England Tackles the Multiplex Channel Problem

The simultaneous transmission of two high-speed telegraphic services and one telephone service over the same wavelength was recently demonstrated with this apparatus at the English Beam Station at Bridgewater. The demonstration, which was made in the presence of David Sarnoff, Vice-President of the Radio Corporation of America, was conducted between stations at Bridgewater, England (receiving), and Montreal, Canada (transmitting). Mr. G. A. Mathieu, who collaborated with Senatore Marconi in designing the system, is shown speaking into the telephone. It is claimed that this apparatus diminishes fading to a great extent, and thus gives constant volume of speech and signals. The engineering details of the system employed are not available at present.

A FILTER THAT SAVES 5 KILOCYCLES

This picture shows part of the speech input, modulating, filter and amplifying apparatus at the Rocky Point station of the Radio Corporation of America, where radiotelephonic transmission to Europe is carried on. The filter suppresses the carrier wave and one of the side-bands, thus halving the width of the channel necessary for transmission

Can We Multiplex Our Radio Channels?

By Albert F. Murray

THE progress of radio in the past has been so rapid, due to scientific genius and manufacturing skill, that a large part of the American public is now in the frame of mind in which it believes that almost anything is possible in the way of future developments. This attitude is held not only by the lay enthusiast for radio, but by some serious experimenters and technically minded men. New developments are expected to be realized almost by magic, and technical problems of the most difficult nature immediately solved by some new product of the inventor's skill. So it is that whenever some advance is made in radio, the press and the public immediately greet it as the herald of a new radio Utopia, without consideration of what technical, practical, or manufacturing obstacles are in the way.

THE solution of the problem of broadcast congestion is perhaps the most pressing of the needs of the broadcast listener to-day, and many people seem only too willing to believe that the solution will come, mysteriously, from some new invention. And so, when Dr. Lee DeForest some time ago made the statement that some 500,000 radiotelegraph stations could be disposed on the short-wave channels from 10 to 200 meters by means of a system of "double modulation," the press and general public believed that the long expected solution of the broadcasting problem was solved, and "double modulation" would soon multiplex all radio channels.

Mr. Murray considers the multiplexing of radio channels by means of "double modulation" from a technical and practical angle, shows how the system works, exactly what advantages may be realized from it, and what defects have kept it from being used so far. A method of multiplying channels—that of "single side-band" transmission—is also examined in a similar way. It is this second method which Mr. Murray considers most possible, its present practicality being limited by the need of skilful operation and precision instruments.

—THE EDITOR.

We can understand then, in view of this attitude, the great stir of interest which some time ago was occasioned by press reports in which a well-known radio engineer outlined a "double tuning" system which was said would multiply each of the present radio channels by 100, thus making room for all those who are clamoring for space in the crowded ether. Concurrently, the question of finding space in the short-wave bands for the radio traffic of many corporations and private enterprises engaged the attention of the Federal Radio Commission. The natural result is that many of the radio public are now asking, "Is there really anything in these new radio systems?"

Regarding the proposed "double tuning" system, suppose we consider these questions: Is it a new or novel system? Will it multiply the existing radio channels? Are there good chances of this system being used in our country? How can more radio channels be made available?

IS THE SYSTEM NOVEL?

FIRST, the system referred to in the press reports as "double tuning" is usually more accurately described by the name of "double modulation" or "multiplex radio telephony." In radio, "modulation" means the "moulding" of the radio wave at the transmitter by voice frequen-

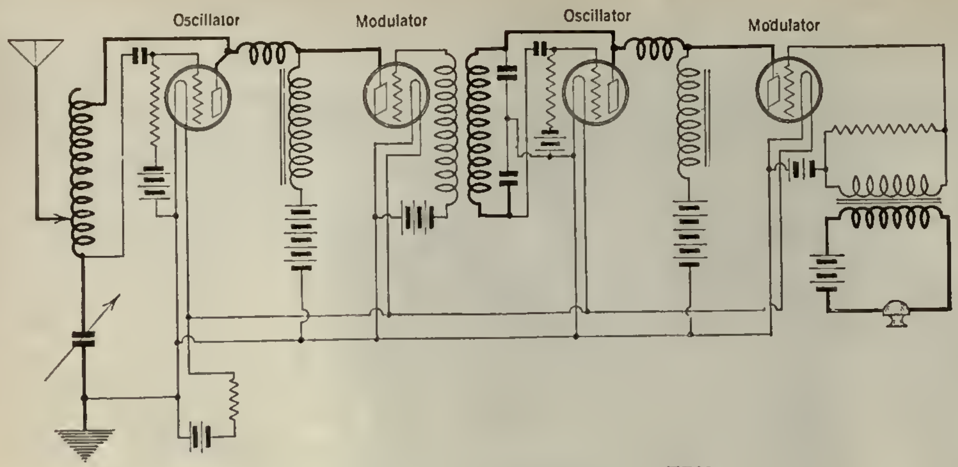


FIG. I. A DOUBLE MODULATION SYSTEM

This diagram, which is reproduced from Morecroft's "Principles of Radio Communication," shows a circuit for transmitting by the double modulation system

cies picked up by the microphone. The device which allows the voice to be superimposed upon the radio wave is called the "modulator." The idea of double tuning or double modulation applied to a radio transmitter was shown in a patent by John Stone Stone more than 17 years ago. Just who was first to disclose a complete workable system, the writer does not know; but a sytsem similar to that described in the press reports was built by the Western Electric Company for the U.S. Navy prior to 1919. A description of this multiplex radio telephone system was given by Craft and Colpitts in the *Proceedings* of the A.I.E.E. (about 1919). For several years preceding and following this date, John Hays Hammond, Jr. was interested in double modulation systems, and his engineers developed complete multiplex radio telegraph installations which were tested by the U.S. Signal Corps and the U.S. Navy. It was while doing development work and research on these sets that the writer first became familiar with double modulation systems. In Morecroft's *Principles of Radio Communication* (pages 680–83, 1st ed.) written in 1921, complete diagrams for a double modulation system are shown. One of these diagrams is reproduced in Fig. 1. If the reader is interested in the actual connections to use in building such a transmitter or receiver, he is referred to these pages.

Just a few random references to the use of multiplex radio are given here. The engineer recently advocating its use, being a well-known pioneer in the radio field, famous for his inventions, must not have intended to claim novelty for this system. However, reporters of his address did infer that "double tuning" is new.

Before answering the next question, "Will double modulation multiply all existing radio channels?" it is necessary to describe briefly the arrangement of our present broadcasting system so as to form a background against which different systems may be viewed and compared.

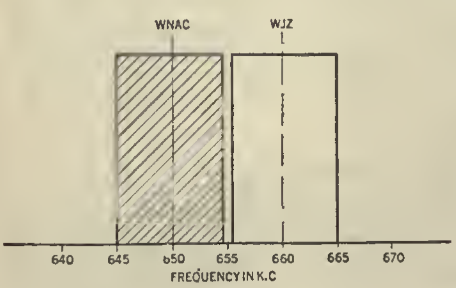


FIG. 2

WHAT IS A RADIO CHANNEL?

A RADIO channel is a band of radio frequencies, the width of which is determined by the type of transmission. Two such channels located in the broadcast "spectrum" are shown diagramatically in Fig. 2.

The word "spectrum," which is often employed in the study of light waves, has found increasing use in connection with radio waves. This is because a continuous electric wave appears in the radio spectrum as a straight line, located at a certain point in the frequency scale, exactly as a light line having a single color stands out in the light spectrum. Fig. 2 shows the location of the two radio channels assigned by the Federal Radio Commission to stations WJZ and WNAC. Each channel is designated by a number, which corresponds to the frequency (in kilocycles) or to the wavelength (in meters), of the point at which the *center* of the channel is located. Thus, looking at Fig. 2 we can say station WJZ (New York) operates on the 660-kc. channel and WNAC (Boston) on the 650-kc. channel.

Since the width of radio channel depends upon the type of transmission, a list of channel widths, in frequency, required by three well-known types of transmission is given as follows: (a) Radio telephony (broadcasting), 10 kc.; (b) Interrupted or tone-modulated c.w. telegraphy, about 2 kc.; (c) Unmodulated c.w. telegraph, less than 0.3 kc., depending upon the keying speed (words per minute). These widths remain the same whether transmission takes place in the longer or shorter wavebands, assuming precautions are taken to maintain the frequency of the radio generator constant.

The present broadcast spectrum extends from 550 kc. to 1500 kc. In order to provide for the maximum number of transmitting stations each channel is limited to 10 kc., the minimum width which will give satisfactory reproduction of music. The total number of channels available on this basis is 95. With our present serious station interference and hundreds of would-be broadcasters waiting for space in the ether, the question of the most economical use of this band is important, and it is this problem which we are considering.

THE RESULT OF MODULATION

WITH the help of Fig. 3, which shows one of the radio channels of Fig. 2 magnified, let us examine the nature of the wave disturbance caused in the ether by a radio telephone transmitting station. We will suppose that the spectrum resulting from a transmitter (such as WJZ) is shown here. When the microphone is idle, that is, no modulation taking place, the radio frequency carrier wave only is radiated. This is accurately located at the assigned frequency of 660 kc., and is represented by a single line in the spectrum. Now suppose the microphone at the station is energized by a steady musical tone of, say, 1000 cycles; the result is the formation of so-called "side-bands" shown in Fig. 3 by the shorter lines on either side of the central carrier-wave.

Digressing for a moment, if this is a picture of the frequency spectrum from a transmitter, how is it that we can hear at the receiver the musical tone impressed on the microphone? The reason we hear the 1000-cycle tone is because after the carrier-wave and either side-band has entered the receiver, they "beat" together in the detector (or de-modulator) circuit, and produce a tone of the original modulating frequency. This explanation of why the radio telephone receiver "works" is somewhat different from that usually given in popular radio articles which omit the important point of "beats" in the detector circuit and do not explain the need of the presence of the carrier-wave at the receiver.

The process of modulation at a radio transmitter is fairly complex, but it is not necessary for the reader to go into the mechanism of modulation in order to understand some of the simpler results of the process. It is necessary, however, to accept the fact that when a carrier-wave is modulated, upper and lower side-bands appear as shown in Fig. 3. Each of these is spaced from the carrier-wave by an amount equal to the frequency of the modulating tone. From this fact it is evident that, the higher the pitch of the musical note striking the microphone, the broader will be the band in the ether occupied by the transmitter at that moment. Those persons complaining that one local broadcasting station is much "broader" than another should note this point. Usually the alleged "broadness of wave" of a particular transmitter is due to the broader tuning of the listener's receiver at this frequency or to the greater power radiated by this particular transmitter.

If neither of the stations shown in Fig. 2 ever used modulation frequencies above the highest on the ordinary piano keyboard or the highest reached by the piccolo (that is, fundamental frequencies of about 4600 cycles) there would be no overlapping of one station into the channel of the other—provided, of course, both carrier waves were on their assigned frequencies. In many transmitters sudden modulation peaks may cause momentary shifting of the carrier frequency or other effects, resulting in intermittent interference being noted in neighboring radio channels.

It is understood, of course, that from the tone quality standpoint it is desirable, if permitted, to transmit modulation frequencies of higher than 5000 cycles because harmonics of various musical instruments range above this figure. And these add a great deal to the naturalness of broadcast music.

We have now defined a radio channel, shown

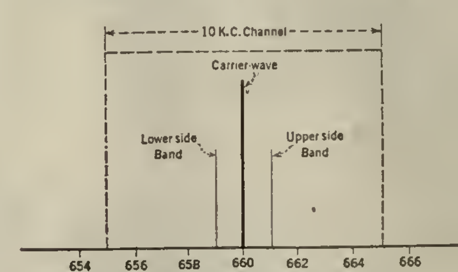
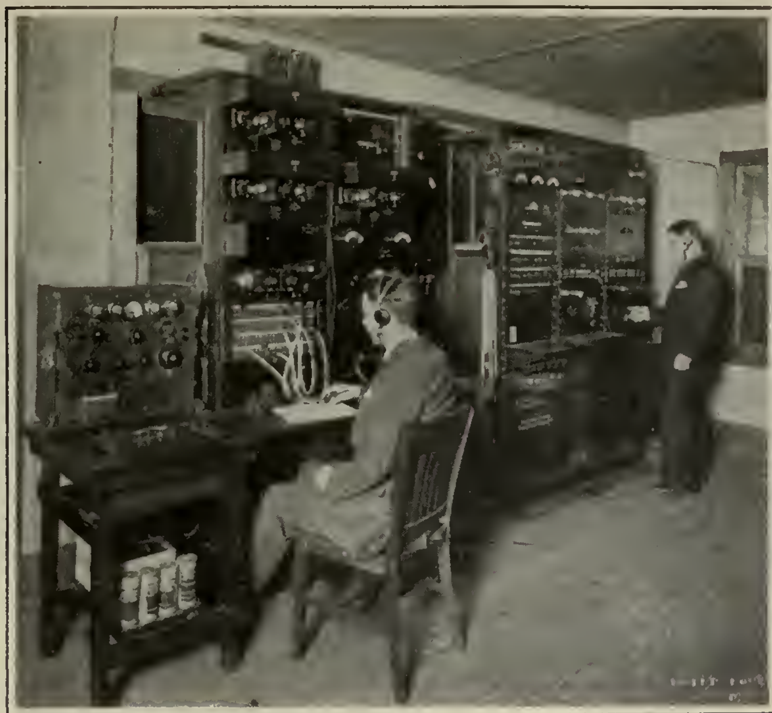


FIG. 3

that its width for broadcasting is 10 kc., and shown that the side-bands, which vary in response to the voice frequencies from 50 to 5000 cycles, occupy the full width of this channel. We are now ready to consider the more unusual system of double modulation, sometimes called "secret radio," "selective signalling," and "double tuning."



AT THE RECEIVING END

This apparatus is part of that used for the reception of single side-band signals at the Houlton, Maine, station of the American Telephone & Telegraph Co. The operator at the right is adjusting the apparatus used to pick up the signal, and the man at the left is responsible for the wire line to New York

THE DOUBLE MODULATION SYSTEM

A BRIEF outline of such a system will be mentioned so that the reader will understand how double modulation can be used at an experimental broadcasting station employing this system.

Instead of modulating the usual carrier wave by audio frequency currents, an intermediate frequency (i.f.), above the limit of audibility—say 20,000 cycles—is used. This intermediate frequency is, in turn, modulated by speech frequencies. The resultant is a modulated carrier wave superimposed upon another carrier which is radiated in the usual manner.

In receiving such a doubly modulated wave, it is necessary to tune to and detect the radio-frequency carrier wave, which could be, say, 660 kc.; then tune to and detect the intermediate frequency of 20 kc. and, if desired, amplify the audio-frequency signal resulting from the second detection.

A transmitter and receiver that work in the above manner are shown schematically in Fig. 4. The audio frequencies (50 to 5000 cycles) are picked up by the microphone, and are impressed on the i.f. oscillator (or generator) by means of the first modulator. The modulated output of the i.f. oscillator acts on the second modulator arranged to modulate the r. f. oscillator (or generator) so that a doubly modulated wave may be radiated from the antenna.

Only the bare fundamentals are shown at the receiver; namely, an r. f. tuner (660 kc.) and detector which feeds its inaudible output into an i.f. tuner (20 kc.) and detector. In the output of the latter are connected telephones in which the desired signal can be heard.

SEMI-SECRET TRANSMISSION

SINCE our radio receivers of to-day are intended for the reception of single-modulated signals, we do not have the second receiver unit of Fig. 4 (i.f. tuner and detector). Hence, by the use of certain combinations at the transmitter, intelligible signals from double modulated transmitters cannot be received with ordinary receivers. For this reason, engineers term such a system "semi-secret."

Some readers will doubtless ask the question, "What about the super-heterodyne—it possesses an intermediate tuner and detector." To convert a super-heterodyne into a double modulation system receiver, as in Fig. 3, it will usually be necessary, first, to alter the fixed-tune i.f. amplifier so that it can be tuned to any desired transmitted intermediate frequency (20 to 100 kc.), and, second, to eliminate the r.f. heterodyning oscillator, which is unnecessary.

An editorial in *Radio News* not so long ago stated that the rapid modulations necessary for television could be superimposed on the present carrier wave of a broadcast transmitter by means of double modulation so that *no additional channels* would be required. As we know, this same double-tuning system has been offered by others as a means for greatly increasing the broadcast channels now available in a given wave-band. The fallacy in both of the above views will be pointed out in the paragraphs to follow.

THE CHANNEL NEEDED FOR DOUBLE MODULATION

FIG. 5 illustrates the radio spectrum lines resulting from the radiation of a double-modulated radiophone transmission. In the center we have the r. f. carrier-wave located at the assigned frequency, which we will take in this example as 660 kc. Spaced equally, on either side, are the upper and lower i.f. waves separated from the carrier by the selected intermediate frequency of 20 kc. Associated with each of these are the usual upper and lower a.f. sidebands separated from the i.f. line by 1000 cycles, since, at the moment this radio spectrum was recorded, it is assumed that a steady 1000-cycle note was sounded at the microphone. If the highest fundamental musical note were played (about 5000 cycles), these side-bands would move to a position such that the two outermost bands would reach the dotted lines which indicate the limits demanded by a single channel when the double-modulation system is used. We note from Fig. 5 that this width is 50 kc. Compare this with the ordinary broadcast channel shown in Fig. 2, the width of which is only 10 kc.

Let us take this a step farther, both because it is interesting to see what happens in the ether when a single carrier-wave is multiplexed so as to carry several simultaneous conversations and also because we find that when more than one intermediate frequency is used the frequency band per conversation is less than 50 kc. wide.

Fig. 6 shows the location of the spectrum lines resulting from the simultaneous transmission of two independent audio signals, one on an intermediate frequency of 20 kc. (the lines for which

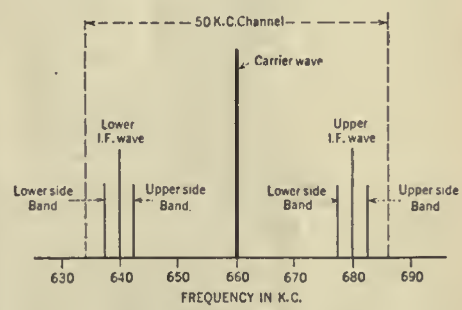


FIG. 5

are identical with those of Fig. 5), and the second on, say, 30 kc. The point to note is that the total band width here measures 70 kc., or 20 kc. more than that of Fig. 5, which is for a single conversation. To summarize, we may say the width of band required for the first multiplex channel is 50 kc. with an additional 20 kc. for each additional channel.

We conclude, therefore, that the number of broadcasters in any given wavelength band would not be multiplied if double modulation were used but actually decreased by more than one-half.

THE PRO AND CON OF DOUBLE MODULATION

LACKING the ability to glimpse into the future, we can only guide our speculations by the technical facts that we know about the infant radio developments of to-day. By weighing their advantages and disadvantages it

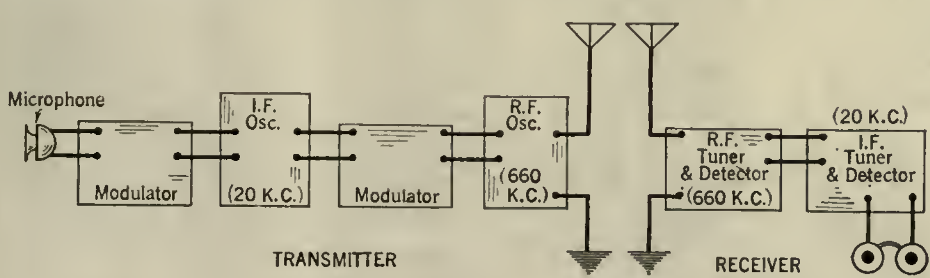


FIG. 4

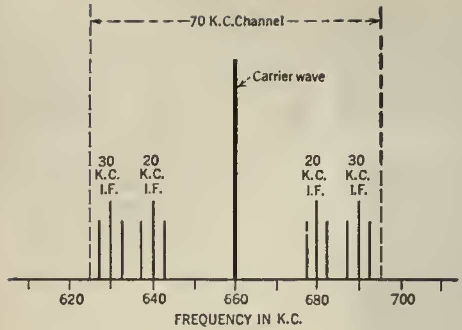


FIG. 6

should be possible to form an opinion of the likelihood of their future adoption.

The advantages of the double modulation system are:

1. Greater selectivity and freedom from static because of the double tuning feature at the receiver.

2. The advantage of semi-secrecy, if desired. Here is a system which could answer the question, "How can programs be sold to the listener?" It is very doubtful, however, if the listening public of the United States would react favorably to the proposition of paying for their radio programs.

The disadvantages of double modulation are:

1. The number of simultaneous broadcasts (or the number of conversations) would have to be greatly reduced because the width of radio channel per conversation is more than double that required for the present system of broadcasting.

2. The amount of local interference set up by a double modulation transmitter would be very serious if harmonics from the oscillators generating the carrier and intermediate waves were allowed to be radiated.

3. More costly and complicated transmitting and receiving apparatus due to extra tuning controls, tubes, and amplifiers.

Minor technical disadvantages have been omitted since these could probably be overcome by engineering development work. So far as the writer knows, there are no radio stations in our country making use of the straight double modulation system for other than experimental purposes. If this is the case, in spite of the fact that the system has been known for many years, we would infer that the disadvantages outweigh the advantages.

In concluding that our present system will not be supplanted by that of straight double modulation we see that the underlying reasons for this conclusion are based principally on the technical characteristics of this little-known radio system. It has been the object of this article to explain, as simply as possible, these characteristics.

THE SINGLE SIDE-BAND SYSTEM

MOST of the advantages incorrectly attributed to the double modulation system can be realized in the "single side-band" system. Great interest surrounds any workable system which allows the same waveband in the ether to carry, without mutual interference, twice as many conversations as it can at present. This is what single side-band transmission will do. The following paragraphs answer the questions of: What is this system? How does it work? and What will it do?"

Single side-band transmission is the transmission of modulation frequencies by the radiation of only one side-band, the other side-band and carrier wave being suppressed at the transmitter. Refer for a moment to Fig. 3 showing the spectrum lines of the ordinary transmitter. At the instant Fig. 3 was recorded we assumed that a constant musical tone of 1000 cycles (1 kc.) was impressed upon the microphone. During a musical selection the audio frequencies, as we know, may vary erratically and rapidly from 50 to 5000 cycles (or more). To represent the resulting movement of the side-bands from moment to moment, they are shown in Fig. 8 as dotted lines occupying a frequency space of 4950 cycles. Also, in this figure it is indicated that the carrier-wave and lower side-band are suppressed, leaving only the upper side-band to be radiated into the ether. The width of radio channel required for this system of broadcasting is less than 5 kc., or half of that demanded by the present system. This is an important step in the right direction.

Let us see how such a telephone signal can be received. Due to the absence of a transmitted carrier wave, messages from such a transmitter would not be understandable on our ordinary receivers. However, the carrier wave, which is steady in frequency, can be supplied locally at the receiver by an oscillating tube. Its transmission through the ether is thus made unnecessary.

In receiving signals from a single side-band transmitter, using the receiver arrangement shown in Fig. 7, the local oscillator supplying the carrier-wave (which is no longer a "carrier") would be set by the operator at exactly 660 kc. to correspond in frequency with the suppressed carrier. This must be done by ear, since if the frequency of this local beat oscillator is even very slightly off, the received signal will not have its natural quality. For instance, the voice of the best announcer could, by misadjustment, be made to resemble that of an old woman!

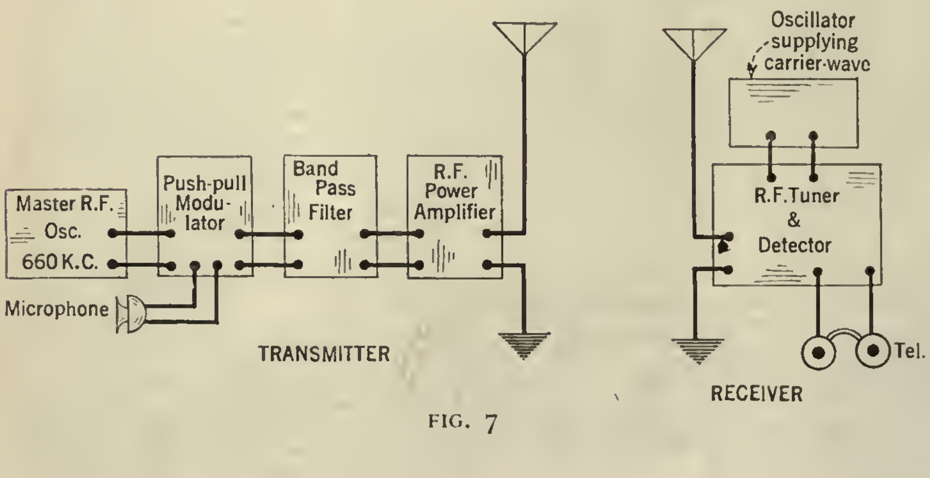


FIG. 7

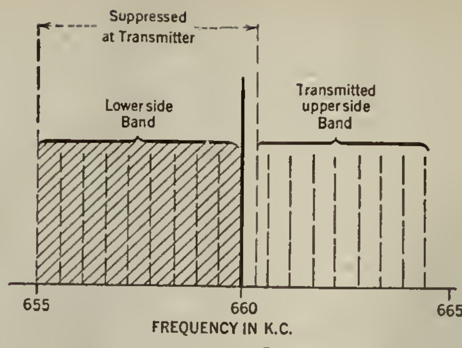


FIG. 8

To complete the answer to "How does it work?" brief mention will be made of the apparatus at the transmitter which accomplishes the suppression of the side-band and the carrier. Fig. 7 illustrates the schematic outline of one type of transmitter. The voice energy and that from the master r.f. oscillator is fed into a push-pull modulator, so connected as to suppress the carrier-wave (the frequency of which is determined by the master r.f. oscillator). Then the output of this modulator is passed through a filter and the undesired side-band is removed, leaving only one side-band (which varies in frequency from 50 to 5000 cycles as the voice frequency varies) to be amplified by the power amplifier and finally to be radiated from the antenna.

CAN IT BE PERFECTED?

THIS system affords radio telephony requiring only one-half the channel width required at present. It allows an increase in sharpness of tuning at the receiver without reducing fidelity, thus providing more selectivity. Much less power is necessary at the transmitter, since the carrier wave is not radiated. Generally there is less distortion and variation in received signal strength due to fading, because the locally generated carrier is steady. These are some of the advantages that occur with single side-band transmission. When it is coupled with double modulation still other advantages appear, one of which is the possibility of a high degree of secrecy when certain combinations are used.

The disadvantages are: Increased complication of apparatus; more skill required in the operation of the receiver; and, in our present broadcast band, the disadvantage that all our receivers would require modification. The most serious of these disadvantages is the difficulty of setting and maintaining the local oscillator at the desired frequency. Assuming transmission to take place at 1000 kc. the exactness with which the oscillator must be set is 1 part in 100,000. In the present state of technical development, this would require a highly skilled operator and precision instruments. Development work is needed to overcome the demand for such accuracy in order to make ordinary single side-band reception practical for everyone's use in the broadcast waveband.

It is the single side-band system (combined with double modulation) that has been selected for use in the American Tel. & Tel. Co.'s transatlantic radio link between the United States and Great Britain. The two photographs show parts of the apparatus used.

It seems logical to suppose that single side-band transmission will grow in use for point-to-point communication and the time will come when it will be used for the broadcasting of speech, music, and vision.