BINAURAL TRANSMISSION ON A SINGLE CHANNEL

By transmitting two sets of sidebands, one displaced 90 degrees from the other, two separate audio-signals may be transmitted over a single r-f channel. The system, which employs amplitude and frequency modulated signals simultaneously, has been successfully demonstrated in the laboratory

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WHEN sound is transmitted by the ordinary system over telephone lines or by radio, only a single channel is provided, and audio perspective is entirely lost since the phase displacement between the sounds received by the two ears bears no relation to what happens at the transmitter. Binaural reception has been demonstrated using two microphones, set up at suitable locations on each side of a stage on which the orchestra was seated. Each microphone is connected by a separate telephone channel to one of two loud speakers placed similarly to the microphones but on the stage of another auditorium. To those listening in the second auditorium the auditory effect is nearly the same as though the orchestra were actually playing on the stage instead of being reproduced by loud speakers.

Another demonstration[1] used a dummy with two microphones placed on its head instead of ears. Each microphone was connected by a separate channel to one receiver of a double head-set. When the headsets were worn by spectators they found themselves effectively removed to the location of the dummy's head insofar as sounds were concerned. The demonstration was so realistic that when some one stepped up behind the dummy and asked him to turn around a number of the listeners actually did so before they realized from whence the sounds had come.

While binaural systems may be applied to radio channels just as readily as to wire circuits there is one very serious obstacle from a practical point of view, that is the need for two separate channels for the transmission of a single program. This means that the extension of binaural transmission to the broadcast band is practically prohibited until the development of some new method which will eliminate the need of two separate radio channels. Evidently the desirable solution would permit transmission of both audio channels over the same carrier frequency, thus using but one radio channel and reducing to a minimum the additional investment required to convert one of the present "monaural" transmitters to handle a binaural system.

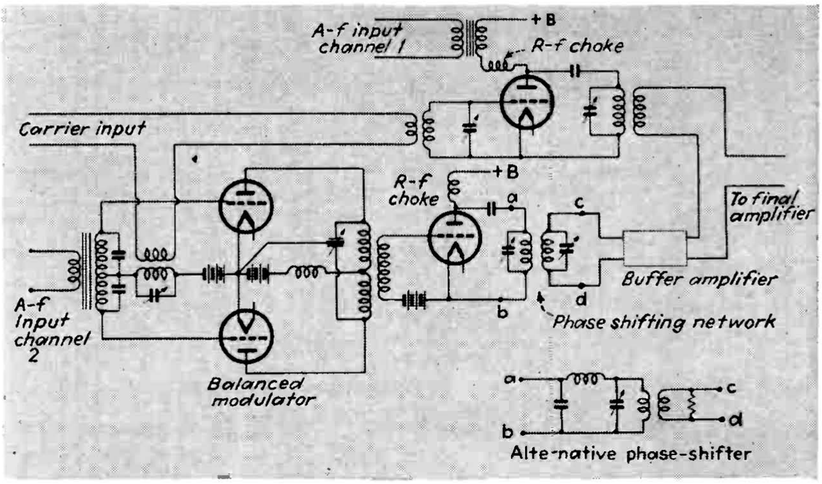


Fig. 1—Combination of a conventional amplitude modulator and a balanced modulator with a 90-degree phase-shift network, used for combining two audio inputs on a single carrier

A comparatively simple solution along these lines is shown in the diagram of Fig. 1. If this is compared with a conventional transmitter, the additional equipment required is seen to be a balanced modulator preceded by a phase-shifting network, together with the necessary audio equipment for handling the second channel. The function of the balanced modulator and phase-shifting network is to provide a second set of sidebands displaced 90 degrees from the first (or normal) set.

It is well known that an amplitude-modulated wave in which the carrier has been shifted 90 degrees is a good approximation of a frequency-modulated wave in which the amount of frequency swing is small compared with the applied audio frequency and is proportional to the audio frequency. Thus, the transmitter may be thought of as one in which the signal from the first microphone is transmitted by amplitude modulation, and that from the second microphone is transmitted by frequency modulation, both on the same carrier with the bandwidth due to both modulations being no greater than that of a conventional transmitter. A conventional receiver, when accurately tuned, will reproduce the signal from the first microphone but will not respond to that from the second, while a modified receiver, described in a later paragraph, will respond to the signal from the second microphone but not to that from the first.

The operation of the system shown in Fig. 1 may be explained by means of vector diagrams as in Fig. 2. Fig. 2A represents normal amplitude modulation with the carrier being represented by vector 1. Actually, this vector must rotate at an angular velocity ω, where the carrier frequency is $\omega/2\pi$, but if the vector is assumed to be a mechanical arrow rotating at this velocity and illuminated by a stroboscopic light of carrier frequency, it would appear to stand still. Similarly the upper sideband may be represented by vector 2, for any given audio frequency, rotating at an angular velocity $\omega + q$, where the audio frequency is $q/2\pi$. When illuminated by the stroboscopic light this vector will evidently appear to rotate in a *counterclockwise* direction at a velocity q. In a similar manner vector 3 will represent the lower sideband, apparently revolving in a *clockwise* direction at a velocity q.

Fig. 2B shows three similar vectors to represent the carrier and sidebands in the additional modulator of Fig. 1. The carrier is shifted 90 degrees and the sideband vectors are spaced equally on either side of this carrier. Since a balanced modulator is used the carrier is removed and the vectors shown in Fig. 2C represent the output. When the outputs of the two modulators are combined the result will be a single carrier and two sets of sidebands as shown in Fig. 2D.

The expression for the total output as shown in Fig. 2D is

$$e = E \sin \omega t + \frac{aE}{2} \sin (\omega + q) t + \frac{aE}{2} \sin (\omega - q) t + \frac{aE}{2} \cos (\omega + q) t + \frac{aE}{2} \cos (\omega - q) t \quad (1)$$

At the receiver only sidebands 2 and 3 of Fig. 2D will produce an audio output provided the gain of the receiver at the two frequencies $(\omega + q)/2\pi$ and $(\omega - q)/2\pi$ is the same. The receiver must be either so broadly tuned as to provide equal

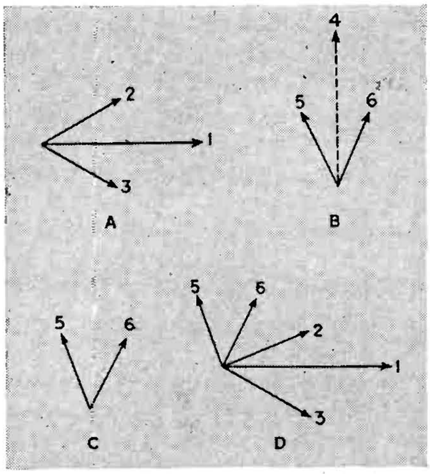


Fig. 2—Vector relationships of the two sets of sidebands, the combined signal representing simultaneous amplitude and frequency modulation

response over the entire bandwidth or tuned to exact resonance so that the attenuation of both sidebands is the same. Under these conditions the two audio components of frequency $q/2\pi$ resulting from the interaction of sidebands 2 and 3 with the carrier will be additive while those resulting from the interaction of sidebands 5 and 6 will be opposite in phase and will cancel.

Proof of the foregoing may be readily made for a receiver using a square law detector. The equation of the detector current, in terms of the applied voltage, is

$$i = I_o + Ae + Be^2 \quad (2)$$

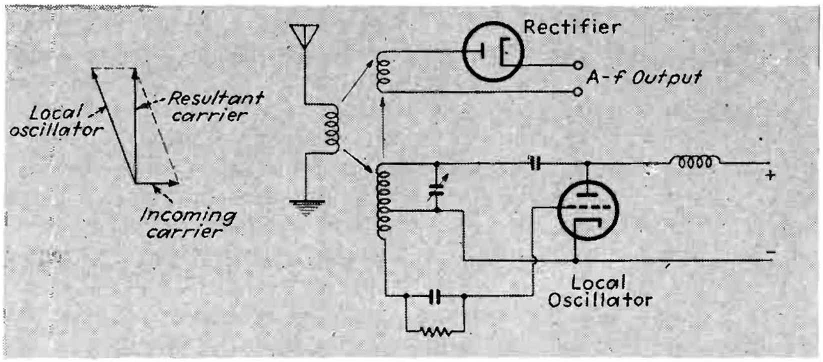
where I_o is the quiescent d-c component of current flowing, e is the impressed voltage given by Equation (1), and A and B are constants whose magnitudes are determined by the characteristics of the detector. When Equation (1) is substituted in (2) and the terms expanded to segregate the various frequency components it will be found that the statements of the preceding paragraph are correct. Similar results will be obtained with a linear detector.

It is quite possible to construct a receiver which is capable of reproducing the audio signal from sidebands 5 and 6 instead of from 2 and 3. One method of so doing has been described by one of the authors.[2] As used in the present application, the process consists essentially of shifting the phase of the carrier at the receiver by 90 degrees and then applying ordinary detecting methods. Thus, sidebands 5 and 6 will be placed in the same phase relative to the shifted carrier as were 2 and 3 before shifting, while 2 and 3 will be placed in the position of 5 and 6 (except for a phase reversal of 180 degrees which does not affect the cancellation process). Such a receiver will then reproduce the output from the second microphone while the conventional receiver will reproduce the output from the first microphone. The output from each receiver may be applied to a separate loud speaker and, if acoustic problems are properly solved, binaural reception will result.

The circuit of Fig. 3B shows a simple form of the phase-shifting receiver. A local oscillator is adjusted to the same frequency as the incoming carrier and is then coupled to the input from the antenna in such a manner as to tend to lock in step with the carrier at a phase displacement of a little more than 90 degrees, just enough more so that the vector sum of the oscillator output and the incoming carrier will produce a resultant carrier shifted 90 degrees from the incoming, as shown in Fig. 3A. Obviously this resultant carrier will cause the signal from sidebands 5 and 6 to be reproduced while that from 2 and 3 will be rejected.

The segregation of the two chan-

Fig. 3—Basic receiver circuit (B) with vector representation (A) of the action of the local oscillator on the resulting carrier



nels at the point of reception may best be performed in the output of the intermediate amplifier of a superheterodyne receiver, since the frequency of the local oscillator need not then be varied when tuning to a different station. A circuit diagram of such a receiver is shown in Fig. 4. The only extra equipment over that of a conventional receiver is the additional second detector and a-f system together with the local oscillator required for shifting the phase of the carrier. A receiver built especially for reception of binaural programs would undoubtedly contain all parts in a single cabinet except one of the speakers. This would be separately mounted for proper placement in the room when the receiver was installed. On the other hand binaural reception equipment could be added to an old receiver by providing a transmission line to be coupled to the output of the i-f amplifier. This would supply a second unit consisting of a linear detector, a-f amplifier, local oscillator and speaker for reproducing the second channel.

An experimental binaural receiver circuit used to test the system is shown in Fig. 4. The coils are coaxially wound on the same diameter. Distances d_1, d_2 and d_3 are adjustable. Coupling d_1 is first adjusted to give the desired frequency lock-in range on the lock-in oscillator VT_2. The value of grid leak also controls the lock-in range. Coupling d_2 is then adjusted with no incoming signal to give the correct r-f voltage on the grid leak rectifier VT_1. This voltage should be from 3 to 10 times larger than the strongest signal which it is desired to receive. A damping resistor is inserted to make sure that the rectifier does not respond to frequency modulation directly, thereby causing some slight second harmonic distortion. This resistor will not be necessary unless the circuit has high Q. The switch S changes from frequency-modulation to amplitude modulation. When the switch is closed the receiver responds only to frequency modulation, and when it is open the receiver responds only to amplitude modulation. The input may be either radio frequency or intermediate frequency. The values of the constants given are for r-f operation in the broadcast band.

Rather crude listening tests showed that the principles as outlined herein are correct, and that the system is practical. As far as can be determined from these tests, the degree of separation of the two channels is quite satisfactory. However, it is difficult to make quantitative binaural measurements without an auditorium and a large number of listeners, as in the Bell System demonstrations. In place of such an investigation, another experiment was substituted which was not only easier to perform, but was also a more severe test of the ability of the proposed circuits to supply two channels for a binaural system. This demonstration was carried out at the University of Washington in collaboration with E. D. Scott, as part of a program of investigation into the general problems of frequency modulation.

In this demonstration a small transmitter was amplitude modulated in the usual manner, but frequency modulation was also applied to the oscillator unit by means of a diode-terminated transmission line as described by Eastman and Scott.[3]

This frequency modulation differed from that of Major Armstrong's recent work in that the frequency swing was made somewhat less than the highest audio frequency to be transmitted. Thus only the first order sidebands were of importance for high audio frequencies and the required bandwidth was not increased. At the lower audio frequencies many higher order sidebands were present, but it has been shown[2] that these cause no distortion. Furthermore, these higher order sidebands caused no undesired response in the amplitude-modulation receiver since they cancel in the same manner as explained before. Two separate modulations were applied simultaneously from two phonographs, one to the amplitude modulating system and the other to the frequency-modulating system.

At the receiver the two programs were separated by the method just described, and it was found that even with the crude laboratory equipment available the background sound of one program in the output of the other was more than 30 db down. While this was perhaps not sufficient separation to provide two entirely different programs with satisfactory elimination of crosstalk it would certainly be sufficient for two programs which are the same except for a slight difference in time phase.

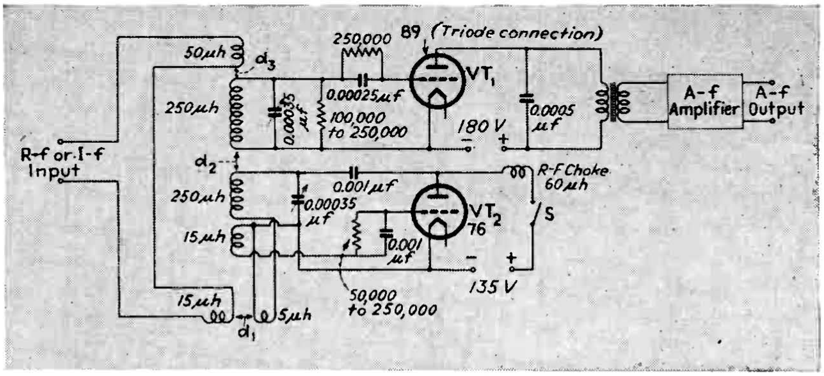


Fig. 4—Portion of a receiver, between i-f amplifier and audio amplifier, suitable either for amplitude- or frequency-modulated waves

It should be noted that the demodulator shown in Fig. 3 can be adjusted so that the diode plate current is proportional to either the instantaneous frequency deviation of the transmitter or to the instantaneous phase deviation, depending on the circuit constants of the local oscillator. In the double program demonstration described above, the output was made proportional to frequency deviation because of the method used to modulate the transmitter, while in the carrier-shifting method of approximating frequency modulation shown in Fig. 1, the output would be made proportional to phase shift.

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[1] Bell Laboratories Record: June 1933, p. 286.

[2] J. R. Woodyard, "Application of the Autosynchronized Oscillator to Frequency Demodulation", *Proc. I.R.E.*, May 1937, p. 612.

[3] A. V. Eastman and E. D. Scott, "Transmission Lines as Frequency Modulators", *Proc. I.R.E.*, July 1934, p. 878 (vol. 22). An improved frequency modulator of the same type was described by Austin V. Eastman, "Fundamentals of Vacuum Tubes", pp. 360–362; McGraw-Hill Book Co. (1937).