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Utilizing WWV Transmissions

By the Engineering Department, Aerovox Corporation

THE National Bureau of Standards, through the regular transmission of standard frequencies from its station WWV, effectively places the national primary radio-frequency standard at the disposal of every laboratory and shop in this country and in many other parts of the world.

WWV is maintained and operated exclusively for the purpose of disseminating standard frequencies. The station, located at Beltsville, Md., near Washington, D. C., achieves nation-wide coverage by employing four carrier frequencies. Carrier power at each frequency is 10 kilowatts.

Two of the standard-frequency transmissions are made day and night, one throughout the night, and the remaining one throughout the day.

The following schedule is maintained:

2.5 Mc. 7:00 p.m. to 9:00 a.m. EWT (2300 to 1300 GMT).
5 Mc. Broadcast continuously day and night.
10 Mc. Broadcast continuously day and night.
15 Mc. 7:00 a.m. to 7:00 p.m. EWT (1100 to 2300 GMT).
(The times given are those at Washington, D. C.)

In addition to the standard radio frequencies, represented by the four carriers, there are disseminated also two standard audio frequencies (440 and 4000 cycles per second being employed simultaneously to modulate the 5-, 10-, and 15-megacycle carriers, and 440 cycles only to modulate the 2.5-Mc. carrier) and a standard time pulse. The latter is of 0.005 second (5 milliseconds) duration, consists of five cycles (each 1 millisecond in duration), appears upon each of the carriers, and is a highly accurate time signal. For identification of 1-minute intervals, the pulse is omitted on the 59th second of each minute.

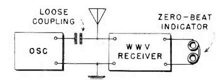

Figure 1

On each hour and also on each five minutes after the hour, the two audio frequencies are interrupted for exactly one minute for station announcement and to provide an interval for checking against the pure carrier in the absence of modulation. The announcement is made by signing the station call letters, WWV, in the International Morse Code, except that a detailed voice announcement is made at the hour and half-hour. These interruptions of modulation furnish an additional standard-time check, since their beginnings are synchronized with the time signals of the U. S. Naval Observatory.

The accuracy of each of the radio and audio frequencies transmitted by WWV is better than 1 part in 10 million. Accuracy of the time interval marked each second by the pulse is to 10 microseconds, and accuracy of the 1-, 4-, and 5-minute intervals, which are synchronized with the seconds pulses and marked by the beginning and ending of the intervals of interrupted modulation, is 1 part in 10 million.

Numerous variables, some as yet unpredictable, must be considered when estimating radio station coverage. Skip-distance effects, ground attenuation, and seasonal variations are representative of these factors. However, the choice of carrier frequencies and transmitter output power at WWV insure reasonable coverage throughout the day and night. The Bureau states, "Of the radio frequencies on the air at a given time, the lowest provides service to short distances, and the highest to great distances. Reliable reception is in general possible at all times throughout the United States and the North Atlantic Ocean, and fair reception throughout the world."

STANDARD-FREQUENCY RECEPTION

The type of receiver to be employed for picking up WWV emissions will depend upon the frequency chosen, closeness of indications desired, and distance of the receiving antenna from Washington, D. C. Depending upon the daytime effect upon the carrier frequencies, any short-wave or ali wave receiver will be capable of receiving one or more of the standard-frequency transmissions. For best results, however, a communication-type

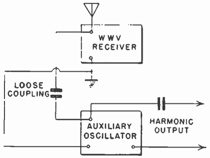

Figure 2

superheterodyne is recommended and this receiver should be equipped with automatic volume control and a crystal filter for best results. Diversity reception will probably be found invaluable in localities where severe fading is experienced. Tone-control systems should be switched off during reception of the standard frequencies.

When a superheterodyne receiver is employed, care must be taken to distinguish between the real and image signals emitted by a local oscillator being referred to the standard frequency. If the signal-to-image ratio of the receiver is high, the image intensity will be markedly lower than that of the real signal. In other sets, particularly those having no preselection, signal and image intensities will be approximately equal, and one may be distinguished from the other only by reference to the superheterodyne oscillator frequency.

For example: The superheterodyne oscillator may be set by the receiver manufacturer either higher or lower than the signal frequency to which the dial is adjusted. In most cases, the oscillator frequency will be higher than the signal frequency (by an amount equal to the intermediate frequency). In such a case, the superheterodyne oscillator will be operated (e.g., with a 456-kc. i.f.) at 5456 kc. when the receiver is set for the 5000-kc. WWV signal. There will then be *two* signals which will beat with the oscillator to yield the 456-kc. i.f. signal—the real signal at 5000 kc. and the image at 5912 kc.

The real signal is thus the lower in frequency of the two and so may be identified. If the superheterodyne oscillator were set lower in frequency than the signal, it would operate upon 4544 kc. for a signal frequency of 5000 kc. The image would then be at 4088 kc. and the real signal at 5000 kc. In this case, the real signal is identified as the one higher in frequency.

METHODS OF REFERENCE

Both the radio- and audio-frequency emissions from WWV may be utilized for standardizing purposes. The various practical methods for comparing local frequencies to the standard signals will be described in the following paragraphs.

Comparison of Low-Frequency R.F. Oscillators. This is the most common application of the standard frequencies and refers to the standardization of radio-frequency oscillators operated at some frequency lower than that of the standard signal. Such equipment includes *frequency standards* (which are generally operated at fundamental frequencies of 50, 100, 250, 500, or 1000 kc.), *signal generators,* and *test oscillators.* These devices may be loosely-coupled directly to the WWV receiver, as shown in Figure 1, through a small capacitor, or by linking the insulated output lead (from the oscillator) about the antenna post of the receiver.

1. Tune-in sharply one of the WWV signals.
2. Couple the oscillator, the fundamental of which must be some submultiple of the WWV frequency. (A 10-kc. oscillator, for example, will furnish a 50th harmonic at 5 Mc., 100th at 10 Mc., or 150th at 15 Mc.). Note that a beatnote is set up between the oscillator harmonic and the received signal.
3. Adjust the oscillator frequency control for exact zero beat. At zero beat with the modulated WWV signal, all roughness or waxing and waning will disappear. Closer zero beat adjustment may be obtained by beating with the pure carrier during the intervals when modulation is interrupted. A zero-beat indicator, such as output ac voltmeter, magic eye, or cathode ray tube, will give closer indications than will aural indicators, such as headphones or speaker.

Various methods are available for correcting the oscillator frequency. In self-excited oscillators, a small trimmer capacitor, connected in parallel with the tank, serves this purpose. In crystal oscillators, a small trimmer may be connected in parallel with the crystal holder, a small padder capacitor in series, or the air gap between the quartz plate and the upper electrode may be made adjustable. A final close correction may be made by adjusting the crystal temperature, when oven-mounting is employed.

Direct Comparison of R.F. Oscillator. When local oscillators are capable of delivering signals of fundamental frequency coinciding with one or more of the standard frequencies, their output may be referred directly to the latter. The same arrangement as shown in Figure 1 would be employed.

Thus, an oscillator or signal generator set to 2.5, 5, 10, or 15 megacycles might be adjusted by beating directly against these standard frequencies.

Extension of Frequency Range. Frequencies which are higher in value than either of the standard frequencies may not be checked in either of the manners just described. A special setup for extending the range of measurement is shown in Figure 2.

An auxiliary oscillator is operated at one of the standard frequencies and is corrected precisely. Its output will then contain the fundamental and harmonics of this standard emission to a high order. Harmonic points will appear as spot frequencies separated by 2.5 Mc. when the auxiliary oscillator fundamental is 2500 kc., 5 Mc. for 5000 kc., 10 Mc. for 10,000 kc., and 15 Mc. for 15,000 kc. The harmonic points from the latter two will extend well into the very-high-frequency region and may be employed for calibrating receivers, monitors, and other equipment embracing signal detection.

Non-detecting equipment, such as oscillators, signal generators, and wavemeters operated at higher points than the standard signals, will require a somewhat different arrangement. A set-up for calibration of this equipment is given in Figure 3.

As in the previous case, an auxiliary oscillator (A) is operated at a fundamental coinciding with one of the standard frequencies, against which it is precisely corrected. Output of this oscillator, in addition to being loosely coupled to the WWV receiver, is loosely coupled to an aperiodic detector, which in turn is followed by an audio amplifier and zero-beat indicator.

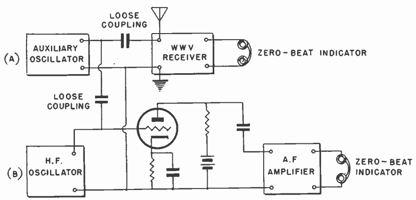

Figure 3

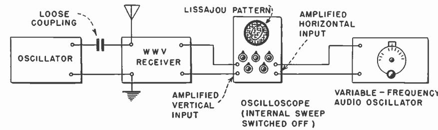

Figure 4

The high-frequency oscillator under test (B) is also loosely-coupled to the aperiodic detector and its output voltage accordingly may beat against one of the harmonics delivered by oscillator A. The exactness of its setting to any one of these harmonics may be checked by means of the zero-beat indicator.

By this arrangement, or a comparable one, the standard frequencies may be extended into the very-high-frequency spectra. Precision of the method depends upon the closeness of setting of oscillator A to the standard frequency, and of oscillator B to the harmonics of oscillator A.

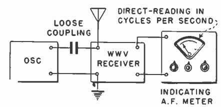

Figure 5

Radio-Frequency Deviation. In some cases, it is not possible or desirable to correct the frequency of an oscillator under test. This oscillator may be operated in any of the conditions discussed in the preceding cases, and one of its harmonics may fall close to (but not coincide with) a standard frequency signal. If the deviation from the standard frequency is not more than 50 kilocycles plus or minus, it may be measured by means of the arrangement shown in Figure 4.

The oscillator under test is loosely coupled to the WWV receiver, as in the previous cases. The a.f. output voltage of the receiver is delivered to the amplified vertical input of a cathode ray oscilloscope, and the output voltage of a variable-frequency a.f. oscillator delivered to the amplified horizontal input. Internal timing and synchronizing is switched off. All measurements must be carried out during intervals when tone modulation is absent from the WWV carrier.

Interaction of the two a.f. voltages will produce a typical set of patterns on the oscilloscope screen. When the frequency of the a.f. oscillator is adjusted exactly to that of the beat note between the r.f. oscillator under test and the standard frequency signal, the oscilloscope pattern will become a *stationary* circle or ellipse. At that point, the deviation frequency may be read directly from the dial of the a.f. oscillator. To determine whether the r.f. oscillator frequency is higher or lower than the standard frequency (plus or minus deviation), it is necessary only to remove the antenna connection (but not the oscillator coupling) from the receiver, to interrupt the standard frequency and note the dial position of the oscillator signal with respect to the WWV signal.

Deviation measurements may be made, in the same manner just described, upon high-frequency signals checked by the arrangement shown in Figure 3. In this case, the problem is to measure deviation of the signal from oscillator B from some harmonic of oscillator A.

In deviation measurements, one manipulation may be eliminated by employing a direct-reading electronic audio frequency meter in place of the audio oscillator and oscilloscope. This scheme is illustrated by Figure 5. The a.f. meter will then indicate deviation directly and automatically in cycles per second.

Audio-Frequency Comparisons. Local audio frequencies may be referred directly to the tone modulation of WWV signals by means of the simple arrangement shown in Figure 6. The a.f. output voltage from the WWV receiver is delivered to the amplified vertical input of a cathode ray oscilloscope; a.f. output voltage from the audio oscillator under test to the amplified horizontal input. Sweep and synchronization within the oscilloscope are switched off.

If comparisons are to be made against the 440-cycle frequency, the standard signal is tuned in normally. If the 4000-cycle frequency is required, however, the receiver is detuned somewhat, as this higher tone will be found in the sidebands.

When the local a.f. oscillator frequency coincides with 440 or 4000 cycles, the oscilloscope pattern will be a stationary circle or ellipse. Harmonics or subfundamentals of the two modulation frequencies may be identified by means of Lissajou's Figures. A wide assortment of audio-frequency tests is thus afforded.

Non-electrical tone-generating devices capable of maintaining sustained sound, such as bells, horns, chimes, and whistles, may have their frequencies checked in the same manner, except that a suitable audio amplifier is substituted for the a.f. oscillator in Figure 5. A microphone is provided at the input of this amplifier to pick up sound waves from the device under test.

Comparison of Non-Coincident Frequencies. Radio frequencies which do not coincide with the standard frequencies, either in fundamental or harmonics, may be checked by means of a receiver or monitor which has previously been standardized against WWV.

For example, the receiver or monitor dial may be calibrated at a multiplicity of points by means of a low-frequency standard oscillator (operated at 50, 100, 500, or 1000 kilocycles) which has previously been standardized against WWV. The unknown signal is then tuned-in on the receiver and the position of the signal noted with reference to adjacent harmonics from the standard oscillator. The unknown frequency may then be determined either in terms of a beat note with one of the harmonics or by interpolation on the receiver dial.

BEST STANDARD FREQUENCY

The frequency which is chosen from the four WWV carriers for a given measurement will be governed by several common factors, principally reception conditions and location of harmonics from the oscillator under test. In instances where several of the standard frequencies are received equally well and the oscillator frequency is lower than the lowest standard frequency, it will be advisable to employ the higher of the received standard frequencies. In this way, greater accuracy of measurement is obtained.

An example might be the checking of a 1000-kc. secondary standard oscillator. If both the 5- and 10-megacycle standard frequency signals are received equally well, either of these might be employed—the 5th harmonic of the oscillator being referred to 5 Mc. or the 10th to 10 Mc. However, a shift of 1 cycle at 1000 kc. will show up as a 10-cycle change at 10 megacycles, while only as a 5-cycle change at 5 megacycles.

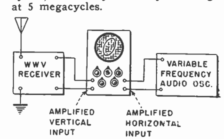

Figure 6