

AUTOMATIC WAVEMETER CALIBRATION

PHOTOGRAPHIC METHOD GIVING TABULAR NUMERICAL RESULTS

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THE precision of wavemeter measurement cannot exceed the accuracy of the calibration, which is commonly recorded in a handbook or a calibration chart attached to the instrument. Re-calibration is necessary at intervals dependent on the use made of the wavemeter. Where the instrument is subjected to rigorous working conditions, as experienced with the Armed Services, the necessity of frequent re-calibration becomes onerous.

The Type BC221 heterodyne frequency meter, for instance, occupies a skilled technician for fifteen days, for it has 3,252 calibration points. The wavemeter in question is one used in large quantities and in order to speed up re-calibration an automatic apparatus† has been designed. The whole process of re-calibration from the generation of standard frequencies to the photographic recording of dial readings is entirely automatic and the apparatus can deal with five wavemeters per day.

A series of calibration frequencies (of the order of one part in 10^7 accuracy) are provided by a frequency standard. These are compared with the output frequency of the wavemeter under test. The wavemeter output frequency is continuously varied by a mechanical drive which simultaneously operates a mechanical counter. There is always a direct relationship between the counter and the position of the wavemeter tuning control.

The calibration frequencies and the continuously changing output frequency of the wavemeter are compared, using the heterodyne principle. After comparison an output is obtained which causes

pulses are applied as one input to a mixer circuit (4). The output from the wavemeter (5) under test passes to an amplifier (6) and thence to the mixer (4). The wavemeter has its tuning dial firmly coupled to a mechanical drive consisting of an electric motor (7) and a precision gear box (8).

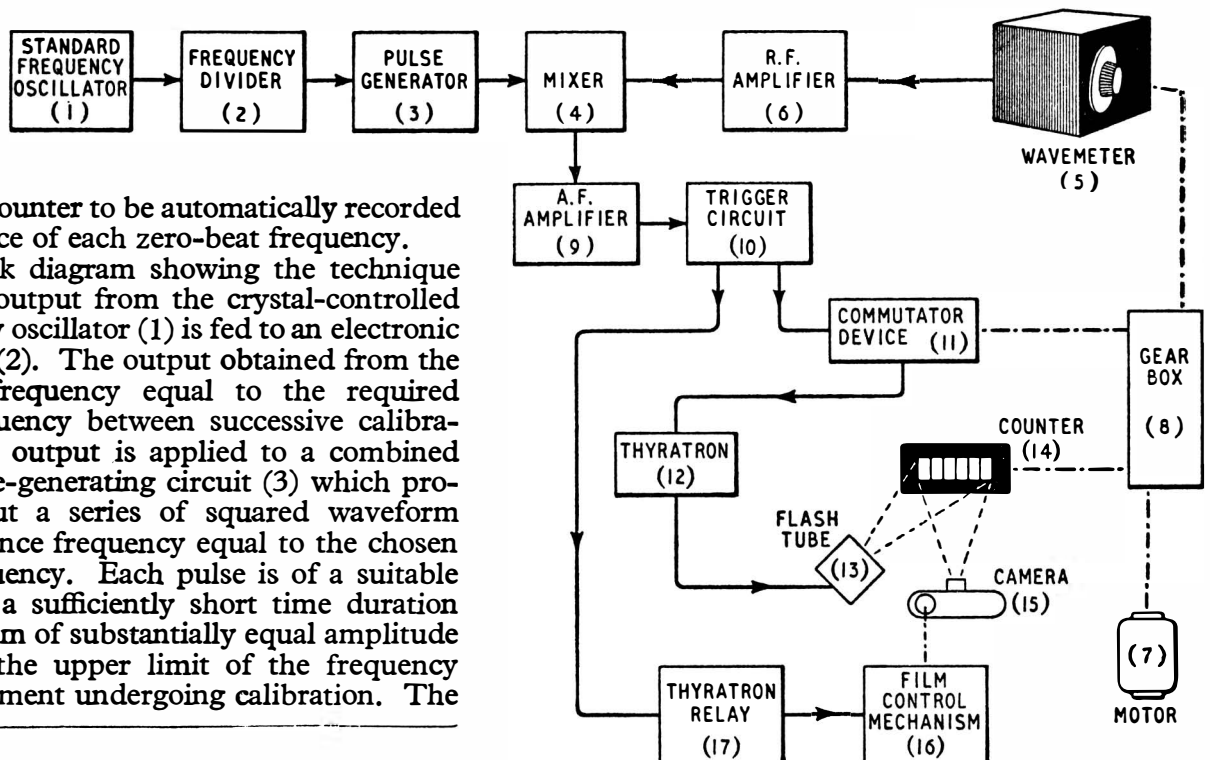
The output from the mixer circuit is amplified by a low-frequency amplifier (9), and applied as the input to a mono-stable trigger circuit (10).

One pulse output from the trigger circuit is fed via a commutator device (11) to effect the triggering of a thyatron circuit (12) which provides a firing pulse for the photographic flash tube (13) arranged evenly to illuminate a mechanical multi-digit counter (14). This is driven at a suitable speed to synchronize with the tuning control of the wavemeter and indicates the same figures as the wavemeter dial reading. Alternatively, it can be arranged to indicate the angular position of the wavemeter dial. When used with the BC221 heterodyne frequency meter the former arrangement is employed.

In correct alignment with the viewing aperture of the counter is a camera (15). At each flash of the tube (13) an image of the counter is recorded. The camera has a film wind-on control which is mechanically coupled to a solenoid-actuated mechanism (16).

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Fig. 1. Block diagram showing main components and functions of the equipment.



indications of the counter to be automatically recorded upon the occurrence of each zero-beat frequency.

Fig. 1 is a block diagram showing the technique employed. The output from the crystal-controlled standard frequency oscillator (1) is fed to an electronic frequency divider (2). The output obtained from the divider is at a frequency equal to the required increment of frequency between successive calibration points. This output is applied to a combined squaring and pulse-generating circuit (3) which provides at its output a series of squared waveform pulses at a recurrence frequency equal to the chosen increment of frequency. Each pulse is of a suitable amplitude and of a sufficiently short time duration to ensure a spectrum of substantially equal amplitude harmonics up to the upper limit of the frequency range of the instrument undergoing calibration. The

† Patent applied for.

The film control mechanism is supplied with energizing current pulses from a thyratron and relay circuit (17) whose control input is connected to an output from the trigger circuit (10) to ensure that the film is moved on for each exposure.

It will be assumed that the wavemeter has a frequency range of 100 to 200 kc/s, that its tuning control is capable of being read to one part in 10,000 of its complete range of movement, and that calibration is to be effected at every 2 kc/s over the wavemeter frequency range. In such circumstances the desired recurrence frequency for the pulse output from the circuit (3) is 2 kc/s and the standard frequency source (1) may operate at, say, 100 kc/s with the divider (2) effecting division by a ratio of 50:1. The motor (7) will be arranged to cause movement of the control of the wavemeter (5) over its complete range of movement while counter (14) is being moved from zero to a count state of 10,000.

The pulse input to the mixer (4) from circuit (3) comprises a series of equal-amplitude harmonics of the recurrence frequency (i.e., 2, 4, 6, 8 kc/s and so on upwards) to a frequency above the maximum operating frequency (200 kc/s) of the wavemeter. This implies a pulse width less than 1 μ sec. In consequence there will be produced at the output of the mixer circuit (4) a succession of zero beats, the first occurring when the wavemeter output is 100 kc/s, the second when the output is 102 kc/s, the third when the output is 104 kc/s and so on. The other harmonics of the 2-kc/s pulse repetition frequency are filtered from the mixer output in the amplifier (9) in which the bandwidth is arranged to be of very limited and low value, say 50 c/s in the present instance, so that a trigger input will be supplied by the amplifier to the trigger circuit (10) just before, but sufficiently close to, each occurrence of a zero beat output from the mixer. The small error so introduced (in this case about 0.05%) can be compensated for, if the wavemeter-dial rotation/frequency law is substantially linear, by offsetting the counter indication by a suitable amount from the dial indication. If this is not possible, increased accuracy can be obtained at the expense of speed by reducing the bandwidth of the amplifier (9).

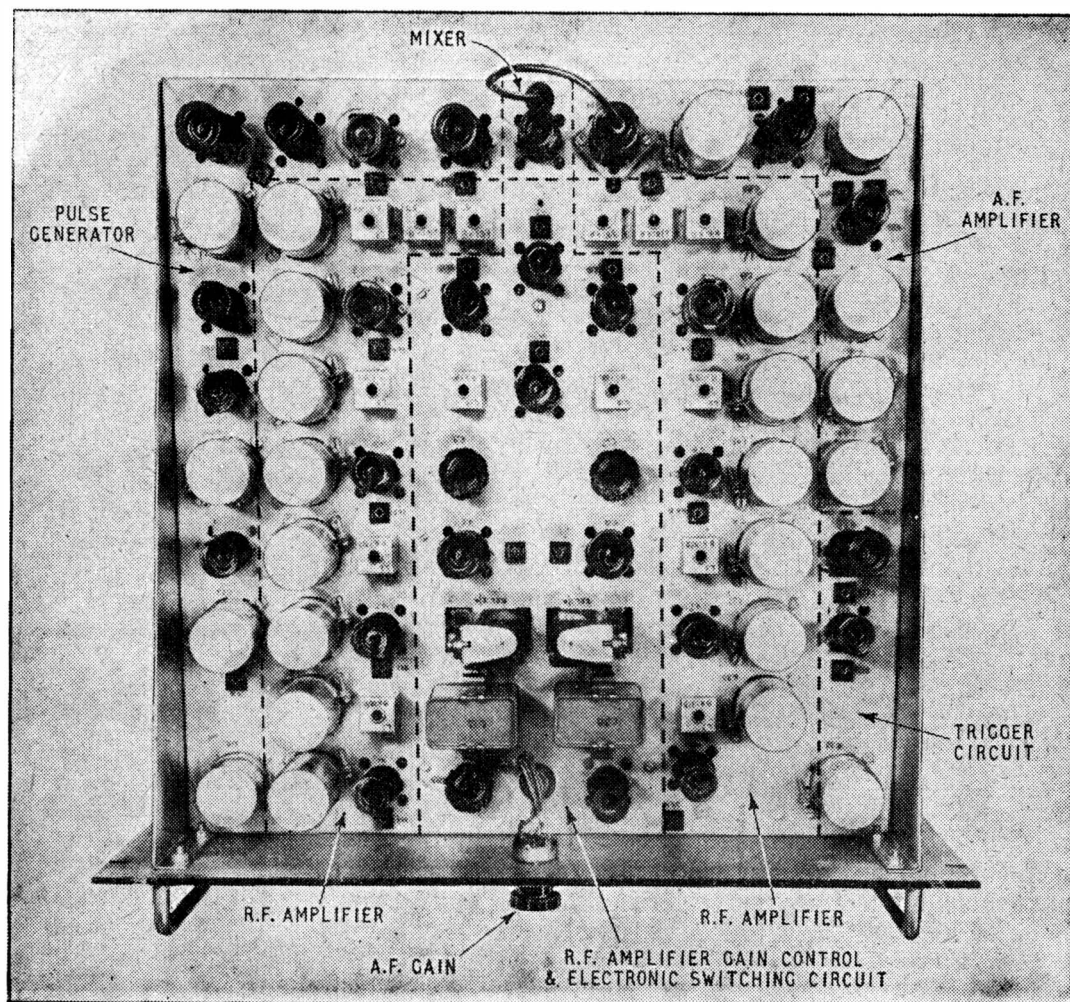
When triggering of the circuit (10) occurs, an output of appropriate polarity is available to operate the commutator circuit (11). This commutator is necessary in order to delay the photographic exposure until the next occasion on which the

counter figures are all in line, since the least significant digit drum is continuously in motion. This is achieved by switching a bi-stable (flip-flop) circuit "on" with the pulse from the trigger circuit (10) and "off" with the next pulse derived from a photocell pick-up head energized by light interrupted by a slotted disc. This disc has ten slots and is fixed to the counter input shaft, the position of each slot corresponding to one of the ten positions in which all figures are in line. To avoid a blurred image a flash duration of approximately 100 μ sec is employed. When this occurs a photographic recording is made of the instantaneous indication of the counter.

The output pulse from the trigger circuit (10) terminates after a pre-determined time interval which is made long enough (with respect to the speed of movement of the wavemeter control) to prevent another triggering of the circuit (10) until the next zero beat is approached. Fig. 2 shows the amplitude/time output of the amplifier (9) during operation. The thyratron and relay circuit (17) operates after the exposure. By closing the associated relay contacts the solenoid-actuated mechanism (16) winds on the camera film to the next recording position in readiness for the next cycle of operation which occurs when the next zero beat is reached.

This procedure is repeated at wavemeter output frequency intervals equal to the recurrence frequency (i.e. 2 kc/s) of the pulses fed to the mixer over the whole of the frequency range for which calibration of the wavemeter is desired.

The characteristics of the optical system are so chosen that the developed film is produced at the correct size and pitch of figures and with a positive



Plan view of chassis. The dotted lines indicate subdivisions of function.

Part of the automatic calibration equipment showing mechanical drive for wavemeter tuning control.

image (black on white) so that it may be cut and mounted directly into a calibration booklet for the particular instrument, in which columns of the appropriate frequencies have already been printed.

The range of instruments which may be calibrated by the apparatus described can be extended by the employment of ancillary equipment, such as a frequency divider interposed between the wavemeter and the r.f. amplifier, when the wavemeter is one operating at very high frequencies. It may also be more convenient to use a servo-mechanism for the drive system between the motor (7) and the elements (5), (11) and (14).

Operation of the apparatus over other frequency ranges can best be described by examples. For instance, calibration has been effected at 10-kc/s intervals from 20 to 40 Mc/s. This required the

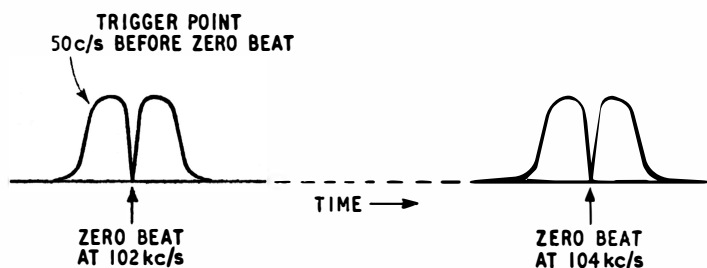
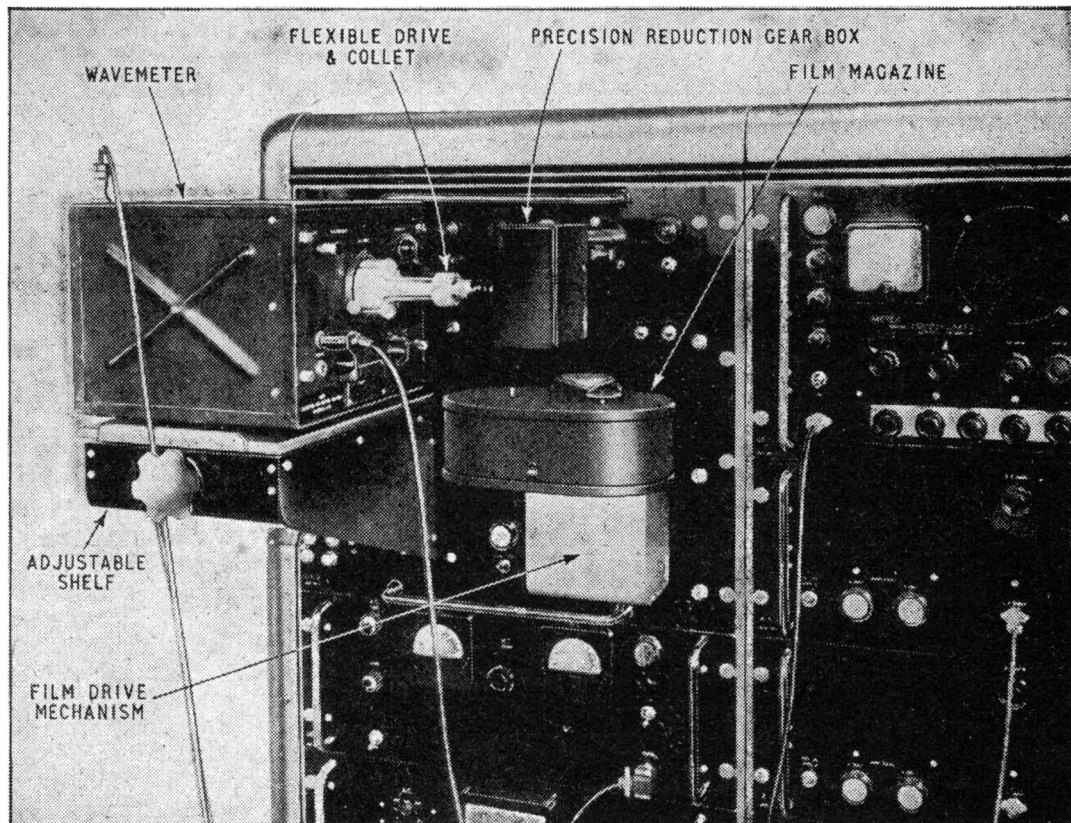


Fig. 2. Output amplitude/time characteristic of amplifier (9) during operation.

INDEX OF DIAL SETTINGS		INDEX OF FREQUENCIES—KILOCYCLES	
FREQUENCY RANGE	DIAL	FREQUENCY	DIAL
230 - 235	485 - 470	230.0 489.0 938.0 1888.0	4.1.0
485 - 470	939 - 940	230.1 490.2 939.4 1888.8	4.1.1
1980 - 1988		230.2 491.4 938.8 1884.6	4.1.2
		230.3 492.6 938.2 1880.4	4.1.3
		230.4 493.8 937.6 1876.2	4.1.4
		230.5 495.0 937.0 1872.0	4.1.5
		230.6 496.2 936.4 1867.8	4.1.6
		230.7 497.4 935.8 1863.6	4.1.7
		230.8 498.6 935.2 1859.4	4.1.8
		230.9 499.8 934.6 1855.2	4.1.9
		231.0 501.0 934.0 1851.0	4.2.0
		231.1 502.2 933.4 1846.8	4.2.1
		231.2 503.4 932.8 1842.6	4.2.2
		231.3 504.6 932.2 1838.4	4.2.3
		231.4 505.8 931.6 1834.2	4.2.4
		231.5 507.0 931.0 1830.0	4.2.5
		231.6 508.2 930.4 1825.8	4.2.6
		231.7 509.4 929.8 1821.6	4.2.7
		231.8 510.6 929.2 1817.4	4.2.8
		231.9 511.8 928.6 1813.2	4.2.9
		232.0 513.0 928.0 1809.0	4.3.0
		232.1 514.2 927.4 1804.8	4.3.1
		232.2 515.4 926.8 1800.6	4.3.2
		232.3 516.6 926.2 1796.4	4.3.3
		232.4 517.8 925.6 1792.2	4.3.4
		232.5 519.0 925.0 1788.0	4.3.5
		232.6 520.2 924.4 1783.8	4.3.6
		232.7 521.4 923.8 1779.6	4.3.7
		232.8 522.6 923.2 1775.4	4.3.8
		232.9 523.8 922.6 1771.2	4.3.9
		233.0 525.0 922.0 1767.0	4.4.0
		233.1 526.2 921.4 1762.8	4.4.1
		233.2 527.4 920.8 1758.6	4.4.2
		233.3 528.6 920.2 1754.4	4.4.3
		233.4 529.8 919.6 1750.2	4.4.4
		233.5 531.0 919.0 1746.0	4.4.5
		233.6 532.2 918.4 1741.8	4.4.6
		233.7 533.4 917.8 1737.6	4.4.7
		233.8 534.6 917.2 1733.4	4.4.8
		233.9 535.8 916.6 1729.2	4.4.9
		234.0 537.0 916.0 1725.0	4.5.0
		234.1 538.2 915.4 1720.8	4.5.1
		234.2 539.4 914.8 1716.6	4.5.2
		234.3 540.6 914.2 1712.4	4.5.3
		234.4 541.8 913.6 1708.2	4.5.4
		234.5 543.0 913.0 1704.0	4.5.5
		234.6 544.2 912.4 1700.0	4.5.6
		234.7 545.4 911.8 1695.8	4.5.7
		234.8 546.6 911.2 1691.6	4.5.8
		234.9 547.8 910.6 1687.4	4.5.9
		235.0 549.0 910.0 1683.2	4.6.0

Specimen of calibration table as it appears after the film record has been registered with the printed frequency table.

generation of a pulse of duration less than $10\mu\text{sec}$ with a time jitter less than $1\mu\text{sec}$.

In general, almost any frequency-calibration problem can be tackled by similar equipment. An important application is the automatic calibration of radio receivers where a high order of accuracy and a large number of calibration points are involved. The calibration record may then be in the form of a flexible scale (e.g., 35-mm film), coupled to the tuning mechanism, on which are recorded the frequencies to which the receiver may be tuned.

Further Developments

In order to eliminate the complication involved in photographic processing, a printing counter is under development. This is designed to replace the optical system and is provided with a mechanical storage device which enables a print to be made without interrupting the continuous drive to the input shaft.

The advantages of the system described may be summed up as follows:

- (1) The elimination of human error during calibration;
- (2) The elimination of human error in copying figures or in interpolation;
- (3) The reduction of electrical error due to long-term temperature changes, thus disposing of the necessity for using a temperature-controlled calibration room;
- (4) The increased speed of output and consequent reduction of staff.

As in other fields to which automation can be introduced, these advantages are economically realized where adequate numbers of similar instruments are to be dealt with and where the requirements of accuracy and multiplicity of calibration points are such as to justify the design of suitable equipment. Where large numbers of instruments are involved, a considerable economic advantage may be gained over hand-calibration methods.