May 6, 1941. F. K. VREELAND 2,241,078

MULTIPLEX COMMUNICATION

Filed Nov. 1, 1937 6 Sheets-Sheet 1

Fig. 1.

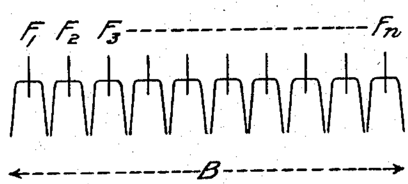


Fig. 2.

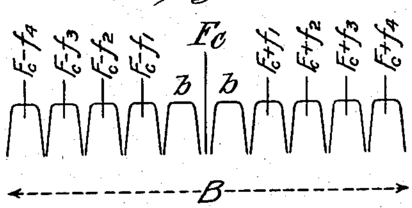
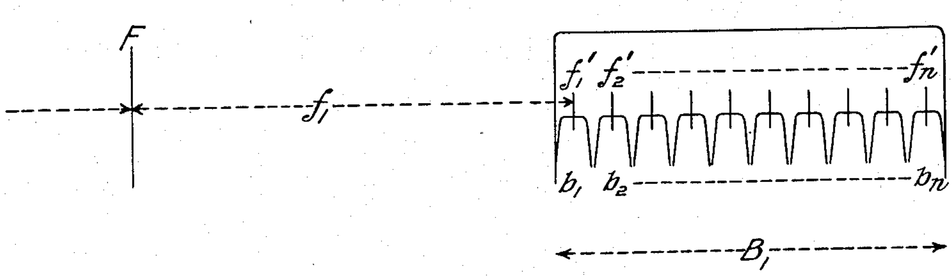


Fig. 3.



INVENTOR

Frederick K. Vreeland

BY

Darby & Darby

ATTORNEYS

May 6, 1941. F. K. VREELAND 2,241,078

MULTIPLEX COMMUNICATION

Filed Nov. 1, 1937

6 Sheets-Sheet 2

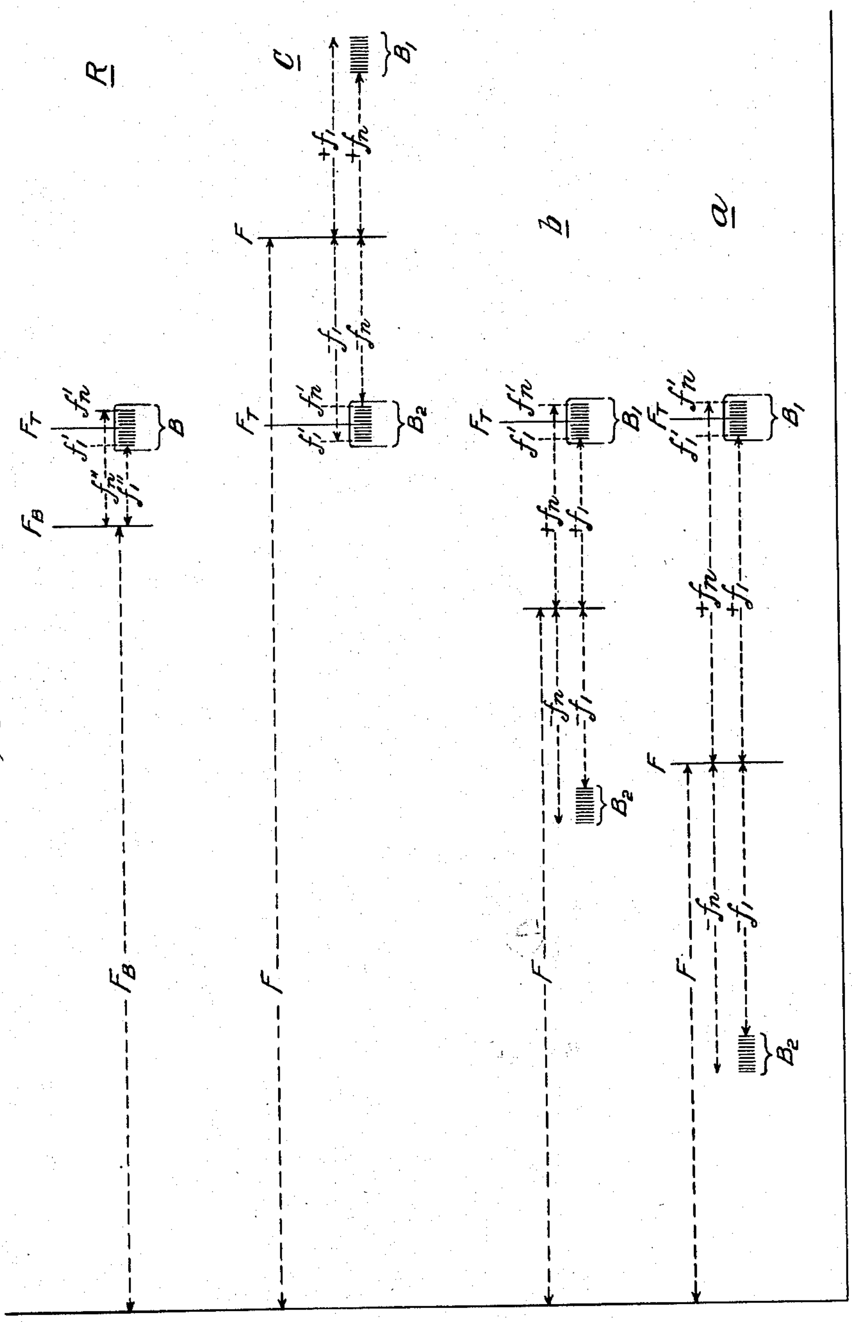


Fig. 4.

INVENTOR

Frederick K. Vreeland

BY

Darby & Darby

ATTORNEYS

May 6, 1941. F. K. VREELAND 2,241,078

MULTIPLEX COMMUNICATION

Filed Nov. 1, 1937 6 Sheets-Sheet 3

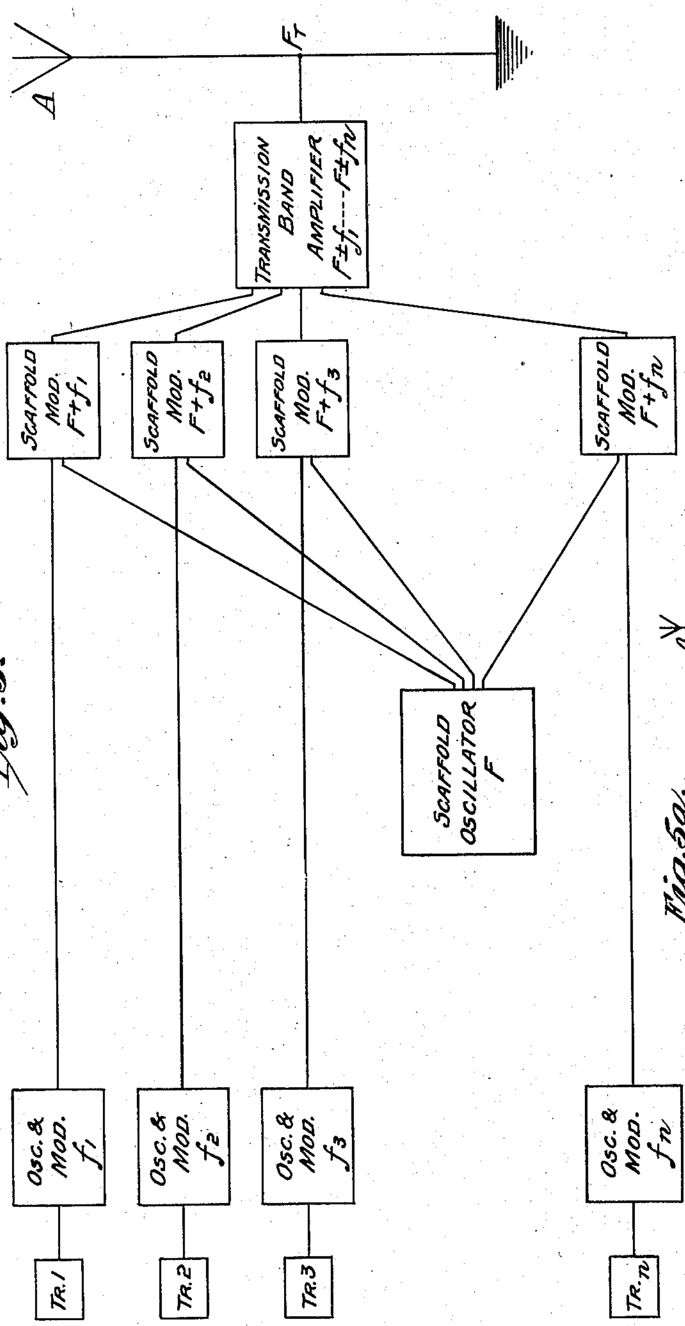


Fig. 5.

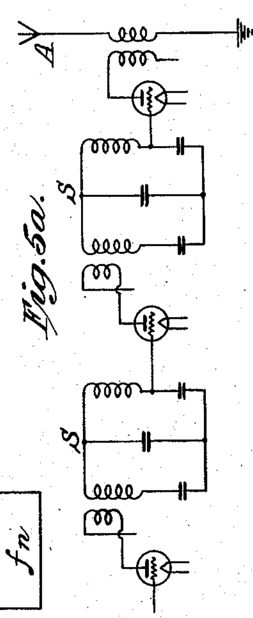


Fig. 5a.

INVENTOR
Frederick K. Vreeland
BY
Darby & Darby
ATTORNEYS

May 6, 1941.

F. K. VREELAND

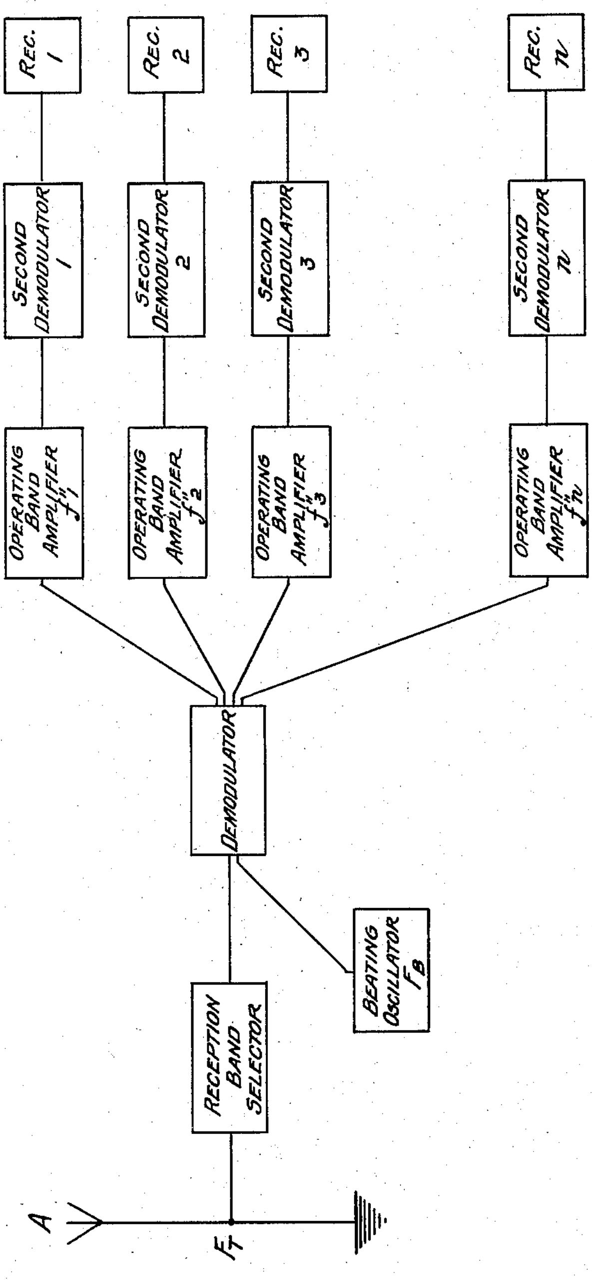
2,241,078

MULTIPLEX COMMUNICATION

Filed Nov. 1, 1937

6 Sheets-Sheet 4

Fig. 6.

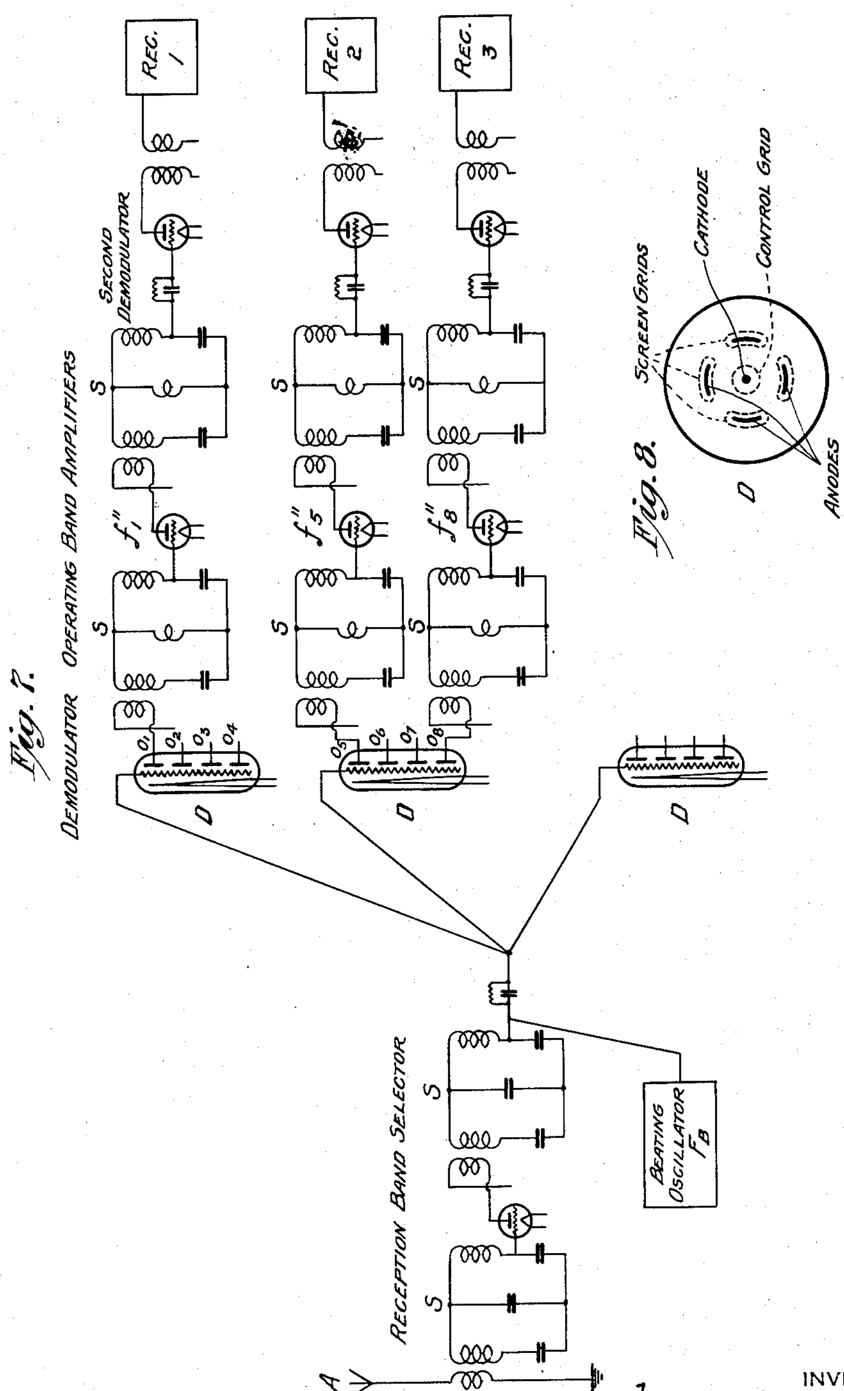


INVENTOR
Frederick K. Vreeland
BY
Darby & Darby
ATTORNEYS

May 6, 1941. F. K. VREELAND 2,241,078

MULTIPLEX COMMUNICATION

Filed Nov. 1, 1937 6 Sheets-Sheet 5



INVENTOR
Frederick K. Vreeland
BY
Darby & Darby
ATTORNEYS

May 6, 1941. F. K. VREELAND 2,241,078

MULTIPLEX COMMUNICATION

Filed Nov. 1, 1937 6 Sheets-Sheet 6

Fig. 9.

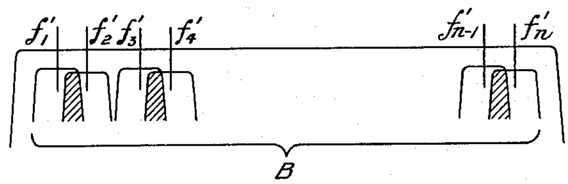


Fig. 9a.

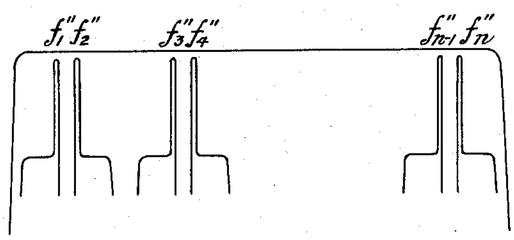
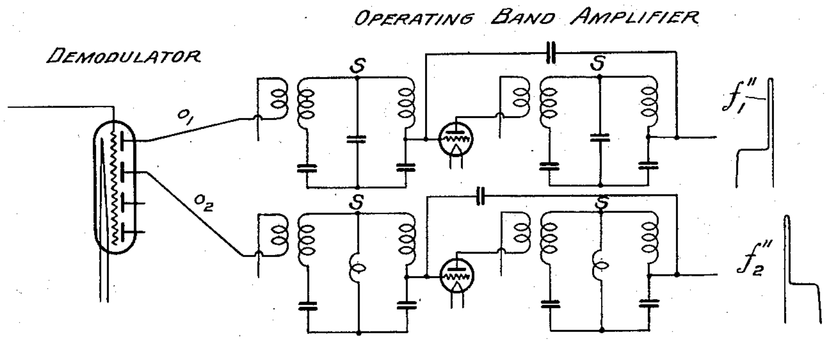


Fig. 10.



INVENTOR
Frederick K. Vreeland
BY
Darby & Darby
ATTORNEYS

Patented May 6, 1941

2,241,078

UNITED STATES PATENT OFFICE

2,241,078

MULTIPLEX COMMUNICATION

Frederick K. Vreeland, Montclair, N. J.

Application November 1, 1937, Serial No. 172,159

6 Claims. (Cl. 179—15)

The invention herein described is a system of multiplex communication.

The object of the invention is to operate a number of sets of sending and receiving apparatus within a relatively narrow transmission band. It is particularly adapted to the operation of apparatus, such as graphic recorders, which require a substantial band of frequencies for their operation. It permits the transmission and reception of a number of such operating bands in close juxtaposition over a single transmission band without mutual interference and with a minimum of transmission band width.

It is customary at the present time to assign operating radio channels with a band width limited to ten kilocycles. Ordinarily a single set of sending and receiving apparatus is operated over each such channel. By the use of the present invention a considerable number of sets of sending and receiving apparatus, each occupying a substantial band of frequencies, may be operated simultaneously over one such channel without overstepping the limit of transmission band width and without interference between the several operating bands.

In the specific case where the sending and receiving sets include electrically operated typewriters or other graphic recording apparatus, each of which occupies ordinarily an operating band width of the order of 1000 cycles, including both operating side bands, the present invention permits the operation of more than ten such sending and receiving sets over a single ten kilocycle transmission band simultaneously and without interference between the several operating bands.

In general, if the total allowable transmission band width be designated as B, and the operating band width ordinarily occupied by each sending and receiving set, including both side bands, be designated as b, then the number of sets that may be operated over the transmission band B may be equal to or greater than B/b.

In the drawings,

Figure 1 illustrates graphically the relation of a plurality of transmission bands each having its own carrier wave;

Figure 2 illustrates a plurality of operating modulation bands superimposed on a carrier frequency within the transmission band;

Figure 3 illustrates a plurality of operating modulation bands, each with a carrier frequency built on a scaffold frequency outside of the transmission band;

Figure 4 illustrates several phases of the invention;

Figure 5 is a block diagram illustrating a typical embodiment of the invention at the transmitting end;

Figure 5a is a schematic diagram of a part of the transmitting apparatus;

Figure 6 is a similar block diagram for the receiving end;

Figure 7 is a schematic diagram showing in greater detail the arrangement of a suitable form of receiving apparatus;

Figure 8 shows the arrangement of a multiple anode demodulator;

Figure 9 shows a typical transmission band with overlapping operating side bands;

Figure 9a shows a corresponding reception band in which the overlapping bands are separated; and

Figure 10 shows a suitable construction of apparatus for separating the overlapping bands.

When a number of sending and receiving sets are operated in the usual way, each on its own wave frequency, F_1, F_2, F_3, etc. modulated as required to operate the several sets, the resulting transmission bands are as shown in Fig. 1. If an attempt is made to operate a number of such sets within the limits of a single ten kilocycle wave assignment B, extreme precision of the several wave frequencies will be required, and extraordinary selectivity will be required to receive the several transmission bands without interference or trimming of the side bands. Under the usual practice the technical difficulties are practically prohibitive.

Some of these difficulties may be overcome by the use of a single carrier wave frequency, F_C, modulated at subfrequencies f_1, f_2, f_3, etc., which are modulated in turn by the operating pulses employed by the several sets. If the carrier frequency F_C lies within the transmission band and both side bands are transmitted, as shown in Fig. 2, the modulation sub-frequencies f_1, etc. must be sufficiently low to keep the entire modulation band within the required limits of width. Thus with a band width of ten kilocycles, the highest modulation sub-frequency will be less than 5000 cycles. Where each sub-frequency carries its own modulation band of the order of 1000 cycles wide, including both side bands, the conditions are not favorable for good band selection. In the case of the central band, b, the carrier wave F_C should be modulated directly by the operating pulses, without a sub-frequency.

In the full embodiment of the present invention all these difficulties are overcome, and a high degree of efficiency and band selectivity are obtained. The preferred arrangement is shown graphically in Fig. 3.

Here the transmission band is built up on a scaffold frequency F, which is not required for transmission and which lies outside the transmission band and is modulated at a plurality of relatively high sub-frequencies f_1, f_2, . . . f_n. The values of these sub-frequencies are so chosen that the sum of each of these frequencies and the scaffold frequency, $F+f_1$, $F+f_2$, . . . $F+f_n$, or the difference, $F-f_1$, $F-f_2$, . . . $F-f_n$, lies within the designated transmission band and constitutes a super-carrier frequency, on which the operating pulses are superimposed. The super-carrier frequencies are designated as f_1', f_2', . . . f_n'. The superposition of the operating pulses on the super-carrier frequencies is accomplished by modulating each of the sub-frequencies, f_1, f_2, . . . f_n, in accordance with the operating pulses of one of the several sending sets, with the result that the corresponding super-carrier frequency is similarly modulated. The resulting operating modulation bands are shown in the drawings as b_1, b_2, . . . b_n, Fig. 3, each superimposed on its super-carrier frequency f_1', f_2', . . . f_n' and each, in the case illustrated, with both its side bands.

The frequencies f_1, f_2, . . . f_n, when thus modulated, function as sub-carrier frequencies which, with their superimposed operating pulses or signal modulations, are elevated to the frequency level of transmission while preserving their true relations to their respective modulation frequencies and to each other.

The space between the first operating modulation band b_1 and the scaffold frequency F is not occupied by any working frequency. The frequencies represented by this space are not needed for the transmission. Neither is the scaffold frequency F. In the preferred form of the invention, therefore, one of the side bands, B_1 or B_2, is selected for transmission and the other side band and the scaffold frequency are eliminated. The selected band, B_1, is shown in Fig. 3.

The values of the scaffold frequency F and the modulation sub-frequencies f_1, f_2, . . . f_n, may be chosen within a wide range, but the sub-frequencies are preferably made large with respect to the total band width B and a substantial fraction of the scaffold frequency F. Then the separation of the band B_1 or B_2 from the scaffold frequency F may be accomplished very simply by means of a band-selective transmitter amplifier, preferably employing band selector couplings of the type shown in my United States Patents Nos. 1,725,433 and 1,850,973, or an amplifier of the type shown in my United States Patents Nos. 1,666,518, 1,682,874 and 1,730,987, or other equivalent means, may be employed.

For any given transmission band that it is desired to transmit, having a mid-frequency F_T and a band width B, the values of the scaffold frequency F and the several modulation sub-frequencies, f_1, f_2, etc. are so chosen that each of the super-carrier frequencies, f_1', f_2', . . . f_n', being the sum of the scaffold frequency and the sub-frequency, $F+f_x$, or their difference $F-f_x$, as the case may be, lies within the band bounded by the frequencies

$$F_T+\frac{B}{2} \text{ and } F_T-\frac{B}{2}$$

for each value of f_x from f_1 to f_n. In the former case the upper side band is selected for transmission, in the latter case the lower side band. Usually the difference between the successive sub-frequencies f_1, f_2, etc. is made approximately equal to the operating band width b.

It will thus be seen that the transmission of the several operating bands is accomplished by means of a transmission band of frequencies having a spread equal to the sum of the several operating bands, in the simple form of the invention here described the total band width being n x b, as above explained. In the specific case cited as an example, ten sets of sending and receiving apparatus each occupying a 1000 cycle band may be operated over a 10 kilocycle transmission band. Means for further increasing the number of sets operated will be described. The transmission is accomplished simply without special refinements in frequency control, the difference between the sub-frequencies f_1, f_2, etc. being sufficiently large to be regulated by ordinary tuning means.

The form of the transmitted band is independent of the value of the scaffold frequency F, which is eliminated, and its position in the frequency scale depends not on the suppressed scaffold frequency but on the sum of $F+f_1$, $F+f_2$, etc. or their difference, $F-f_1$, $F-f_2$, etc., as the case may be. Any desired transmission band may thus be built on any desired scaffold frequency, within wide limits, provided the modulation sub-frequencies are sufficiently large fractions of the scaffold frequency for effective selection of the band, as explained.

In receiving the transmitted band it is first separated from interfering waves, preferably by a suitable band selective receiver, which will accomplish the necessary selection without distortion of the selected band. The received band is then combined with a locally generated oscillation that beats with the received frequencies in the manner explained in my U. S. Patents Nos. 1,239,852 and 1,544,081. The combined beat current that results is demodulated, and in the demodulated current a plurality of beat carrier frequencies are found corresponding to the original modulation frequencies, though usually having different values, each with its operating transmission band.

An important feature of the present invention resides in the fact that the frequency of the beating oscillation, F_B, need not be the same as the transmitter scaffold frequency, F. Preferably it is a different frequency whose value is nearer to the transmitted wave frequencies, so that the beat carrier frequencies are lower than the transmitter modulation sub-frequencies and suitable for efficient band selection. Since there is no necessity of having the beat carrier frequencies, f_1'', f_2'', . . . f_n'', the same as the corresponding transmitter modulation frequencies f_1, f_2, etc., the beating frequency F_B is so chosen that the difference between the adjacent beat frequencies f_1'', f_2'', . . . f_n'', is a substantial fraction of the value of these frequencies, and preferably such a fraction that the several beat operating bands carried by these beat frequencies may be separated from each other by band selectors operating at their maximum efficiency. For example, the operating band width, b, may be of the order of 1% or 2% of the beat carrier frequencies, f_1'', f_2'', . . . f_n''. The several beat operating bands may then be separated easily from each other and selectively received without distortion by band selective circuits, which are preferably embodied in band amplifiers of the type set forth in my U. S. Patents Nos. 1,725,433 and 1,850,973, or the type set forth in my U. S. Patents Nos. 1,666,518, 1,682,874, and 1,730,897.

The output of each of these band selective circuits, which are preferably also amplifiers, when demodulated, will then be a precise replica of the corresponding band of operating pulses by which the transmitter frequencies f_1, f_2, etc. were modulated, and ready to operate one of the receiving recorders or typewriters, or other receiving apparatus.

As specific examples of the working of the system three cases are shown in Fig. 4, designated as *a*, *b* and *c*, respectively. In each case the scaffold frequency is shown at F in the horizontal scale of frequencies. One limiting modulation sub-frequency is designated as f_1, and the other as f_n. The resulting modulation band is indicated as comprising the two side bands, B_1 and B_2 respectively. In cases *a* and *b* the upper side band B_1 is selected for transmission and in case *c* the lower side band B_2 is selected. The spread of the band covers the range $f_n - f_1$ plus a small amount depending on the sub-modulation of these frequencies. The mid-point of the band has the frequency

$$F_T = F + \frac{f_1 + f_n}{2}$$

which is the nominal transmission frequency.

In case *a*, the values of $f_1 \ldots f_n$ are comparatively large and the value of F is correspondingly small. In case *b*, smaller values of $f_1 \ldots f_n$ are chosen, and F is correspondingly larger. In case *c*, $f_1 \ldots f_n$ have the same values as in case *b*, though in reversed order, but the lower side band is selected for transmission and the scaffold frequency F is made correspondingly large. In all these assumed cases, and in an unlimited number of other cases that might be used, the form of the transmission band and its position in the frequency scale are the same. In each case the values of $f_1 \ldots f_n$ are made sufficiently large with respect to F to permit effective selection of the desired side band for transmission and the rejection of the other side band and the scaffold frequency.

The following numerical examples will illustrate cases *a*, *b* and *c* respectively:

Assume that the nominal transmission frequency is 10,000 kilocycles, corresponding to a wave length of 30 meters, and that the permitted band spread is 10 kc. In case *a* let the scaffold frequency F be taken as 9,500 kc. Then the modulation sub-frequencies $f_1 \ldots f_n$ may be 496 kc. to 504 kc. respectively and the corresponding transmission band frequencies will be 9,996 to 10,004 kc. respectively, with a mid-frequency of the transmission band of 10,000 kc., as required.

In case *b*, let the scaffold frequency F be 9,800 kc. Then the modulation sub-frequencies $f_1 \ldots f_n$ may be 196 kc. to 204 kc. respectively and the corresponding transmission band frequencies will be 9,996 kc. to 10,004 kc. as before.

In case *c*, let the scaffold frequency F be 10,200 kc. Then the modulation sub-frequencies $f_1 \ldots f_n$ may be 204 kc. to 196 kc. respectively and the corresponding lower side band frequencies selected for transmission will be 9,996 kc. to 10,004 kc. as before.

These results are indicated in the following table:

$F=9{,}500$		$F=9{,}800$	
$f_1 \ldots f_n$	$F+(f_1 \ldots f_n)$	$f_1 \ldots f_n$	$F+(f_1 \ldots f_n)$
496	9996	196	9996
497	9997	197	9997
498	9998	198	9998
499	9999	199	9999
500	$F_T=10000$	200	10000
501	10001	201	10001
502	10002	202	10002
503	10003	203	10003
504	10004	204	10004

$F—10{,}200$	
$f_1 \ldots f_n$	$F-(f_1 \ldots f_n)$
204	9996
203	9997
202	9998
201	9999
200	10000
199	10001
198	10002
197	10003
196	10004

The transmission bands are thus identical in all the cases.

Also in each of the cases assumed the difference between the transmission band frequency F_T and the scaffold frequency F—500 kc. or 5% in case *a* and 200 kc. or 2% in cases *b* and *c*—is sufficient for the effective separation of the selected transmission band from the other side band and the scaffold frequency by band selection.

R, Fig. 4, represents a typical receiver arrangement for receiving either of these identical transmission bands. The beating frequency F_B is shown as nearer to the frequencies of the transmission band than the scaffold frequency, F, so that the beat carrier frequencies $f_1'' \ldots f_n''$ are relatively low and their spacing is relatively large, permitting easy separation of their operating bands.

The advantages of the flexibility afforded by this system will now be readily understood. In the transmitter, in order to get efficient separation of the selected transmission band from the other side band and the scaffold frequency F, it is desirable to have the modulation frequencies $f_1, f_2, \ldots f_n$, relatively large, and a substantial fraction of the scaffold frequency F. On the other hand, to get the most efficient band selection in the receiver, the corresponding beat frequencies $f_1'', f_2'', \ldots f_n''$ should be comparatively small. For example, in the case assumed for illustration, the frequency of the beating oscillation, F_B, may be 9,950 kc., giving beat carrier frequencies of the order of 50 kc., or it may be 9,900 kc., giving beat carrier frequencies of the order of 100 kc. The operating band width of 1000 cycles will then be approximately from 1 to 2% of the beat carrier frequency, a value which permits highly efficient band selection by very simple means. Or the frequency of the beating oscillation may be 10,050 to 10,100 kc., giving the same beat frequencies, of the order of 50 to 100 kc., with a like result. This result is the same in either of the assumed transmitter cases, *a*, *b* and *c*, in which the modulation sub-frequencies were from 2 to 10 times as great as the corresponding beat frequencies in the receiver, though in each case the demodulated operating pulses are exact replicas of the corresponding transmitter operating pulses.

These results are indicated in the following table:

F_B=9,950 kc. $f_1'' \ldots f_n''$	F_B=9,900 kc. $f_1'' \ldots f_n''$	F_B=10,050 kc. $f_1'' \ldots f_n''$	F_B=10,100 kc. $f_1'' \ldots f_n''$
46	96	54	104
47	97	53	103
48	98	52	102
49	99	51	101
50	100	50	100
51	101	49	99
52	102	48	98
53	103	47	97
54	104	46	96

It will also be understood that this relation of maximum efficiency in the receiving band selectors is achieved for any transmission band frequency. For example, if the transmission band frequency F_T be 20,000 kc., instead of 10,000 kc. as assumed above, the scaffold frequency F may be made 19,500 kc. and the modulation sub-frequencies from 496 to 504 kc., in which case the super-carrier frequencies $F+(f_1 \ldots f_n)$ will be from 19,996 to 20,004 kc. If now the frequency of the beating oscillation be made 19,950 kc. the beat frequencies will be 46 to 54 kc., i. e., of the order of 50 kc., the same result that was obtained in the case first assumed.

This results in great simplicity of construction and operation, since the same operating band selectors and amplifiers may be used in the receiving system for the separating of the several operating bands, regardless of the transmission band frequency F_T. In the transmitting system a like simplification is achieved, since the same modulating frequencies and modulators are used as on the longer wave.

This simplification is a feature of great practical importance, since in handling traffic it is necessary to change the transmission frequency from time to time to meet the varying atmospheric conditions. It will be seen that by using the present invention as described the change from the 10 megacycle wave to the 20 megacycle wave, or to any other suitable wave frequency, is made with no change in either the transmitting or receiving apparatus except in the transmitter scaffold frequency, F, and in the transmission band selector and at the receiver the change in the reception band selector and in the frequency of the beating oscillation, F_B. In practice it is desirable to have these two frequencies accurately adjusted in advance with crystal control. The change from one to the other may then be made quickly and easily. It is not necessary to have accurate adjustment of the transmission band selector, since this is required merely to separate the transmission band from the widely separated scaffold frequency and the rejected side band, hence a band characteristic that is much broader than the selected transmission band will be effective. Nor is it necessary in the reception band selector, which is a relatively unimportant accessory to the operating band selectors.

Further simplicity is gained by the fact that extreme precision of the several frequencies used is not required. The only frequencies that require accurate control are the transmitter scaffold frequency F and the beating frequency at the receiver, F_B. The modulation sub-frequencies $f_1 \ldots f_n$ are only from 2% to 5% as large as the scaffold frequency F, in the cases assumed, and hence require only 1/50 to 1/20 as great accuracy. This accuracy can be secured by ordinary tuned circuits. In the receiver the accuracy required to separate ten or more channels having band widths of 1 kc. each on a transmission frequency of 10,000 to 20,000 kc., in the cases assumed, is no greater than that required in an ordinary broadcast receiver, and this extraordinary result is accomplished by very simple means.

Comparing the illustrative values given in the last table for the beat carrier frequencies resulting from demodulation with the corresponding values given in the other tables for the several sub-carrier frequencies and for the super-carrier frequencies produced by modulation, it will be noted that the carrier frequencies are preserved in their true mutual relations notwithstanding the fact that the demodulation is performed at a higher frequency level than that of the original modulation, that is, the differences between the values of the several carrier frequencies remain unchanged. These differences between adjacent carriers in the cases assumed are 1 kilocycle in each case. The precision of these relations permits the rigid and precise selectivity needed to separate the channels with their exceptionally close spacing at the high transmission frequencies. It will be understood further that the modulation bands also are preserved in their true mutual frequency relations with the carriers, i. e., the difference between each modulation frequency and its carrier frequency remains constant, although the frequencies are raised and lowered over a wide range. This preservation of the true mutual relations of the modulation frequencies to their carrier frequencies results in producing at the receiver a precisely accurate reproduction of the several frequencies of the transmitted operating pulses, and provides the rigid precision necessary to operate printers or other graphic recorders.

By transmitting the carriers with their modulation bands and using band selectors in the transmitters and receivers, the several frequencies of carrier and modulations in each band are preserved in their true mutual relations in amplitude as well as in frequency, that is, their ratios remain constant, so that each received channel is a replica of the transmitted operating pulses in amplitude as well as in frequency.

The invention is not limited to any specific form of apparatus. The structural features of the drawings are illustrative of suitable forms of apparatus in which the invention may be embodied.

Fig. 5 is a block diagram showing the relations of the several parts of such an apparatus. Here Tr_1, Tr_2, . . . Tr_n, are the several operating transmitters whose signal pulses are to be transmitted in multiplex. When graphic recorders are to be operated these are preferably mechanisms that form the signal pulses required to operate the recorders. A number of such recorders are known, any of which may be operated over this system. When it is desired to transmit voice or other audible signals, the operating transmitters may be telephone transmitters. Or both voice and recorder channels may be transmitted simultaneously, the spacing of the several sub-carrier frequencies being suitably arranged for the different widths of operating bands required for voice and code channels. In this respect the system has complete flexibility.

Osc. and mod. f_1, f_2, . . . f_n, comprise the sub-oscillators or other generators which generate the modulation sub-frequencies, f_1, f_2, . . . f_n, respectively, and the modulating means whereby these frequencies are modulated in accordance with the signal pulses formed by the several operating transmitters. These generating and modulating means may be of any suitable type, as will be understood.

Scaffold oscillator F is the generator, preferably crystal-controlled, which produces the oscillations of scaffold frequency F. This feeds into a plurality of modulating means, Scaffold mod. $F+f_1$, . . . Scaffold mod. $F+f_n$, each of which receives also the output of one of the sub-oscillators and modulators. These scaffold modulators serve to modulate the scaffold frequency in accordance with the several modulation sub-frequencies and the signal pulses which they carry. The output of each of these scaffold modulators comprises the scaffold frequency, F, together with the two modulation side band frequencies, $F+f_x$ and $F-f_x$. Also, adjacent to each of the modulation frequencies $F+f_x$ is the band of frequencies resulting from the modulation of the sub-carrier, f_x, by the operating pulses, whose spread is equal to the operating band width b, the several modulation sub-frequencies f_x being so chosen that the several bands b lie adjacent to each other and together form a side band B of the width which it is desired to transmit, there being two such side bands, one of which is to be selected for transmission.

The outputs of the several carrier modulators are impressed together on the power amplifier, which is preferably combined with the transmission band selector to form a transmission band amplifier, as shown. The transmission band amplifier is designed to select one of the two modulation bands B and exclude the other side band as well as the scaffold frequency F, and to step up its amplitude to the power required for transmission. This selected and amplified transmission band is then impressed on the radiating means or antenna A and transmitted.

It will be understood that a transmission line may be substituted for the radiating means when line transmission is to be used.

A suitable form of transmission band amplifier is shown in Fig. 5*a*, being of the type set forth in my U. S. Patents Nos. 1,725,433 and 1,850,973 and designed as there explained to pass and amplify the desired transmission band, as explained above. The amplifier band characteristic is preferably made wider than the transmission band, so that precise adjustment is not necessary, but not so wide as to pass the scaffold frequency F. Two band selective coupling units S, S, are shown.

A suitable form of receiving apparatus for carrying out the invention is shown in Fig. 6. Here a receiving collector or antenna A feeds into a reception band selector, as shown, which is preferably combined with an amplifier to form a reception band amplifier. This is preferably of the type set forth in my U. S. Patents Nos. 1,725,433 and 1,850,973, and designed to select and amplify the desired transmission band and exclude undesired signals. Beating osc. F_B is a local source of alternating current of frequency F_B designed to beat with the frequencies of the transmission band at beat frequencies suitable for efficient band selection, as already explained. The output of this source, which is preferably crystal controlled, is impressed on the output circuit of the reception band amplifier and the resulting combined beat current is fed into a demodulator as shown. The demodulator has a plurality of output circuits, each of which feeds into one of a plurality of operating band amplifiers, as shown. The demodulator may have a separate detector tube for each operating band, or preferably it consists in one or more multiple anode tubes, D, as shown in Figs. 7 and 8. Each of the demodulator output circuits feeds into one of a plurality of operating band selectors, which are preferably combined with amplifiers to form a plurality of operating band amplifiers as shown. Each of the operating band selectors is designed to select one of the operating bands of width b, whose beat carrier frequencies are f_1'', f_2'', . . . f_n'', as explained. These beat carrier frequencies, each of which is equal to the sum or difference of the beating frequency and one of the transmitted super-carrier frequencies, are so chosen that the operating band selectors operate at high efficiency in separating the several operating bands from each other.

The output of each operating band amplifier feeds into a second demodulator, whose demodulated output is now an exact replica of the operating pulses supplied by one of the operating transmitters shown in Fig. 5, and is used to operate one of the receiving or recording devices marked *Rec.*

Fig. 7 is a schematic diagram showing in greater detail suitable circuits for the reception band selector and the operating band amplifiers indicated in block form in Fig. 6. They are shown of the type set forth in my U. S. Patents Nos. 1,725,433 and 1,850,973, comprising band selector units S, S, which is highly efficient for this purpose. It shows also a form of multiple anode demodulator, which is well adapted to this purpose, each demodulator unit, D, D, D, having a plurality of output circuits, O_1, O_2, O_3, etc. The output circuits O_1, O_5 and O_8 are shown with their operating band amplifiers for selecting the operating bands f_1'', f_5'', and f_8'', respectively. Each of the operating band amplifiers is shown as including two band selective coupling units S.

Fig. 8 shows in greater detail a suitable form of construction for such a multiple anode demodulator, the anodes which feed the several output circuits being arranged symmetrically about the central cathode and the control grid. Each of the anodes is shown as surrounded by a screen grid, which is preferably employed, preventing interaction between the several output circuits O_1, O_2, O_3, etc.

It will be understood that the several operating transmitters, Tr_1, Tr_2, etc., and receivers, $Rec._1$, $Rec._2$, etc., need not all be located at the same places. For example, they may be placed in any desired location and wired to central transmitting and receiving stations.

In the arrangements thus far described each of the operating bands of width b is transmitted in its entirety, including both side bands, and the several bands are so spaced as to avoid overlapping. It will be understood that one of the side bands may be suppressed by any suitable means, as is known, in which case the number of channels that may be operated in multiplex by the present invention will be doubled.

Another and simpler means for increasing the number of multiplexed channels is by the use of the system set forth in my United States Patent No. 2,134,677, in which a frequency-selective regenerative feedback is applied to an amplifier with a band selective circuit in such manner that a carrier frequency is super-amplified with respect to its side band frequencies, causing superselectivity and producing when demodulated an amplified replica of the original modulations. By substituting this system for the simple operating band amplifiers of Figs. 6 and 7, each operating band selector may be designed to select the beat carrier frequency and one side band only, rejecting the other side band. When this system is used the modulation sub-frequencies $f_1, f_2, \ldots f_n$, may be so chosen that the modulation side bands, having the super-carrier frequencies $f_1', f_2', \ldots f_n'$, overlap in pairs, as shown in Fig. 9. At the receiver, the corresponding operating bands of beat frequency $f_1'', f_2'', \ldots f_n''$ are fully separated and selectively received by selecting the beat carrier and lower side band of one channel and the beat carrier and upper side band of the adjacent, partly overlapping channel, the overlapping side bands of each channel being eliminated, as explained in the above mentioned patent. A typical reception band is shown in Fig. 9a. A suitable arrangement for accomplishing this is shown in Fig. 10, the first output circuit O_1 being shown with a band carrier selector of the form shown in Fig. 3 of the aforesaid patent, selecting the lower side band of the beat carrier frequency f_1'', which is super-amplified with respect to the amplitudes of the modulation frequencies, and the second output circuit O_2 having a band carrier selector of the type shown in Fig. 1 of that patent, selecting the upper side band of the beat carrier frequency f_2'' which is also super-amplified, the overlapping side bands being thus eliminated.

It will be understood that the invention is not limited to the particular forms of apparatus shown for illustration, but other suitable apparatus may be employed.

What I claim is:

1. The method of multiplex communication by a plurality of groups of signal frequencies which consists in producing a plurality of high carrier frequencies closely spaced in the frequency scale by modulating a frequency not required for transmission with a plurality of low carrier frequencies relatively widely spaced in comparison with their frequency scale, separating a band of frequencies including the several high carrier frequencies from the frequency not required for transmission, transmitting the separated carrier frequencies, superimposing signal modulations on the several high carrier frequencies by modulating the low carrier frequencies with the several groups of signal frequencies, transmitting the superimposed signal modulations with the high carrier frequencies, receiving the transmitted carrier frequencies with their modulations, combining the received frequencies with a beating frequency having a value closer to the received frequencies than the frequency not required for transmission, demodulating the combined frequencies and producing by the combination and demodulation modulated beat carrier frequencies at a lower frequency level than the modulated low carrier frequencies and relatively more widely spaced in the frequency scale but preserving the beat carrier frequencies and their modulations in their true mutual relations, selectively separating and separately demodulating the several modulated beat carrier frequencies and producing by the demodulation replicas of the several groups of signal frequencies.

2. The method of multiplex reception of a plurality of communication channels each comprising a carrier frequency with modulation frequencies in their true mutual relations, which consists in receiving a band of frequencies including the several channels, combining the received frequencies with a beating frequency outside the band, demodulating the combined frequencies and producing by the combination and demodulation beat carrier frequencies with their beat modulation frequencies at a lower frequency level but in their true mutual relations, selectively separating the beat frequencies into bands, each including a beat carrier frequency with at least one side band of its modulation frequencies, while preserving the frequencies of each band in their true frequency relations, by super-amplifying the received beat carrier frequencies to an amplitude that is large with respect to the amplitudes of their modulation frequencies and super-selecting each super-amplified carrier with its modulation frequencies, demodulating the separated and super-amplified frequencies and producing by the super-amplification and demodulation amplified replicas of the modulations of the several channels.

3. The method of multiplex communication which consists in modulating a plurality of carrier frequencies by operating pulses, elevating the frequencies of the modulated carriers to a frequency level of communication by modulation of a scaffold frequency not required for communication, transmitting and receiving the elevated modulated carriers, reducing the received modulated carriers to a lower frequency level suitable for selective separation by combining them with a beating frequency, selectively separating and demodulating the reduced modulated carrier frequencies at said lower level, producing by such demodulation replicas of the original operating pulses, changing the frequency level of communication of the several modulated carriers by changing the scaffold frequency and changing the beating frequency by such an amount that the received modulated carriers are reduced to the same lower frequency level and likewise separated and demodulated, producing by such demodulation like replicas of the original operating pulses.

4. The method of multiplex communication which consists in modulating by operating pulses a plurality of carrier frequencies having such values that their modulation bands overlap in pairs, with one-half of each modulation band non-overlapping, transmitting and receiving such modulated carrier frequencies with their overlapping modulation bands, selectively receiving each modulated carrier with the non-overlapping half of its modulation band and rejecting the overlapping parts of the modulation bands, demodulating the selected modulated carriers and producing by such selection and demodulation true separated replicas of the original operating pulses.

5. The method of multiplex communication which consists in generating a scaffold frequency not required for transmission, producing a plurality of carrier frequencies by modulating the scaffold frequency by a plurality of lower frequencies, selectively separating a band of frequencies including the several carrier frequencies from the scaffold frequency, transmitting the selected carrier frequencies, superimposing operating modulations on the several transmitted carrier frequencies by modulating the lower frequencies, producing by the modulation and superposition a plurality of closely adjacent modulated

super-carriers, effecting precise regulation of the super-carrier frequencies by regulating the single scaffold frequency, effecting precise spacing of the closely adjacent modulated super-carriers and their modulation frequencies by a less precise control of the modulated lower frequencies, receiving and effectively separating the closely adjacent modulated super-carriers by combining them with a beating frequency that is closer to the frequencies of the modulated super-carriers than the scaffold frequency, producing thereby a plurality of modulated beat carriers that are relatively widely spaced in their frequency scale, and selectively receiving and separately demodulating the several modulated beat carriers.

6. The method of multiplex communication which consists in modulating by operating pulses a plurality of carrier frequencies having such values that their modulation bands overlap in pairs, with one-half of each modulation band non-overlapping, transmitting and receiving such modulated carrier frequencies with their overlapping modulation bands, super-amplifying each carrier with respect to its modulation band, selectively separating each super-amplified carrier with the non-overlapping half of its modulation band from the overlapping parts of the modulation bands, demodulating the super-amplified and separated modulated carriers and producing by such separation and demodulation true separated replicas of the original operating pulses.

FREDERICK K. VREELAND.