Type 103-B meter, and internal for the Type 105-B meter. A prerequisite for measurement with the MFM is that frequency be known within a few percent; in common transmitter practice this is true.

A few of the features of the MFM which contribute to excellent performance and convenient operation are:

- Frequency coverage is continuous from 100 kc. to 175 mc. when the MFM is operated as a monitor near the transmitter.
- Percentage deviation of a transmitter from its assigned frequency may be read directly from a curve.
- Changes in frequency assignments can be accommodated without changes in the MFM itself.
- The ratio-coupled oscillator circuit, a development of these Laboratories, has exceptional frequency stability.
- The frequency-control condenser is built on a machinist's micrometer and is inherently rugged and precise.
- The mechanism of the micrometer plus the multiple-turn dial and Veeder counter produces a scale easy to read, accurate to 0.0005% in frequency.
- The Type 105-B MFM has a precision crystal calibrator with a unique method of temperature control.

2.0 PRINCIPLES OF OPERATION

2.01 Heterodyne, or Beat Reception

Operation of the MFM is based upon the heterodyne, or beat effect of two radio frequencies. If two oscillations of different frequencies are combined in one electrical circuit, the result is a third oscillation whose peak, or crest, value varies periodically. The frequency of the peaks is equal to the difference between the two original frequencies. The difference is called the heterodyne, or beat frequency; when it is made smaller than a few thousand cycles per second, and passed through a rectifier or detector, it is audible in headphones or loudspeaker.

By suitable manipulation as outlined in Section 4.07 and 4.08, beat frequencies of the order of one cycle per second can be distinguished using only headphones or loudspeaker as indicator. This condition is called zero beat. Since the original frequencies themselves usually are greater than one million cycles per second, the accuracy of setting one against the other, at zero beat, is greater than one part in a million. Therein lies a great advantage of the heterodyne method of frequency measurement; namely, the error in adjusting the MFM frequency to the frequency being measured can be made negligible.

2.02 Harmonics

The lowest frequency at which an oscillator produces current is called the fundamental frequency. In addition to the fundamental there are present in all oscillators or transmitters harmonic frequencies, or harmonics, which are exact integral multiples of the fundamental frequency—that is, exactly 2, 3, 4, 5, etc., times the fundamental frequency. These additional frequencies are identified as second harmonic, third harmonic, etc. In general, the harmonics are weaker than the fundamental, and become weaker the higher the harmonic number. Under certain conditions in frequency-measurement work, harmonics as high as the 300th can be utilized.

The block marked "1" in Fig. 2 indicates graphically the range of fundamental frequency covered by the average MFM, when the dial is rotated from minimum to maximum. Simultaneously, the second harmonic will cover the block marked "2"; the third will cover the block "3", and so on. At 17 megacycles the ranges begin to overlap and the harmonic coverage is continuous at all higher frequencies.

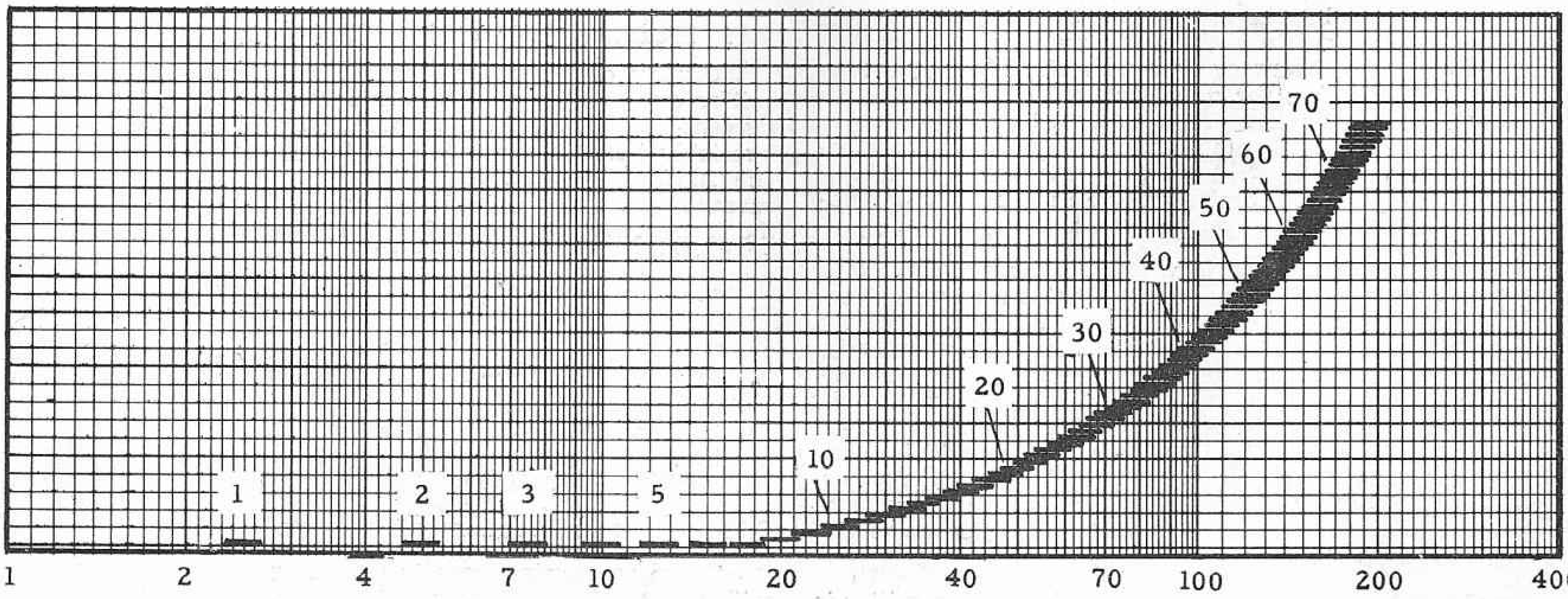


Fig. 2. Fundamental and Harmonic Frequency Ranges of the MFM. Numbers refer to harmonics: e.g., 3 equals third harmonic.

It can be seen that tuning from end to end of the MFM dial causes more than one MFM harmonic to fall on a given frequency, above 17 mc. For instance, in Fig. 2, the line corresponding to 150 mc. crosses eight MFM harmonics; correspondingly, a 150-mc. transmitter will be heard at eight spots over the MFM dial. This fact can be used to advantage where extreme accuracy of measurement is required; a reading can be taken at each of the spots, and the average of all the readings will be two or three times more accurate than just one reading.

In order to produce a heterodyne note against a transmitter, it is necessary that the MFM fundamental frequency or one of its harmonic frequencies coincide with the fundamental of the transmitter, or with one of the harmonic frequencies of the transmitter.

The harmonics which may be involved in any particular measurement must be known at the time calculations are made of the MFM frequency and dial reading. However, in subsequent practical operation, there is little need for this knowledge; because, even though the heterodyne action and zero beat actually take place at the harmonic frequency, the charts read only in terms of the transmitter fundamental frequency.

2.03 Measurements on Transmitters and Oscillators

The fact that harmonics as well as fundamental frequencies can be made to create a beat note, makes it possible for the MFM having a limited range to measure transmitters over a wide range.

The common measuring procedure on transmitters is to operate the MFM in the vicinity of the transmitter and listen with headphones plugged into the PHONES jack. The word transmitter, in this discussion, applies equally well to simple oscillators, to oscillator-amplifiers, and to oscillator-multiplier-amplifier combinations.

Harmonics are present in the electric and magnetic fields close to a transmitter, and they are generated in a detector or rectifier upon which only a fundamental is impressed. If the transmitter frequency is such that it cannot beat with any setting of the MFM fundamental, then it may beat with an MFM harmonic; or, failing these a harmonic of the transmitter will beat with the fundamental or a harmonic of the MFM. Combinations which are adequate for measurement can be had from transmitter frequencies of 100 kc. to 175 mc., and the MFM coverage as a monitor is continuous throughout that range.

For example, a transmitter on 272 kc. would be measured by listening to its ninth harmonic at 2448 kc. beating against the meter fundamental also at 2448 kc. (harmonic ratio = 9/1); a transmitter on 1706 kc. would be monitored by beating its third harmonic, 5118 kc., against the second harmonic of the meter fundamental frequency, 2559 kc. (harmonic ratio = 3/2); and a transmitter frequency of 152,270 kc. would be monitored with a meter frequency of 2496.230 kc. (harmonic ratio = 1/61).

More than one beat note can be heard from a given transmitter, as the MFM dial is rotated over its entire range. The loudest normally occurs when the MFM harmonic is the lowest, because the lowest harmonic is strongest.

Two points should be observed when choosing a harmonic ratio, with which to calculate a chart and measure an operating frequency: for maximum accuracy choose an MFM frequency near the calibration check point; for a louder beat signal choose the lowest feasible MFM harmonic. These cannot be rigorous rules, for often one conflicts with the other. They are guides, particularly to be employed with Table 1 on page 18. Other harmonic combinations will work and if desired may be utilized for double-checking a measurement.

There may be a question as to whether serious errors could arise with the MFM, by adjusting to zero beat on a wrong harmonic combination; that is, one different from that for which the chart is calculated. In practical operation the chances are negligible, provided that the oscillator frequency is known approximately, within 2 or 3 percent. Under this assumption, there will be only one loud beat note in the calculated region of the MFM dial. Should other beat notes be heard nearby they will be very much weaker, coming from considerably higher harmonics; or, because of the extended dial range, beats comparable in loudness will be so far removed from the calculated dial region as to obviously warrant rejection.

In normal practice the frequency of oscillator or transmitter is known within 2 or 3 percent, for reasons such as quartz-crystal control, dial calibrations on the equipment itself, values of circuit elements, or dial calibrations on an auxiliary receiver.

If the frequency is not known approximately, it is recommended that an absorption wavemeter be employed to measure it. An absorption wavemeter comprises a coil and condenser, or a tuned section of a transmission line, or a tuned cavity, with a device for indicating r-f current or voltage; the wavemeter is coupled to the source of unknown frequency and tuned for maximum response of the indicator; the frequency or wavelength is read from a scale or calibration; the overall accuracy averages 1 to 2 percent.

The distance at which the MFM detector can be operated from an oscillator or transmitter depends upon the power, the frequency, and the coupling to the MFM. The distance ranges from a few inches for a tenth-watt oscillator at 175 mc., to several miles for a 1-kw. transmitter at the MFM fundamental.

Figure 3 is a curve indicating the level of tone heard with headphones plugged into the MFM, for transmitter frequencies ranging above 5 megacycles. The voltage was measured across war-surplus Type HS-23, high-impedance, magnetic headphones in the output of the MFM, with audible beat frequencies of 1,000 to 2,000 cycles. The values shown are conservative; the signal from a 10-watt transmitter at 157.53 mc., near the top rated frequency of the MFM, ranged from 120 to 800 millivolts. The minimum usable headphone signal is in the order of 10 to 20 millivolts. With extra care, the 105-B meter has been used to calibrate signal generators up to 500 mc., by connecting the generator output directly to the MFM tip jack. The crystal calibrator in the MFM creates a headphone signal of 10 to 15 volts, rms.

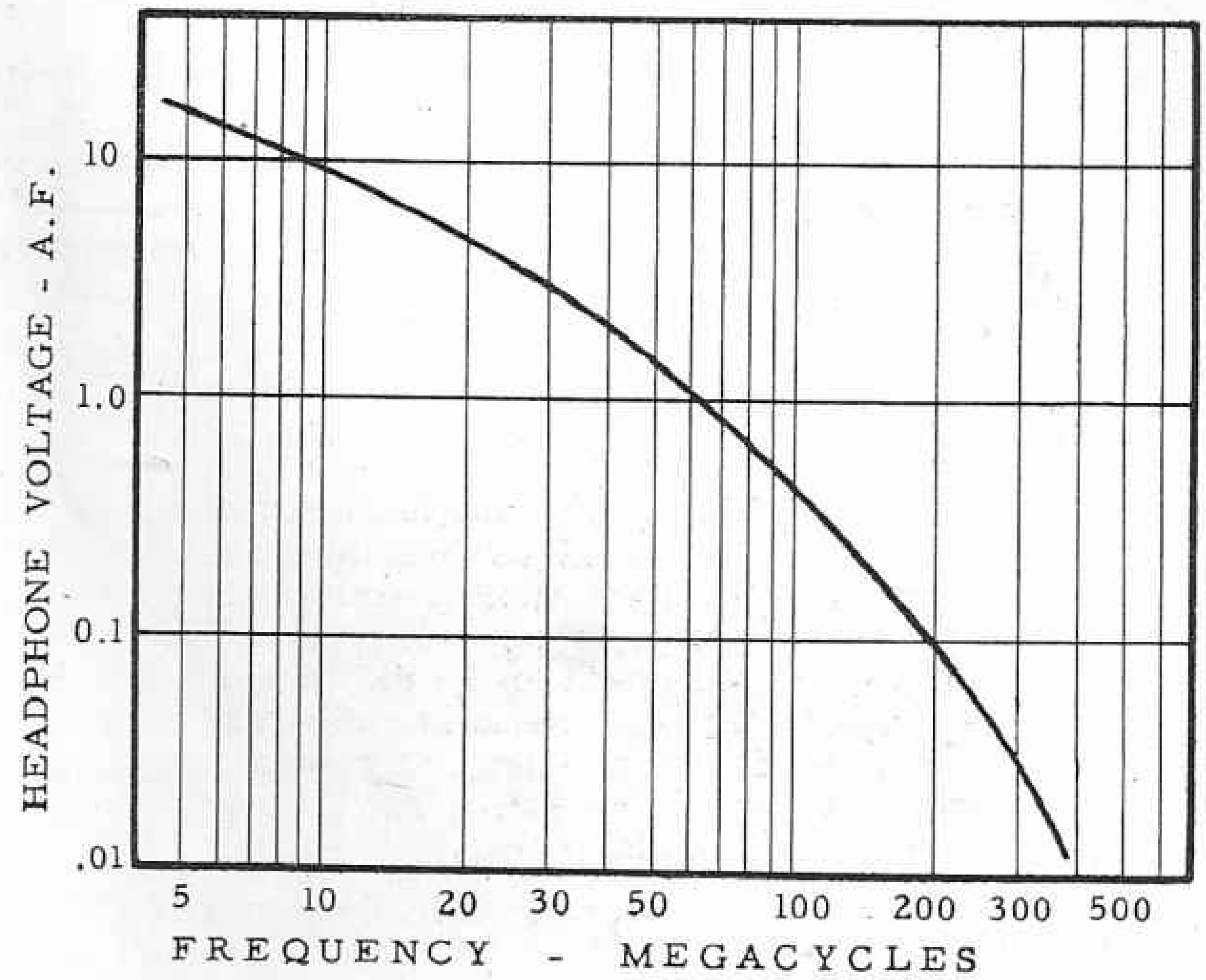


Fig. 3. Typical headphone signal from MFM when measuring transmitters. Selector switch on XMTR.

The MFM can be used to monitor frequency-modulation transmitters; the common measuring procedure, with MFM located near the transmitter and headphones plugged into the meter, is employed. The carrier frequency is measured when unmodulated, and the reading so obtained is for the center frequency.

2.04 Measurements on Received Signals

Usually only the fundamental frequency of a distant transmitter can be picked up on a receiver. Although harmonics are present locally around a transmitter, they are not radiated appreciably because the output and antenna circuits are tuned to the fundamental and discriminate against them. Consequently, measurements on received signals are limited to combinations of the transmitter fundamental against the meter fundamental, and of the transmitter fundamental against the meter harmonics; in other words, the MFM coverage on received signals is discontinuous. It is limited to the ranges depicted on Fig. 2.

The signal picked up by the antenna and applied to the receiver input constitutes one beating voltage; the MFM is coupled to the input and generates the other beating voltage. Listening to the beat tone is done at the receiver output with headphones or speaker.

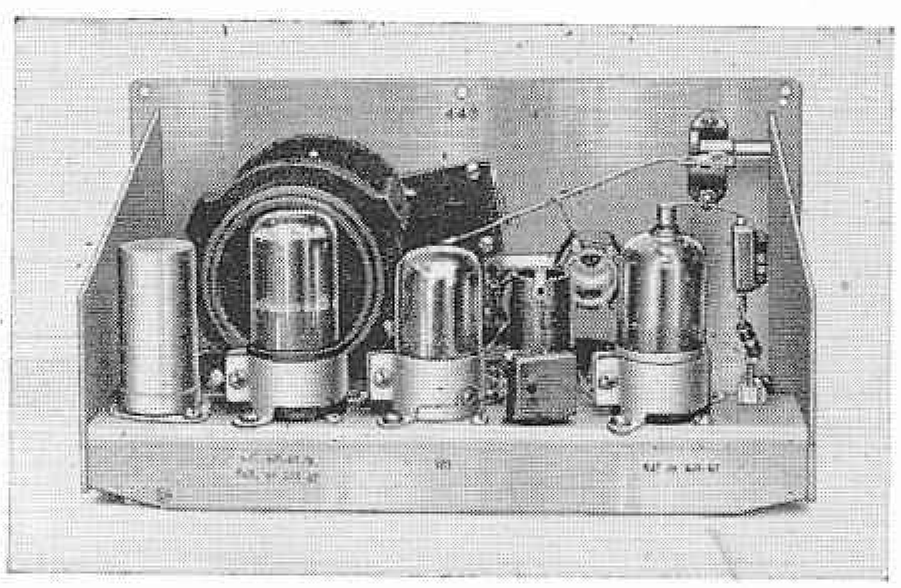
2.05 Types of Frequency Measurements

There are several aspects regarding frequency measurements with the MFM. The instrument may be used (1) to adjust equipment to a specified frequency, (2) to determine the deviation of a transmitter from a specified frequency, and (3) to measure the absolute frequency of a transmitter in kilocycles.

In the first aspect mentioned above, "equipment" can mean either an oscillator or a receiver. If an oscillator, the required frequency is known. For this frequency an MFM dial reading is calculated (Sec. 5.06 to 5.09). The operational procedure is first to employ the absorption wavemeter; then set the MFM to the calculated dial reading, and adjust the oscillator, listening for zero beat on the MFM. Examples of this application are placing a variable-frequency military transmitter on a communication-net frequency; grinding a quartz crystal to a specified frequency; and final calibration of a variable-frequency transmitter in production. If a receiver, the approach is first to tune up roughly with a conventional signal generator; then feed the receiver from the MFM, with its dial set at the calculated reading for the required frequency; tuning indication is by rectified RF or IF in the receiver detector, or limiter. See Sec. 4.11.

In the second aspect the problem is to measure the difference between the true frequency of the transmitter, and a specified frequency. This can be done conveniently with a plotted graph, or Deviation Calibration chart (Sec. 5.04); it covers a very narrow range on either side of the specified frequency, with MFM dial reading for the horizontal scale and percentage deviation from specified frequency for the vertical scale. The procedure in measurement is to adjust the MFM to zero beat with the transmitter, take the dial reading, and from the chart read the percentage deviation, plus or minus.

The most important example of this application is a radio station, operating under license from the Federal Communcations Commission, on a specific frequency assigned by that agency. The regulations require that the station be maintained on frequency within a stipulated tolerance which is stated in percent, except for entertainment-broadcast stations. The Deviation Calibration chart is particularly adapted to this application because the reading provided is in percent, in the same kind of units as FCC tolerance.



Rear view of the Type 105-B, with case removed.

Another method of determining deviation is by means of dial constants. It is less convenient because it involves computations at the time of measurement. The Transmitter Chart has space for listing the dial constants in cycles at the specified frequency, and in percentage. The procedure in measurement is to place the MFM at zero beat with the equipment, and take the difference between the resultant dial reading, and the dial reading for the specified frequency. Multiplying this difference by the first dial constant will produce the deviation in cycles, or by the other dial constant will yield the percentage deviation. The deviation is plus if the MFM reading is high, and minus if it is low.

The third aspect mentioned above concerns transmitter or oscillator frequency measurements of general nature. When starting from scratch, it is necessary to determine the unknown frequency by some auxiliary means, to within a few percent. Then the MFM is tuned over its range to find the loudest beat note, at which point a zero-beat dial reading is taken and converted to MFM frequency. Dividing the approximate frequency (obtained by auxiliary means) by the MFM frequency, a quotient is obtained which will be very close to an integer, or an integral fraction; the exact integer or fraction is the correct harmonic ratio. (This operation can be performed very handily by one familiar with a slide rule.) Multiplying the MFM frequency in kc. by the integral number or fraction gives the absolute frequency of the equipment in kc.

There is another method of determining an oscillator frequency, when starting from scratch. The method is to couple the oscillator to the MFM, listen with headphones in the PHONES jack, and tune the MFM over its range. At each point where a beat note is heard, the dial reading is taken, and the corresponding MFM frequency is calculated.

The method can be broken down into two parts: Part 1, when the oscillator is much lower than the MFM in frequency, and Part 2, when it is much higher. In both parts, call one of the recorded MFM frequencies, f1, and call the next higher frequency f2.

In Part 1, the oscillator frequency is simply equal to f2 minus f1, or f2 — f1.

In Part 2, the oscillator frequency is equal to the product of f1 and f2, divided by the difference; or is equal to $\frac{f1 \times f2}{f2 - f1}$.

The average MFM range is 2330 to 2670 kc.; thus f2 cannot be larger than 2670 kc., while f1 cannot be smaller than 2330 kc., and the difference (f2 — f1) cannot be more than 340 kc. This limits the use of Part 1 to oscillators with a frequency 340 kc. or lower.

Going the other way, Part 2 requires that tuning the MFM over its range produce a harmonic beat note on at least two spots. Inspection of Figure 2 shows that this will occur consistently at oscillator frequencies of 35 mc. or higher. Thus Part 2 is limited to oscillators above 35 mc.

In either Part 1 or Part 2, care must be taken to get readings only on consecutive harmonics, of the same order of signal strength, and to disregard or skip over possible weaker beats from higher combinations. The oscillator frequency obtained in these methods does not have an accuracy equal to the MFM accuracy, because it is obtained as the difference of two large numbers. However, the answer so obtained is sufficient to indicate the harmonic being used for f1 or f2; then multiplying MFM frequency by the exact harmonic number will yield a fully accurate oscillator frequency.

2.06 Deviation

Deviation in general is the amount of departure from some set standard. In modern mobile radio, there can be two kinds of frequency deviation; the rapid, dynamic deviation which results from modulation in FM systems, and the relatively slow drift or deviation of the carrier frequency which occurs over hours or months. In connection with the MFM, deviation means the carrier, or center-frequency deviation.

There is an important difference between frequency changes expressed in percent, and the same changes expressed in kilocycles, viz.: the deviation in percent is the same whether measured at a fundamental or a harmonic; but the deviation in kilocycles, measured at the fundamental must be multiplied by the harmonic number when going to a higher frequency, and divided by the harmonic number when going to a lower frequency.

This may be illustrated by an example: suppose that a transmitter with assigned frequency of 2400.000 kc. is actually at 2400.240 kc. The deviation is plus 0.240 kilocycles, and is plus 0.01 percent; $(\frac{0.240 \text{ kc.}}{2400 \text{ kc.}} \times 100 = 0.01\%)$. The second harmonic of the assigned frequency is 4800.000 kc., and the second harmonic of the actual frequency is 4800.480 kc.; thus the deviation at the second harmonic is 0.480 kilocycles which is twice that at the fundamental. But the percentage deviation at the second harmonic is 0.01 percent, $(\frac{0.480 \text{ kc.}}{4800 \text{ kc.}} \times 100 = 0.01\%)$; which is the same as it was at the fundamental.

The Deviation Calibration chart could be plotted using kilocycles deviation instead of percentage, possibly to greater advantage in some classes of work. However, it is common practice to evaluate the stability of oscillators in terms of fractional frequency changes, expressed in units such as cycles per megacycle, parts per million, or percentage. Also, the tolerances specified by the Federal Communications Commission are in percentage, and are of the same order of magnitude for frequencies widely separated in the spectrum. A deviation of 0.01% would correspond to 0.245 kilocycles if the station were at 2450 kc., and to 15.227 kilocycles if the station were assigned 152,270 kc.

If curves were plotted showing kilocycles deviation for several frequencies, a different vertical scale would have to be drawn for each specific frequency, and the different curves would lie at various angles on one sheet. On the other hand, a chart plotted in percentage deviation needs only one vertical scale for many frequencies, is less susceptible to confusion in reading the scales, is considerably more compact, and gives results directly comparable with the FCC tolerance. Because of these considerations, the Deviation Calibration supplied with the MFM is plotted using a percentage scale.

2.07 Frequency Tolerance and Monitor Accuracy

One of the ways to rate monitor accuracy is by means of a "probability curve", as drawn in Fig. 4. Such a curve illustrates graphically the chances that, out of a given number of measurements, how many will be wrong by +.001%, how many by 00%, or by - .0002%. A curve of this sort can be made from a large group of readings in the field under widely varying conditions, or from a series of laboratory tests with all pertinent factors made purposely variable. The "limit of accuracy" could be defined, from a probability curve, as the accuracy which contains 90% of the readings—that is, out of a total of 100 readings, 10 readings probably would be worse than this limit. Or, some other percentage, say 95 or 97%, could be taken as a basis. Figure 4 represents actual test data on the MFM, and is discussed further in Sec. 4.02.

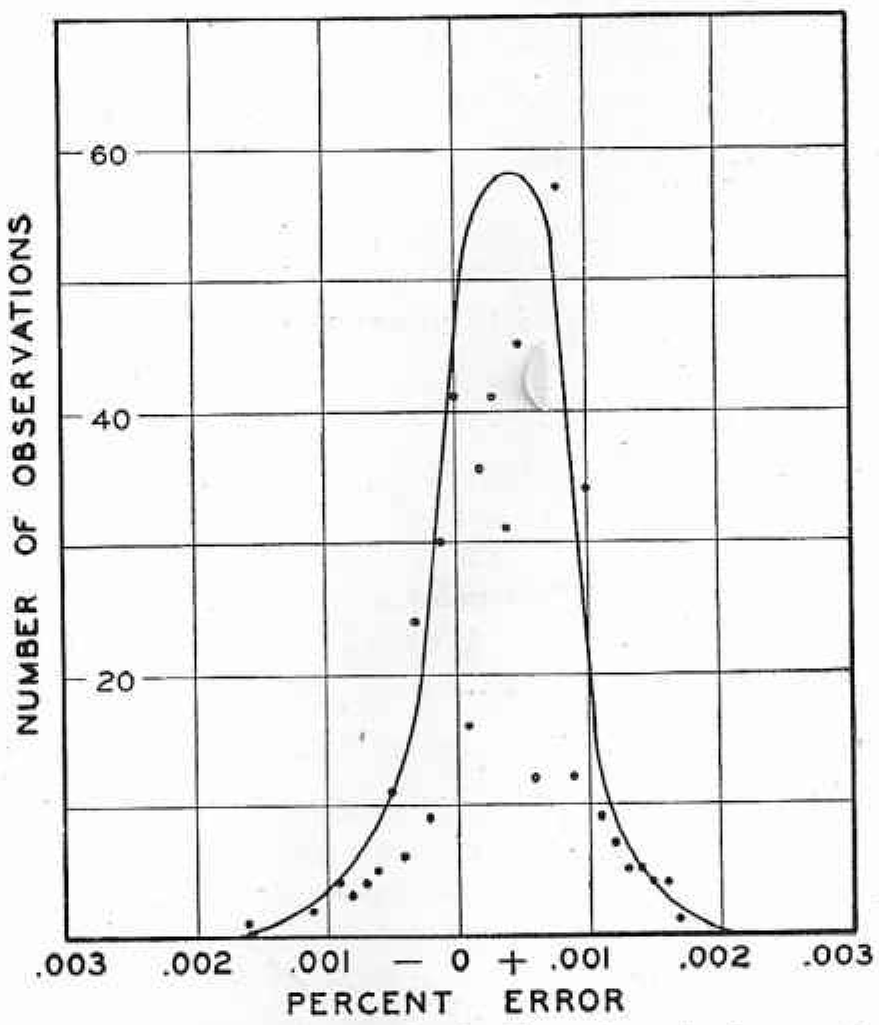


Fig. 4. The "probability" method of rating instrument accuracy, showing distribution of errors about zero.

The method of rating accuracy by means of a probability curve appears informative, and fair alike to customer, governing agency, and instrument manufacturer. Some accuracy rating systems have assumed certain variations in the error-producing factors, and then totaled the resultant errors to obtain an accuracy figure. The method assumes that all errors occur simultaneously, and in the same direction; it is an eminently safe engineering approach, but is ultra-conservative and not quantitively useful in practice. At one time the FCC regulations required that the "limit of error" of the monitor should equal the station frequency tolerance.

3.0 DESIGN AND CONSTRUCTION

3.01 Ratio-Coupled Oscillator

The variable-frequency oscillator in the MFM employs the ratio-coupled circuit*, a development of these Laboratories. The salient feature of the circuit is that the oscillator tube is tapped down into the inductance coil as far as is practical, so that it is connected across about one-fourth of the coil turns. The coil acts as a transformer, and an impedance or change of impedance in the oscillator tube, when referred to the circuit as a whole, is reduced by an amount depending on the ratio of tube turns to total coil turns.

As a result, the oscillation frequency is determined largely by the inductance and capacity of the tuned circuit, and not by the attached apparatus which is needed to drive the oscillations. Quantitively, changes of any nature associated with the tube, including changes in temperature, filament or plate or screen voltages, in loading, interelectrode capacities, or even those incurred by replacement with another tube, have from ten to fifteen times less effect on frequency than in more conventional oscillators.

3.02 Frequency Stability Curves

Figures 5 through 12 show typical frequency runs on the MFM. Some of the curves are tracings, others are originals, from strip charts made by a recording audio-frequency meter. The MFM under test was adjusted to produce a beat note against a secondary-standard quartz-crystal and the beat note was impressed upon the recorder.

The frequency variation of the MFM during warm up, just after turning on the POWER and PLATE switches, is depicted in Fig. 5, for three separate meters. The meters are identified as A, B, and C on this and the following curves. The amount of frequency change during warm-up seems to depend chiefly on the 6J7 oscillator tube; with a selected tube it can be as low as 75 cycles per megacycle, and reach stabilization in 20 minutes. The warm-up characteristic also depends on the past history of the instrument; one which has been warm and dry will stabilize faster than one which has been on the shelf, un-energized in humid weather. In general, the MFM frequency becomes sufficiently stabilized in one hour, to permit routine measurements.

The temperature-frequency characteristics for the three different meters are given in Fig. 6. These curves were obtained by energizing the units in an ambient temperature of 120° F. (48.9° C.) until equilibrium was attained. Then, at zero minutes minus 2 on the diagram, they were quickly shifted to a temperature of 70° F. (21.1° C.) and the recording started.

* "An Improvement in Constant-Frequency Oscillators", G. F. Lampkin, Proc. I.R.E., March, 1939, Pg. 199.

There are two points which may be noted from Fig. 6. One, is the transient effect on the frequency caused by the abrupt change in temperature, which on one curve amounts to 130 cycles per mc. at about 30 minutes; apparently, different parts of the oscillator circuit respond at different rates to the change of temperature, and even though the static or long-time temperature coefficient of frequency may be zero, the transient or dynamic coefficient may have appreciable magnitude. An analogy can be found in mechanics, with respect to the static and dynamic balance of rotating members. The second point is the degree of temperature correction for the complete MFM oscillator. One of the meters shows a net change of only 25 cycles per megacycle for a temperature variation of 27.8° C.; the poorest meter shows 100 cycles per megacycle over the same range, (3.6 cycles per mc. per °C.).

Shifting the position of the MFM case can cause the frequency to change. This is illustrated in Fig. 7, in which the three meters in turn, after resting on their feet in frequency equilibrium, were turned on their backs at zero minutes minus 1. Apparently there is a redistribution of air-convection currents inside the box, affecting different components to different degrees. This effect stabilizes in about 20 minutes, and is the reason that the MFM position should not be changed during any one series of measurements.

Figure 8 illustrates frequency change immediately after turning the PLATE switch on, for the three separate meters. The magnitude of the change again is a function of the particular 6J7 tube, and the equilibrium time again is about 20 minutes.

The typical effect of line voltage on frequency is shown in Fig. 9. For this and the succeeding curves the frequency scale is expanded five times, to show effects better. The MFM was subjected to a step change from 113 to 125 AC line volts (10%), then from 125 to 101 volts (20%), and then back to 113 volts. In each case there is a quick frequency shift lasting 2 or 3 seconds probably due to plate voltage, then a slower negative drift from cathode temperature. The net change indicated on the curve, from 113 to 125 volts, would be from —9 to —23 cycles per mc., or $\frac{-14 \text{ c./mc.}}{+12 \text{ volts}}$, or —1.2 c./mc./volt.

These performance curves in general indicate poorer stability than was had in the older Type 103 and Type 105 meters. The reason is that the 6J7 oscillator tube in the older models was operated at a power level one-sixth of that in the present models.

The next three curves, Figures 10, 11, and 12, show what can be accomplished in the way of short-time stability with the MFM. In the first curve the MFM was operated from the production-

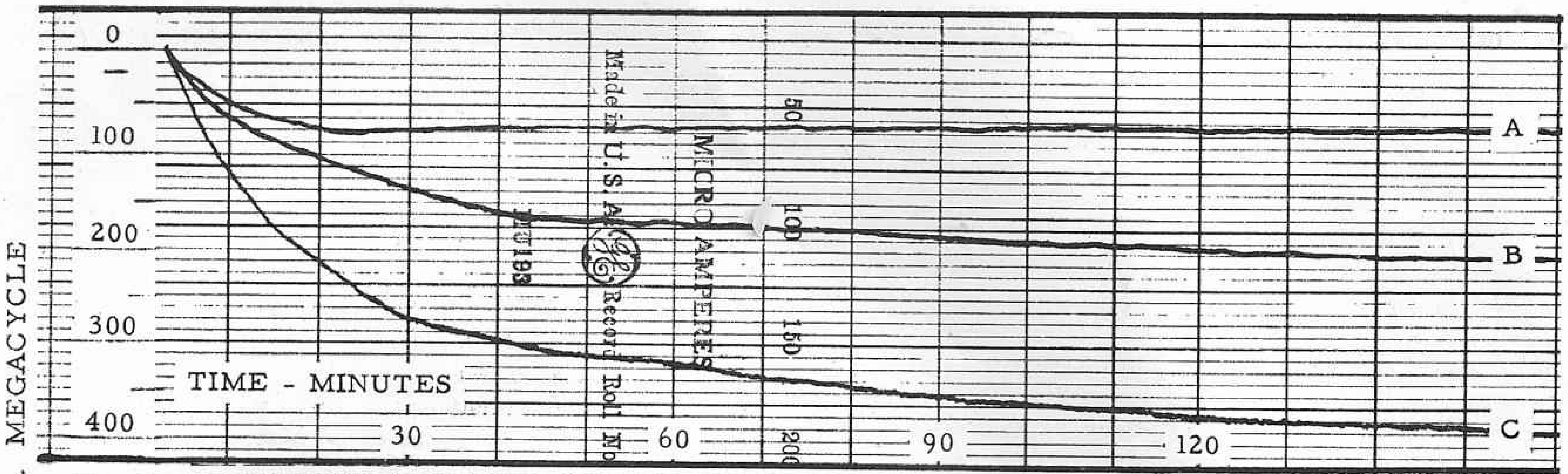


Fig. 5. FREQUENCY CHANGE DURING WARM-UP, AFTER TURNING POWER AND PLATE ON.

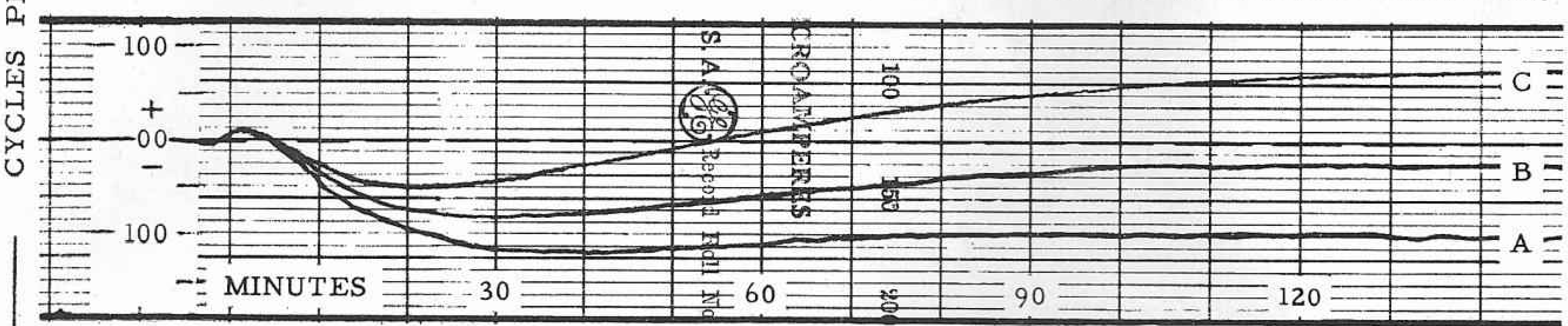


Fig. 6. RESPONSE TO STEP CHANGE IN AMBIENT TEMPERATURE: 120° to 70° F.

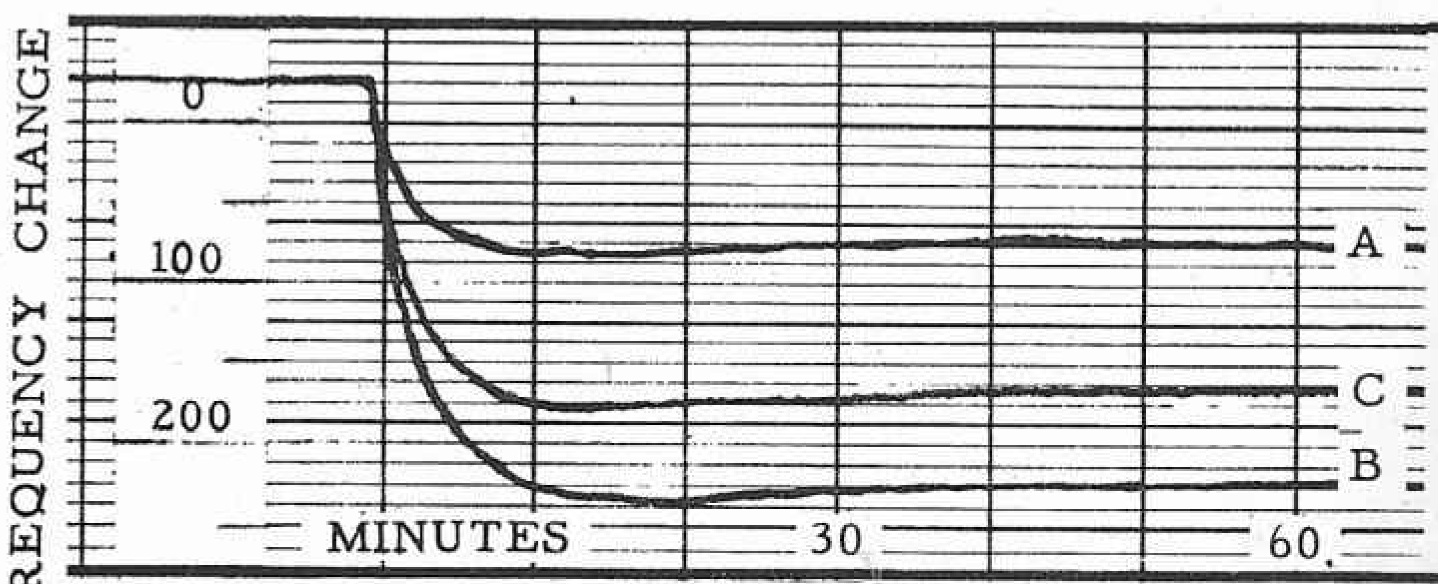


Fig. 7. MFM SHIFTED FROM FEET TO BACK

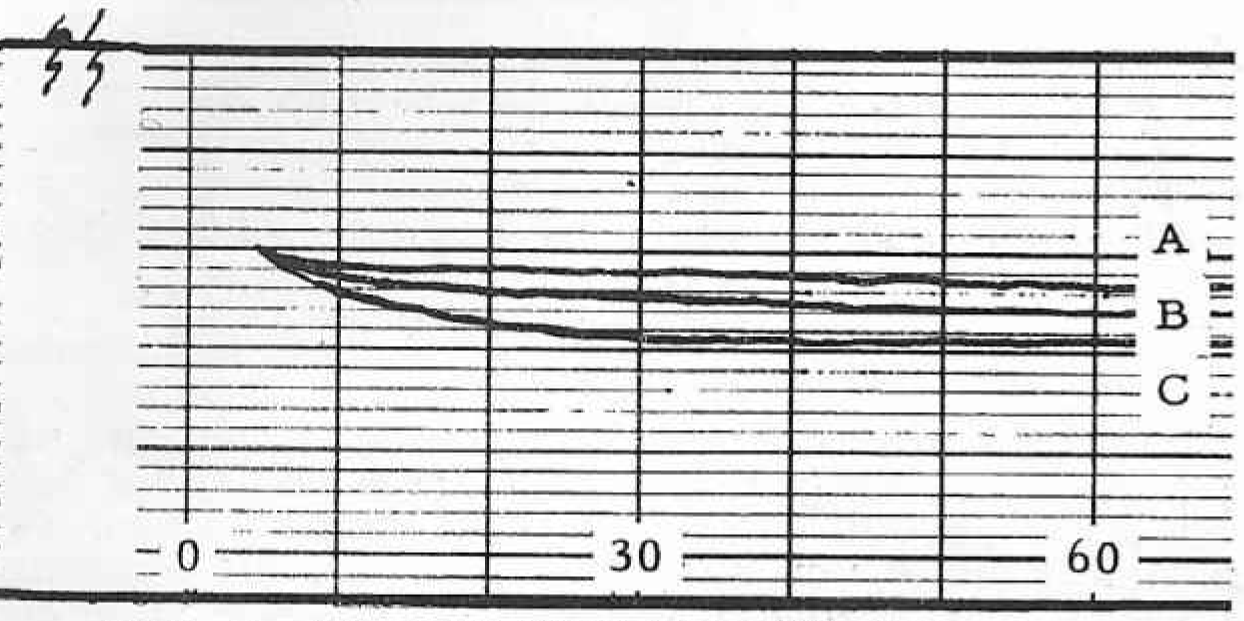
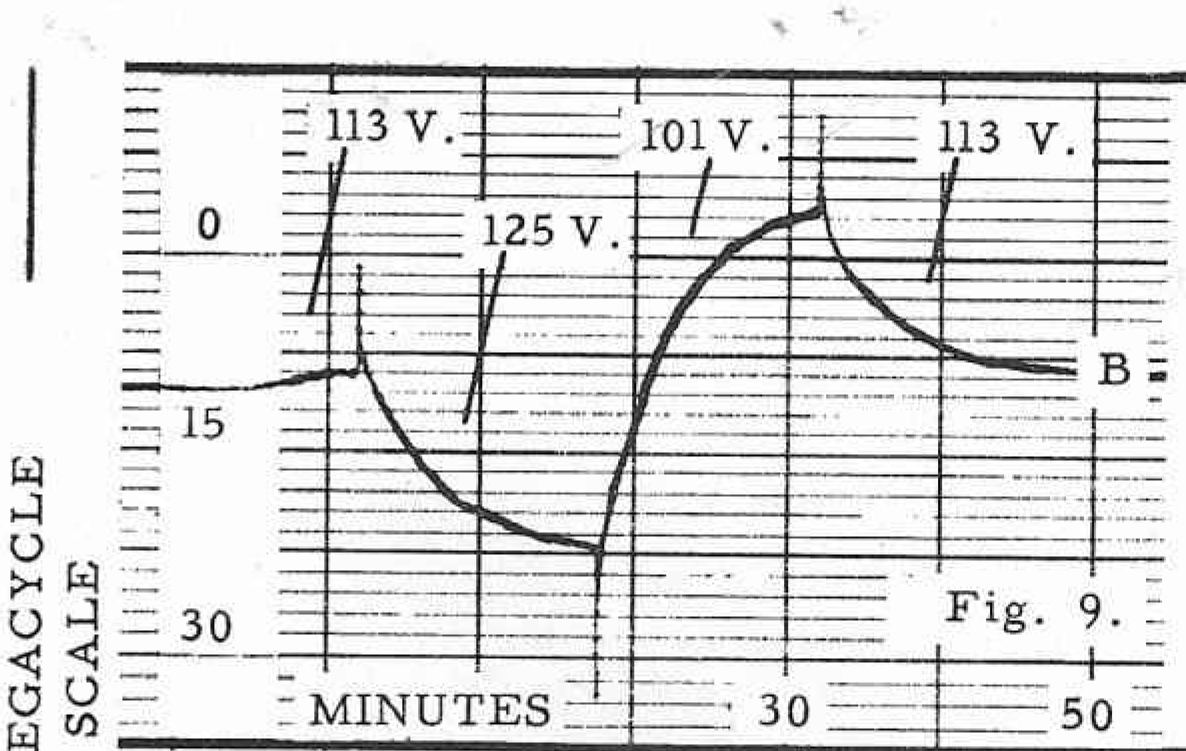
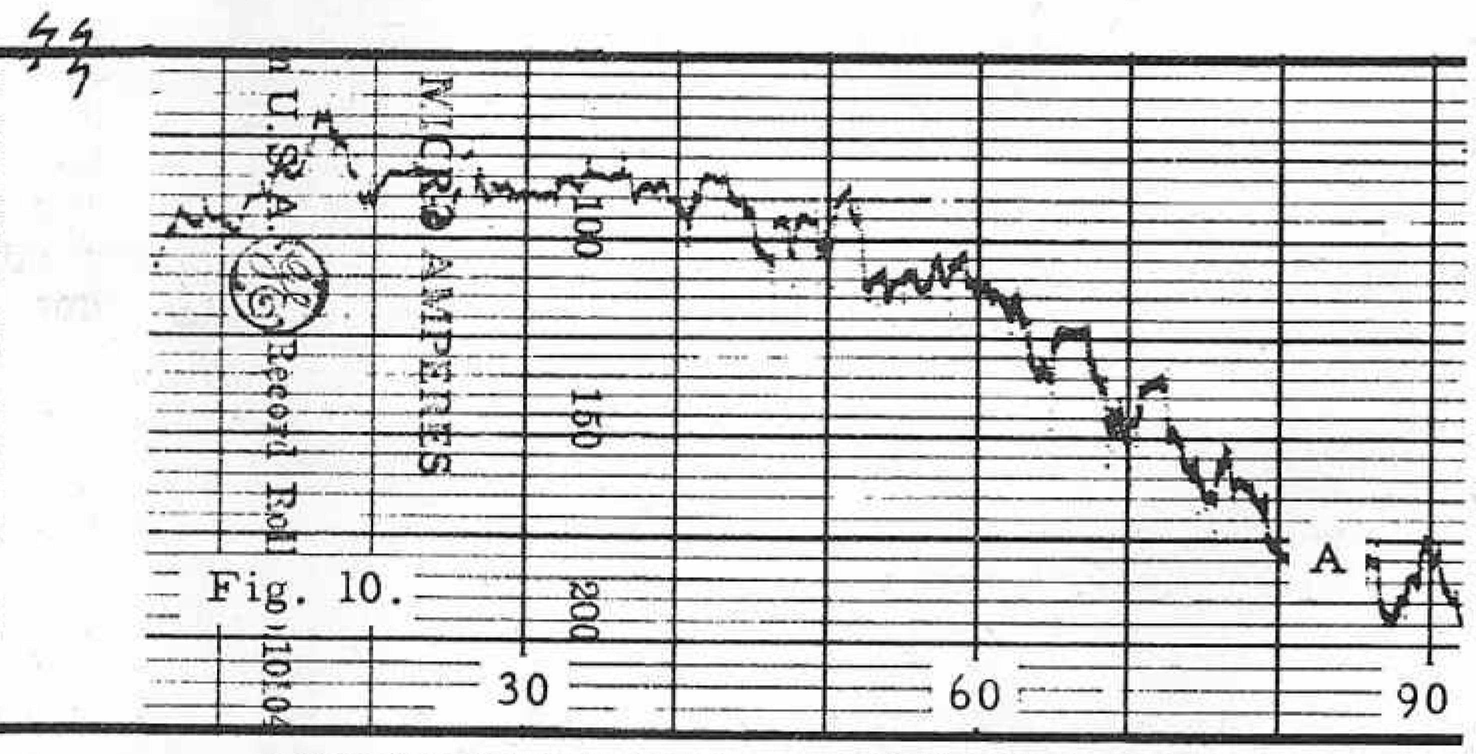


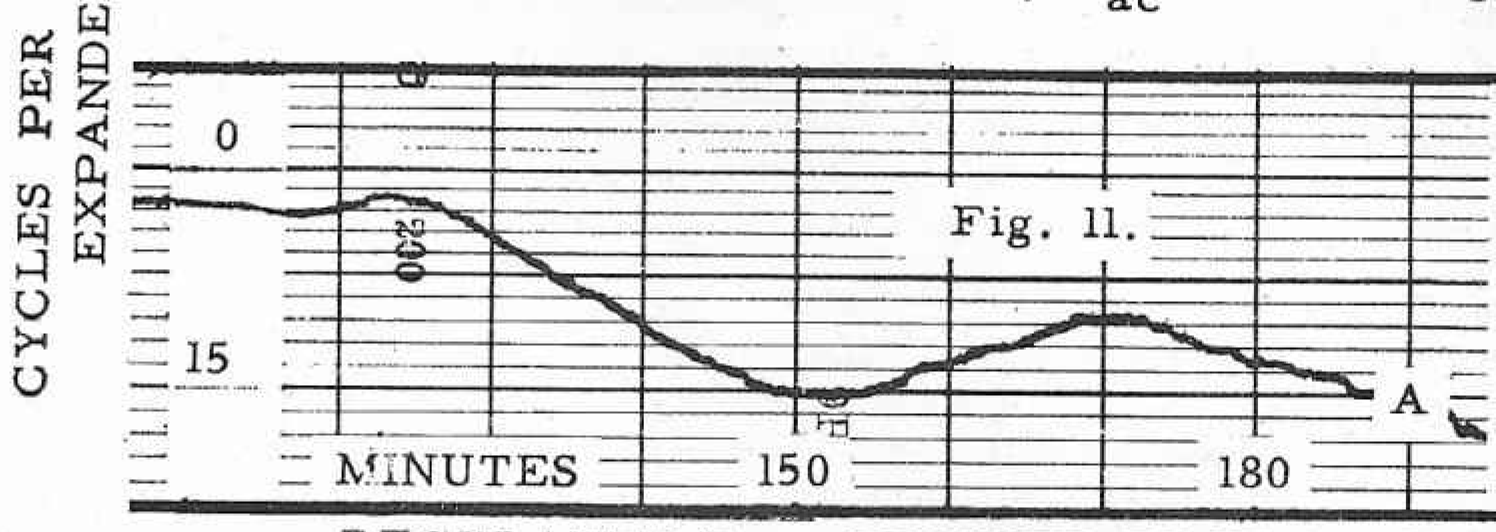
Fig. 8. PLATE SWITCH TURNED ON



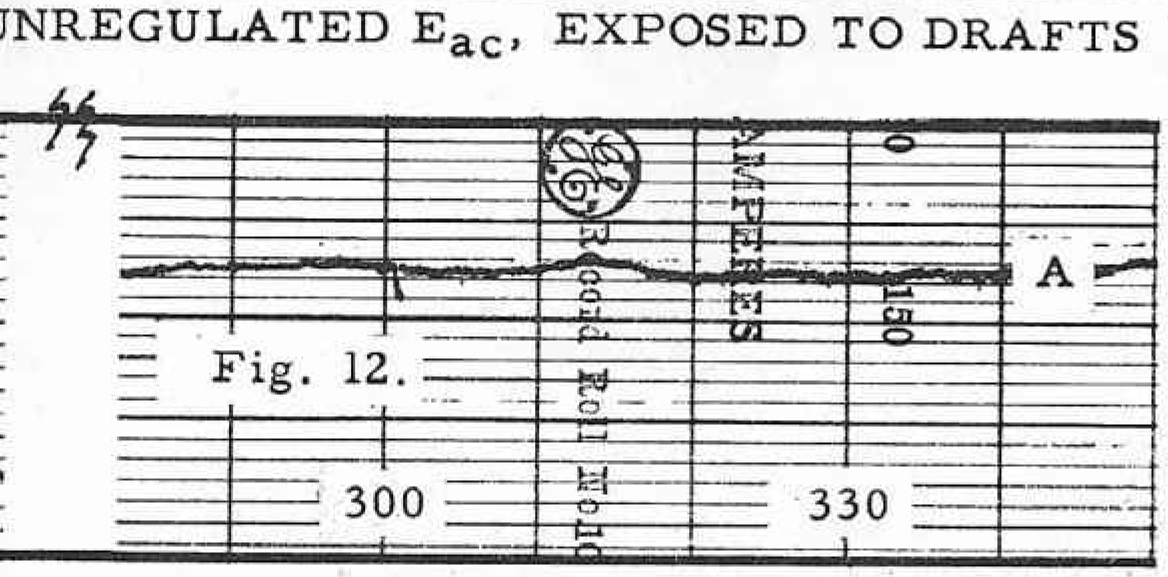
STEP CHANGES IN LINE VOLTS, E_{ac}



UNREGULATED E_{ac}, EXPOSED TO DRAFTS



REGULATED E_{ac}, EXPOSED TO DRAFTS



REGULATED E_{ac}, IN CELOTEX BOX

Figures 5 to 12. Typical Frequency Curves on the MFM, when exposed to intentional error factors.

and-machine-shop AC line, fed by rural electric service, and purposely exposed to drafts from open windows and fans; the frequency wandered considerably over periods of a minute or two due to line-voltage instability, and over periods of one-quarter to one hour due to ambient-temperature variations. In Fig. 11, the conditions were the same except that AC voltage was regulated by a Raytheon voltage stabilizer rated at 115 volts r.m.s. output, $+-1\%$; here the short-time jiggles have been removed, but the long-time creeping remains. Finally, in Fig. 12, still exposed to drafts and on the regulator, the MFM was encased in a box made from ½" Celotex, with a Plexiglas face covering the top 4" of the panel. As suggested by this curve, the stability of the MFM, over a period of one to two hours, can be held within 1 or 2 parts per million.

A cheap but effective AC-voltage regulator for the MFM can be made from a 60-watt light bulb and two VR-105 voltage regulator tubes, connected back to back across the line. Fig. 13 gives the circuit hookup; the regulated input to the MFM will be

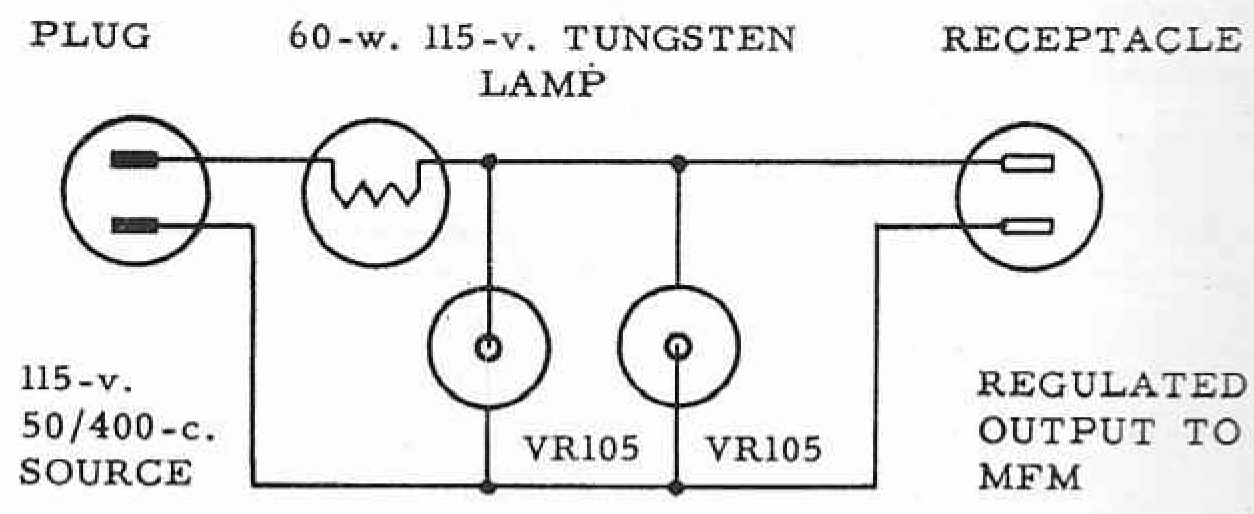


Fig. 13. Circuit diagram of AC voltage regulator for the Micrometer Frequency Meter.

approximately 100 volts, rms, and line-voltage variations will be cut by a factor of 3. The regulator works with AC input from 105 to 125 volts; to protect the VR-105 tubes, it is best not to operate them with the MFM load cut off; if hum is experienced in the headphones, try reversing the MFM power plug into the regulator.

The information regarding frequency stability is presented so the operator may have a better idea of the capabilities of the MFM. Of course, not all the factors operate at one time on the frequency, or in the magnitudes intentionally shown, nor do they all cause changes which add up in the same direction. When making measurements on transmitters, the short-time stability of the MFM carries the greatest importance—that is, stability during the five to fifteen minutes needed to make a series of readings, after the oscillator is checked against WWV or the crystal calibrator. The guarantee of accuracy for the MFM is conservative, incorporating a safety factor of two to five.

3.03 Micrometer Condenser

A machinist's micrometer is the foundation of the tuning condenser. A tapered rotor is mounted on the micrometer spindle and is spun in and out of an insulated tubular stator. The rotor and stator constitute two plates of the condenser. Surrounding the stator is another tubular electrode, the pad ring, which is grounded to the rotor and adds the fixed capacity necessary for band spreading. The relative dimensions of the rotor, stator, and pad ring determine the frequency spread of the variable-frequency oscillator; the spread averages 1.14 to 1 (ratio of maximum to minimum frequency) and cannot readily be changed. However, it is entirely feasible to build special meters with the center of the spread located at other points in the spectrum.

The condenser assembly is fabricated from steel and brass, copper-plated overall. The brass makes up a portion of the pad ring, and the three support bars. The parts are proportioned such that, due to the differential thermal expansion of brass and steel, the temperature coefficient of capacity is a few parts per million per degree Centigrade at all positions of the rotor.

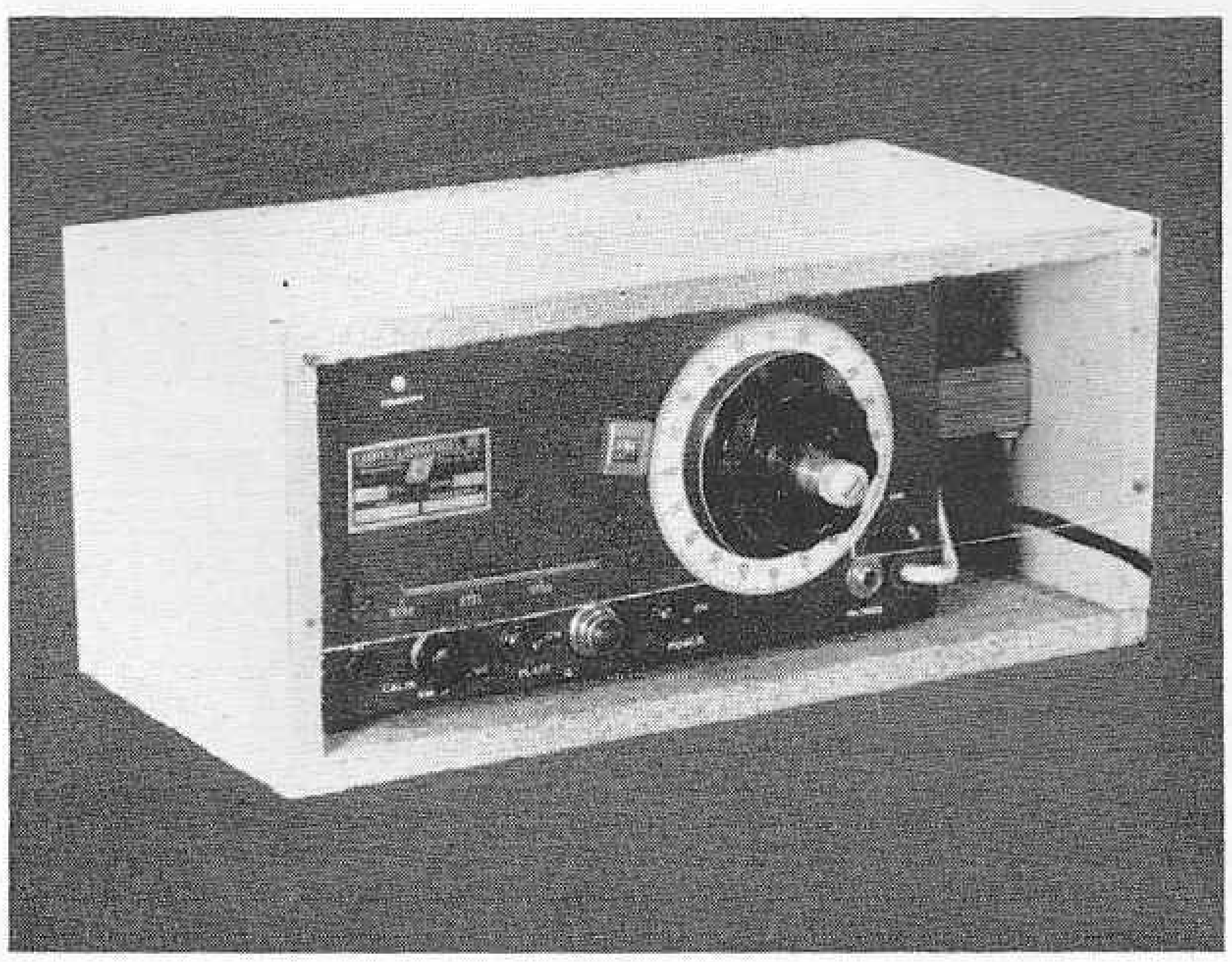
The condenser rotor in current models of the MFM has a rate of taper which produces a straight-line-percentage change in frequency; that is, one dial division represents very nearly the same percentage change in frequency at any portion of the dial range.

3.04 Scale Linearity

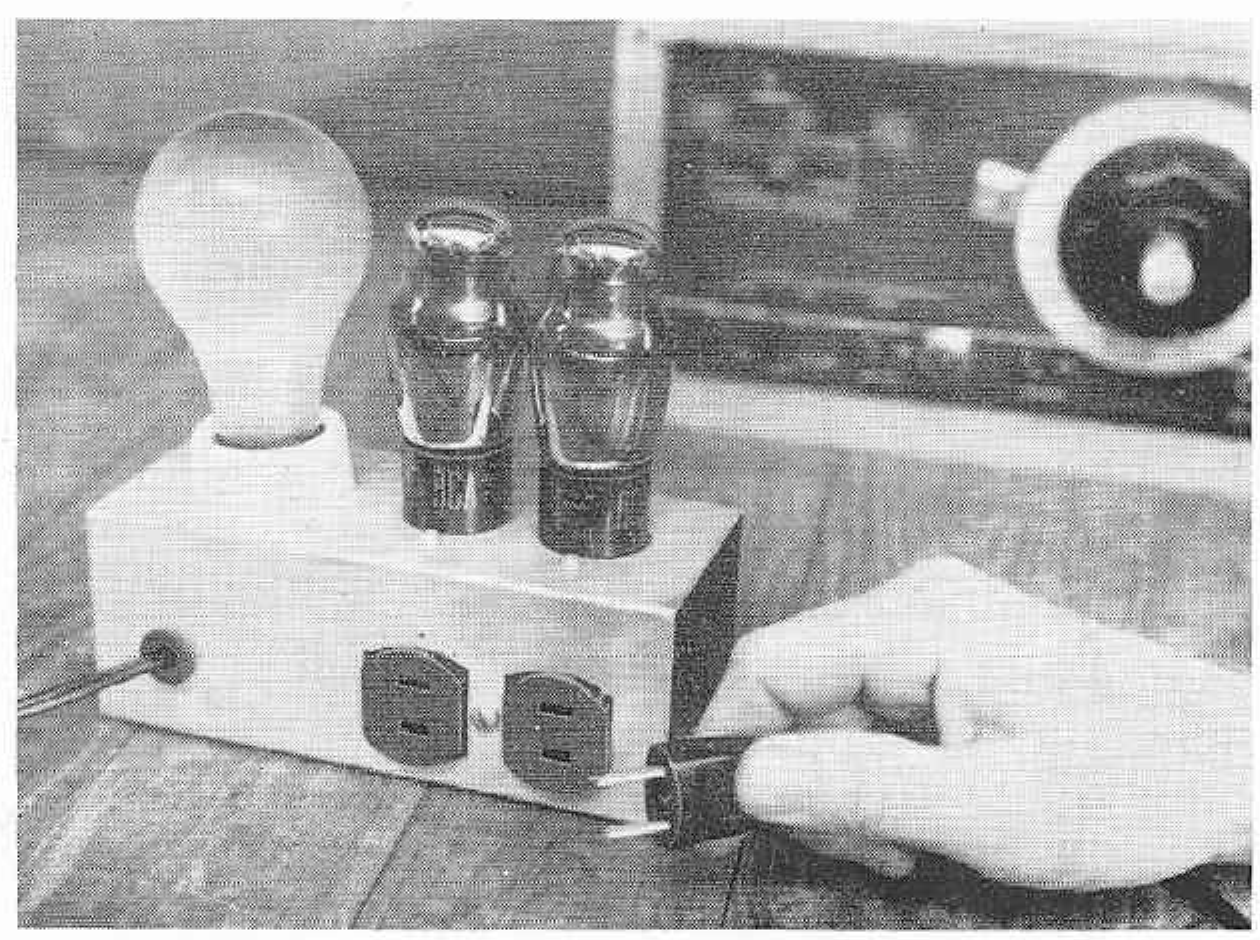
One possible source of error in the MFM is non-linearity of the frequency-control scale, between the points of the Standard Calibration Table. All usual methods of calculation for intermediate readings, assume that the relation between frequency and dial reading is perfectly linear over this range. If the condenser rotor ran true over its surface to 0.00005", if the inside diameter of the stator were concentric with the axis of rotation to the same limits, if the circular dial scale were accurately engraved and accurately centered, plus a few other things, then the relation would be perfectly straight. Actually, it is never perfect but is slightly curved, singly or doubly, about the true, straight line between two consecutive calibration points. Thus the calculated dial reading for an intermediate point could be a few tenths of a dial division different from the actual point, either high or low.

An obvious way to lessen non-linear error is to take calibration points closer together. The spacing on the Standard Calibration Table is 10 kc.; it is possible to set up spacings of 5, 2 or even 1 kc. should special demands warrant.

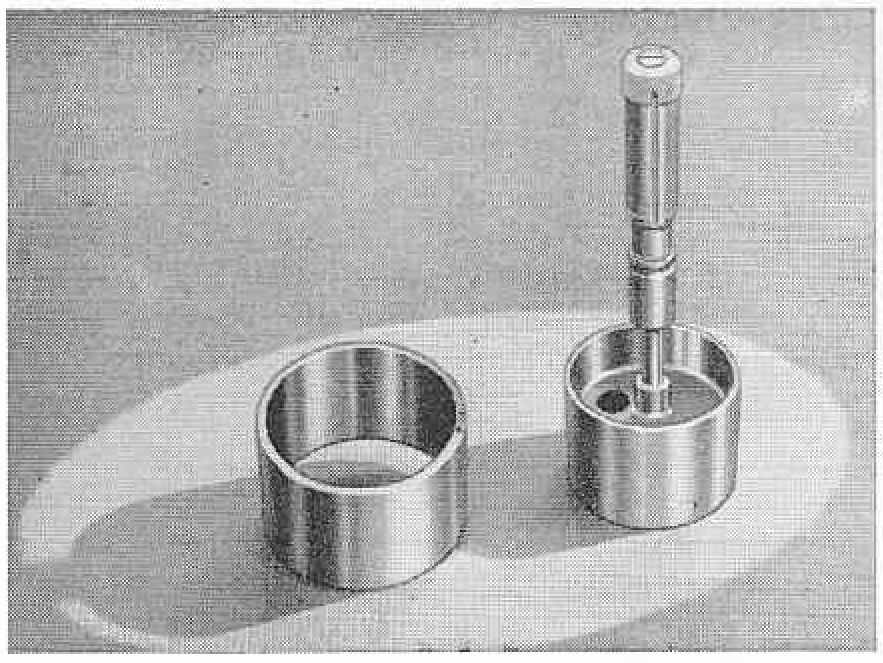
The production test for linearity of the MFM dial may be of interest. It is illustrated in Fig. 14. The MFM under test is set to a dial reading of 600.0, in the region of maximum capacity where non-linearity is likely to be greatest. The test MFM is fed through an RF amplifier to an audio detector. An auxiliary MFM is adjusted to zero beat with the test MFM, feeding through a second RF amplifier into the same audio detector. With the auxiliary dial undisturbed, the test MFM is put at a dial reading of 400.0. Then a distorted audio wave, applied to the second RF amplifier, is used to amplitude-modulate the auxiliary MFM, thereby creating side frequencies above and below its frequency; the frequency, f, of the audio generator, is increased or decreased so that the fourth-harmonic side frequency falls at zero beat on the test MFM. Thus, for a change of exactly 200 divisions on the test MFM dial, an RF marker system has been set up, accurately divided into four parts, since the audio harmonics are exactly 1, 2, 3, and 4 times the audio frequency.



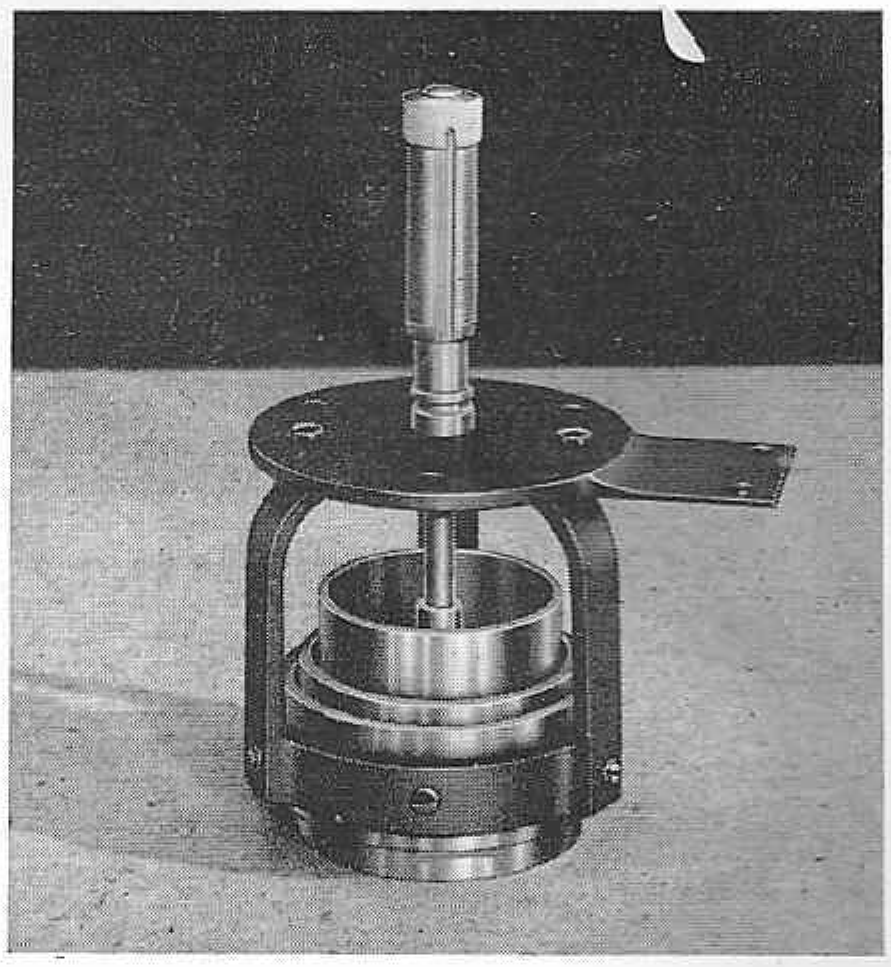
MFM mounted in Celotex box with Plexiglas cover, for improved frequency stability in drafty atmsopheres.



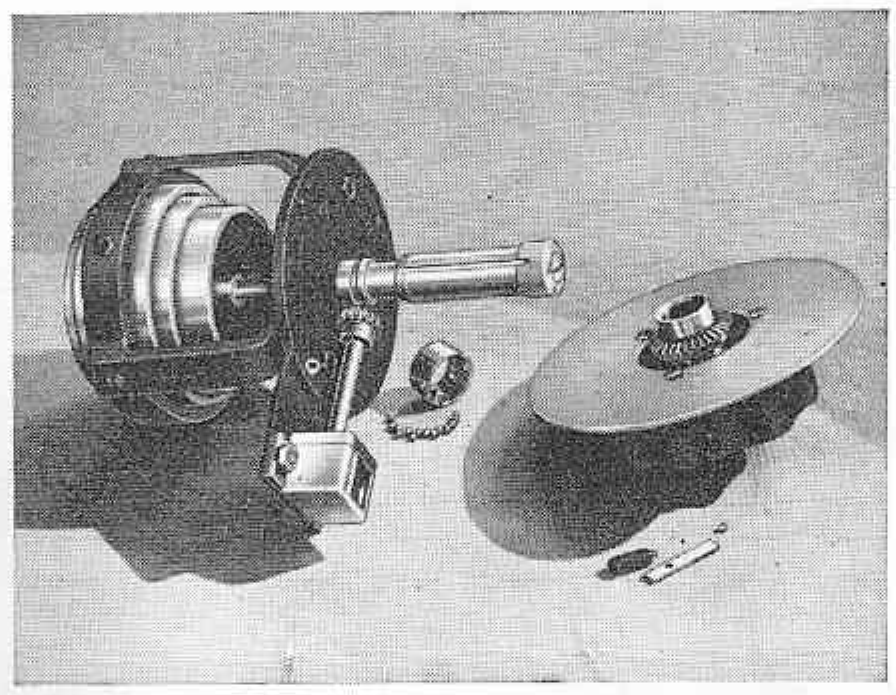
A simple, effective line-voltage regulator for the MFM, made from one 60-watt lamp and two VR-105 tubes.



Exploded view of micrometer head, tapered rotor, and tubular stator.



Assembled micrometer condenser, showing rotor, stator, pad and support rings.



Exploded view of dial mechanism.

Referring to Fig. 14, the auxiliary RF carrier has been aligned to 600 dial on the test MFM, and the side frequency (RF carrier minus the 4th harmonic of the audio frequency, f) has been aligned to 400 dial. Turning the test MFM dial upward will give a zero beat or flutter near 450, 500, and 550 dial, and a system check at 600.0 to see that nothing has shifted. The total non-linearity is taken as the absolute sum of the highest, and lowest departures from the 50-division points. Typical test-MFM production readings shown are 450.3 (0.3 division high), 500.0 (zero error), and 549.9 (0.1 division low), or a total non-linearity of 0.4 dial division. Present tolerance for this test is 1.0 division maximum.

The condenser spindle and the dial mechanism are lapped in before final calibration. In normal usage over a period of years very little wear occurs in the spindle screw threads. The effect of wear on accuracy is minimized by adhering to a standard procedure in adjusting the dial, as outlined in Sec. 4.06. Finally, there is provision for taking up wear, which can be accomplished in our shop if and when overhaul becomes advisable.

3.05 Dial Mechanism

The main frequency control is a dial 4 inches in diameter, which is coupled rotationally to the micrometer spindle with negligible backlash by means of a spring, ball, and raceway. The dial is constrained adjacent to the MFM panel by a radial-and-thrust ball bearing, while the spindle and thimble travel in and out of the dial sleeve. The Veeder counter functions only to tally the dial turns; it is driven by bevel gears which do not enter into the connection between the dial and spindle and whose backlash has no effect on the accuracy of reading.

3.06 Oscillator Inductance

The oscillator inductance coil has a temperature coefficient which can be adjusted during final test, so as to make the overall MFM temperature coefficient of frequency relatively small.

The coil is wound on a six-ribbed form of polystrene, and the wire tends to assume the shape of a hexagon. The sides of the hexagon are not truly straight but assume curvature somewhat between an arc of a circle and a chord of a circle. Since the thermal expansion of polystyrene is greater than that of copper, as the coil temperature increases the turns are pulled more nearly straight, the average diameter of the coil decreases, and the inductance decreases. The temperature coefficient of inductance depends upon many factors, among which are the relative radial and axial expansion of form and wire, the elasticity and diameter of the wire, and the initial position of the wire turns with respect to the chords of the circle. The last factor can be controlled after winding; portions of the turns can be raised or depressed with respect to the chord and thereby the temperature coefficient of inductance can be controlled. The coefficient itself varies with temperature. Over a range of 70° F. to 120° F., the present manufacturing tolerance is —8 to + 4 MFM dial divisions. Since one MFM dial division approximates 17 cycles per megacycle, the larger tolerance of 8 dial divisions is equivalent to

$$\frac{8 \text{ dial div.} \times 17 \text{ c./mc.}}{(120° \text{ F.} - 70° \text{ F.})} = \frac{136}{50} = 2.72 \text{ c./mc./°F.} = 4.9 \text{ c./mc./°C.}$$

3.07 Crystal Calibrator

The crystal calibrator in the standard Type 105-B MFM has a fundamental frequency close to 7500 kc., which beats with the third harmonic of the variable-frequency MFM oscillator. Two advantages accrue thereby: there is no tendency for one oscillator to "pull" into step with the other when setting for zero beat, as would be the case if the crystal fundamental were the same as the MFM fundamental; and the precision of setting to the calibrator is enhanced, because the beat frequency changes three times as fast at 7500 kc. as it would at 2500 kc.

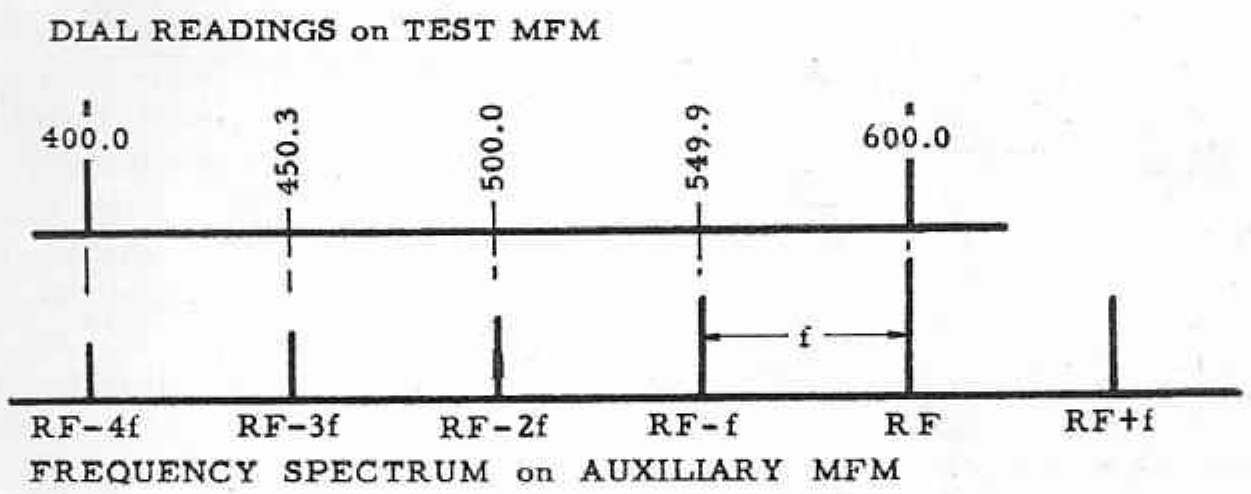


Fig. 14. Linearity test method for the MFM. "RF" is the carrier frequency of the auxiliary MFM; "f" is the audio modulating frequency.

The crystal is a low-drift cut, mounted in the military Type HC-6 hermetically-sealed metal holder. The electrodes are vacuum-deposited and the crystal plate is wire-mounted in an atmosphere of dry nitrogen. This construction is particularly immune to frequency shifts due to electrode displacement, mechanical shock, ageing, and atmospheric pressure and humidity.

The crystal-oscillator circuit is of the type described by Cady*, in which the quartz crystal is connected across the tuning condenser of a conventional Colpitts oscillator. One half of a 7F7 dual-triode is the oscillator tube. This Cady circuit has been employed in the MFM, beginning with Type 105, Serial No. 1419; Type 105-A, Serial No. 1541, and in the Type 105-B. Laboratory measurements of the stability of the Cady crystal oscillator do not show a great deal of difference, compared to the circuit used

* "The Piezo Electric Resonator", W. G. Cady, Proc. I.R.E., April 1922, page 83.

in earlier models of the MFM. These measurements were made to show the effect upon crystal frequency, of intentional changes in filament voltage, plate voltage, line voltage, 7F7 oscillator tubes, plate-to-ground capacity, grid-to-ground capacity, and mechanical shock. However, field experience on many meters, over a period of months to years, indicates the worst departure of the Cady calibrator to be around 5 cycles per million, whereas the older circuit had errors up to 25 cycles per million.

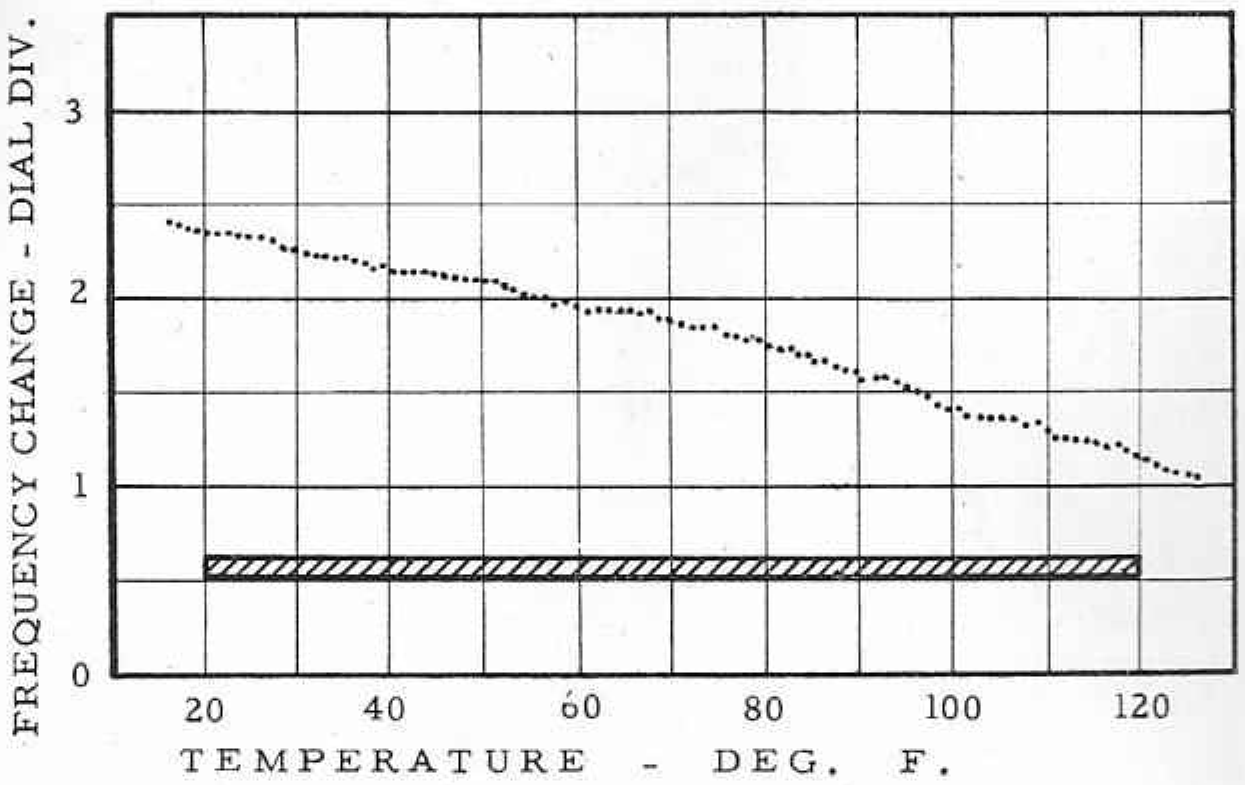
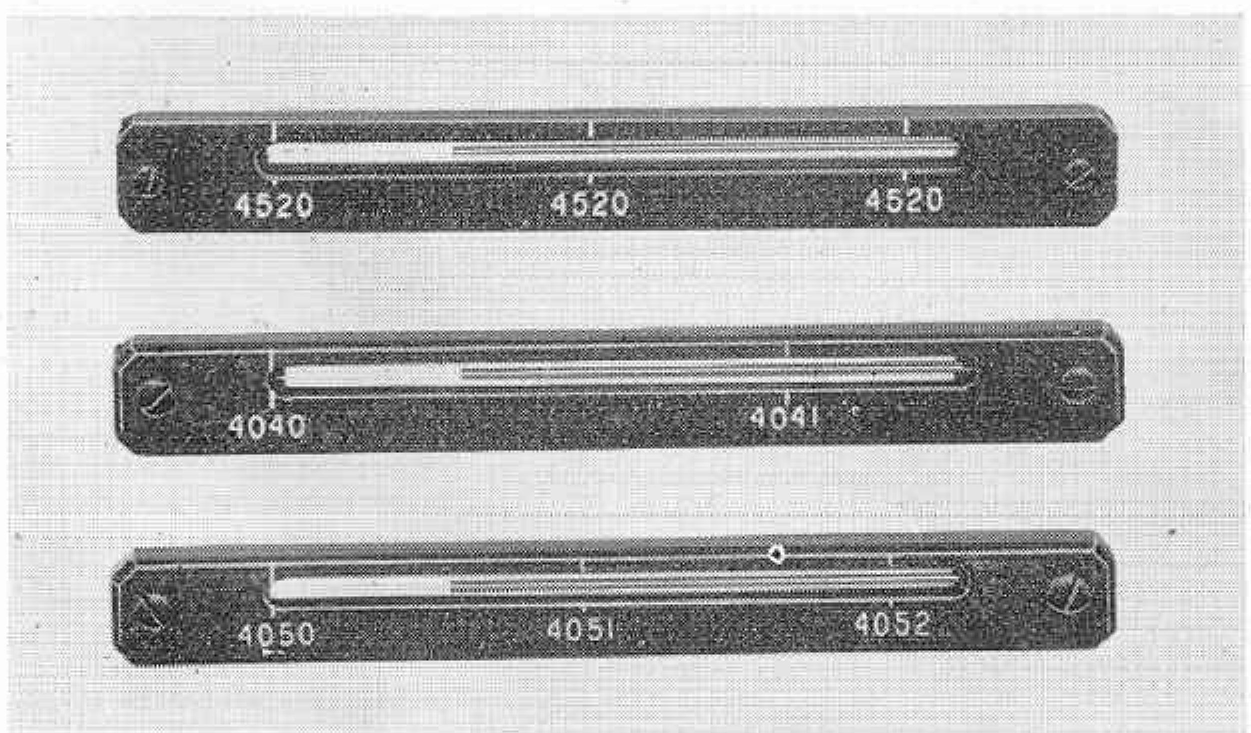


Fig. 15. Typical temperature-frequency curve on calibrator crystal in MFM. One dial division is approximately 0.0017%.

In order to minimize the error due to variable temperature of the crystal calibrator, we have developed a new technique. In production, the frequency of each crystal is measured over a total temperature range of 100° F., centered approximately on room temperature; the frequency variation, expressed in terms of MFM dial divisions, is plotted against temperature; points from this curve are transferred to a scale on a thermometer, which is individually engraved to fit the crystal. The crystal holder is mounted inside the MFM panel, just behind and in thermal contact with the bulb of the thermometer on the front of the panel. Then, if the crystal temperature changes, and correspondingly its frequency, the thermometer scale automatically indicates the new and correct dial calibration point.

A typical shape of the frequency-temperature curve, for the low-drift crystal in the MFM, is drawn in Fig. 15. It can immediately be noted that, compared with the AT or BT low-drift cut, these crystals are exceptionally flat. The cross-hatched horizontal block represents the range of temperature encompassed by the average thermometer scale. Depending chiefly on minor variations in the angle of crystal cut, the frequency curve can droop downward to the right, as shown, can increase to the right, or can be flat within a few tenths of a dial division. In the latter special case, the thermometer could be discarded but for the sake of uniformity it is retained and engraved with three scale marks all numbered the same. The top thermometer in the photograph has this special, flat scale. In the other instances, the thermometer scale will average two or three dial divisions increasing either to the right or to the left.

This technique of engraving a dial scale on a thermometer replaces the conventional thermostat-and-heater apparatus, and in comparison is inexpensive, space-saving, and trouble-free.



Typical thermometer scales, for different crystals in different meters. The top scale is for an exceptionally flat crystal.

The dial setting for checking calibration against WWV remains constant, because the frequency of WWV remains constant.

3.08 Untuned Detector, Audio Amplifier

A 7F7 triode with relatively high amplification factor functions as an untuned grid-leak detector in the MFM. Being untuned, it will respond to a wide range of frequencies from below 100 kc. to above 175 mc. The output of the detector is resistance-coupled to one-half of a 6SN7 dual triode, which functions as an audio amplifier to feed the headphone jack. Audio output is taken through a coupling capacitor, so that the phone-jack is grounded, and shock proof. Either high-impedance magnetic headphones or crystal headphones will work in the jack. No attempt is made to preserve quality in the audio system—the object is to obtain a distinct zero beat, and distortion sometimes aids this object.

3.09 Selector Switch

In the "B" models of the MFM, a selector switch has been incorporated to give optimum three-way performance. When on the XMTR position, the MFM oscillator and the MFM tip jack are both capacity-coupled to the input of the untuned detector. When the switch is on CALIB., plate voltage is applied to the crystal oscillator, and the direct connection from the MFM oscillator to detector grid is broken, leaving only stray capacity coupling. This is sufficient for best match of crystal-oscillator and VFO input to the detector, producing a 10 to 15-volt signal on the headphones.

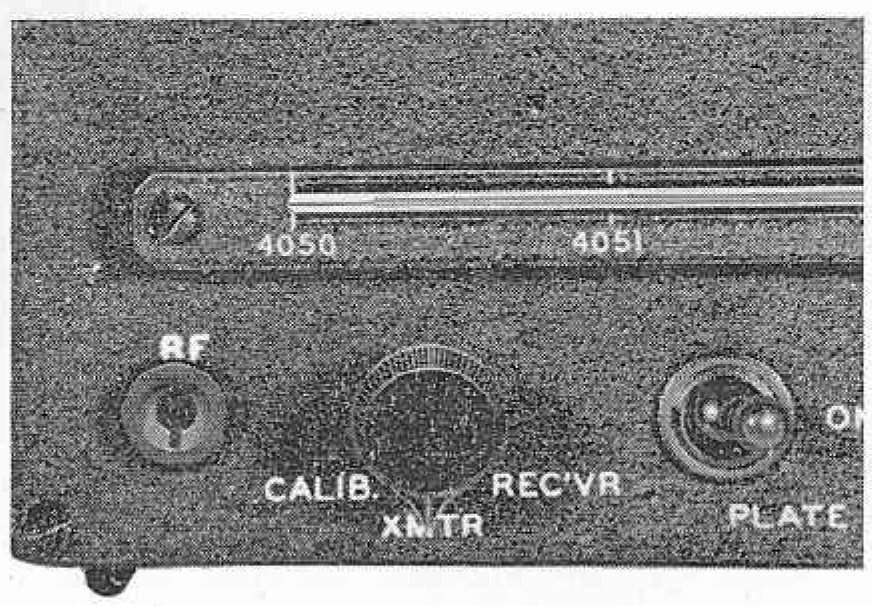
In the REC'VR position the output of the MFM VFO is connected directly across a germanium-diode harmonic generator, and an RF choke which acts as a DC return for the diode. The distorted output is capacity-coupled to the tip jack, and the harmonics generated are ample for final alignment of receivers up to 175 mc. See Sec. 4.11.

3.10 Power Supply

The power required for the MFM filaments is 1.2 amperes at 6.3 volts, AC or DC, and for the plates is 13 milliamperes at 280 volts DC. Both are supplied by a built-in transformer-rectifier-filter system which operates from a 115-volt source, 50 to 400 cycles AC, drawing approximately 25 watts. The second half of the 6SN7 dual triode acts as a diode power rectifier. The MFM case is insulated from the power line, and the attachment plug is non-polarized. There is no danger of shock from the case. The pilot light and the line fuse are replaceable from outside the MFM case, without tools.

For operation on batteries, a special MFM can be supplied with an octal plug and cable coming from the case. This plug is wired so that it can be used with the customer's own octal socket and battery sources; or it can be plugged into the special socket on the MFM power transformer, for operation on the usual 115-volt, 50/400-cycle AC supply. In either case, the POWER and PLATE switches on the MFM will perform their usual control functions.

For operation from a storage battery, there are inverters on the market, having typical ratings of 6-volt DC input, and 115-volt, 60-cycle AC output, at 35 to 40 watts. Such inverters are made by Terado Co., American Television & Radio Co., Cornell-Dubilier, and others.



Selector switch on the Type 105-B MFM. The 103-B instrument does not have the CALIB. position for the switch.

4.0 OPERATING DETAILS

4.01 Skew

When the Micrometer Frequency Meter, or MFM, was introduced some fourteen years ago, the accuracy was guaranteed to 0.01%. The guarantee followed tests made by an independent agency, under purposely unfavorable conditions of operation, which tests showed a maximum error of 0.005% and an average absolute error of 0.0016%. Since that time, many operators realized that the MFM was inherently capable of greater precision and have used it with confidence to 0.0025%. With tightened tolerances on station-frequency measurement required by the Federal Communications Commission, it is profitable to examine more critically the performance of the MFM.

Present frequency tolerances for the public-safety, land-transportation, and industrial radio services are in general, 0.01% below 50 mc. and 0.005% above 50 mc. The FCC has stated by letter that the frequency-measuring means should be sufficiently accurate to permit reading to one-half these tolerances.

The original accuracy tests on the MFM were made at 2350 kc. and at 2650 kc., which points were 150 kc. removed from the calibration check-point at 2500 kc., and near the extreme ends of the dial. One of the chief sources of error under these conditions is "skew," or twisting of the dial tracking around the check point, due to aging of the VFO components. Since the MFM is standardized near the midpoint of the dial, the skew error approaches zero at this point, and becomes worst at the extreme dial ends. By restricting operation to within 50 kc. of the check-point, the error from skew can be made relatively small. The MFM fundamental frequency will come out within 50 kc. of 2500 kc. for all transmitter frequencies above 70 mc., and for approximately half the frequencies below.

Originally, readings on the MFM dial were made to the nearest whole division. With reduction of skew error it is practical to take dial readings to the 0.1 division, estimated by eye. Different observers may differ in their estimate by as much as 0.2 or 0.3 dial division, but the net results will be more accurate than by the old approximation. The Standard Calibration Table for the MFM is now given to the 0.1 dial division over its entire range, and the figures may be depended upon to this precision in any part of the dial scale which is within 50 kc., fundamental frequency, of a dial checkpoint.

4.02 Accuracy Tests

Extended tests of MFM accuracy have been made both in our laboratory and by an independent frequency-measuring service. The results of all these tests are plotted in Fig. 16, and show the probability and magnitude of error in the Type 105-B models of the meter. This is the same curve shown in Figure 4. The tests comprise over five hundred (500) separate readings in two different parts of the country, over a period of two months. They were made on two separate meters, picked at random off the shelf, by six different observers of whom three were skilled and three unskilled, on six different transmitter frequencies. Each observation included the whole procedure of standardizing against the calibrator crystal, adjusting to the transmitter frequency, and reading the deviation calibration curve. The simulated transmitter frequencies were known to better than 0.0001%.

Each point plotted in Fig. 16 indicates a particular value of error for the MFM, and the number of observations which came out on that error. The smooth curve was drawn on the outside observations. This curve illustrates graphically that the worst error found was 0.0017%, and that 90% of all the readings were within 0.001%. It might be noted that the peak of the curve does not come at zero; investigation proves that the reason for the residual error is nonlinearity of the dial between the 10-kc. calibration points, and drift of the crystal calibrator. Where WWV is used for a standard, instead of the internal calibrator, the crystal error ranging up to 2 or 4 parts per million, would be eliminated; but the skirts of the probability curve would not change appreciably.

4.03 Guaranteed Accuracy

The accuracy of the "B" models of the Micrometer Frequency Meter is guaranteed better than 0.0025% above 70 mc., and better than 0.005% below 70 mc.

The accuracy of older models of the MFM will be within the 0.0025% guarantee if they are operated as follows:

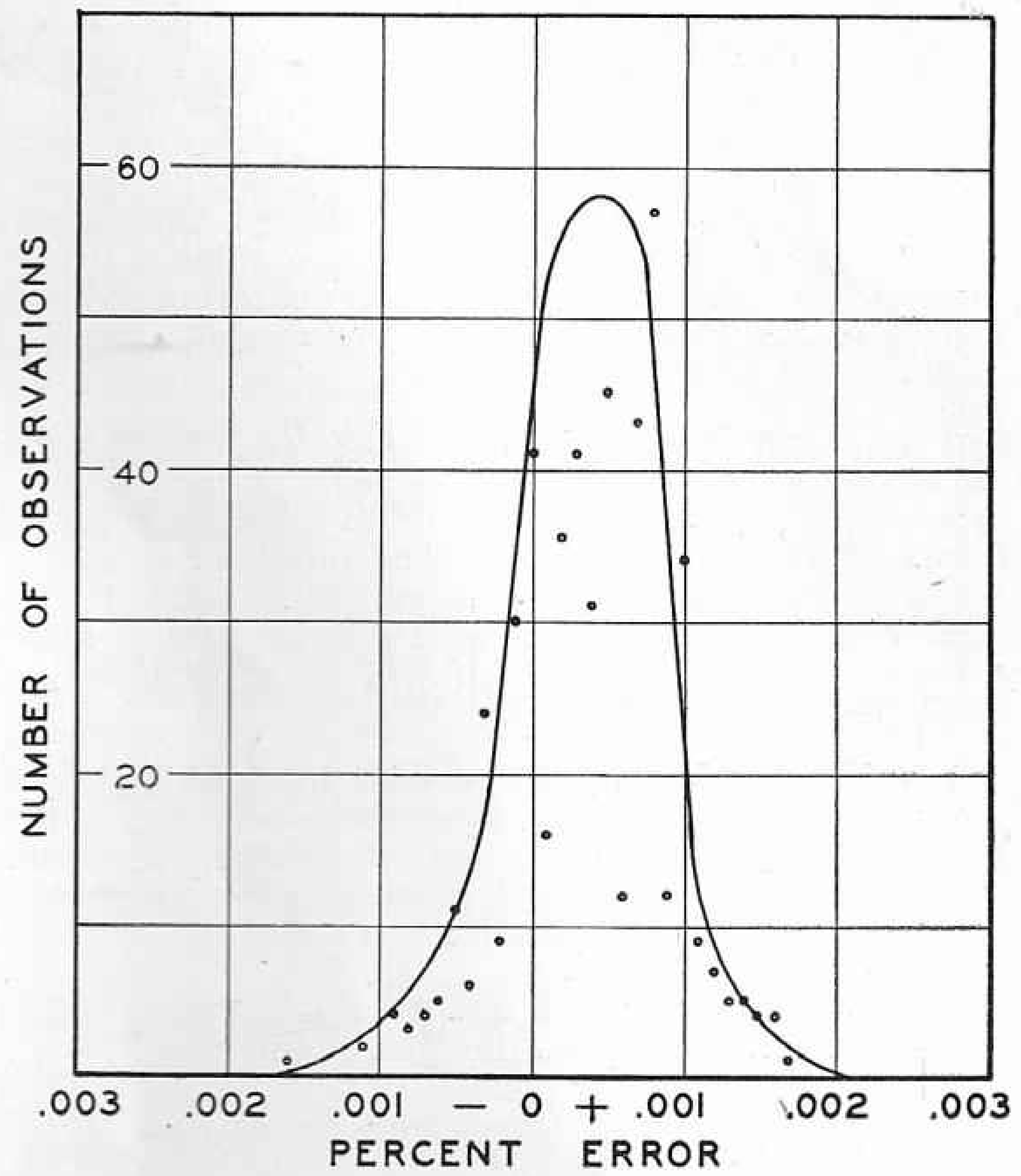


Fig. 16. Results of 502 accuracy tests on the MFM. The worst single error is 0.0017%, and over 90% of the tests were closer than 0.001%.

(1) Use an MFM fundamental frequency within 50 kc., (approximately 1200 dial divisions) of the calibration checkpoint.

(2) Make all dial readings and settings to the estimated 0.1 division.

(3) Standardize the calibration against a Cady crystal circuit (Type 105-A, Serial 1541, or later; Type 105, Serial 1419, or later; and Type 105-B); standardize the calibration against WWV; or standardize with the old, pre-Cady circuit provided the crystal is checked against WWV every three months, and a correction applied to the thermometer scale if necessary.

4.04 Installation

The normal position of the MFM is resting on the four rubber feet with the panel vertical. The instrument can be used on its back with the panel horizontal. However, in changing from one position to the other there is a redistribution of convection currents inside the meter which causes a dial change of five to fifteen divisions over a period of fifteen to twenty minutes. (See Fig. 7). Therefore, during any one series of measurements the MFM should be used in the position in which the calibration was checked.

Improved stability of the ratio-coupled oscillator, over long periods of time, will be had if the filaments of the tubes in the MFM are energized continuously. This is true especially in humid climates, because the inside of the meter will have a temperature a few degrees higher than the atmosphere and will remain relatively dry.

Further, the MFM can be encased in a box, say of ½" Celotex board, as illustrated on page 8. The front was partially closed with Plexiglas leaving space to get at the controls. This setup was tested and yielded the curve in Fig. 12. Enclosures of this sort will protect the MFM from drafts or sudden changes in ambient temperature, and will produce overall frequency stability of a few parts per million for a period of an hour or more.

4.05 Controls

The controls are listed in the specifications on page 2, and are identified on the photograph. The selector switch is distinctive of the "B" models of the MFM.

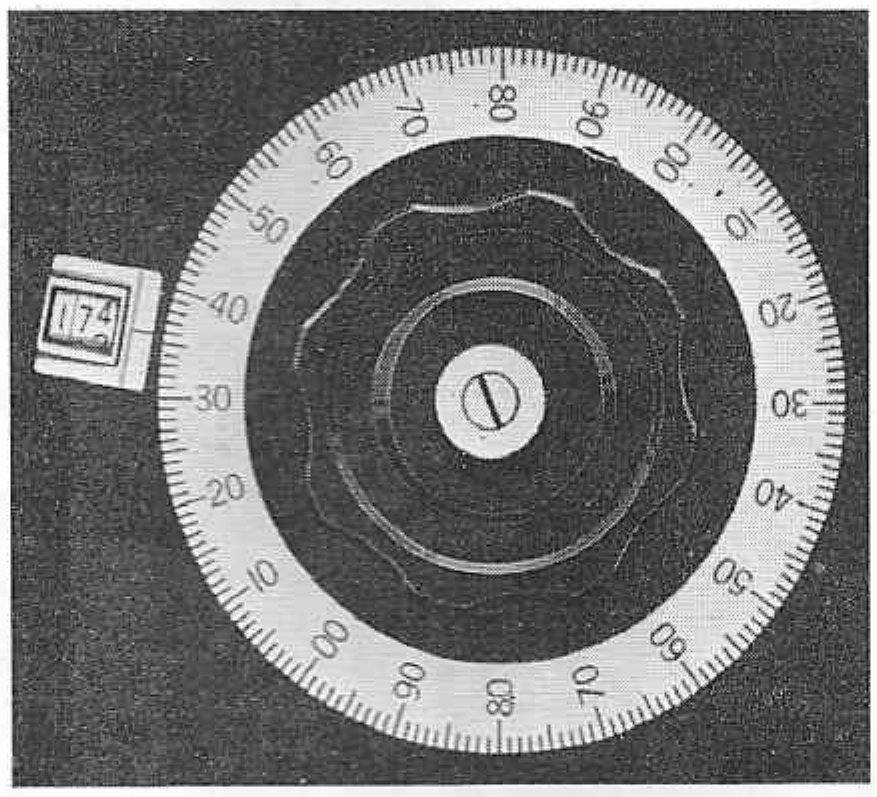
4.06 Dial Readings

Dial readings generally consist of five figures. The first two are taken from the two left-hand wheels of the Veeder counter, and the last three from the circular dial scale, reading to one tenth of a dial division, estimating by eye. The third counter wheel is ignored, since its indication only approximates that of the first dial figure; some operators obscure this wheel with aluminum paint or masking tape. If the second Veeder wheel is changing, read its smaller figure if the 4-inch dial is in the 90's, or the higher figure if the dial is past 00. Following the sequence of Veeder numbers as the dial is slowly rotated past 00 helps avoid mistakes.

When adjusting the dial to a reading, ALWAYS come precisely to final setting, starting from a point at least half a turn, or 100 divisions, lower. This rule applies whether adjusting the dial to zero beat or placing it at a predetermined setting. If the correct reading should be passed accidentally, return to the starting region and repeat the approach. Dial settings can be duplicated closely and the effects of backlash will be a minimum, if this standard procedure is followed.

The MFM has an English micrometer head which provides a dial range of 40 turns, or 0 to 8,000 divisions. There are stops which limit the rotation below 0 and above 8000. When the dial approaches the limits of its travel, reasonable care must be exercised not to jam or override the stops.

The dial readings for the Standard Calibration Table are given to 0.1 dial division, as are the Dial Differences.



Precision dial, set to reading of 1735.7.

4.07 Adjustment to Zero Beat

The initial step in setting the MFM to zero beat is positively to identify the beating voltages. This is true when listening with headphones in the MFM or when listening at the output of a receiver. Turn the MFM dial so that a heterodyne tone is heard from the frequency to be measured. Cut off alternately the plate switch on the MFM, and the source of the frequency to be measured; in each case the tone must disappear. If it does not disappear, the beat is coming from spurious voltages.

Next, while listening to the tone, adjust the r-f coupling to the MFM for maximum audibility. For example, change the length of the pickup wire, its distance from the frequency source, or its polarization. Finally, set the dial by coming just to zero beat from the low side, as detailed in the preceding section.

Of course, beat frequencies below 15 or 20 cycles per second cannot be distinguished by ear; also, there are times when the beat note may be so weak as to be inaudible below a few hundred cycles per second; again, the zero-beat region may be several divisions wide if the MFM is located near a high-powered transmitter whose frequency coincides with the MFM fundamental, for the meter will be pulled into step with the transmitter at low beat frequencies.

For all such situations there is a simple rule-of-thumb manipulation which will yield good results, viz.: turn the dial slowly and continuously upward through the zero-beat region, and note mentally the two readings, one where audibility ceases and the other where audibility recommences; the mid-point between these two readings is the correct dial reading. With a little practice the difference can be split by eye, while going through the zero-beat valley.

Precise settings to zero beat can be made if the frequency being measured can be amplitude-modulated with tone or music, or if an auxiliary r-f source can be made to superimpose a 500-to 1,000-cycle beat on top of the zero beat. First get the approximate reading for zero beat; then turn on the source of the auxiliary tone and again approach this reading, slowly; a flutter will be heard superimposed on the audible tone and the dial can be put as close as 1 cycle per second to true reading, by slowing the flutter. It is important to check the approximate reading first, because spurious flutters can be picked up at other points. These refinements have been found useful in many aplications, and may or may not be useful depending upon the demands of a particular case.

4.08 Auxiliary Radio Receiver

An auxiliary radio receiver is required in conjunction with the Type 103-B MFM, for reception of standard-frequency emissions from WWV. A receiver is also a useful adjunct to the MFM in many kinds of laboratory, development, and production work. As a rule, the harmonics of equipment under test can be picked up on the receiver and the MFM frequency coverage is continuous; where conditions indicate that a beat will occur at a certain harmonic frequency the receiver must actually be tuned to that frequency. The average receiver of course offers greater sensitivity, selectivity, and power output than the two-tube MFM detector and amplifier.

When heterodyning received signals with the MFM, it is important that the two voltages impressed on the receiver input, from the signal and from the MFM, be approximately equal. If not equal when using AVC, the stronger signal drives the receiver gain down and weakens even further the weaker signal. An S meter on the receiver may be used to judge the two input levels, reading one while the other is cut off.

Another way of judging is to listen at the receiver output to a beat between the two voltages, and make changes in the respective input couplings till the beat is loudest. The size of the receiving antenna controls the signal voltage, while the length of tip-jack wire and its separation from the receiver input fix the MFM voltage. One extreme in coupling is: a large antenna connected to the receiver, and no wire in the MFM tip jack—the signal relatively is strongest. The other extreme is with no antenna on the receiver, and a short wire connection between tip jack and receiver input—the MFM relatively is strongest. Between these two extremes a balance of input usually can be had.

Assuming equality of input, turn the receiver audio gain to a comfortable level and tune the MFM dial toward zero beat; when the beat comes down to 10 or 15 cycles per second turn the gain to maximum; there usually will be a recognizable flutter in the hum or background noise of an otherwise unmodulated carrier and the flutter can be slowed to a cycle or so. A regenerative receiver, a communications receiver, or other type adapted to continuous-wave-telegraph reception has a means for superimposing an auxiliary heterodyne on the zero beat, simply by cutting on the BFO or beat oscillator. Always, when emphasizing slow beat frequencies with an auxiliary tone, the precaution of first getting the approximate MFM dial reading must be observed to prevent false readings.

With a superheterodyne receiver care must be taken not to tune the MFM incorrectly to the image of a signal. A check can be made by slightly moving the receiver dial; if the pitch of the beat note between the MFM and the signal-to-be-measured is not varied thereby, the MFM frequency is correct.

Accurate results cannot be had by beating a signal in a super-regenerative receiver, since the multiplicity of beat notes precludes any positive setting. A signal may or may not be heterodyned in a frequency-modulation receiver, depending mostly on the efficiency of the limiter and discriminator in the receiver; the heterodyne process produces amplitude modulation of the signal, to which a good FM receiver is insensitive. However, FM transmitters can be monitored by means of the detector in the MFM as noted in Sec. 2.03.

4.09 Calibration Checks

Any source of frequency which is accurate to better than 0.0001% is suited for standardizing the calibration of the MFM. A list of the principal calibration sources is outlined below:

Calibration Source	Calibration Point	Beat Reception using
(1) Radio Station WWV	2500 kc.	Aux. receiver
(2) MFM Crystal Calibrator	Thermometer Reading	MFM detector
(3) Broadcast Transmitter	From Tables 1 and 2	MFM det. or Aux. receiver.
(4) 100-kc. Sub-standard checked against WWV	2300, 2400, 2500 2600, and 2700 kc.	Aux. receiver, or MFM detector

Line (1) constitutes the routine check for the Type 103-B MFM. Line (2) is routine for the 105-B meter and applies only to this model.

The following uniform procedure is recommended for standardizing the calibration of the MFM, against any of the various sources of standard frequency: set the MFM dial at the calibration point corresponding to the standard frequency; adjust the MFM trimmer screw for zero beat on the standard. Rock the trimmer from tone to tone on either side and stop in the middle, or utilize an auxiliary heterodyne or tone modulation, to facilitate precise setting. It is preferable to standardize the calibration prior to each series of measurements lasting ten to fifteen minutes.

The national standard of frequency is made available to the public by transmissions from radio station WWV, Bureau of Standards, Washington, D. C. Schedules of the transmissions are published in QST, and in the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, or may be obtained from the Bureau. One or more of the current transmissions on 2500, 5000, 10,000, 15,000, 20,000 kc., and higher, can be picked up on a short-wave receiver, anywhere in the United States during the 24-hour day.

4.10 Crystal Calibrator Check

Since emissions from WWV are the final authority for frequency measurements in the United States, it is advisable periodically to compare the MFM crystal calibrator against WWV.

The complete procedure for checking the crystal calibrator follows: have the MFM energized, PLATE and POWER switches on, selector switch on XMTR, for at least one hour. Pick up the standard-frequency transmission from WWV, on a receiver, on any of the frequencies of 2.5, 5, 10, 15, 20, 25 or 30 mc. If the receiver has a beat-frequency oscillator, turn it off. Place a pick-up wire in the MFM tip jack, and lay the wire near the receiver antenna. Get the MFM dial reading for 2500 kc. from its standard Calibration Table. Set the dial 5 to 15 divisions away from the 2500-kc. reading, so as to produce a readily distinguishable beat note on WWV, heard with headphones or loudspeaker at the receiver output. Adjust the coupling between the MFM wire and the receiver antenna for loudest beat note. Set the MFM dial exactly to the calibrated reading for 2500 kc., coming just to this setting from at least one-half turn below and estimating to 0.1 division, by eye. Turn the trimmer screw on the MFM for zero beat on WWV during a period of no modulation, and check for a slow flutter of less than 1 or 2 cycles per second on the tone during modulation, still listening at the receiver output. Then with headphones in the MFM, turn the selector switch to CALIB. but don't touch the trimmer; adjust the dial for zero beat on the crystal, coming just to this point from at least one-half turn lower setting. Read the dial scale to 0.1 division. This reading should be the same as shown by the thermometer on the MFM panel. If the difference is greater than 0.3 dial division, mark or paste the correction on the thermometer. For instance, if zero beat on the crystal comes at 4126.5, and the thermometer shows 4126.0, the correction is plus 0.5, to be added to all thermometer indications.

4.11 Alignment of Receivers

The "B" models of the MFM are especially suited for final, accurate alignment of radio receivers; provided of course that a harmonic falls on the receiver frequency. The region above 20 mc., where the MFM harmonic coverage is continuous, is the region where most fixed-frequency, crystal-controlled, mobile receivers operate. Good, present-day mobile receivers have selectivity band-widths of the order of 10 to 20 kc.; at 150 mc., 5 kc., is equivalent to $\frac{5\text{ kc.}}{150{,}000\text{ kc.,}}$ or .0033%. If a selective receiver drifts only .0033% off the transmitter frequency, it can be riding the selectivity skirt and noticeable deterioration in reception can result. Commercial signal generators, having frequency-calibration scales accurate from 0.5% to 2.0%, are useful for rough alignment of RF and IF stages, but obviously other means must be employed for final alignment.

The input signal to the receiver should be weak, only a few microvolts, so as to simulate "fringe area" conditions, and, as noted above, should be within 2 or 3 kc. of the transmitter frequency. One method is to employ the transmitter itself as a source, and drive the mobile installation several miles away for receiver tuneup; this has disadvantages such as cluttering up the air with test transmissions and time lost in traveling. Another method is to set a commercial signal generator to zero beat on the transmitter frequency, either directly or using a frequency meter as an intermediary; the success of this method depends mostly on the ease with which zero-beat can be obtained against the signal generator, and on the short-time frequency stability of the generator. Not many wide-range generators are satisfactory in the latter respect, at 150 mc. A third method is to utilize a crystal-controlled signal generator, either custom-built to frequency or as in test sets provided by some of the mobile-radio manufacturers; this method in general is good, provided that the crystal drift is small. A fourth method is to utilize an MFM.

The "B" models of the MFM have a crystal-diode harmonic generator which is cut in by the selector switch, in the REC'VR position. A typical curve showing level of MFM harmonic output is given in Fig. 17. This curve was obtained by setting an MFM at or near 2500 kc., the selector switch on REC'VR, and connecting the RF tip jack with a 12" wire directly to the input of a receiver. The MFM and receiver were placed on, and connected to a common metal ground sheet. The receiver was tuned to the MFM (or vice versa), and a reading was noted on an S-meter, a second-detector DC-voltmeter, or limiter DC microammeter; then a Hewlett-Packard Type 608A signal generator was substituted for the MFM, tuned to the receiver frequency, and the attenuator set for the same S-meter deflection, after which the attenuator output in microvolts or millivolts was noted. With the MFM selector switch on XMTR, the output voltage is roughly 1/10 that shown in Fig. 17. If impedances are matched between MFM REC'VR output and receiver input, the harmonics will be roughly

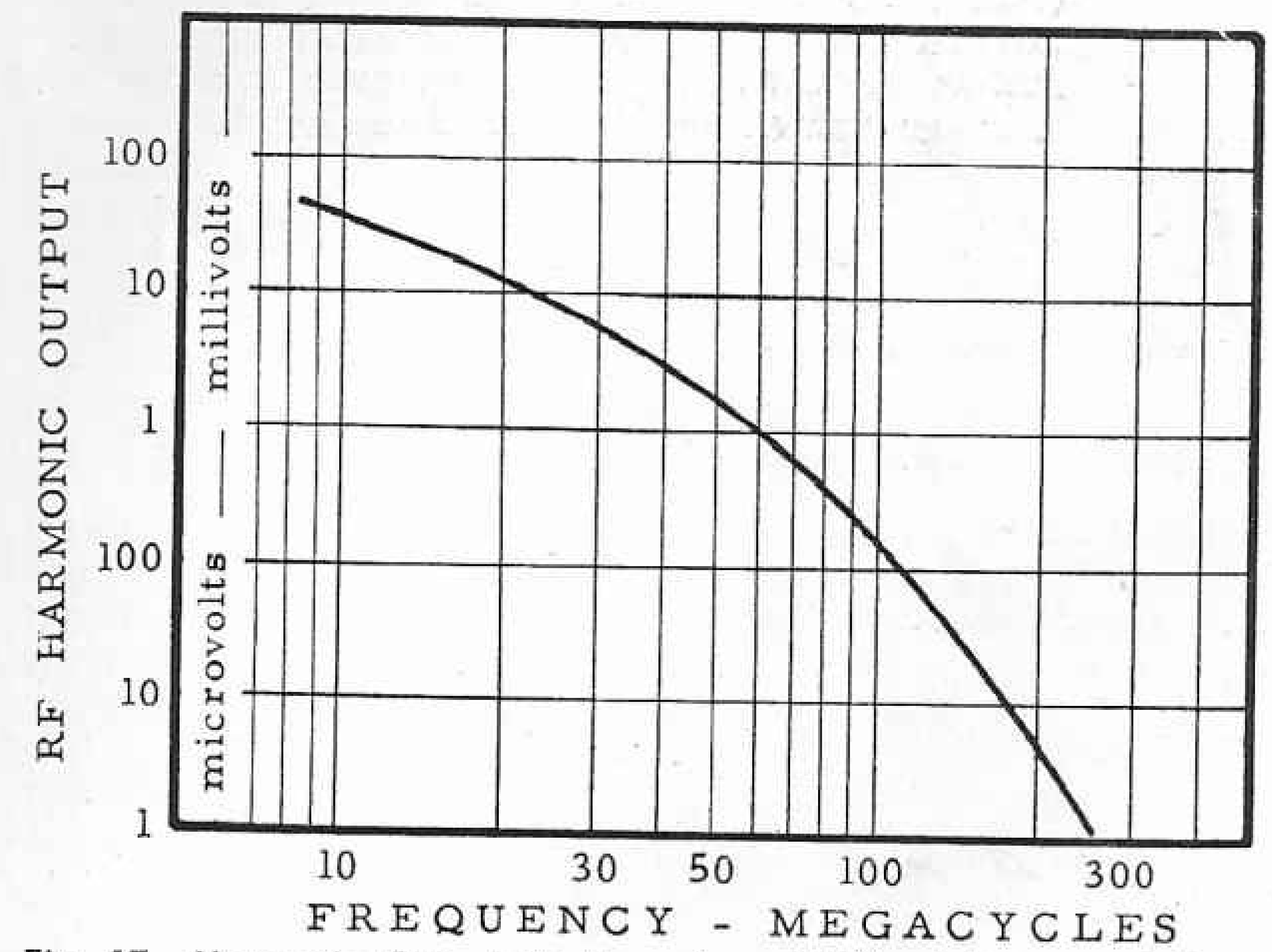


Fig. 17. Harmonic Output Voltage from MFM. Selector switch on REC'VR, no impedance matching to receiver.

twice the values drawn. The "no-load" voltage at the MFM RF jack averages 10 volts, rms, with selector switch either on XMTR or on REC'VR; this was measured with a Hewlett-Packard Model 410-A VTVM, having AC input impedance of 6 megohms shunted by 1.3 mmfd.

Since the ouput of the MFM is unmodulated, indication of maximum tuning is best had from the rectified IF voltage or current (DC) in the receiver. Mobile FM receivers usually have provision to measure first-limiter and second-limiter DC microamperes, and discriminator-balance DC microamperes. AM receivers usually have a diode second detector plus a load resistor, across which a DC electronic VTVM can be connected; any AVC should be disabled while aligning. The coupling to the receiver should be kept small during the tuning process, just enough to give a usable deflection on the tuning meter. The receiver stages throughout are tuned for maximum DC limiter current, or maximum second-detector DC voltage; in addition, the FM discriminator must be balanced.

The FCC assigns a frequency tolerance to a transmitter, but is not concerned with receiver tuning. Assuming the base transmitter to be in tolerance, there still could be a difference of several kc., at 150-mc., between assigned frequency and actual frequency. This could amount to 1 or 2 dial divisions on the MFM. For receiver alignment it is a good idea to mount the MFM in the Celotex box; after it has stabilized, standardize it, and then determine the exact dial reading for the base transmitter. Keep the MFM on this reading for aligning the mobile receivers.

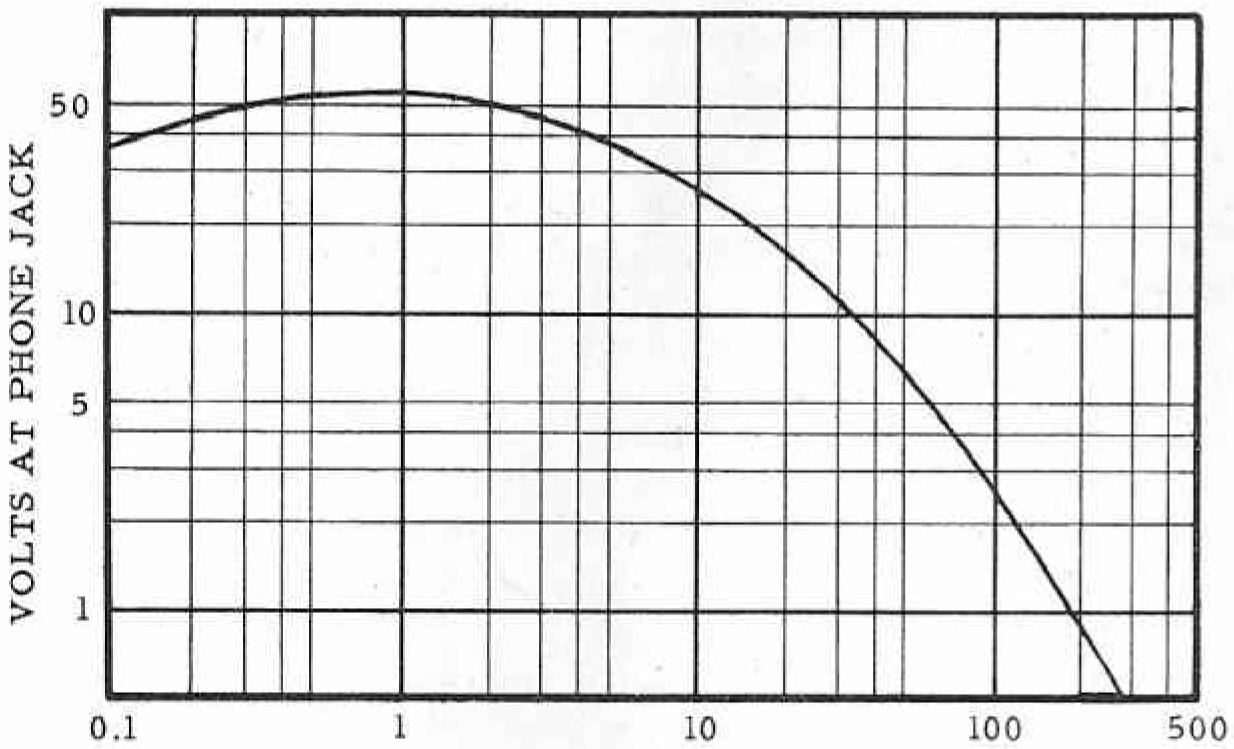


Fig. 18. The 105-B MFM as a beat-frequency generator. RMS voltage on 100,000-ohm load, selector switch on CALIB.

However, when one receiver must pick up several mobile transmitters, the technique is to adjust all the latter as closely as possible to assigned center frequency, and likewise put the receiver on center frequency.

4.12 The MFM as a Beat-Frequency Generator

The 105-B MFM will function itself as a beat-frequency generator, up to 200 or more kc., by setting the selector switch on CALIB. The beat between VFO and calibrator crystal will create an audio voltage at the MFM phone jack; the level on a 100,000-ohm load varies from 1 to 50 volts, over a range of 200 kc. to 100 cycles, as drawn in Fig. 18. Photographs of typical wave shapes are shown in Fig. 19. The audio-frequency calibration, starting from zero beat, is about 125 cycles per MFM dial division; it can be calculated more closely using your Standard Calibration Table and equation (2) in Sec. 5.11, remembering that transmitter (crystal-calibrator) kc. is 7500.

4.13 Miscellaneous Suggestions

It may be desirable in some cases to add a tuned circuit at the tip jack of the MFM, if interference is present from modulated transmitters on other frequencies, or if measuring frequencies above 40 or 50 mc. The added circuit should tune roughly to the frequency being measured or to the harmonic frequency on which the beat actually arises. The tuning may consist of a coil and condenser in parallel, or simply a coil, connected from tip jack to grounded panel. The MFM pickup wire may attach to the tip jack or may be tapped down into the coil. The tuning is not critical.

Another expedient is to place one end of the pickup wire in the tip jack and ground the other end to the panel, thus converting a high-impedance input to a low-impedance input.

To use coaxial feed between an antenna and the MFM, a pi-type impedance-matching section should be provided at the MFM input. The condensers and coil in the matching section should be of such sizes as would normally resonate at the pickup frequency. This method also is useful for cutting out interference from a nearby transmitter on a widely different frequency.

4.14 Maintenance

The Type 103-B and Type 105-B circuit diagram is clipped inside the rear cover. The diagram contains a parts-and-function list, gives component values, and typical voltage readings at various circuit points.

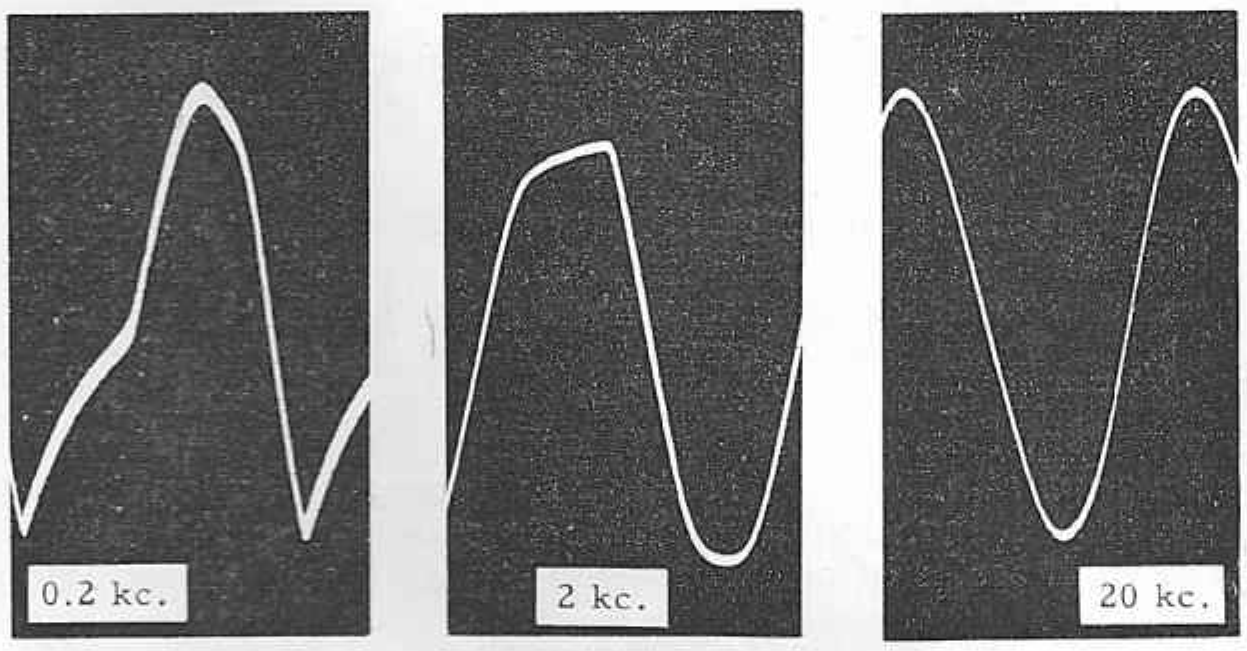


Fig. 19. MFM as beat-frequency generator. Typical wave shapes, available at PHONES Jack.

The MFM is protected by a 1-ampere, 250-volt, 3AG fuse mounted in a panel fuse holder. The fuse can be replaced by unscrewing, with fingers, the cap of the holder. Likewise, the pilot lamp is accessible by removing the red translucent cap. The pilot lamp is a Mazda No. 40, 6.3-volt, 150-milliampere, brown-bead, miniature-screw-base type.

Changes or repairs other than replacement of a fuse, a pilot lamp, or vacuum tube should not be attempted. Moving a wire, connecting the oscillator coil and micrometer condenser, about an inch will shift the dial readings 20 to 30 divisions. Some apparently minor changes in the VFO circuit often necessitate a complete recalibration.

Ordinarily any of the tubes, 6J7, 7F7, or 6SN7 can be replaced without major effect on the calibration—provided none of the open wires are moved. If the 6J7 is replaced, the VFO calibration can subsequently be spot checked against WWV or the internal calibrator. If the 7F7 is changed, it is a good idea to check the crystal promptly on WWV and make thermometer correction should it be necessary. The metal 6J7 tube has the bakelite cap removed, to eliminate calibration changes due to moisture absorption in the bakelite. The removal technique is first to unsolder the wire protruding through the metal cap, then with diagonal cutters lift the metal crimp all around the bakelite, a little at a time. The 6J7-GT type is satisfactory in the first socket, provided it oscillates with line voltage as low as 100. Quite often the first indication of a poor 6J7 tube is a wide frequency variation with line-voltage change. Production tolerance on this test is a total variation of 1.0 dial division, from +15% to —15% line volts, allowing 1 minute drift between each voltage.

5.0 CALIBRATIONS AND TABLES

5.01 Definitions

Definitions of terms used in this section are:

MFM Frequency = Fundamental frequency of Micrometer Frequency Meter, in kc.

Transmitter Frequency = Output frequency of transmitter, in kc.

Harmonic Ratio = Factor which, multiplied against Transmitter Frequency, yields MFM Frequency. It appears in Table 1 as an approximate decimal number, and as the exact fraction. The numerator or first number of the fraction is the transmitter harmonic, the denominator is the MFM harmonic.

Deviation = Difference between Transmitter Frequency and its assigned frequency, expressed in cycles per second, or in per cent. It is plus when the transmitter frequency is high, or minus when low.

Dial Difference = Number of dial divisions, on Standard Calibration Table, from a calibrated 10-kc. reading to the next higher calibrated 10-kc. reading.

Dial Constant = Change in frequency for a change of one dial division on the MFM, expressed in cycles at a specified frequency, or in per cent.

5.02 Standard Calibration Table

The Standard Calibration Table for a particular MFM, identified by type and serial number, is inserted following the last page of this booklet. For purposes of explanation, there is reproduced below part of a Standard Calibration Table; it lists MFM Frequency at 10-kc. intervals (column headed KC); the corresponding Dial Reading (column headed DIAL); and the Dial Difference to the next higher dial reading (column headed DIFF.). The sample table does not apply to any particular meter; it is included for illustrative purposes only, to be used in connection with examples worked out in the following sections.

PARTIAL STANDARD CALIBRATION TABLE
Type 000 MFM .... Serial 0000

KC.	DIAL	DIFF.
2440	2719.6	246.7
2450	2966.3	245.8
2460	3212.1	245.2
2470	3457.3	244.5
2480	3701.8	243.7
2490	3945.5	242.5
2500	4188.0	241.7
2510	4429.7	240.6
2520	4670.3	239.8
2530	4910.1	239.0
2540	5149.1	

SAMPLE ONLY — DO NOT USE WITH ANY MFM

5.03 Transmitter Chart

The Transmitter Chart on the back cover provides space for information, needed to monitor various transmitter frequencies. Columns 1 and 2 are for channel identification and transmitter frequencies. MFM Dial Reading, column 3, is calculated for each frequency as explained in Sections 5.06 to 5.09. Transmitter Deviation per Dial Division, in column 4, is a dial constant in cycles per second for the specified frequency, and is calculated as explained in Sec. 5.11 using formula (2). Transmitter Deviation per Dial Division, in column 5, is a dial constant in percentage and is obtained using formula (3) in Sec. 5.11. Columns 6 and 7 of the Transmitter Chart are spares for individual requirements.

5.04 Deviation Calibration Chart

A Deviation Calibration chart is supplied with the MFM, if the customer advises the specific operating frequency, or frequencies. The chart measures 6" x 9" and can accommodate as many as six frequencies, one graph line for each frequency; the coordinates of the graph are percentage deviation, ranging from plus .01% to minus .01%, and MFM dial reading. Each curve, or graph line, has the transmitter frequency written just above it.

A portion of a Deviation Calibration is reproduced in Fig. 20. On the actual chart, the horizontal-axis dial readings are lettered in red; each ruling encountered going in a horizontal direction is equivalent to 0.2 dial division. On the vertical axis, percentage deviation is given in black; each ruling met moving vertically represents 0.0002 percent. The deviation is plus above, and minus below, the heavy center line. To illustrate the method of using the chart, refer to Fig. 20, and assume the MFM reading is 3967.4; the nearest identified line to the left is 3966.0—start here, move five lines to the right (5 lines x 0.2 div. per line = 1.0 dial div.), which is 3967.0, one more line is 3967.2, and one more is 3967.4, as shown by the vertical dotted line; run up this dotted line to the graph; then from the intersection cross over to the left on the horizontal dotted line, to the percentage-deviation scale; reading this scale in the same sequence as above, start at -.002%, five lines lower is -.003%, then count down to -.0032, -.0034, -.0036, and so to the dotted line at -.00365, or -.0037% in round numbers.

In the other example, the dial reading is 3970.7, which is reached from 3970.0 by counting 3½ lines to the right; the graph intersection comes 4 lines above +.001%, or at +.0018%.

5.05 Tables

Table 1, beginning on page 18 is for converting Transmitter Frequency to MFM Frequency, using mathematics no more complicated than addition. It encompasses transmitter frequencies from 100 kc. to 56 mc., and its usage is explained in Sec. 5.06 and 5.08.

Table 2 is provided to convert MFM Frequency to MFM Dial Divisions, as explained in Sec. 5.07. Except for one multiplication, correcting for tenths of dial divisions in the Dial Difference figure, Table 2 involves only arithmetical addition. Both Tables 1 and 2 are reprinted from earlier Engineering Data Sheets.

Table 3 on page 17 extends Transmitter Frequencies from 56 mc. to 175 mc., and requires long division to change these frequencies into MFM KC. See Sec. 5.08.

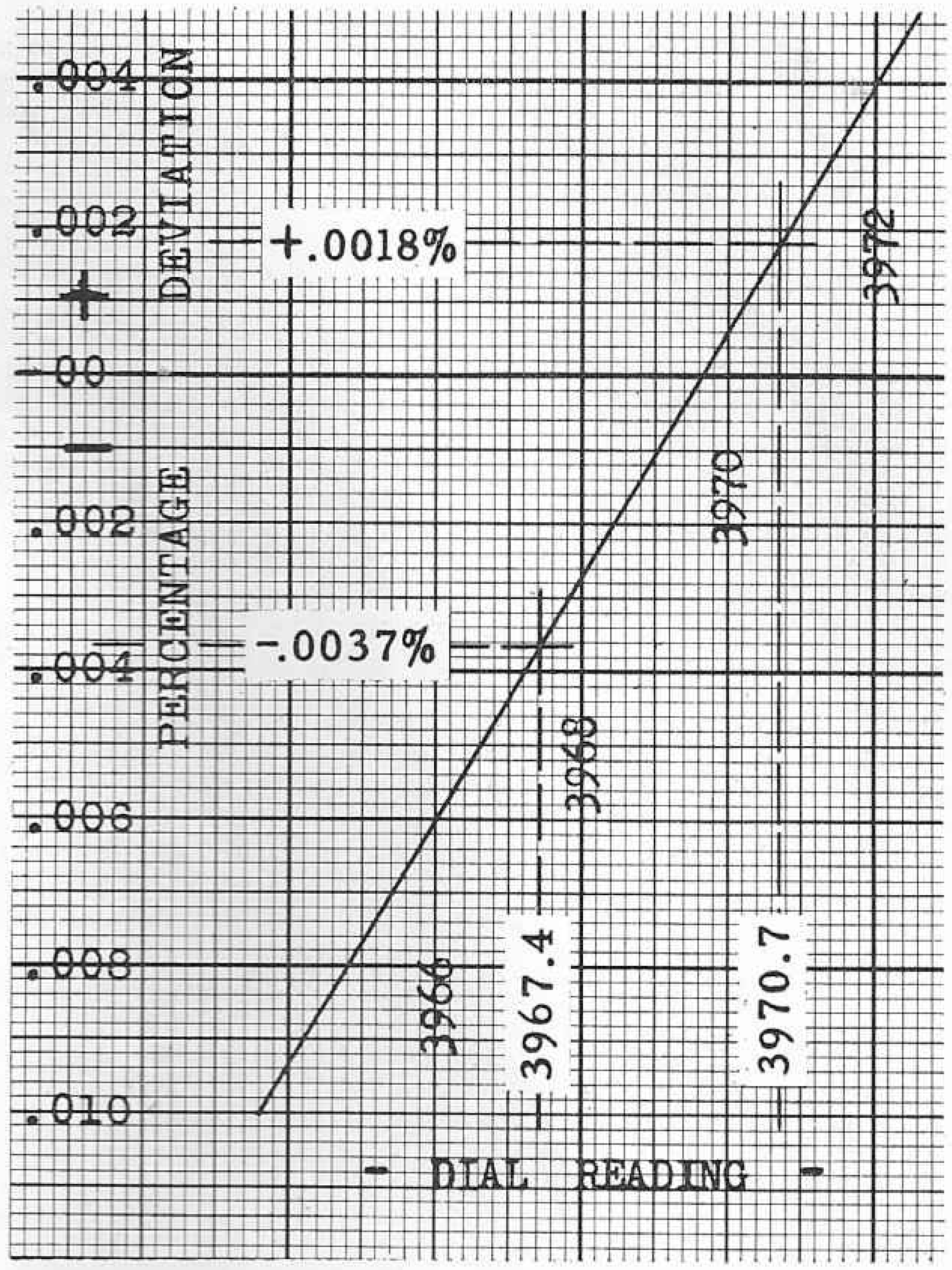


Fig. 20. Portion of a Deviation Calibration chart, illustrating method of reading scales.

There are several methods by which one can calculate MFM frequencies and dial readings. Alternative methods are outlined in the different sections, and which approach to use depends on one's familiarity with the processes involved. All computations should be double checked; one way is to put aside the first completed result, do the problem again, and compare the two answers. If large trouble should be encountered, write and tell us where it arises, and we shall do our best to straighten it out.

Of course, we can always give prompt, accurate service on complete Deviation charts, for one to one hundred frequencies, at nominal cost.

5.06 Given Transmitter Frequency, to find MFM Frequency (by addition)

The explanation is based upon the use of Table 1, and is keyed to an example in which Transmitter Frequency is assumed to be 14,757.5 kc. Alphabetical letters are used to identify the different parts of the problem in the text and on the work sheet.

On a work sheet, write the Transmitter Frequency, A, in kc. Rewrite it broken down as far as possible into thousands B, hundreds C, tens D, units E, and half F. In Table 1A in the column headed XMTR. KC., find the nearest frequency BC smaller than the given transmitter frequency A, in this case 14,700 kc.; read to the right and choose the MFM Frequency BC2. Write BC2 on the work sheet and also G the harmonic-ratio decimal number. In Table 1B, in the left-hand column headed Xmtr. Kc., locate each of the figures D, E, and F; read to the right into the column headed by G, and get D2 equivalent to D, E2 equivalent to E, and F2 equivalent to F. Add all the parts BC2, D2, E2, and F2; the sum H is the required MFM Frequency, in kc.

Example:

	Transmitter Frequency		MFM Frequency
A	................14,757.5 kc.	G =	.167 Harmonic ratio
B	................14,000. kc. }	—BC2	..............2450.000 kc.
C	................700. kc. }		
D	................50. kc.	—D2	..............8.333 kc.
E	................7. kc.	—E2	..............1.167 kc.
F	.... .5 kc.	—F2	..............0.083 kc.
A	................14,757.5 kc.	—H	..............2459.583 kc.

When choosing BC2, keep in mind that it is preferable to locate the MFM Frequency as close as possible to the calibration check point, 2500 kc. Sometimes Table 1A will show XMTR KC directly in tens of KC (i.e., 830 kc.), and again only in thousands of KC (i.e., 37,000 kc.). Use all shown in Table 1A, and obtain the balance of XMTR KC from Table 1B.

5.07 Given MFM Frequency, to find Dial Reading (by addition)

The explanation is based upon use of the Sample Calibration Table on page 15, and Table 2; and is keyed to an example in which MFM Frequency is assumed to be 2459.583 kc.

Write on a work sheet the MFM Frequency H, in kc. Rewrite the MFM Frequency broken down into tens I, units J, tenths K, hundredths L, and thousandths M, of kc. From the Sample Calibration Table, for the frequency I, obtain the dial reading I2 and write it on the work sheet; also record the Dial Difference N, taken from the third column of the Sample Calibration Table.

In Table 2, first find the column headed by the Dial Difference N, disregarding for the moment the tenths of dial divisions (Y = 0.8) in this figure; in the left-hand column called MFM KC., locate each of the figures J, K, and L; go to the right from each into the column headed by Dial Difference N, and get the corresponding numbers J2, K2, and L2. For M, thousandths of MFM KC, use the hundredths figure in this column, get the dial divisions from the N column, and move its decimal point one place to the left, giving M2. Add all the parts I2, J2, K2, L2, and M2, obtaining a total, P. To take into acount Y, the tenths of dial divisions in N, write JK the units-and-tenths figures from MFM KC (9.5 kc.); move the decimal point one place to the left (.95 kc.); multiply this by Y (0.8 div.), obtaining the product Q. Add Q to P; the sum R is the required MFM Dial Reading.

Example:

MFM Frequency			**Dial Reading**		
H	2459.583	kc.	N = **245.8** Dial Difference		
I	2450.	kc.	I2	2966.3	div.
J	9.	kc.	J2	220.50	div.
K	.5	kc.	K2	12.25	div.
L	.08	kc.	L2	1.96	div.
M	.003	kc.	M2	.074	div.
H	2459.583	kc.	P	3201.084	div.
Y (0.8 div.) x JK (9.5 kc) x 0.1			Q	.760	div.
			R	3201.844	div.

5.08 Given Transmitter Frequency, to Find MFM Frequency (by multiplication and division)

The explanation is given in three parts, the first two concerning Table 1 and the third concerning Table 3. First assume that Transmitter Frequency is 14,757.5 kc., as in Sec. 5.06 above. On a work sheet, write down Transmitter Frequency, in kc. In Table 1A, in the column headed XMTR KC., find the listed frequency (in this case 14,800 kc.) nearest to Transmitter Frequency; in opposite columns look for the MFM Frequency (2466.667 kc.) nearest to 2500 kc., and find just above in the same column the fractional harmonic ratio, 1/6. Multiply Transmitter Frequency by 1/6, which is the same as dividing by 6; the result, 2459.583, is the required MFM Frequency, in kc.

Example:

Transmitter Frequency . . 14,757.5 kc. Harmonic Ratio . .1/6

$$14757.5 \text{ kc.} \times 1/6 = \frac{14{,}757.5 \text{ kc.}}{6},$$

```
or    6 | 14,757.50000 kc.
          2,459.5833   kc. = MFM Frequency
```

A further illustration involves a harmonic fraction with a numerator greater than 1. Assume Transmitter Frequency to be 11,820 kc.; Table 1A shows that a harmonic ratio of 3/14 yields an MFM Frequency closest to 2500 kc. Multiply Transmitter Frequency by 3, the numerator of the harmonic ratio, then divide the result by 14, the denominator of the fraction; the answer is MFM Frequency, 2532.857 kc.

Example:

Transmitter Frequency . . 11,820 kc. Harmonic Ratio . . **3/14**

$$\text{MFM Frequency} = 11{,}820 \text{ kc.} \times 3/14 = \frac{11{,}820 \text{ kc.} \times 3}{14};$$

$$\text{MFM Frequency} = \frac{35{,}460 \text{ kc.}}{14}$$

MFM Frequency = 2532.857 kc.

```
        2 532.857+kc.
   14 | 35,460.000  kc.
        28
         74
         70
          46
          42
           40
           28
            12 0
            11 2
                80
                70
                100
                 98
```

To illustrate the use of Table 3, for frequencies above 56 mc., assume Transmitter Frequency is 157,530 kc. In the left-hand column of Table 3, find the bracket (156,240 to 158,770 kc.) which contains this frequency; opposite in the right-hand column obtain 63, the MFM harmonic. Divide Transmitter Frequency by the MFM harmonic, and the answer, 2500.476 kc. is the MFM Frequency.

Example:

Transmitter Frequency . . 157,530 kc. MFM Harmonic . .**63**

MFM Frequency = 157,530 kc. ÷ 63

2 500.476+kc. = **MFM Frequency**

```
        2 500.476+kc.
   63 | 157,530.000 kc.
        126
         31 5
         31 5
           030 0
            25 2
             4 80
             4 41
               390
               378
```

5.09 Given MFM Frequency, to find Dial Reading (by proportion)

Take MFM Frequency as 2459.583 kc. and write it on a work sheet. From the Sample Calibration Table put down 2450 kc., the calibrated frequency next lower than the MFM Frequency, and also the corresponding Dial Reading, 2966.3, and the Dial Difference, 245.8.

MFM Frequency . . . . .2459.583 kc.
Calibration point . . . . .2450.000 kc. = 2966.3 dial div.
9.583 kc.

Dial Difference . . . . **245.8** dial div.

The dial difference is the number of dial divisions to the next 10-kc. calibrated point, so:

10 kc. = 245.8 dial divisions, and
1 kc. = 24.58 dial divisions. Then

9.583 kc. = 9.583 x 24.58 = 235.55 dial divisions.

Add these dial divisions to the ones for 2450 kc., and the answer is the MFM dial reading for 2459.583 kc.:

Calibration point . . .	2450.000 kc.	=	2966.3 dial div.
	9.583 kc.	=	235.55 dial div.
MFM Frequency =	2459.583 kc.	=	3201.85 dial div.

5.10 Given Dial Reading, to find MFM Frequency (by proportion)

Suppose the MFM Dial Reading is 3201.8 dial divisions; write it on a work sheet. From the Sample Calibration Table, obtain the next lower calibrated dial reading, 2966.3 div., the corresponding frequency, 2450 kc., and the Dial Difference, 245.8 div.:

MFM Dial Reading	3201.8 dial div.	
Calibration Point	2966.3 dial div.	= 2450.000 kc.
	235.5 dial div.	

By subtraction, the MFM Dial Reading is 235.5 divisions higher than the 2450-kc. reading. For a Dial Difference of 245.8 divisions the frequency is 10 kc. higher. By proportion,

$$\frac{235.5 \text{ div.}}{245.8 \text{ div.}} \times 10 \text{ kc.} = 9.5809 \text{ kc.}$$

Rewriting the calibration-point figures, and adding the increases for both dial divisions and kc., gives the answer for MFM Frequency, 2459.5809 kc., or 2459.581 kc. in round numbers:

Calibration point ..	2966.3 dial div.	= 2450.0000 kc.
	+ 235.5 dial div.	= + 9.5809 kc.
MFM Dial Reading	= 3201.8 dial div.	= 2459.5809 kc. = MFM Freq.

This figure for MFM Frequency would check more closely with previous figures if all computations had been carried out to more decimal places.

5.11 Formulas

Various quantities connected with frequency measurements and the MFM can be calculated by means of the following formulas:

Dial Constant { cycles per dial division, at MFM Frequency } $= \dfrac{10{,}000}{\text{Dial Diff.}}$ (1)

Dial Constant { cycles per dial division, at Transmitter Frequency } $= \dfrac{10{,}000}{\text{Dial Diff.} \times \text{Harmonic Ratio (fraction)}}$ (2)

Dial Constant { per cent frequency change per dial division, at any frequency } $= \dfrac{1{,}000}{\text{Dial Diff.} \times \text{MFM Frequency (kc.)}}$ (3)

Transmitter Deviation (cycles per second) .... $= \%\ \text{Deviation} \times \text{Transmitter Frequency (kc.)} \times 10$ (4)

Transmitter Deviation (per cent) .... $= \dfrac{\text{Cycles Deviation}}{\text{Transmitter Frequency (kc.)} \times 10}$ (5)

TABLE 3. For Converting Transmitter Frequency, 56,000 to 175,000 KC., to MFM Frequency.

Divide Transmitter Frequency by the indicated MFM Harmonic

Transmitter Frequency, KC.	MFM Harmonic
53,750 to 56,250	22
56,250 to 58,750	23
58,750 to 61,250	24
61,250 to 63,750	25
63,750 to 66,250	26
66,250 to 68,750	27
68,750 to 71,250	28
71,250 to 73,750	29
73,750 to 76,250	30
76,250 to 78,750	31
78,750 to 81,250	32
81,250 to 83,750	33
83,750 to 86,250	34
86,250 to 88,750	35
88,750 to 91,250	36
91,250 to 93,750	37
93,750 to 96,250	38
96,250 to 98,750	39
98,750 to 101,250	40
101,250 to 103,750	41
103,750 to 106,250	42

Transmitter Frequency, KC.	MFM Harmonic
106,250 to 108,750	43
108,750 to 111,250	44
111,250 to 113,760	45
113,760 to 116,260	46
116,260 to 118,750	47
118,750 to 121,250	48
121,250 to 123,750	49
123,750 to 126,260	50
126,260 to 128,750	51
128,750 to 131,250	52
131,250 to 133,750	53
133,750 to 136,240	54
136,240 to 138,770	55
138,770 to 141,250	56
141,250 to 143,765	57
143,765 to 146,240	58
146,240 to 148,740	59
148,740 to 151,270	60
151,270 to 153,740	61
153,740 to 156,240	62

Transmitter Frequency, KC.	MFM Harmonic
156,240 to 158,770	63
158,770 to 161,240	64
161,240 to 163,750	65
163,750 to 166,250	66
166,250 to 168,775	67
168,775 to 171,250	68
171,250 to 173,750	69
173,750 to 175,000	70

Examples for Taxicab Channels

Transmitter KC.	MFM Harmonic	MFM Frequency
152,270	61	2496.230
152,330	61	2497.213
152,390	61	2498.197
152,450	61	2499.180
157,530	63	2500.476
157,590	63	2501.429
157,650	63	2502.381
157,710	63	2503.333

For Table 1, See Next Page.

Table 1. For converting Transmitter Frequency (Xmtr KC.) to MFM Frequency

Harmonic ratio in **heavy type**, Sec. 1A, is printed as decimal figure to facilitate cross-reading into Sec. 1B; and as exact fraction to indicate transmitter-harmonic and MFM-harmonic numbers.

XMTR. KC.	SEC. 1A. MFM FREQUENCY, KC.; Harmonic Ratio in **Heavy Type**							
	24.0*24/1	**23.0*23/1**	**22.0*22/1**	**21.0*21/1**				
100	2400.000	2300.000	2200.000	2100.000	**20.0*20/1**			
10	2640.000	2530.000	2420.000	2310.000	2200.000	**19.0*19/1**	**18.0*18/1**	
20	2880.000	2760.000	2640.000	2520.000	2400.000	2280.000	2160.000	**17.0*17/1**
30	**16.0*16/1**		2860.000	2730.000	2600.000	2470.000	2340.000	2210.000
40	2240.000				2800.000	2660.000	2520.000	2380.000
		15.0*15/1						
150	2400.000	2250.000	**14.0*14/1**			2850.000	2700.000	2550.000
60	2560.000	2400.000	2240.000	**13.0*13/1**			2880.000	2720.000
70	2720.000	2550.000	2380.000	2210.000				
80		2700.000	2520.000	2340.000	**12.0*12/1**			
90		2850.000	2660.000	2470.000	2280.000			
	11.0*11/1							
200	2200.000	**10.5*21/2**	2800.000	2600.000	2400.000			
10	2310.000	2205.000	**10.0*10/1**	2730.000	2520.000			
20	2420.000	2310.000	2200.000		2640.000			
30	2530.000	2415.000	2300.000	**9.50*19/2**	2760.000			
40	2640.000	2520.000	2400.000	2280.000				
					9.00*9/1			
250	2750.000	2625.000	2500.000	2375.000	2250.000			
60	**8.50*17/2**	2730.000	2600.000	2470.000	2340.000			
70	2295.000	**8.00*8/1**	2700.000	2565.000	2430.000			
80	2380.000	2240.000	2800.000	2660.000	2520.000			
90	2465.000	2320.000		2755.000	2610.000			
			7.50*15/2					
300	2550.000	2400.000	2250.000		2700.000			
10	2635.000	2480.000	2325.000	**7.00*7/1**	2790.000			
20	2720.000	2560.000	2400.000	2240.000				
30		2640.000	2475.000	2310.000				
40		2720.000	2550.000	2380.000				
					6.50*13/2			
350			2625.000	2450.000	2275.000			
60			2700.000	2520.000	2340.000			
70	**6.00*6/1**		2775.000	2590.000	2405.000			
80	2280.000			2660.000	2470.000			
90	2340.000			2730.000	2535.000			
400	2400.000	**5.50*11/2**			2600.000			
10	2460.000	2255.000			2665.000			
20	2520.000	2310.000	**5.33*16/3**		2730.000			
30	2580.000	2365.000	2293.333					
40	2640.000	2420.000	2346.667					
				5.00*5/1				
450	2700.000	2475.000	2400.000	2250.000				
60	2760.000	2530.000	2453.333	2300.000				
70		2585.000	2506.667	2350.000				
80		2640.000	2560.000	2400.000	**4.67*14/3**			
90		2695.000	2613.333	2450.000	2286.667			
500	**4.50*9/2**	2750.000	2666.667	2500.000	2333.333			
10	2295.000		2720.000	2550.000	2380.000			
20	2340.000	**4.33*13/3**		2600.000	2426.667			
30	2385.000	2296.667		2650.000	2473.333			
40	2430.000	2340.000		2700.000	2520.000			
550	2475.000	2383.333		2750.000	2566.667			
60	2520.000	2426.667	**4.00*4/1**		2613.333			
70	2565.000	2470.000	2280.000		2660.000			
80	2610.000	2513.333	2320.000		2706.667			
90	2655.000	2556.667	2360.000					
600	2700.000	2600.000	2400.000					
10	2745.000	2643.333	2440.000	**3.67*11/3**				
20		2686.667	2480.000	2273.333				
30		2730.000	2520.000	2310.000				
40			2560.000	2346.667				
					3.50*7/2			
650			2600.000	2383.333	2275.000			
60			2640.000	2420.000	2310.000			
70	**3.33*10/3**		2680.000	2456.667	2345.000			
80	2266.667		2720.000	2493.333	2380.000			
90	2300.000			2530.000	2415.000			
		3.25*13/4						
700	2333.333	2275.000		2566.667	2450.000			
10	2366.667	2307.500		2603.333	2485.000			
20	2400.000	2340.000		2640.000	2520.000			
30	2433.333	2372.500		2676.667	2555.000			
40	2466.667	2405.000		2713.333	2590.000			
750	2500.000	2437.500	**3.00*3/1**		2625.000			
60	2533.333	2470.000	2280.000		2660.000			
70	2566.667	2502.500	2310.000		2695.000			
80	2600.000	2535.000	2340.000		2730.000			
90	2633.333	2567.500	2370.000					
800	2666.667	2600.000	2400.000					
10	2700.000	2632.500	2430.000					
20	2733.333	2665.000	2460.000	**2.75*11/4**				
30		2697.500	2490.000	2282.500				
40		2730.000	2520.000	2310.000				

XMTR. KC.	SEC. 1B. MFM FREQUENCY, KC.; Harmonic Ratio in **Heavy Type**									
	24.0	**23.0**	**22.0**	**21.0**	**20.0**	**19.0**	**18.0**	**17.0**	**16.0**	**15.0**
9.	216.000	207.000	198.000	189.000	180.000	171.000	162.000	153.000	144.000	135.000
8.	192.000	184.000	176.000	168.000	160.000	152.000	144.000	136.000	128.000	120.000
7.	168.000	161.000	154.000	147.000	140.000	133.000	126.000	119.000	112.000	105.000
6.	144.000	138.000	132.000	126.000	120.000	114.000	108.000	102.000	96.000	90.000
5.	120.000	115.000	110.000	105.000	100.000	95.000	90.000	85.000	80.000	75.000
4.	96.000	92.000	88.000	84.000	80.000	76.000	72.000	68.000	64.000	60.000
3.	72.000	69.000	66.000	63.000	60.000	57.000	54.000	51.000	48.000	45.000
2.	48.000	46.000	44.000	42.000	40.000	38.000	36.000	34.000	32.000	30.000
1.	24.000	23.000	22.000	21.000	20.000	19.000	18.000	17.000	16.000	15.000
.5	12.000	11.500	11.000	10.500	10.000	9.500	9.000	8.500	8.000	7.500
	14.0	**13.0**	**12.0**	**11.0**	**10.5**	**10.0**	**9.50**	**9.00**	**8.50**	**8.00**
9.	126.000	117.000	108.000	99.000	94.500	90.000	85.500	81.000	76.500	72.000
8.	112.000	104.000	96.000	88.000	84.000	80.000	76.000	72.000	68.000	64.000
7.	98.000	91.000	84.000	77.000	73.500	70.000	66.500	63.000	59.500	56.000
6.	84.000	78.000	72.000	66.000	63.000	60.000	57.000	54.000	51.000	48.000
5.	70.000	65.000	60.000	55.000	52.500	50.000	47.500	45.000	42.500	40.000
4.	56.000	52.000	48.000	44.000	42.000	40.000	38.000	36.000	34.000	32.000
3.	42.000	39.000	36.000	33.000	31.500	30.000	28.500	27.000	25.500	24.000
2.	28.000	26.000	24.000	22.000	21.000	20.000	19.000	18.000	17.000	16.000
1.	14.000	13.000	12.000	11.000	10.500	10.000	9.500	9.000	8.500	8.000
.5	7.000	6.500	6.000	5.500	5.250	5.000	4.750	4.500	4.250	4.000
	7.50	**7.00**	**6.50**	**6.00**	**5.50**	**5.33**	**5.00**	**4.67**	**4.50**	**4.33**
9.	67.500	63.000	58.500	54.000	49.500	48.000	45.000	42.000	40.500	39.000
8.	60.000	56.000	52.000	48.000	44.000	42.667	40.000	37.333	36.000	34.667
7.	52.500	49.000	45.500	42.000	38.500	37.333	35.000	32.667	31.500	30.333
6.	45.000	42.000	39.000	36.000	33.000	32.000	30.000	28.000	27.000	26.000
5.	37.500	35.000	32.500	30.000	27.500	26.667	25.000	23.333	22.500	21.667
4.	30.000	28.000	26.000	24.000	22.000	21.333	20.000	18.667	18.000	17.333
3.	22.500	21.000	19.500	18.000	16.500	16.000	15.000	14.000	13.500	13.000
2.	15.000	14.000	13.000	12.000	11.000	10.667	10.000	9.333	9.000	8.667
1.	7.500	7.000	6.500	6.000	5.500	5.333	5.000	4.667	4.500	4.333
.5	3.750	3.500	3.250	3.000	2.750	2.667	2.500	2.333	2.250	2.167
	4.00	**3.67**	**3.50**	**3.33**	**3.25**	**3.00**	**2.75**			
9.	36.000	33.000	31.500	30.000	29.250	27.000	24.750			
8.	32.000	29.333	28.000	26.667	26.000	24.000	22.000			
7.	28.000	25.667	24.500	23.333	22.750	21.000	19.250			
6.	24.000	22.000	21.000	20.000	19.500	18.000	16.500			
5.	20.000	18.333	17.500	16.667	16.250	15.000	13.750			
4.	16.000	14.667	14.000	13.333	13.000	12.000	11.000			
3.	12.000	11.000	10.500	10.000	9.750	9.000	8.250			
2.	8.000	7.333	7.000	6.667	6.500	6.000	5.500			
1.	4.000	3.667	3.500	3.333	3.250	3.000	2.750			
.5	2.000	1.833	1.750	1.667	1.625	1.500	1.375			

Table 1 (Cont.). For converting Transmitter Frequency (Xmtr. KC.) to MFM Frequency

XMTR. KC.	SEC. 1A. MFM FREQUENCY, KC.; Harmonic Ratio in **Heavy Type**							
			3.00*3/1	**2.75*11/4**				
850			2550.000	2337.500	**2.67*8/3**			
60			2580.000	2365.000	2293.333			
70			2610.000	2392.500	2320.000			
80			2640.000	2420.000	2346.667			
90			2670.000	2447.500	2373.333			
900	**2.50*5/2**		2700.000	2475.000	2400.000			
10	2275.000		2730.000	2502.500	2426.667			
20	2300.000			2530.000	2453.333			
30	2325.000			2557.500	2480.000			
40	2350.000			2585.000	2506.667			
950	2375.000			2612.500	2533.333			
60	2400.000			2640.000	2560.000			
70	2425.000	**2.33*7/3**		2667.500	2586.667			
80	2450.000	2286.667		2695.000	2613.333			
90	2475.000	2310.000		2722.500	2640.000			
1000	2500.000	2333.333			2666.667			
10	2525.000	2356.667	**2.25*9/4**		2693.333			
20	2550.000	2380.000	2295.000		2720.000			
30	2575.000	2403.333	2317.500	**2.20*11/5**				
40	2600.000	2426.667	2340.000	2288.000				
1050	2625.000	2450.000	2362.500	2310.000	**2.17*13/6**			
60	2650.000	2473.333	2385.000	2332.000	2296.667			
70	2675.000	2496.667	2407.500	2354.000	2318.333			
80	2700.000	2520.000	2430.000	2376.000	2340.000			
90	2725.000	2543.333	2452.500	2398.000	2361.667			
1100		2566.667	2475.000	2420.000	2383.333			
10		2590.000	2497.500	2442.000	2405.000			
20		2613.333	2520.000	2464.000	2426.667			
30	**2.00*2/1**	2636.667	2542.500	2486.000	2448.333			
40	2280.000	2660.000	2565.000	2508.000	2470.000			
1150	2300.000	2683.333	2587.500	2530.000	2491.667			
60	2320.000	2706.667	2610.000	2552.000	2513.333			
70	2340.000		2632.500	2574.000	2535.000			
80	2360.000		2655.000	2596.000	2556.667			
90	2380.000		2677.500	2618.000	2578.333			
1200	2400.000		2700.000	2640.000	2600.000			
10	2420.000		2722.500	2662.000	2621.667			
20	2440.000			2684.000	2643.333			
30	2460.000			2706.000	2665.000			
40	2480.000				2686.667			
		1.83*11/6						
1250	2500.000	2291.667			2708.333			
60	2520.000	2310.000	**1.80*9/5**					
70	2540.000	2328.333	2286.000					
80	2560.000	2346.667	2304.000					
90	2580.000	2365.000	2322.000					
1300	2600.000	2383.333	2340.000	**1.75*7/4**				
10	2620.000	2401.667	2358.000	2292.500				
20	2640.000	2420.000	2376.000	2310.000				
30	2660.000	2438.333	2394.000	2327.500				
40	2680.000	2456.667	2412.000	2345.000				
1350	2700.000	2475.000	2430.000	2362.500				
60	2720.000	2493.333	2448.000	2380.000	**1.67*5/3**			
70		2511.667	2466.000	2397.500	2283.333			
80		2530.000	2484.000	2415.000	2300.000			
90		2548.333	2502.000	2432.500	2316.667			
1400		2566.667	2520.000	2450.000	2333.333			
10		2585.000	2538.000	2467.500	2350.000			
20	**1.60*8/5**	2603.333	2556.000	2485.000	2366.667			
30	2288.000	2621.667	2574.000	2502.500	2383.333			
40	2304.000	2640.000	2592.000	2520.000	2400.000			
1450	2320.000	2658.333	2610.000	2537.500	2416.667			
60	2336.000	2676.667	2628.000	2555.000	2433.333			
70	2352.000	2695.000	2646.000	2572.500	2450.000			
80	2368.000	2713.333	2664.000	2590.000	2466.667			
90	2384.000		2682.000	2607.500	2483.333			
						1.50*3/2		
1500	2400.000		2700.000	2625.000	2500.000	2250.000	**1.40*7/5**	
1600	2560.000		2880.000	2800.000	2666.667	2400.000	2240.000	**1.33*4/3**
1700	2720.000	**1.25*5/4**			2833.333	2550.000	2380.000	2266.667
1800		2250.000	**1.20*6/5**	**1.17*7/6**		2700.000	2520.000	2400.000
1900		2375.000	2280.000	2216.667		2850.000	2660.000	2533.333
	1.14*8/7				**1.12*9/8**	**1.11*10/9**		
2000	2285.714	2500.000	2400.000	2333.333	2250.000	2222.222	2800.000	2666.667
100	2400.000	2625.000	2520.000	2450.000	2362.500	2333.333	**1.00*1/1**	2800.000
200	2514.286	2750.000	2640.000	2566.667	2475.000	2444.444	2200.000	
300	2628.571		2760.000	2683.333	2587.500	2555.556	2300.000	
400	2742.857			2800.000	2700.000	2666.667	2400.000	
	.889*8/9							**.900*9/10**
2500	2222.222	**.875*7/8**	**.857*6/7**		2812.500	2777.778	2500.000	2250.000
600	2311.111	2275.000	2228.571	**.833*5/6**			2600.000	2340.000
700	2400.000	2362.500	2314.286	2250.000	**.800*4/5**		2700.000	2430.000
800	2488.889	2450.000	2400.000	2333.333	2240.000		2800.000	2520.000
900	2577.778	2537.500	2485.714	2416.667	2320.000			2610.000

XMTR. KC.	SEC. 1B. MFM FREQUENCY, KC.; Harmonic Ratio in **Heavy Type**									
	3.00	**2.75**	**2.67**	**2.50**	**2.33**	**2.25**	**2.20**	**2.17**	**2.00**	**1.83**
9.	27.000	24.750	24.000	22.500	21.000	20.250	19.800	19.500	18.000	16.500
8.	24.000	22.000	21.333	20.000	18.667	18.000	17.600	17.333	16.000	14.667
7.	21.000	19.250	18.667	17.500	16.333	15.750	15.400	15.167	14.000	12.833
6.	18.000	16.500	16.000	15.000	14.000	13.500	13.200	13.000	12.000	11.000
5.	15.000	13.750	13.333	12.500	11.667	11.250	11.000	10.833	10.000	9.167
4.	12.000	11.000	10.667	10.000	9.333	9.000	8.800	8.667	8.000	7.333
3.	9.000	8.250	8.000	7.500	7.000	6.750	6.600	6.500	6.000	5.500
2.	6.000	5.500	5.333	5.000	4.667	4.500	4.400	4.333	4.000	3.667
1.	3.000	2.750	2.667	2.500	2.333	2.250	2.200	2.167	2.000	1.833
.5	1.500	1.375	1.333	1.250	1.167	1.125	1.100	1.083	1.000	.917
	1.80	**1.75**	**1.67**	**1.60**	**1.50**	**1.40**	**1.33**	**1.25**	**1.20**	**1.17**
90.	162.000	157.500	150.000	144.000	135.000	126.000	120.000	112.500	108.000	105.000
80.	144.000	140.000	133.333	128.000	120.000	112.000	106.667	100.000	96.000	93.333
70.	126.000	122.500	116.667	112.000	105.000	98.000	93.333	87.500	84.000	81.667
60.	108.000	105.000	100.000	96.000	90.000	84.000	80.000	75.000	72.000	70.000
50.	90.000	87.500	83.333	80.000	75.000	70.000	66.667	62.500	60.000	58.333
40.	72.000	70.000	66.667	64.000	60.000	56.000	53.333	50.000	48.000	46.667
30.	54.000	52.500	50.000	48.000	45.000	42.000	40.000	37.500	36.000	35.000
20.	36.000	35.000	33.333	32.000	30.000	28.000	26.667	25.000	24.000	23.333
10.	18.000	17.500	16.667	16.000	15.000	14.000	13.333	12.500	12.000	11.667
9.	16.200	15.750	15.000	14.400	13.500	12.600	12.000	11.250	10.800	10.500
8.	14.400	14.000	13.333	12.800	12.000	11.200	10.667	10.000	9.600	9.333
7.	12.600	12.250	11.667	11.200	10.500	9.800	9.333	8.750	8.400	8.167
6.	10.800	10.500	10.000	9.600	9.000	8.400	8.000	7.500	7.200	7.000
5.	9.000	8.750	8.333	8.000	7.500	7.000	6.667	6.250	6.000	5.833
4.	7.200	7.000	6.667	6.400	6.000	5.600	5.333	5.000	4.800	4.667
3.	5.400	5.250	5.000	4.800	4.500	4.200	4.000	3.750	3.600	3.500
2.	3.600	3.500	3.333	3.200	3.000	2.800	2.667	2.500	2.400	2.333
1.	1.800	1.750	1.667	1.600	1.500	1.400	1.333	1.250	1.200	1.167
.5	.900	.875	.833	.800	.750	.700	.667	.625	.600	.583
	1.14	**1.12**	**1.11**	**.900**	**.889**	**.875**	**.857**	**.833**	**.800**	
90.	102.857	101.250	100.000	81.000	80.000	78.750	77.143	75.000	72.000	
80.	91.429	90.000	88.889	72.000	71.111	70.000	68.571	66.667	64.000	
70.	80.000	78.750	77.778	63.000	62.222	61.250	60.000	58.333	56.000	
60.	68.571	67.500	66.667	54.000	53.333	52.500	51.429	50.000	48.000	
50.	57.143	56.250	55.556	45.000	44.444	43.750	42.857	41.667	40.000	
40.	45.714	45.000	44.444	36.000	35.556	35.000	34.286	33.333	32.000	
30.	34.286	33.750	33.333	27.000	26.667	26.250	25.714	25.000	24.000	
20.	22.857	22.500	22.222	18.000	17.778	17.500	17.143	16.667	16.000	
10.	11.429	11.250	11.111	9.000	8.889	8.750	8.571	8.333	8.000	
9.	10.286	10.125	10.000	8.100	8.000	7.875	7.714	7.500	7.200	
8.	9.143	9.000	8.889	7.200	7.111	7.000	6.857	6.667	6.400	
7.	8.000	7.875	7.778	6.300	6.222	6.125	6.000	5.833	5.600	
6.	6.857	6.750	6.667	5.400	5.333	5.250	5.143	5.000	4.800	
5.	5.714	5.625	5.556	4.500	4.444	4.375	4.286	4.167	4.000	
4.	4.571	4.500	4.444	3.600	3.556	3.500	3.429	3.333	3.200	
3.	3.429	3.375	3.333	2.700	2.667	2.625	2.571	2.500	2.400	
2.	2.286	2.250	2.222	1.800	1.778	1.750	1.714	1.667	1.600	
1.	1.143	1.125	1.111	.900	.889	.875	.857	.833	.800	
.5	.571	.562	.556	.450	.444	.438	.429	.417	.400	

Table 1 (Cont.). For converting Transmitter Frequency (Xmtr. KC) to MFM Frequency

SEC. 1A. MFM FREQUENCY, KC.; Harmonic Ratio in **Heavy Type**

XMTR. KC.								
	.889*8/9	**.875*7/8**	**.857*6/7**	**.833*5/6**	**.800*4/5**	**.750*3/4**		**.900*3/10**
3000	2666.667	2625.000	2571.429	2500.000	2400.000	2250.000		2700.000
100	2755.556	2712.500	2657.143	2583.333	2480.000	2325.000	**.714*5/7**	2790.000
200			2742.857	2666.667	2560.000	2400.000	2285.714	
300	**.667*2/3**			2750.000	2640.000	2475.000	2357.143	
400	2266.667				2720.000	2550.000	2428.571	
3500	2333.333	**.625*5/8**				2625.000	2500.000	
600	2400.000	2250.000				2700.000	2571.429	
700	2466.667	2312.500	**.600*3/5**			2775.000	2642.857	
800	2533.333	2375.000	2280.000				2714.286	
900	2600.000	2437.500	2340.000					
				.571*4/7				
4000	2666.667	2500.000	2400.000	2285.714	**.556*5/9**			
100	2733.333	2562.500	2460.000	2342.857	2277.778	**.545*6/11**		
200		2625.000	2520.000	2400.000	2333.333	2290.909		
300		2687.500	2580.000	2457.143	2388.889	2345.455		
400		2750.000	2640.000	2514.286	2444.444	2400.000		
	.500*1/2							
4500	2250.000		2700.000	2571.429	2500.000	2454.545		
600	2300.000		2760.000	2628.571	2555.556	2509.091		
700	2350.000			2685.714	2611.111	2563.636		
800	2400.000			2742.857	2666.667	2618.182		
900	2450.000				2722.222	2672.727		
		454*5/11						
5000	2500.000	2272.727	**.444*4/9**			2727.273		
100	2550.000	2318.182	2266.667					
200	2600.000	2363.636	2311.111	**.429*3/7**				
300	2650.000	2409.091	2355.556	2271.429				
400	2700.000	2454.545	2400.000	2314.286				
5500	2750.000	2500.000	2444.444	2357.143				
600		2545.455	2488.889	2400.000	**400*2/5**			
700		2590.909	2533.333	2442.857	2280.000			
800		2636.364	2577.778	2485.714	2320.000			
900		2681.818	2622.222	2528.571	2360.000			
6000	**.375*3/8**	2727.273	2666.667	2571.429	2400.000			
100	2287.500		2711.111	2614.286	2440.000			
200	2325.000	**364*4/11**		2657.143	2480.000			
300	2362.500	2290.909		2700.000	2520.000			
400	2400.000	2327.273		2742.857	2560.000			
6500	2437.500	2363.636			2600.000			
600	2475.000	2400.000			2640.000			
700	2512.500	2436.364	**.333*1/3**		2680.000			
800	2550.000	2472.727	2266.667		2720.000			
900	2587.500	2509.091	2300.000					
7000	2625.000	2545.455	2333.333					
100	2662.500	2581.818	2366.667					
200	2700.000	2618.182	2400.000					
300	2737.500	2654.545	2433.333	**.308*4/13**				
400		2690.909	2466.667	2276.923				
7500	**.300*3/10**	2727.273	2500.000	2307.692				
600	2280.000		2533.333	2338.462				
700	2310.000		2566.667	2369.231				
800	2340.000		2600.000	2400.000				
900	2370.000		2633.333	2430.769				
		.286*2/7						
8000	2400.000	2285.714	2666.667	2461.538				
100	2430.000	2314.286	2700.000	2492.308				
200	2460.000	2342.857	2733.333	2523.077				
300	2490.000	2371.429	**.273*3/11**	2553.846				
400	2520.000	2400.000	2290.909	2584.615				
8500	2550.000	2428.571	2318.182	2615.385				
600	2580.000	2457.143	2345.455	2646.154				
700	2610.000	2485.714	2372.727	2676.923				
800	2640.000	2514.286	2400.000	2707.692				
900	2670.000	2542.857	2427.273	2738.462				
9000	2700.000	2571.429	2454.545	**.250*1/4**				
100	2730.000	2600.000	2481.818	2275.000				
200		2628.571	2509.091	2300.000				
300		2657.143	2536.364	2325.000				
400		2685.714	2563.636	2350.000				
9500		2714.286	2590.909	2375.000				
600			2618.182	2400.000				
700			2645.455	2425.000				
800	**231*3/13**		2672.727	2150.000				
900	2284.615		2700.000	2475.000				
10000	2307.692		2727.273	2500.000				
100	2330.769			2525.000				
200	2353.846	**.222*2/9**		2550.000				
300	2376.923	2288.889		2575.000				
400	2400.000	2311.111		2600.000				
10500	2423.077	2333.333		2625.000				
600	2446.154	2355.556	**214*3/14**	2650.000				
700	2469.231	2377.778	2292.857	2675.000				
800	2492.308	2400.000	2314.286	2700.000				
900	2515.385	2422.222	2335.714	2725.000				

SEC. 1B. MFM FREQUENCY, KC.; Harmonic Ratio in **Heavy Type**

XMTR. KC.										
	.900	**.889**	**.875**	**.857**	**.833**	**.800**	**.750**	**.714**	**.667**	**.625**
90.	81.000	80.000	78.750	77.143	75.000	72.000	67.500	64.286	60.000	56.250
80.	72.000	71.111	70.000	68.571	66.667	64.000	60.000	57.143	53.333	50.000
70.	63.000	62.222	61.250	60.000	58.333	56.000	52.500	50.000	46.667	43.750
60.	54.000	53.333	52.500	51.429	50.000	48.000	45.000	42.857	40.000	37.500
50.	45.000	44.444	43.750	42.857	41.667	40.000	37.500	35.714	33.333	31.250
40.	36.000	35.556	35.000	34.286	33.333	32.000	30.000	28.571	26.667	25.000
30.	27.000	26.667	26.250	25.714	25.000	24.000	22.500	21.429	20.000	18.750
20.	18.000	17.778	17.500	17.143	16.667	16.000	15.000	14.286	13.333	12.500
10.	9.000	8.889	8.750	8.571	8.333	8.000	7.500	7.143	6.667	6.250
9.	8.100	8.000	7.875	7.714	7.500	7.200	6.750	6.429	6.000	5.625
8.	7.200	7.111	7.000	6.857	6.667	6.400	6.000	5.714	5.333	5.000
7.	6.300	6.222	6.125	6.000	5.833	5.600	5.250	5.000	4.667	4.375
6.	5.400	5.333	5.250	5.143	5.000	4.800	4.500	4.286	4.000	3.750
5.	4.500	4.444	4.375	4.286	4.167	4.000	3.750	3.571	3.333	3.125
4.	3.600	3.556	3.500	3.429	3.333	3.200	3.000	2.857	2.667	2.500
3.	2.700	2.667	2.625	2.571	2.500	2.400	2.250	2.143	2.000	1.875
2.	1.800	1.778	1.750	1.714	1.667	1.600	1.500	1.429	1.333	1.250
1.	.900	.889	.875	.857	.833	.800	.750	.714	.667	.625
.5	450	.444	.438	.429	.417	.400	.375	.357	.333	.312
	600	**571**	**.556**	**.545**	**.500**	**.454**	**.444**	**.429**	**.400**	**.375**
90.	54.000	51.429	50.000	49.091	45.000	40.909	40.000	38.571	36.000	33.750
80.	48.000	45.714	44.444	43.636	40.000	36.364	35.556	34.286	32.000	30.000
70.	42.000	40.000	38.889	38.182	35.000	31.818	31.111	30.000	28.000	26.250
60.	36.000	34.286	33.333	32.727	30.000	27.273	26.667	25.714	24.000	22.500
50.	30.000	28.571	27.778	27.273	25.000	22.727	22.222	21.429	20.000	18.750
40.	24.000	22.857	22.222	21.818	20.000	18.182	17.778	17.143	16.000	15.000
30.	18.000	17.143	16.667	16.364	15.000	13.636	13.333	12.857	12.000	11.250
20	12.000	11.429	11.111	10.909	10.000	9.091	8.889	8.571	8.000	7.500
10.	6.000	5.714	5.556	5.455	5.000	4.545	4.444	4.286	4.000	3.750
9.	5.400	5.143	5.000	4.909	4.500	4.091	4.000	3.857	3.600	3.375
8	4.800	4.571	4.444	4.364	4.000	3.636	3.556	3.429	3.200	3.000
7.	4.200	4.000	3.889	3.818	3.500	3.182	3.111	3.000	2.800	2.625
6.	3.600	3.429	3.333	3.273	3.000	2.727	2.667	2.571	2.400	2.250
5.	3.000	2.857	2.778	2.727	2.500	2.273	2.222	2.143	2.000	1.875
4.	2.400	2.286	2.222	2.182	2.000	1.818	1.778	1.714	1.600	1.500
3.	1.800	1.714	1.667	1.636	1.500	1.364	1.333	1.286	1.200	1.125
2.	1.200	1.143	1.111	1.091	1.000	.909	.889	.857	.800	.750
1.	.600	.571	.556	.545	.500	.455	.444	.429	.400	.375
.5	.300	.286	.278	.273	.250	.227	.222	.214	.200	.188
	.364	**.333**	**.308**	**.300**	**.286**	**.273**	**.250**	**.231**	**.222**	**.214**
90.	32.727	30.000	27.692	27.000	25.714	24.545	22.500	20.769	20.000	19.286
80.	29.091	26.667	24.615	24.000	22.857	21.818	20.000	18.462	17.778	17.143
70.	25.455	23.333	21.538	21.000	20.000	19.091	17.500	16.154	15.556	15.000
60.	21.818	20.000	18.462	18.000	17.143	16.364	15.000	13.846	13.333	12.857
50.	18.182	16.667	15.385	15.000	14.286	13.636	12.500	11.538	11.111	10.714
40.	14.545	13.333	12.308	12.000	11.429	10.909	10.000	9.231	8.889	8.571
30.	10.909	10.000	9.231	9.000	8.571	8.182	7.500	6.923	6.667	6.429
20.	7.273	6.667	6.154	6.000	5.714	5.455	5.000	4.615	4.444	4.286
10.	3.636	3.333	3.077	3.000	2.857	2.727	2.500	2.308	2.222	2.143
9.	3.273	3.000	2.769	2.700	2.571	2.455	2.250	2.077	2.000	1.929
8.	2.909	2.667	2.462	2.400	2.286	2.182	2.000	1.846	1.778	1.714
7.	2.545	2.333	2.154	2.100	2.000	1.909	1.750	1.615	1.556	1.500
6.	2.182	2.000	1.846	1.800	1.714	1.636	1.500	1.385	1.333	1.286
5.	1.818	1.667	1.538	1.500	1.429	1.364	1.250	1.154	1.111	1.071
4.	1.455	1.333	1.231	1.200	1.143	1.091	1.000	.923	.889	.857
3.	1.091	1.000	.923	.900	.857	.818	.750	.692	.667	.643
2.	.727	.667	.615	.600	.571	.545	.500	.462	.444	.429
1.	.364	.333	.308	.300	.286	.273	.250	.231	.222	.214
.5	.182	.167	.154	.150	.143	.136	.125	.115	.111	.107

Table 1 (Cont.). For Converting Transmitter Frequency (Xmtr. KC.) to MFM Frequency

XMTR. KC.	SEC. 1A. MFM FREQUENCY, KC.; Harmonic Ratio in **Heavy Type**				
	.231*3/13	**.222*2/9**	**.214*3/14**		
11000	2538.462	2444.444	2357.143		
100	2561.538	2466.667	2378.571		
200	2584.615	2488.889	2400.000		
300	2607.692	2511.111	2421.429	**.200*1/5**	
400	2630.769	2533.333	2442.857	2280.000	
11500	2653.846	2555.556	2464.286	2300.000	
600	2676.923	2577.778	2485.714	2320.000	
700	2700.000	2600.000	2507.143	2340.000	
800	2723.077	2622.222	2528.571	2360.000	
900		2644.444	2550.000	2380.000	
12000		2666.667	2571.429	2400.000	
100	**.188*3/16**	2688.889	2592.857	2420.000	
200	2287.500	2711.111	2614 286	2440.000	
300	2306.250		2635.714	2460.000	
400	2325.000		2657.143	2480.000	
12500	2343.750	**.182*2/11**	2678.571	2500.000	
600	2362.500	2290.909	2700.000	2520.000	
700	2381.250	2309.091	2721.429	2540.000	
800	2400.000	2327.273		2560.000	
900	2418.750	2345.455		2580.000	
13000	2437.500	2363.636		2600.000	
100	2456.250	2381.818		2620.000	
200	2475.000	2400.000		2640.000	
300	2493.750	2418.182		2660.000	
400	2512.500	2436.364		2680.000	
13500	2531.250	2454.545		2700.000	
600	2550.000	2472.727	**.167*1/6**	2720.000	
700	2568.750	2490.909	2283.333		
800	2587.500	2509.091	2300.000		
900	2606.250	2527.273	2316.667		
14000	2625.000	2545.455	2333 333		
100	2643.750	2563.636	2350.000		
200	2662.500	2581.818	2366.667		
300	2681.250	2600.000	2383.333		
400	2700.000	2618.182	2400.000		
14500	2718.750	2636.364	2416.667		
600		2654.545	2433.333		
700		2672.727	2450.000		
800		2690.909	2466.667	**.154*2/13**	
900		2709.091	2483.333	2292.308	
15000			2500.000	2307.692	**.143*1/7**
16000	**.133*2/15**		2666.667	2461.538	2285.714
17000	2266.667	**.125*1/8**	2833.333	2615.385	2428.571
18000	2400.000	2250.000	**.118*2/17**	2769.231	2571.429
19000	2533.333	2375.000	2235.294		2714.286
				.111*1/9	
20000	2666.667	2500.000	2352.941	2222.222	**.105*2/19**
21000	2800.000	2625.000	2470.588	2333 333	2210.526
22000	**.100*1/10**	2750.000	2588.235	2444 444	2315.789
23000	2300.000		2705.882	2555 556	2421.053
24000	2400.000			2666.667	2526.316
		.091*1/11			
25000	2500.000	2272.727		2777.778	2631.579
26000	2600.000	2363.636	**.083*1/12**		2736.842
27000	2700.000	2454.545	2250.000		
28000	2800.000	2545.455	2333.333	**.077*1/13**	
29000		2636.364	2416.667	2230.769	
30000		2727.273	2500.000	2307.692	
31000			2583.333	2384.615	**071*1/14**
32000			2666.667	2461.538	2285.714
33000	**.067*1/15**		2750.000	2538.462	2357.143
34000	2266 667			2615.385	2428.571
35000	2333.333	**062*1/16**		2692.308	2500.000
36000	2400.000	2250 000		2769.231	2571.429
37000	2466 667	2312 500			2642.857
38000	2533.333	2375 000	**059*1/17**		2714.286
39000	2600.000	2437 500	2294.118		
40000	2666.667	2500.000	2352.941	**.056*1/18**	
41000	2733.333	2562.500	2411.765	2277.778	
42000		2625.000	2470.588	2333.333	**.053*1/19**
43000		2687.500	2529.412	2388.889	2263.158
44000		2750.000	2588.235	2444.444	2315.789
	.050*1/20				
45000	2250.000		2647.059	2500.000	2368.421
46000	2300.000		2705.882	2555.556	2421.053
47000	2350.000	**.048*1/21**		2611.111	2473.684
48000	2400.000	2285.714		2666.667	2526.316
49000	2450.000	2333.333		2722.222	2578.947
			.045*1/22		
50000	2500.000	2380.952	2272.727		2631.579
51000	2550.000	2428.571	2318.182	**.043*1/23**	2684.210
52000	2600.000	2476.190	2363.636	2260.870	2736.842
53000	2650.000	2523.810	2409.091	2304.318	
54000	2700.000	2571.429	2454 545	2347.826	
55000	2750.000	2619.048	2500.000	2391.304	
56000		2666.667	2545.455	2434.783	

XMTR. KC.	SEC. 1B. MFM FREQUENCY, KC.; Harmonic Ratio in **Heavy Type**					
	.231	**.222**	**.214**	**.200**	**.188**	**.182**
90.	20.769	20.000	19.286	18.000	16.875	16.364
80.	18.462	17.778	17.143	16.000	15.000	14.545
70.	16.154	15.556	15.000	14.000	13.125	12.727
60.	13.846	13.333	12.857	12.000	11.250	10.909
50.	11.538	11.111	10.714	10.000	9.375	9.091
40.	9.231	8.889	8.571	8.000	7.500	7.273
30.	6.923	6.667	6.429	6.000	5.625	5.455
20.	4.615	4.444	4.286	4.000	3.750	3.636
10.	2.308	2.222	2.143	2.000	1.875	1.818
9.	2.077	2.000	1.929	1.800	1.688	1.636
8.	1.846	1.778	1.714	1.600	1.500	1.455
7.	1.615	1.556	1.500	1.400	1.312	1.273
6.	1.385	1.333	1.286	1.200	1.125	1.091
5.	1.154	1.111	1.071	1.000	.938	.909
4.	.923	.889	.857	.800	.750	.727
3.	.692	.667	.643	.600	.562	.545
2.	.462	.444	.429	.400	.375	.364
1.	.231	.222	.214	.200	.188	.182
.5	.115	.111	.107	.100	.094	.091

XMTR. KC.	**.167**	**.154**	**.143**	**.133**	**.125**	**.118**	**.111**	**.105**	**.100**	**.031**	**.083**
900.	150.000	138.462	128.571	120.000	112.500	105.882	100.000	94.737	90.000	81.818	75.000
800.	133.333	123.077	114.286	106.667	100.000	94.118	88.889	84.211	80.000	72.727	66.667
700.	116.667	107.692	100.000	93.333	87.500	82.353	77.778	73.684	70.000	63.636	58.333
600.	100.000	92.308	85.714	80.000	75.000	70.588	66.667	63.158	60.000	54.545	50.000
500.	83.333	76.923	71.429	66.667	62.500	58.824	55.556	52.632	50.000	45.455	41.667
400.	66.667	61.538	57.143	53.333	50.000	47.059	44.444	42.105	40.000	36.364	33.333
300.	50.000	46.154	42.857	40.000	37.500	35.294	33.333	31.579	30.000	27.273	25.000
200.	33.333	30.769	28.571	26.667	25.000	23.529	22.222	21.053	20.000	18.182	16.667
100.	16.667	15.385	14.286	13.333	12.500	11.765	11.111	10.526	10.000	9.091	8.333
90.	15.000	13.846	12.857	12.000	11.250	10.588	10.000	9.474	9.000	8.182	7.500
80.	13.333	12.308	11.429	10.667	10.000	9.412	8.889	8.421	8.000	7.273	6.667
70.	11.667	10.769	10.000	9.333	8.750	8.235	7.778	7.368	7.000	6.364	5.833
60.	10.000	9.231	8.571	8.000	7.500	7.059	6.667	6.316	6.000	5.455	5.000
50.	8.333	7.692	7.143	6.667	6.250	5.882	5.556	5.263	5.000	4.545	4.167
40.	6.667	6.154	5.714	5.333	5.000	4.706	4.444	4.210	4.000	3.636	3.333
30.	5.000	4.615	4.286	4.000	3.750	3.529	3.333	3.158	3.000	2.727	2.500
20.	3.333	3.077	2 857	2.667	2.500	2.353	2.222	2.105	2.000	1.818	1.667
10.	1.667	1.538	1.429	1.333	1.250	1.176	1.111	1.053	1.000	.909	.833
9.	1.500	1.385	1.286	1.200	1.125	1.059	1.000	.947	.900	.818	.750
8.	1.333	1.231	1.143	1.067	1.000	.941	.889	.842	.800	.727	.667
7.	1.167	1.077	1.000	.933	.875	.824	.778	.737	.700	.636	.583
6.	1.000	.923	.857	.800	.750	.706	.667	.632	.600	.545	.500
5.	.833	.769	.714	.667	.625	.588	.556	.526	.500	.455	.417
4.	.667	.615	.571	.533	.500	.471	.444	.421	.400	.364	.333
3.	.500	.462	.429	.400	.375	.353	.333	.316	.300	.273	.250
2.	.333	.308	.286	.267	.250	.235	.222	.211	.200	.181	.167
1.	.167	.154	.143	.133	.125	.118	.111	.105	.100	.091	.083
.5	.083	.077	.071	.067	.062	.059	.056	.053	.050	.045	.042
	.077	**.071**	**.067**	**.062**	**.059**	**.056**	**.053**	**.050**	**.048**	**.045**	**.043**
900.	69.231	64.286	60.000	56.250	52.941	50.000	47.368	45.000	42.857	40.909	39.130
800.	61.538	57.143	53.333	50.000	47.059	44.444	42.105	40.000	38.095	36.364	34.783
700.	53.846	50.000	46.667	43.750	41.176	38.889	36.842	35.000	33.333	31.818	30.435
600.	46.154	42.857	40.000	37.500	35.294	33.333	31.579	30.000	28.571	27.273	26.087
500.	38.462	35.714	33.333	31.250	29.412	27.778	26.316	25.000	23.810	22.727	21.739
400.	30.769	28.571	26.667	25.000	23.529	22.222	21.053	20.000	19.048	18.182	17.391
300.	23.077	21.429	20.000	18.750	17.647	16.667	15.789	15.000	14.286	13.636	13.043
200.	15.385	14.286	13.333	12.500	11.765	11.111	10.526	10.000	9.524	9.091	8.696
100.	7.692	7.143	6.667	6.250	5.882	5.556	5.263	5.000	4.762	4.545	4.348
90.	6.923	6.429	6.000	5.625	5.294	5.000	4.737	4.500	4.286	4.091	3.913
80.	6.154	5.714	5.333	5.000	4.706	4.444	4.210	4.000	3.810	3.636	3.478
70.	5.385	5.000	4.667	4.375	4.118	3.889	3.684	3.500	3.333	3.182	3.043
60.	4.615	4.286	4.000	3.750	3.529	3.333	3.158	3.000	2.857	2.727	2.609
50.	3.846	3.571	3.333	3.125	2.941	2.778	2.632	2.500	2.381	2.273	2.174
40.	3.077	2.857	2.667	2.500	2.353	2.222	2.105	2.000	1.905	1.818	1 739
30.	2.308	2.143	2.000	1.875	1.765	1.667	1.579	1.500	1.429	1.364	1.304
20.	1.538	1.429	1.333	1.250	1.176	1.111	1.053	1.000	.952	.909	.870
10.	.769	.714	.667	.625	.588	.556	.526	.500	.476	.455	.435
9.	.692	.643	.600	.562	.529	.500	.474	.450	.429	.409	.391
8.	.615	.571	.533	.500	.471	.444	.421	.400	.381	.364	.348
7.	.538	.500	.467	.438	.412	.389	.368	.350	.333	.318	.304
6.	.462	.429	.400	.375	.353	.333	.316	.300	.286	.273	.261
5.	.385	.357	.333	.312	.294	.278	.263	.250	.238	.227	.217
4.	.308	.286	.267	.250	.235	.222	.211	.200	.190	.182	.174
3.	.231	.214	.200	.188	.176	.167	.158	.150	.143	.136	.130
2.	.154	.143	.133	.125	.118	.111	.105	.100	.095	.091	.087
1.	.077	.071	.067	.062	.059	.056	.053	.050	.048	.045	.043
.5	.038	.036	.033	.031	.029	.028	.026	.025	.024	.023	.022

Table 2. For converting MFM Frequency (MFM KC.) to MFM Dial Divisions

MFM DIAL DIVISIONS; Dial Difference in **heavy type**

MFM KC.	**162**	**163**	**164**	**165**	**166**	**167**	**168**	**169**	**170**	**171**	**172**	**173**	**174**	**175**	**176**	**177**	**178**	**179**	**180**
9.	145.80	146.70	147.60	148.50	149.40	150.30	151.20	152.10	153.00	153.90	154.80	155.70	156.60	157.50	158.40	159.30	160.20	161.10	162.00
8.	129.60	130.40	131.20	132.00	132.80	133.60	134.40	135.20	136.00	136.80	137.60	138.40	139.20	140.00	140.80	141.60	142.40	143.20	144.00
7.	113.40	114.10	114.80	115.50	116.20	116.90	117.60	118.30	119.00	119.70	120.40	121.10	121.80	122.50	123.20	123.90	124.60	125.30	126.00
6.	97.20	97.80	98.40	99.00	99.60	100.20	100.80	101.40	102.00	102.60	103.20	103.80	104.40	105.00	105.60	106.20	106.80	107.40	108.00
5.	81.00	81.50	82.00	82.50	83.00	83.50	84.00	84 50	85 00	85.50	86.00	86.50	87.00	87.50	88.00	88.50	89.00	89.50	90.00
4.	64.80	65.20	65.60	66.00	66.40	66.80	67.20	67.60	68.00	68.40	68.80	69.20	69.60	70.00	70.40	70.80	71.20	71.60	72.00
3.	48.60	48.90	49.20	49.50	49.80	50.10	50.40	50.70	51.00	51.30	51.60	51.90	52.20	52.50	52.80	53.10	53.40	53.70	54.00
2.	32.40	32.60	32.80	33.00	33.20	33.40	33.60	33.80	34 00	34.20	34.40	34.60	34.80	35 00	35.20	35.40	35.60	35.80	36.00
1.	16.20	16.30	16.40	16.50	16.60	16.70	16.80	16.90	17.00	17.10	17.20	17.30	17.40	17.50	17.60	17.70	17.80	17.90	18.00
.9	14.58	14.67	14.76	14.85	14.94	15.03	15 12	15.21	15.30	15.39	15.48	15.57	15.66	15.75	15.84	15.93	16.02	16.11	16.20
.8	12.96	13.04	13.12	13.20	13.28	13.36	13.44	13.52	13.60	13.68	13.76	13.84	13.92	14.00	14.08	14.16	14.24	14.32	14.40
.7	11.34	11.41	11.48	11.55	11.62	11.69	11.76	11.83	11.90	11.97	12.04	12.11	12.18	12.25	12.32	12.39	12.46	12.53	12.60
.6	9.72	9.78	9.84	9.90	9.96	10.02	10.08	10.14	10.20	10.26	10.32	10.38	10.44	10.50	10.56	10.62	10.68	10.74	10.80
.5	8.10	8.15	8.20	8.25	8.30	8.35	8.40	8.45	8.50	8.55	8 60	8.65	8.70	8.75	8.80	8.85	8.90	8.95	9.00
.4	6.48	6.52	6.56	6.60	6.64	6.68	6.72	6.76	6.80	6.84	6.88	6.92	6 96	7.00	7.04	7.08	7.12	7.16	7.20
.3	4.86	4.89	4.92	4.95	4.98	5.01	5.04	5.07	5.10	5.13	5.16	5.19	5.22	5.25	5.28	5.31	5.34	5.37	5.40
.2	3.24	3.26	3.28	3.30	3.32	3.34	3.36	3.38	3.40	3.42	3.44	3.46	3.48	3.50	3.52	3.54	3.56	3.58	3.60
.1	1.62	1.63	1.64	1.65	1.66	1.67	1.68	1.69	1.70	1.71	1.72	1.73	1.74	1.75	1.76	1.77	1.78	1.79	1.80
.09	1.46	1.47	1.48	1.48	1.49	1.50	1.51	1.52	1.53	1.54	1.55	1.56	1.57	1.58	1.58	1.59	1.60	1.61	1.62
.08	1.30	1.30	1.31	1.32	1.33	1.34	1.34	1.35	1.36	1.37	1.38	1.38	1.39	1.40	1.41	1.42	1.42	1.43	1.44
.07	1.13	1.14	1.15	1.16	1.16	1.17	1.18	1.18	1.19	1.20	1.20	1.21	1.22	1.22	1.23	1.24	1.25	1.25	1.26
.06	.97	.98	.98	.99	1.00	1.00	1.01	1.01	1.02	1.03	1.03	1.04	1.04	1.05	1.06	1.06	1.07	1.07	1.08
.05	.81	.82	.82	.82	.83	.84	.84	.84	.85	.86	.86	.86	.87	.88	.88	.88	.89	.90	.90
.04	.65	.65	.66	.66	.66	.67	.67	.68	.68	.68	.69	.69	.70	.70	.70	.71	.71	.72	.72
.03	.49	.49	.49	.50	.50	.50	.50	.51	.51	.51	.52	.52	.52	.52	.53	.53	.53	.54	.54
.02	.32	.33	.33	.33	.33	.33	.34	.34	.34	.34	.34	.35	.35	.35	.35	.35	.36	.36	.36
.01	.16	.16	.16	.16	.17	.17	.17	.17	.17	.17	.17	.17	.17	.18	.18	.18	.18	.18	.18

MFM DIAL DIVISIONS; Dial Difference in **heavy type**

MFM KC.	**181**	**182**	**183**	**184**	**185**	**186**	**187**	**188**	**189**	**190**	**191**	**192**	**193**	**194**	**195**	**196**	**197**	**198**	**199**
9.	162.90	163.80	164.70	165.60	166.50	167.40	168.30	169.20	170.10	171.00	171.90	172.80	173.70	174.60	175.50	176.40	177.30	178.20	179.10
8.	144.80	145.60	146.40	147.20	148.00	148.80	149.60	150.40	151.20	152.00	152.80	153.60	154.40	155.20	156.00	156.80	157.60	158.40	159.20
7.	126.70	127.40	128.10	128.80	129.50	130.20	130.90	131.60	132.30	133.00	133.70	134.40	135.10	135.80	136.50	137.20	137.90	138.60	139.30
6.	108.60	109.20	109.80	110.40	111.00	111.60	112.20	112.80	113.40	114.00	114.60	115.20	115.80	116.40	117.00	117.60	118.20	118.80	119.40
5.	90.50	91.00	91.50	92.00	92.50	93.00	93.50	94.00	94.50	95.00	95.50	96.00	96.50	97.00	97.50	98.00	98.50	99.00	99.50
4.	72.40	72.80	73.20	73.60	74.00	74.40	74.80	75.20	75.60	76.00	76.40	76.80	77.20	77.60	78.00	78.40	78.80	79.20	79.60
3.	54.30	54.60	54.90	55.20	55.50	55.80	56.10	56.40	56.70	57.00	57.30	57.60	57.90	58.20	58.50	58.80	59.10	59.40	59.70
2.	36.20	36.40	36.60	36.80	37.00	37.20	37.40	37.60	37.80	38.00	38.20	38.40	38.60	38.80	39.00	39.20	39.40	39.60	39.80
1.	18.10	18.20	18.30	18.40	18.50	18.60	18.70	18.80	18.90	19.00	19.10	19.20	19.30	19.40	19.50	19.60	19.70	19.80	19.90
.9	16.29	16.38	16.47	16.56	16.65	16.74	16.83	16.92	17.01	17.10	17.19	17.28	17.37	17.46	17.55	17.64	17.73	17.82	17.91
.8	14.48	14.56	14.64	14.72	14.80	14.88	14.96	15.04	15.12	15.20	15.28	15.36	15.44	15.52	15.60	15.68	15.76	15.84	15.92
.7	12.67	12.74	12.81	12.88	12.95	13.02	13.09	13.16	13.23	13.30	13.37	13.44	13.51	13.58	13.65	13.72	13.79	13.86	13.93
.6	10.86	10.92	10.98	11.04	11.10	11.16	11.22	11.28	11.34	11.40	11.46	11.52	11.58	11.64	11.70	11.76	11.82	11.88	11.94
.5	9 05	9.10	9.15	9.20	9.25	9.30	9.35	9.40	9.45	9.50	9.55	9.60	9.65	9.70	9.75	9.80	9.85	9.90	9.95
.4	7.24	7.28	7.32	7.36	7.40	7.44	7.48	7.52	7.56	7.60	7.64	7.68	7.72	7.76	7.80	7.84	7.88	7.92	7.96
.3	5.43	5.46	5.49	5.52	5.55	5.58	5.61	5.64	5.67	5.70	5.73	5.76	5.79	5.82	5.85	5.88	5.91	5.94	5.97
.2	3.62	3.64	3.66	3.68	3.70	3.72	3.74	3.76	3.78	3.80	3.82	3.84	3.86	3.88	3.90	3.92	3.94	3.96	3.98
.1	1.81	1.82	1.83	1.84	1.85	1.86	1.87	1.88	1.89	1.90	1.91	1.92	1.93	1.94	1.95	1.96	1.97	1.98	1.99
.09	1.63	1.64	1.65	1.66	1.66	1.67	1.68	1.69	1.70	1.71	1.72	1.73	1.74	1.75	1.76	1.76	1.77	1.78	1.79
.08	1.45	1.46	1.46	1.47	1.48	1.49	1.50	1.50	1.51	1.52	1.53	1.54	1.54	1.55	1.56	1.57	1.58	1.58	1.59
.07	1.27	1.27	1.28	1.29	1.30	1.30	1.31	1.32	1.32	1.33	1.34	1.34	1.35	1.36	1.36	1.37	1.38	1.39	1.39
.06	1.09	1.09	1.10	1.10	1.11	1.12	1.12	1.13	1.13	1.14	1.15	1.15	1.16	1.16	1.17	1.18	1.18	1.19	1.19
.05	.90	.91	.92	.92	.92	.93	.94	.94	.94	.95	.96	.96	.96	.97	.98	.98	.98	.99	1.00
.04	.72	.73	.73	.74	.74	.74	.75	.75	.76	.76	.76	.77	.77	.78	.78	.78	.79	.79	.80
.03	.54	.55	.55	.55	.56	.56	.56	.56	.57	.57	.57	.58	.58	.58	.58	.59	.59	.59	.60
.02	.36	.36	.37	.37	.37	.37	.37	.38	.38	.38	.38	.38	.39	.39	.39	.39	.39	.40	.40
.01	.18	.18	.18	.18	.18	.19	.19	.19	.19	.19	.19	.19	.19	.19	.20	.20	.20	.20	.20

Table 2 (Cont.) For converting MFM Frequency (MFM KC.) to MFM Dial Divisions

MFM DIAL DIVISIONS; Dial Difference in **heavy type**

MFM KC.	**200**	**201**	**202**	**203**	**204**	**205**	**206**	**207**	**208**	**209**	**210**	**211**	**212**	**213**	**214**	**215**	**216**	**217**	**218**
9.	180.00	180.90	181.80	182.70	183.60	184.50	185.40	186.30	187.20	188.10	189.00	189.90	190.80	191.70	192.60	193.50	194.40	195.30	196.20
8.	160.00	160.80	161.60	162.40	163.20	164.00	164.80	165.60	166.40	167.20	168.00	168.80	169.60	170.40	171.20	172.00	172.80	173.60	174.40
7.	140.00	140.70	141.40	142.10	142.80	143.50	144.20	144.90	145.60	146.30	147.00	147.70	148.40	149.10	149.80	150.50	151.20	151.90	152.60
6.	120.00	120.60	121.20	121.80	122.40	123.00	123.60	124.20	124.80	125.40	126.00	126.60	127.20	127.80	128.40	129.00	129.60	130.20	130.80
5.	100.00	100.50	101.00	101.50	102.00	102.50	103.00	103.50	104.00	104.50	105.00	105.50	106.00	106.50	107.00	107.50	108.00	108.50	109.00
4.	80.00	80.40	80.80	81.20	81.60	82.00	82.40	82.80	83.20	83.60	84.00	84.40	84.80	85.20	85.60	86.00	86.40	86.80	87.20
3.	60.00	60.30	60.60	60.90	61.20	61.50	61.80	62.10	62.40	62.70	63.00	63.30	63.60	63.90	64.20	64.50	64.80	65.10	65.40
2.	40.00	40.20	40.40	40.60	40.80	41.00	41.20	41.40	41.60	41.80	42.00	42.20	42.40	42.60	42.80	43.00	43.20	43.40	43.60
1.	20.00	20.10	20.20	20.30	20.40	20.50	20.60	20.70	20.80	20.90	21.00	21.10	21.20	21.30	21.40	21.50	21.60	21.70	21.80
.9	18.00	18.09	18.18	18.27	18.36	18.45	18.54	18.63	18.72	18.81	18.90	18.99	19.08	19.17	19.26	19.35	19.44	19.53	19.62
.8	16.00	16.08	16.16	16.24	16.32	16.40	16.48	16.56	16.64	16.72	16.80	16.88	16.96	17.04	17.12	17.20	17.28	17.36	17.44
.7	14.00	14.07	14.14	14.21	14.28	14.35	14.42	14.49	14.56	14.63	14.70	14.77	14.84	14.91	14.98	15.05	15.12	15.19	15.26
.6	12.00	12.06	12.12	12.18	12.24	12.30	12.36	12.42	12.48	12.54	12.60	12.66	12.72	12.78	12.84	12.90	12.96	13.02	13.08
.5	10.00	10.05	10.10	10.15	10.20	10.25	10.30	10.35	10.40	10.45	10.50	10.55	10.60	10.65	10.70	10.75	10.80	10.85	10.90
.4	8.00	8.04	8.08	8.12	8.16	8.20	8.24	8.28	8.32	8.36	8.40	8.44	8.48	8.52	8.56	8.60	8.64	8.68	8.72
.3	6.00	6.03	6.06	6.09	6.12	6.15	6.18	6.21	6.24	6.27	6.30	6.33	6.36	6.39	6.42	6.45	6.48	6.51	6.54
.2	4.00	4.02	4.04	4.06	4.08	4.10	4.12	4.14	4.16	4.18	4.20	4.22	4.24	4.26	4.28	4.30	4.32	4.34	4.36
.1	2.00	2.01	2.02	2.03	2.04	2.05	2.06	2.07	2.08	2.09	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17	2.18
.09	1.80	1.81	1.82	1.83	1.84	1.84	1.85	1.86	1.87	1.88	1.89	1.90	1.91	1.92	1.93	1.94	1.94	1.95	1.96
.08	1.60	1.61	1.62	1.62	1.63	1.64	1.65	1.66	1.66	1.67	1.68	1.69	1.70	1.70	1.71	1.72	1.73	1.74	1.74
.07	1.40	1.41	1.41	1.42	1.43	1.44	1.44	1.45	1.46	1.46	1.47	1.48	1.48	1.49	1.50	1.50	1.51	1.52	1.53
.06	1.20	1.21	1.21	1.22	1.22	1.23	1.24	1.24	1.25	1.25	1.26	1.27	1.27	1.28	1.28	1.29	1.30	1.30	1.31
.05	1.00	1.00	1.01	1.02	1.02	1.02	1.03	1.04	1.04	1.04	1.05	1.06	1.06	1.06	1.07	1.08	1.08	1.08	1.09
.04	.80	.80	.81	.81	.82	.82	.82	.83	.83	.84	.84	.84	.85	.85	.86	.86	.86	.87	.87
.03	.60	.60	.61	.61	.61	.62	.62	.62	.62	.63	.63	.63	.64	.64	.64	.64	.65	.65	.65
.02	.40	.40	.40	.41	.41	.41	.41	.41	.42	.42	.42	.42	.42	.43	.43	.43	.43	.43	.44
.01	.20	.20	.20	.20	.20	.20	.21	.21	.21	.21	.21	.21	.21	.21	.21	.22	.22	.22	.22

MFM DIAL DIVISIONS; Dial Difference in **heavy type**

MFM KC.	**219**	**220**	**221**	**222**	**223**	**224**	**225**	**226**	**227**	**228**	**229**	**230**	**231**	**232**	**233**	**234**	**235**	**236**	**237**
9.	197.10	198.00	198.90	199.80	200.70	201.60	202.50	203.40	204.30	205.20	206.10	207.00	207.90	208.80	209.70	210.60	211.50	212.40	213.30
8.	175.20	176.00	176.80	177.60	178.40	179.20	180.00	180.80	181.60	182.40	183.20	184.00	184.80	185.60	186.40	187.20	188.00	188.80	189.60
7.	153.30	154.00	154.70	155.40	156.10	156.80	157.50	158.20	158.90	159.60	160.30	161.00	161.70	162.40	163.10	163.80	164.50	165.20	165.90
6.	131.40	132.00	132.60	133.20	133.80	134.40	135.00	135.60	136.20	136.80	137.40	138.00	138.60	139.20	139.80	140.40	141.00	141.60	142.20
5.	109.50	110.00	110.50	111.00	111.50	112.00	112.50	113.00	113.50	114.00	114.50	115.00	115.50	116.00	116.50	117.00	117.50	118.00	118.50
4.	87.60	88.00	88.40	88.80	89.20	89.60	90.00	90.40	90.80	91.20	91.60	92.00	92.40	92.80	93.20	93.60	94.00	94.40	94.80
3.	65.70	66.00	66.30	66.60	66.90	67.20	67.50	67.80	68.10	68.40	68.70	69.00	69.30	69.60	69.90	70.20	70.50	70.80	71.10
2.	43.80	44.00	44.20	44.40	44.60	44.80	45.00	45.20	45.40	45.60	45.80	46.00	46.20	46.40	46.60	46.80	47.00	47.20	47.40
1.	21.90	22.00	22.10	22.20	22.30	22.40	22.50	22.60	22.70	22.80	22.90	23.00	23.10	23.20	23.30	23.40	23.50	23.60	23.70
.9	19.71	19.80	19.89	19.98	20.07	20.16	20.25	20.34	20.43	20.52	20.61	20.70	20.79	20.88	20.97	21.06	21.15	21.24	21.33
.8	17.52	17.60	17.68	17.76	17.84	17.92	18.00	18.08	18.16	18.24	18.32	18.40	18.48	18.56	18.64	18.72	18.80	18.88	18.96
.7	15.33	15.40	15.47	15.54	15.61	15.68	15.75	15.82	15.89	15.96	16.03	16.10	16.17	16.24	16.31	16.38	16.45	16.52	16.59
.6	13.14	13.20	13.26	13.32	13.38	13.44	13.50	13.56	13.62	13.68	13.74	13.80	13.86	13.92	13.98	14.04	14.10	14.16	14.22
.5	10.95	11.00	11.05	11.10	11.15	11.20	11.25	11.30	11.35	11.40	11.45	11.50	11.55	11.60	11.65	11.70	11.75	11.80	11.85
.4	8.76	8.80	8.84	8.88	8.92	8.96	9.00	9.04	9.08	9.12	9.16	9.20	9.24	9.28	9.32	9.36	9.40	9.44	9.48
.3	6.57	6.60	6.63	6.66	6.69	6.72	6.75	6.78	6.81	6.84	6.87	6.90	6.93	6.96	6.99	7.02	7.05	7.08	7.11
.2	4.38	4.40	4.42	4.44	4.46	4.48	4.50	4.52	4.54	4.56	4.58	4.60	4.62	4.64	4.66	4.68	4.70	4.72	4.74
.1	2.19	2.20	2.21	2.22	2.23	2.24	2.25	2.26	2.27	2.28	2.29	2.30	2.31	2.32	2.33	2.34	2.35	2.36	2.37
.09	1.97	1.98	1.99	2.00	2.01	2.02	2.02	2.03	2.04	2.05	2.06	2.07	2.08	2.09	2.10	2.11	2.12	2.12	2.13
.08	1.75	1.76	1.77	1.78	1.78	1.79	1.80	1.81	1.82	1.82	1.83	1.84	1.85	1.86	1.86	1.87	1.88	1.89	1.90
.07	1.53	1.54	1.55	1.55	1.56	1.57	1.58	1.58	1.59	1.60	1.60	1.61	1.62	1.62	1.63	1.64	1.64	1.65	1.66
.06	1.31	1.32	1.33	1.33	1.34	1.34	1.35	1.36	1.36	1.37	1.37	1.38	1.39	1.39	1.40	1.40	1.41	1.42	1.42
.05	1.10	1.10	1.10	1.11	1.12	1.12	1.12	1.13	1.14	1.14	1.14	1.15	1.16	1.16	1.16	1.17	1.18	1.18	1.18
.04	.88	.88	.88	.89	.89	.90	.90	.90	.91	.91	.92	.92	.92	.93	.93	.94	.94	.94	.95
.03	.66	.66	.66	.67	.67	.67	.68	.68	.68	.68	.69	.69	.69	.70	.70	.70	.70	.71	.71
.02	.44	.44	.44	.44	.45	.45	.45	.45	.45	.46	.46	.46	.46	.46	.47	.47	.47	.47	.47
.01	.22	.22	.22	.22	.22	.22	.22	.23	.23	.23	.23	.23	.23	.23	.23	.23	.24	.24	.24

Table 2 (Cont.) For converting MFM Frequency (MFM KC.) to MFM Dial Divisions

MFM DIAL DIVISIONS. Dial Difference in **heavy type**

MFM KC.	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256
9.	214.20	215.10	216.00	216.90	217.80	218.70	219.60	220.50	221.40	222.30	223.20	224.10	225.00	225.90	226.80	227.70	228.60	229.50	230.40
8.	190.40	191.20	192.00	192.80	193.60	194.40	195.20	196.00	196.80	197.60	198.40	199.20	200.00	200.80	201.60	202.40	203.20	204.00	204.80
7.	166.60	167.30	168.00	168.70	169.40	170.10	170.80	171.50	172.20	1[illegible].90	173.60	174.30	175.00	175.70	176.40	177.10	177.80	178.50	179.20
6.	142.80	143.40	144.00	144.60	145.20	145.80	146.40	147.00	147.60	148.20	148.80	149.40	150.00	150.60	151.20	151.80	152.40	153.00	153.60
5.	119.00	119.50	120.00	120.50	121.00	121.50	122.00	122.50	123.00	123.50	124.00	124.50	125.00	125.50	126.00	126.50	127.00	127.50	128.00
4.	95.20	95.60	96.00	6.40	96.80	97.20	97.60	98.00	98.40	98.80	99.20	99.60	100.00	100.40	100.80	101.20	101.60	102.00	102.40
3.	71.40	71.70	72.00	72.30	72.60	72.90	73.20	73.50	73.80	74.10	74.40	74.70	75.00	75.30	75.60	75.90	76.20	76.50	76.80
2.	47.60	47.80	48.00	48.20	48.40	48.60	48.80	49.00	49.20	49.40	49.60	49.80	50.00	50.20	50.40	50.60	50.80	51.00	51.20
1.	23.80	23.90	24.00	24.10	24.20	24.30	24.40	24.50	24.60	24.70	24.80	24.90	25.00	25.10	25.20	25.30	25.40	25.50	25.60
.9	21.42	21.51	21.60	21.69	21.78	21.87	21.96	22.05	22.14	22.23	22.32	22.41	22.50	22.59	22.68	22.77	22.86	22.95	23.04
.8	19.04	19.12	19.20	19.28	19.36	19.44	19.52	19.60	19.68	19.76	19.84	19.92	20.00	20.08	20.16	20.24	20.32	20.40	20.48
.7	16.66	16.73	16.80	16.87	16.94	17.01	17.08	17.15	17.22	17.29	17.36	17.43	17.50	17.57	17.64	17.71	17.78	17.85	17.92
.6	14.28	14.34	14.40	14.46	14.52	14.58	14.64	14.70	14.76	14.82	14.88	14.94	15.00	15.06	15.12	15.18	15.24	15.30	15.36
.5	11.90	11.95	12.00	12.05	12.10	12.15	12.20	12.25	12.30	12.35	12.40	12.45	12.50	12.55	12.60	12.65	12.70	12.75	12.80
.4	9.52	9.56	9.60	9.64	9.68	9.72	9.76	9.80	9.84	9.88	9.92	9.96	10.00	10.04	10.08	10.12	10.16	10.20	10.24
.3	7.14	7.17	7.20	7.23	7.26	7.29	7.32	7.35	7.38	7.41	7.44	7.47	7.50	7.53	7.56	7.59	7.62	7.65	7.68
.2	4.76	4.78	4.80	4.82	4.84	4.86	4.88	4.90	4.92	4.94	4.96	4.98	5.00	5.02	5.04	5.06	5.08	5.10	5.12
.1	2.38	2.39	2.40	2.41	2.42	2.43	2.44	2.45	2.46	2.47	2.48	2.49	2.50	2.51	2.52	2.53	2.54	2.55	2.56
.09	2.14	2.15	2.16	2.17	2.18	2.19	2.20	2.20	2.21	2.22	2.23	2.24	2.25	2.26	2.27	2.28	2.29	2.30	2.30
.08	1.90	1.91	1.92	1.93	1.9[illegible]	1.94	1.95	1.96	1.97	1.98	1.98	1.99	2.00	2.01	2.02	2.02	2.03	2.04	2.05
.07	1.67	1.67	1.68	1.69	1.69	1.70	1.71	1.72	1.72	1.73	1.74	1.74	1.75	1.76	1.76	1.77	1.78	1.78	1.79
.06	1.43	1.43	1.44	1.45	1.45	1.46	1.46	1.47	1.48	1.48	1.49	1.49	1.50	1.51	1.51	1.52	1.52	1.53	1.54
.05	1.19	1.20	1.20	1.20	1.21	1.22	1.22	1.22	1.23	1.24	1.24	1.24	1.25	1.26	1.26	1.26	1.27	1.28	1.28
.04	.95	.96	.96	.96	.97	.97	.98	.98	.98	.99	.99	1.00	1.00	1.00	1.01	1.01	1.02	1.02	1.02
.03	.71	.72	.72	.72	.73	.73	.73	.74	.74	.74	.74	.75	.75	.75	.76	.76	.76	.76	.77
.02	.48	.48	.48	.48	.48	.49	.49	.49	.49	.49	.50	.50	.50	.50	.50	.51	.51	.51	.51
.01	24	.24	.24	.24	.24	.24	.24	.24	.25	.25	.25	.25	.25	.25	.25	.25	.25	.26	.26

MFM DIAL DIVISIONS; Dial Difference in **heavy type**

MFM KC.	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275
9.	231.30	232.20	233.10	234.00	234.90	235.80	236.70	237.60	238.50	239.40	240.30	241.20	242.10	243.00	243.90	244.80	245.70	246.60	247.50
8.	205.60	206.40	207.20	208.00	208.80	209.60	210.40	211.20	212.00	212.80	213.60	214.40	215.20	216.00	216.80	217.60	218.40	219.20	220.00
7.	179.90	180.60	181.30	182.00	182.70	183.40	184.10	184.80	185.50	186.20	186.90	187.60	188.30	189.00	189.70	190.40	191.10	191.80	192.50
6.	154.20	154.80	155.40	156.00	156.60	157.20	157.80	158.40	159.00	159.60	160.20	160.80	161.40	162.00	162.60	163.20	163.80	164.40	165.00
5.	128.50	129.00	129.50	130.00	130.50	131.00	131.50	132.00	132.50	133.00	133.50	134.00	134.50	135.00	135.50	136.00	136.50	137.00	137.50
4.	102.80	103.20	103.60	104.00	104.40	104.80	105.20	105.60	106.00	106.40	106.80	107.20	107.60	108.00	108.40	108.80	109.20	109.60	110.00
3.	77.10	77.40	77.70	78.00	78.30	78.60	78.90	79.20	79.50	79.80	80.10	80.40	80.70	81.00	81.30	81.60	81.90	82.20	82.50
2.	51.40	51.60	51.80	52.00	52.20	52.40	52.60	52.80	53.00	53.20	53.40	53.60	53.80	54.00	54.20	54.40	54.60	54.80	55.00
1.	25.70	25.80	25.90	26.00	26.10	26.20	26.30	26.40	26.50	26.60	26.70	26.80	26.90	27.00	27.10	27.20	27.30	27.40	27.50
.9	23.13	23.22	23.31	23.40	23.49	23.58	23.67	23.76	23.85	23.94	24.03	24.12	24.21	24.30	24.39	24.48	24.57	24.66	24.75
.8	20.56	20.64	20.72	20.80	20.88	20.96	21.04	21.12	21.20	21.28	21.36	21.44	21.52	21.60	21.68	21.76	21.84	21.92	22.00
.7	17.99	18.06	18.13	18.20	18.27	18.34	18.41	18.48	18.55	18.62	18.69	18.76	18.83	18.90	18.97	19.04	19.11	19.18	19.25
.6	15.42	15.48	15.54	15.60	15.66	15.72	15.78	15.84	15.90	15.96	16.02	16.08	16.14	16.20	16.26	16.32	16.38	16.44	16.50
.5	12.85	12.90	12.95	13.00	13.05	13.10	13.15	13.20	13.25	13.30	13.35	13.40	13.45	13.50	13.55	13.60	13.65	13.70	13.75
.4	10.28	10.32	10.36	10.40	10.44	10.48	10.52	10.56	10.60	10.64	10.68	10.72	10.76	10.80	10.84	10.88	10.92	10.96	11.00
.3	7.71	7.74	7.77	7.80	7.83	7.86	7.89	7.92	7.95	7.98	8.01	8.04	8.07	8.10	8.13	8.16	8.19	8.22	8.25
.2	5.14	5.16	5.18	5.20	5.22	5.24	5.26	5.28	5.30	5.32	5.34	5.36	5.38	5.40	5.42	5.44	5.46	5.48	5.50
.1	2.57	2.58	2.59	2.60	2.61	2.62	2.63	2.64	2.65	2.66	2.67	2.68	2.69	2.70	2.71	2.72	2.73	2.74	2.75
.09	2.31	2.32	2.33	2.34	2.35	2.36	2.37	2.38	2.38	2.39	2.40	2.41	2.42	2.43	2.44	2.45	2.46	2.47	2.48
.08	2.06	2.06	2.07	2.08	2.09	2.10	2.10	2.11	2.12	2.13	2.14	2.14	2.15	2.16	2.17	2.18	2.18	2.19	2.20
.07	1.80	1.81	1.81	1.82	1.83	1.83	1.84	1.85	1.86	1.86	1.87	1.88	1.88	1.89	1.90	1.90	1.91	1.92	1.92
.06	1.54	1.55	1.55	1.56	1.57	1.57	1.58	1.58	1.59	1.60	1.60	1.61	1.61	1.62	1.63	1.63	1.64	1.64	1.65
.05	1.28	1.29	1.30	1.30	1.30	1.31	1.32	1.32	1.32	1.33	1.34	1.34	1.34	1.35	1.36	1.36	1.36	1.37	1.38
.04	1.03	1.03	1.04	1.04	1.04	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.10	1.10
.03	.77	.77	.78	.78	.78	.79	.79	.79	.80	.80	.80	.80	.81	.81	.81	.82	.82	.82	.82
.02	.51	.52	.52	.52	.52	.52	.53	.53	.53	.53	.53	.54	.54	.54	.54	.54	.55	.55	.55
.01	.26	.26	.26	.26	.26	.26	.26	.26	.26	.27	.27	.27	.27	.27	.27	.27	.27	.27	.28