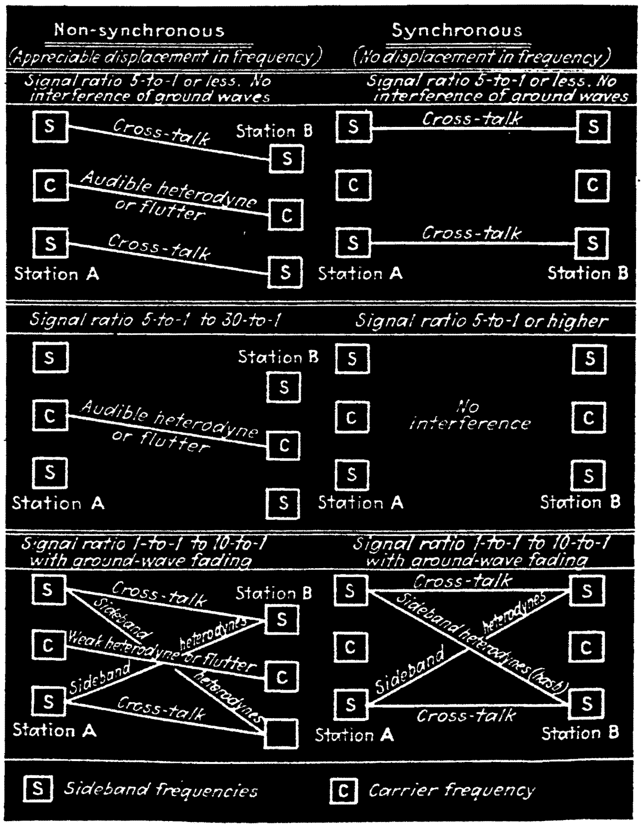
THE PRESENT-DAY STATUS O

Three systems now operating successfully point way to expansion of broadcast facilities

EVER since broadcasting became a major industry it has been clear that the demand for wavelength assignments far exceeds the supply. This fact has been the cause of many gray hairs in the Federal Commission in Washington, who have strived to grant requests for more broadcast-station facilities without destroying clear channels or adding to the interference on shared channels.

The situation has been aggravated by the great political pressure exerted to secure higher station powers and frequency assignments for new stations. Sooner or later it will be no longer possible to avoid increasing interference when a new station goes on the air. This saturation point is not far away, but the demand for additional facilities by commercial, fraternal and educational interests is unabated.

One of the most immediately practical means of opening up new channels for broadcasting without increasing interference lies in the synchronizing of transmitters. Synchronizing, which means simply maintaining the carrier waves of two or more transmitters on the same frequency, within the narrow limits of about one-tenth of a cycle, will not cure all kinds of interference, but it will lessen the interference between stations on shared channels, and it will permit more stations to share the same channel. Comparisons between the types of interference experienced with synchronous and non-synchronous transmission are given in the diagram to the left. It will be noted that under conditions which are practically realizable, no interference whatever occurs between synchronized stations.



A symbolic comparison of types of interference experienced under synchronous and non-synchronous operation of broadcast stations

Effects of synchronizing on reception

When two stations share the same channel simultaneously, a variety of effects may be noticed at the receiver, depending upon the relative location of receiver and transmitters, and upon the difference between the carrier frequencies of the two stations. If the difference between carriers corresponds to an audible frequency, *i.e.*, 20 cycles or more, a heterodyne note of that frequency will be heard in the receiver, even though the ratio of signal strengths received from the two transmitters may be as high as 20 to 1 or higher. Under the regulations of the FCC, it is possible to obtain beat notes as high as 100 cycles per second between stations operating on the same channel, since each is allowed to deviate from its assigned frequency by 50 cycles. Actually, very few audible beat notes arise, since frequency deviations of more than 10 cycles are rare. But even though there is no audible beat note, an inaudible beat usually exists which may give rise to an audible annoying "flutter effect," often noticed on shared channels at night. This flutter arises from the interaction between the inaudible beat note and the noise components received by or generated in the receiver. Finally, even though heterodyning or flutter may not be present, if the signal strengths received are nearly the same, say one-to-one or two-to-one, cross-talk will occur, since both programs will be detected by the receiver.

If the carrier frequencies are precisely the same, *i.e.*, exactly synchronized, no audible or inaudible beat note can occur, and no fluttering appears. Exact synchronism is an ideal which can be approached but never attained, because of the "elastic" quality of even the best frequency control, so the error which can be tolerated must be decided. Most systems of synchronizing used today will maintain the two transmitters in synchronism to within 0.1 cycle, or 36 electrical degrees. This is considered to be the highest allowable deviation for successful synchronous operation; one system, it is claimed, maintains control within one or two electrical degrees.

Since heterodyning and beat notes are eliminated by synchronous operation, trouble arises only when the signals received from two synchronized stations are of approximately the same strength, *i.e.*, ratios from a one-to-one to 10-to-1. When the signals are approximately equal cross-talk is the absolute limitation; it can be cured only by the use of the same program on both stations. Even if the same program is used, still another difficulty arises due to wave-interference between the ground waves of the two stations. When the carriers of the two stations arrive out of phase, they tend to cancel out while the sideband frequencies, being of different wave

BROADCAST SYNCHRONIZING

Improved reception conditions and wider service areas possible. A review of methods used

length, do not. With the carrier much reduced, beating between the sidebands occurs, and the result is a very disagreeable type of distortion.

There are secondary effects of minor importance, but cross-talk and side-band "hash" are the most important technical difficulties which arise between synchronized stations. These difficulties have the practical effect of limiting the separation of the stations to not less than 200 miles. The limiting distance depends to a certain extent upon the power of the stations involved and upon the type of radiation system used in each case, upon the attenuation constant of the surrounding territory, and the population distribution. Under ordinary conditions, two 1,000-watt stations should be separated by at least 200 miles, when sending the same program. Otherwise sideband "hash" will occur within the primary service area of both stations. Between 100-watt stations, the distance may be reduced to 100 miles.

In addition to the requirement of synchronism within 0.1 cycle, it is necessary to synchronize the program circuits when both stations use the same program, as is usually the case. The delay introduced by wire lines averages about 7 milliseconds per 100 miles, so that if the program lines of the two stations differ in length by several hundred miles, a considerable lag may be introduced. In the regions where signals from both stations are received, the resulting echo is quite distinct.

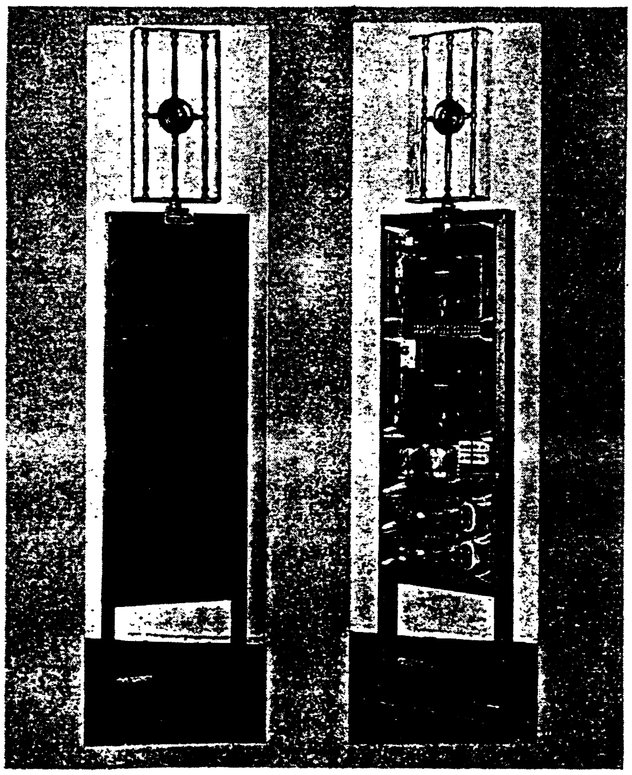
The use of wire lines to carry the synchronizing frequency between the stations introduces several important factors which determine the type of apparatus used. First, the reference frequency must be of audible or at most barely super-audible frequency, otherwise it is impossible to send sufficient energy over the distances required. In the second place, the lines are subject to casual phase shifts and amplitude changes which give an "elastic" quality to the control exercised by the line. In other words, although the average frequency may be maintained with great accuracy, the frequency at any instant may depart from the average by amounts sufficient to throw the two stations temporarily out of synchronism. Various schemes have been devised to overcome these line variations, or at least to lessen their effect on the control. The methods used are well illustrated by the following descriptions of apparatus used by synchronized stations now operating.

WBZ-WBZA in Boston and Springfield, Massachusetts

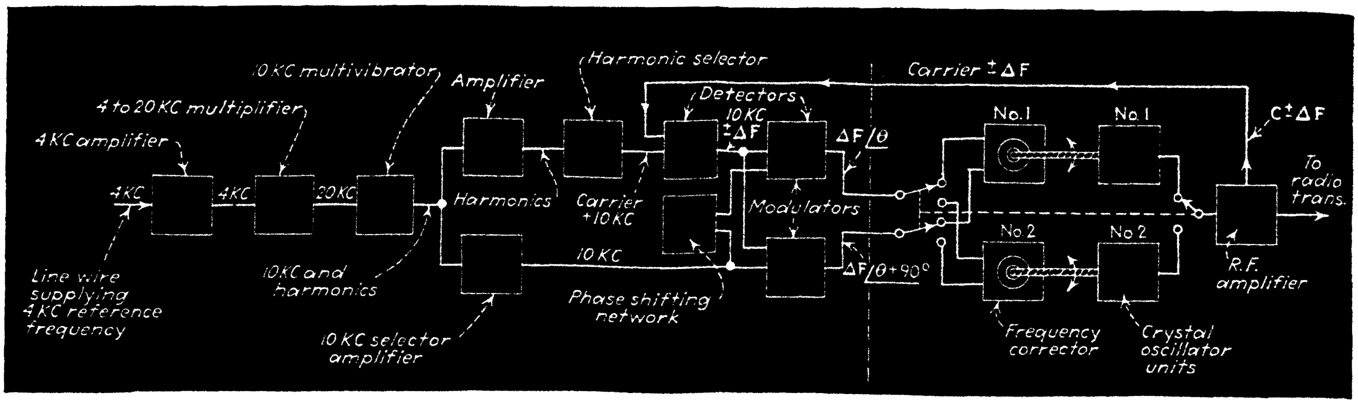
Westinghouse Stations WBZ, 50,000 watts, located at Millis, Mass., and WBZA, 1,000 watts, at Springfield, are operated synchronously, using apparatus developed and installed by the Radio Division of the company. The carrier frequency of the stations, 990 kc., is generated by a stable crystal oscillator at the Springfield station. This frequency is then divided by stable multivibrators 72 times, giving a reference frequency of 13.75 kc., which is then fed through balanced line amplifiers to a program circuit leading to the transmitter at Millis. This program circuit, a single open-wire pair, carries the regular inter-station program, in addition to the reference frequency. Low-pass audio filters having a cut-off at 10 kc are installed at both ends of the line to separate the program from the 13.75 kc reference frequency. The frequency of 13.75 kc is sufficiently low to be transmitted with sufficient level over the short (70-mile) connecting line and still high enough to be well out of the program range.

At the Millis station, the reference frequency from the line is received in a balancing network, amplified through a saturated amplifier whose output is substantially independent of changes of amplitude in the input circuit, and multiplied back to 990 kc. The output of the final multiplier, after passing through a two-stage crystal filter and a buffer, is used directly as the excitation frequency of the transmitter at Millis. Since adverse weather may cause line failure resulting in the loss of the 13.75 kc reference frequency, an automatic relay system is provided to control an emergency crystal oscillator, maintained at normal operating conditions at all times, thus always assuring the proper operating frequency for the transmitter.

This system, the pioneer synchronous installation in this country, has been in continuous commercial operation since 1926. There are several contributing factors which make it possible to synchronize two stations sepa-



Front and rear views of receiver used midway between WHO and WOC, for determining the degree of synchronism between those stations. Manual control was used in this installation



Block diagram showing synchronizing apparatus used at WBBM-KFAB

rated by such a short distance (65 miles air line). Most important is the extremely high attenuation of the territory surrounding both stations. The rocky, dry soil has the effect of producing relatively compact areas of high signal strength. Secondly, the areas in which the signals from the two stations are of comparable intensity are narrow, well-defined, and located in very sparsely populated regions. A directional antenna, used at the Millis transmitter reduces the signal level in these zones. The interference pattern is apparently stationary, showing that the degree of synchronism is very high.

WJZ-WBAL at Bound Brook and Baltimore

WJZ's 50,000-watt transmitter at Bound Brook, N. J., operating on 760 kc. provides a synchronizing signal for WBAL, 2,500 watts, at Baltimore, 150 miles distant from Bound Brook. The stations are synchronized during the night time transmissions only; during the day, WBAL operates on a channel (shared with KTHS in Hot Springs, Ark.) of 1,060 kc with 10,000 watts power. The equipment used for synchronizing is the result of several years of development under the direction of C. W. Horn, Director of Research and Development of the National Broadcasting Company, which company installed the equipment.

In the primary service area of both stations, no interference from either station is experienced by the other. "Hash" areas are known to exist between the two stations, but these have been made to fall in unpopulated regions, and have been localized sufficiently so that the distortion may be overcome by the use of a long antenna (such as a capacity connection to the telephone lines). The use of a directional antenna at WBAL, proper proportioning of power between the stations, and very exact synchronizing have been necessary to secure the present high degree of satisfactory service. No complaints of poor reception which can be traced to the synchronous operation have been received.

According to Mr. Horn, one of the important problems in this installation was maintaining synchronism to within three or four electrical degrees, so that the pattern of the distortion areas would remain stationary. This high degree of precision cannot be maintained by wire lines, except as the line variations are averaged over a long period. It is necessary, therefore, to provide a very stable frequency source at each transmitter whose frequency could be compared with the average frequency received from the line, but which would not follow the instantaneous variations in the line. Such a "fly-wheel" effect is produced in this case by the use of a highly accurate temperature-controlled tuning fork. The reference frequency, 4,000 cycles per second, is supplied by the master frequency source of the Bell System, the Marrison clock in New York, which maintains an accuracy of nearly 1 part in 100,000,000. This frequency is used to control both WJZ and WBAL.

The 4,000-cycle signal is received from the line, amplified through a saturated amplifier and buffer stages, and applied directly through an electromagnetic drive to the tuning fork. The tuning fork tends to maintain a very accurate frequency of 4,000 cycles of its own accord, but if it deviates from that value, the control from the line pulls it back. The vibration of the fork induces a voltage in a second coil, which, when amplified and multiplied, provides any frequency from 1,500 to 550 kc. The 760-kc frequency is picked off and used as the excitation frequency for the transmitter. The inertia of the tuning fork system prevents incidental variations in the line from exercising any control, but allows the average frequency whose accuracy is extremely high, to maintain control.

This system, while highly satisfactory, is not the final form of synchronizing developed by NBC. The problem is still being studied by this organization, and refined methods of obtaining even closer approaches to absolute synchronism are now in process of development.

WBBM-KFAB, Chicago and Lincoln, Nebraska

WBBM operates on a frequency of 770 kc, with 25,000 watts power; KFAB, synchronized with WBBM, operates with 5,000 watts power, at a distance of 480 miles from the WBBM transmitter. These stations have been operating synchronously since January, 1934. The equipment used is the standard Western Electric Synchronization System, developed by the Bell Telephone Laboratories.

The system used, shown in the accompanying illustration, operates as follows: The standard Bell System 4,000-cycle signal is received over the wire line, and is amplified at 4,000 cycles. A 5-times multiplier increases this frequency to 20 kc, the output of which is fed to a multivibrator which provides 10 kc. and all the harmonics required for any broadcast frequency up to 1,500 kc. (the 150th harmonic). These harmonics are then led to a circuit which amplifies them and selects the one which is 10 kc. higher than the desired carrier (in this case, the case of WBBM-KFAB, this is 770 plus 10, or 780 kc.). A portion of the carrier output of the transmitter is mixed with this 780 kc. in a detector whose output therefore consists of 10 kc. plus or minus whatever frequency deviation is present in the carrier of the station. By another path the 10 kc. fundamental of the multivibrator is amplified and applied, through a 90-deg. phase-shifting network, to a detector where it is mixed with the 10 kc. $\pm \Delta f$. The result is $\Delta f\underline{/\theta}$, the deviation from the correct frequency with an arbitrary phase angle. In a separate circuit the 10-kc. multivibrator output is combined with the 10-kc. $\pm \Delta f$, but without the phase shift. The result is $\Delta f\underline{/\theta + 90^\circ}$ with the same arbitrary phase angle, but advanced 90 degrees.

These two outputs, $\Delta f\underline{/\theta}$ and $\Delta f\underline{/\theta + 90^\circ}$ are fed to a two-phase synchronous motor which is connected mechanically to the trimmer condenser in the crystal control circuit of the transmitter. When a frequency deviation appears, the voltages acting on the motor cause it to turn in the proper direction to correct the deviation. The time-lag involved is appreciable, but small enough to give practically continuous correction. Duplicate frequency correctors and crystals are provided.

According to reports of the engineering staffs of these stations, the system has operated with complete success since its installation. It has been found that if the carriers of the two stations were synchronized to within 0.5 cycle, no adverse effects could be noticed by trained observers using modern receivers, even when the signals were at their extreme low fading level.