Aug. 10, 1926. 1,595,135

H. A. AFFEL

CARRIER CURRENT SIGNAL SYSTEM

Filed Jan. 27, 1922 3 Sheets-Sheet 1

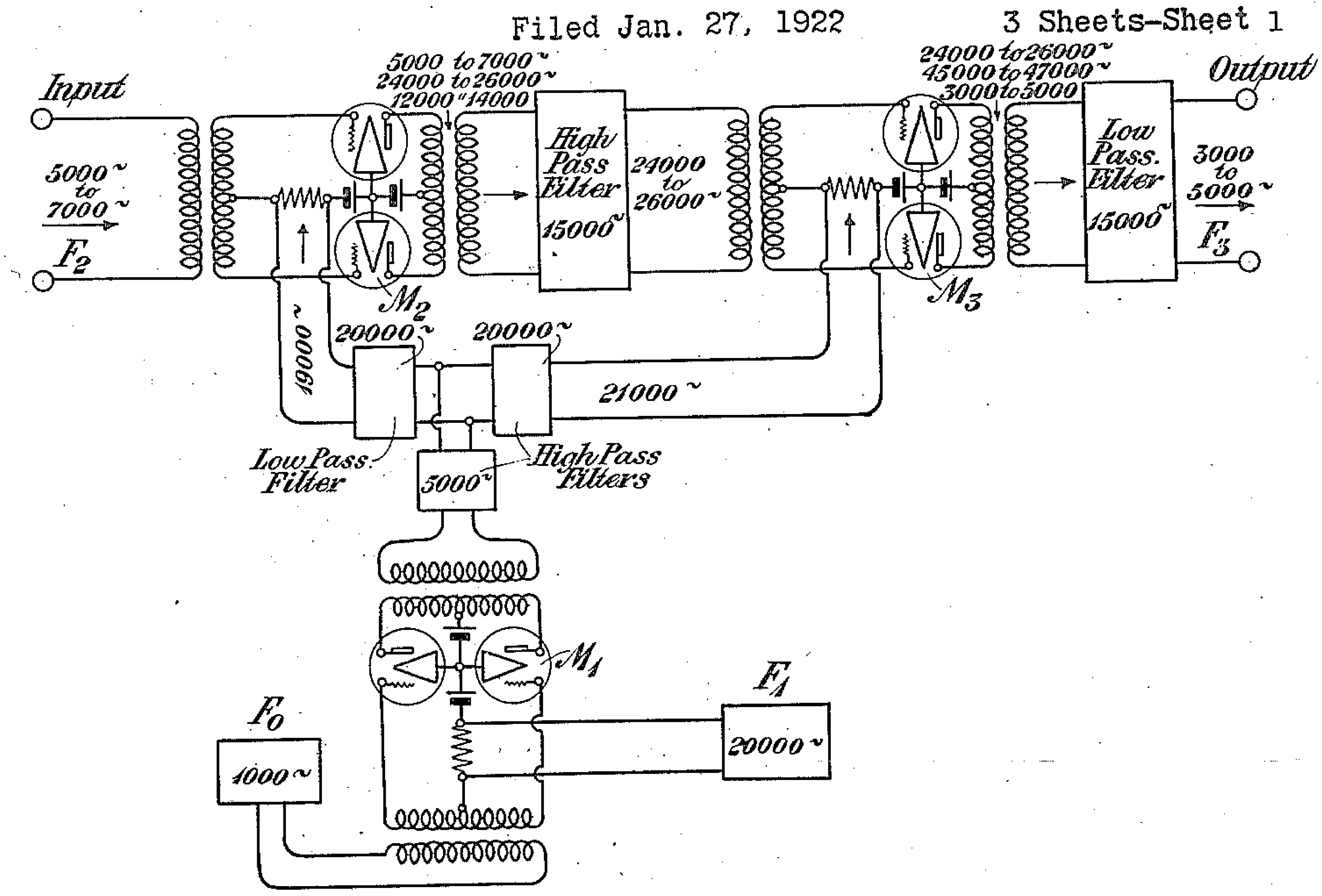

Fig. 1

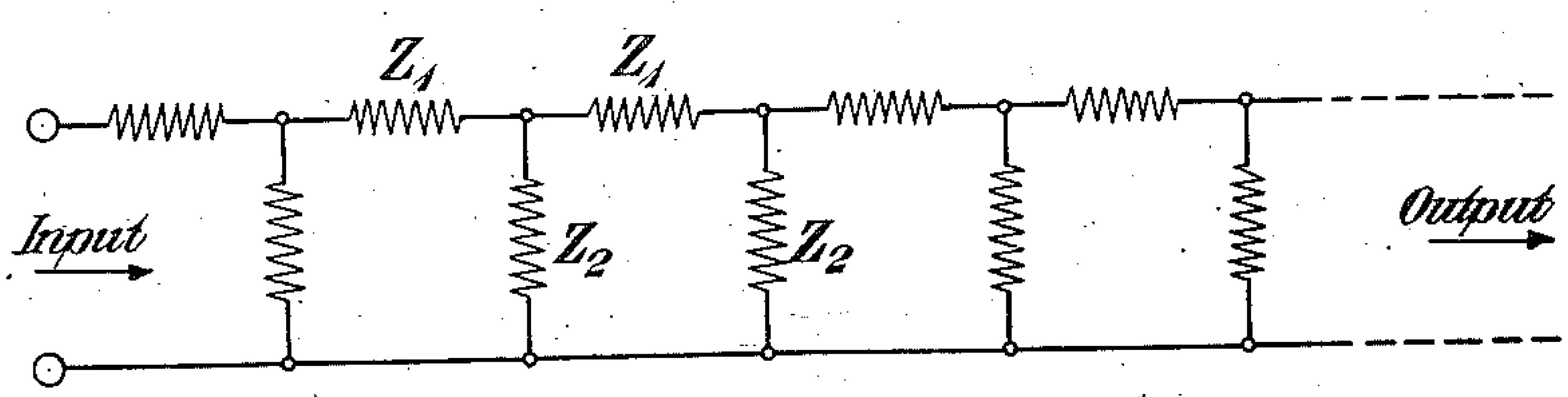

Fig. 1a

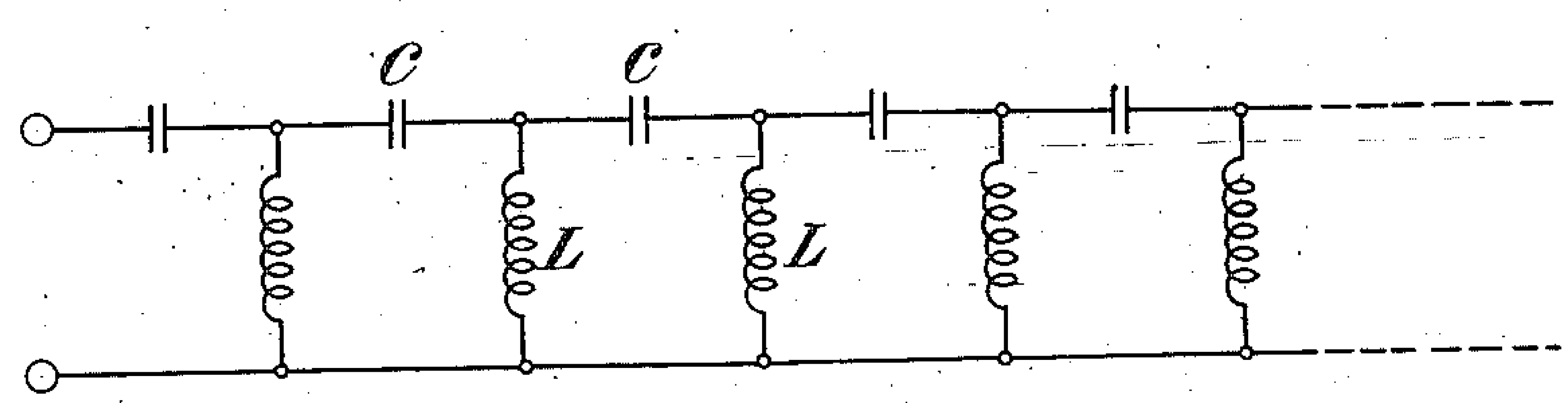

Fig. 1b

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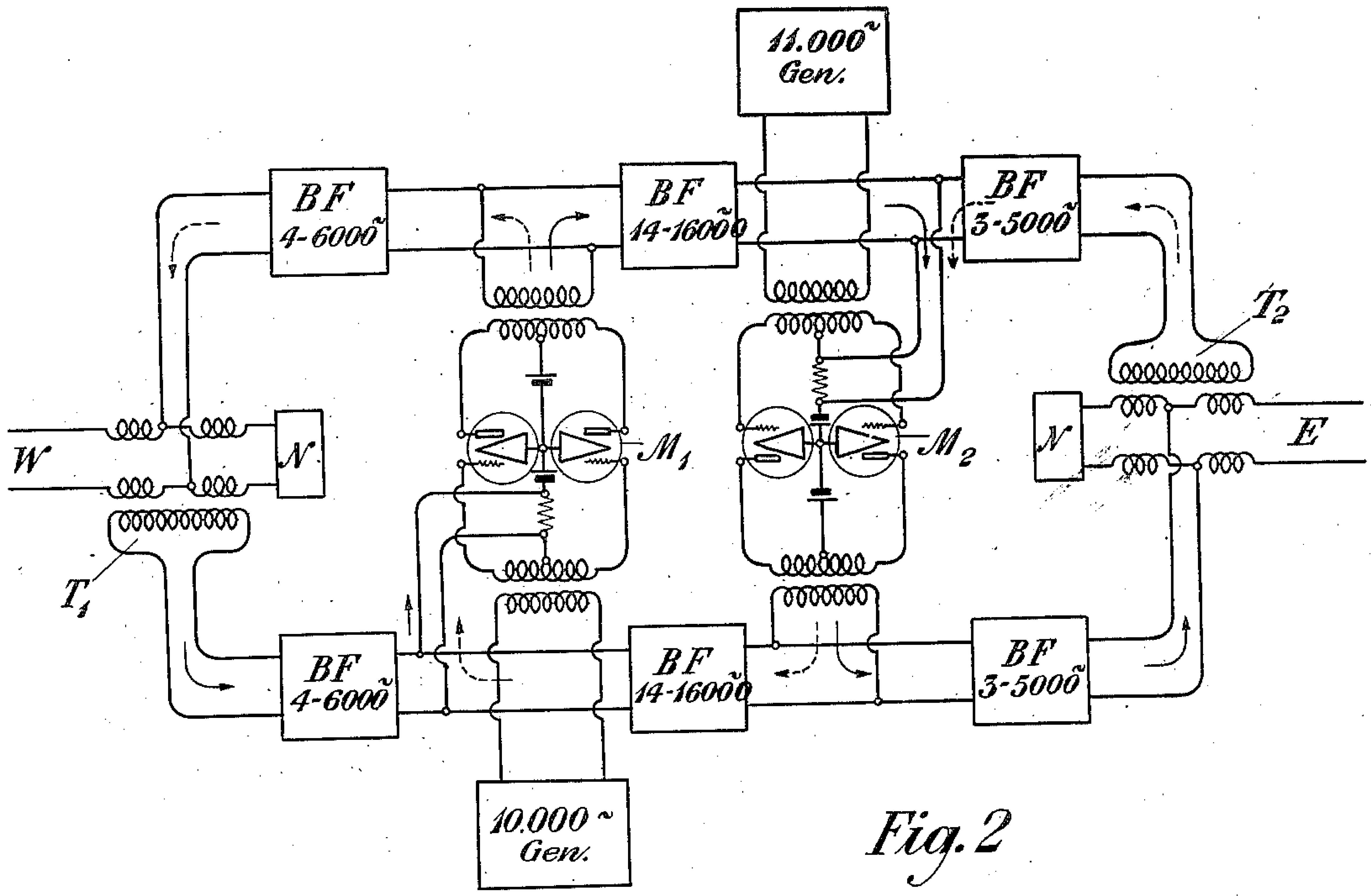

Fig. 2

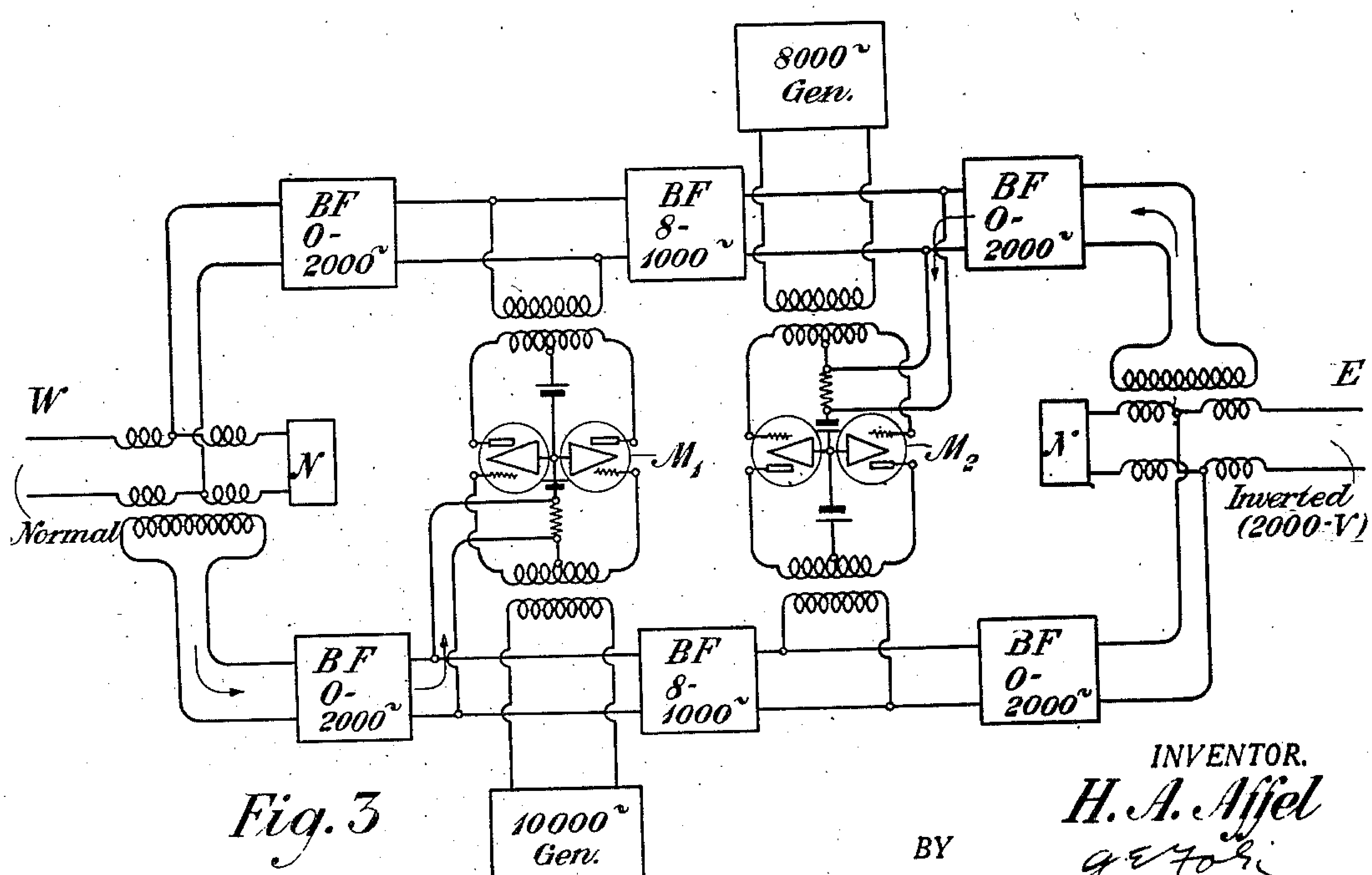

Fig. 3

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3 Sheets-Sheet 3

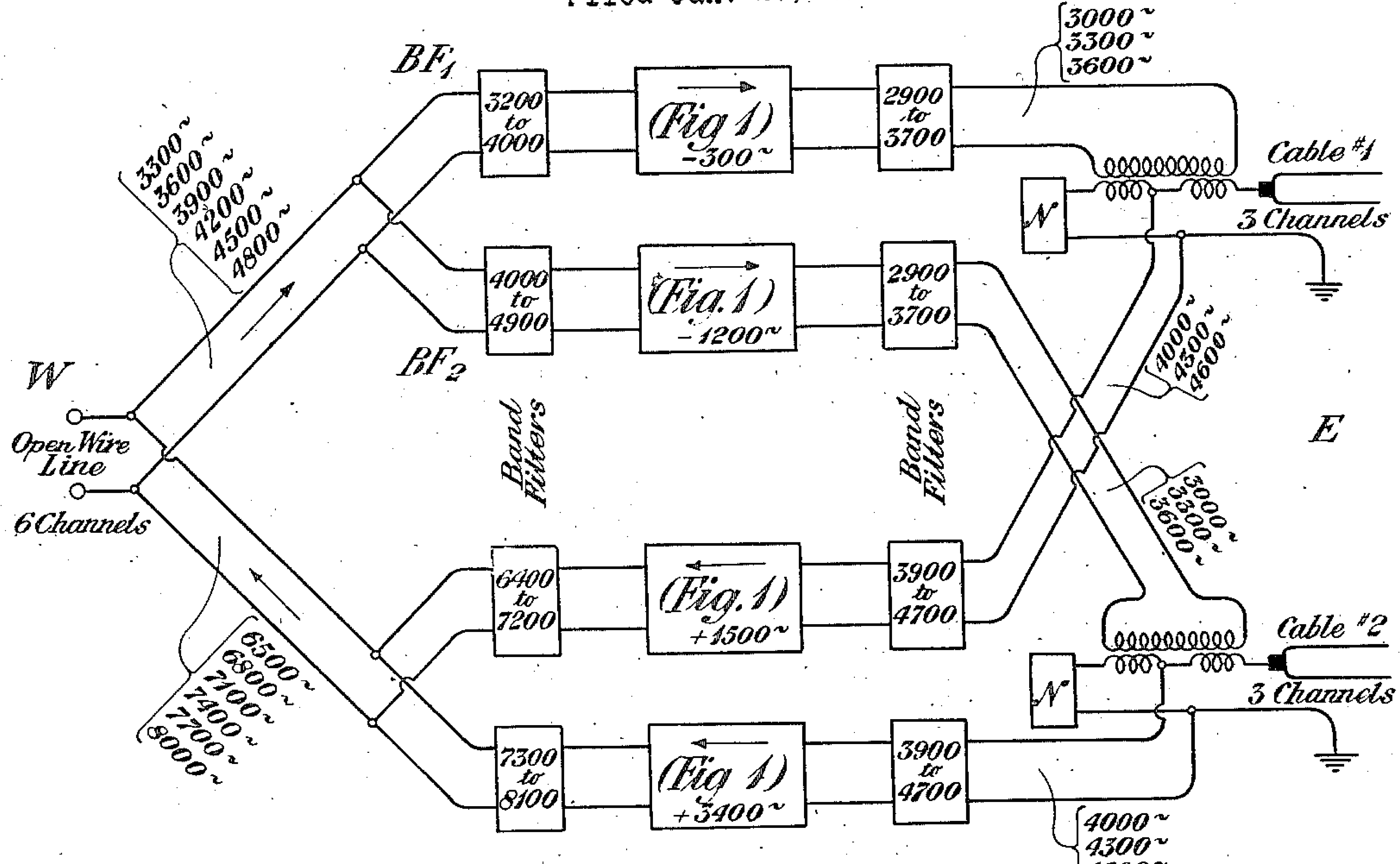

Fig. 4

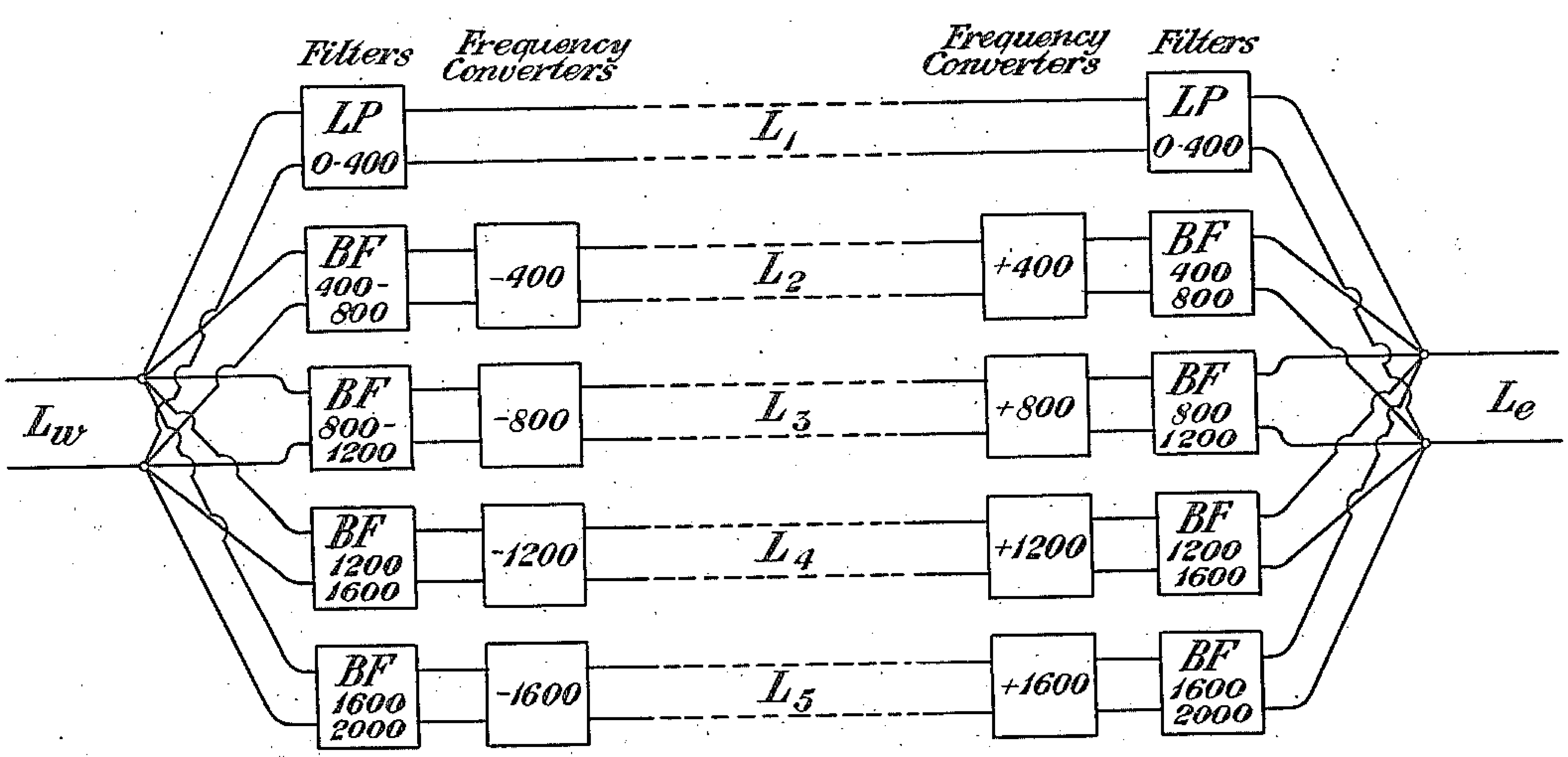

Fig. 5

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UNITED STATES PATENT OFFICE.

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CARRIER-CURRENT SIGNAL SYSTEM.

Application filed January 27, 1922. Serial No. 532,298.

The principal object of my invention is to provide a new and improved system of carrier current transmission. Another object is to provide, in a carrier current system, for shifting a band of frequencies over a comparatively narrow frequency interval. Certain other objects of my invention have to do with providing for secrecy in carrier current transmission, shifting a frequency band to a range of values most suitable for transmission over a given line, and separating a frequency band into narrower bands and transmitting them separately. These and other objects of my invention will be made apparent on consideration of a few specific examples which I have chosen for presentation in this specification. It will be understood that the following description refers to these examples and that the invention is defined in the appended claims.

The drawings are diagrams. The symbol ~ will be understood to mean "cycles per second". Figure 1 shows a system for shifting a frequency band of 5000–7000~ to a band of 3000–5000~. Figs. 1ª and 1ᵇ are diagrams of wave filters. Fig. 2 shows a two-way repeater system with a moderate frequency shift between the input and the output. Fig. 3 shows a two-way repeater system with a frequency inversion between the input and output. Fig. 4 shows a repeater system between two parallel circuits on one side and a single circuit on the other side, the single circuit carrying a total frequency range corresponding to double the range of one of the two parallel circuits, and Fig. 5 shows a system for carrying a voice frequency range of 0–2000~ over five lines, each carrying 0–400~.

Referring to Fig. 1, this shows a one-way system by which alternating currents of various frequencies from 5000~ to 7000~ are shifted to corresponding frequencies lying between 3000 and 5000~. The modulator M_1 modulates 20000~ frequency from the generator F_1 with 1000~ frequency from the generator F_0. This modulator M_1 comprises two three-electrode vacuum tubes connected as shown in the diagram. This connection serves to eliminate the carrier frequency (namely 20000~) from the output of the modulator system. The output frequencies from the modulator M_1 will accordingly be 1,000~, 19000~ and 21000~. These go to a high-pass filter whose critical frequency is 5000~, which accordingly suppresses the 1000~ frequency. This high pass filter of critical frequency 5000~ belongs to the general type of filters shown in Fig. 1ª having series impedances Z_1 and shunt impedances Z_2 in alternation. When impedance Z_1 is represented physically by a condenser C and impedance Z_2 is represented physically by an inductance L, the filter takes the form shown in Fig. 1ᵇ and becomes a high pass filter, with critical frequency

$$f=\frac{1}{4\pi\sqrt{LC}}.$$

Other well-known combinations give the low pass filter and the band pass filter. The remaining frequencies passed by this filter of critical frequency 5000~ are separated into respective branch conductors by the two filters of critical frequency 20000~, one being low-pass and the other high-pass. Accordingly, the 19000~ frequency goes over the conductors as shown in Fig. 1, as the carrier current for the modulator M_2, and the 21000~ frequency goes as the carrier current for the modulator M_3.

The 19000~ frequency in the modulator M_2 is modulated by the input currents of various frequencies from 5000 to 7000~. Accordingly, the output of the modulator M_2 will be made up of frequency bands of 5000–7000~, 12000–14000~ and 24000–26000~.

This composite output going to the high-pass filter whose critical frequency is 15,000~, the output of this filter will be only the last mentioned band, viz, 24000 to 26000~. This frequency range is applied to modulate the 21000~ frequency in the modulator M_3, and accordingly in the output from modulator M_3 there will be found the three frequency bands 3000–5000~, 24000–26000~ and 45000–47000~. This composite output goes to the low-pass filter whose critical frequency is 15000~, and accordingly the final output is only 3000 to 5000~.

It will be seen that the output frequency band 3000 to 5000~ lies adjacent to the input frequency band 5000 to 7000~. Further, it will be seen that this shift of a frequency band to an adjacent frequency band is accomplished by shifting first to a distant band and then back to the adjacent band. More specifically, the band 5,000–

7,000~ is shifted to 24000–26000~, which is then shifted back to 3000–5000~.

If it had been attempted to make the shift directly from the input frequency band to the output frequency band, that is, from 5000–7000~ to 3000–5000~, this would have involved a carrier frequency of 2000~. The output from the modulator would have been 3000 to 5000~, 5000 to 7000~ and 7000 to 9000~. These bands lie so close together that it might have been impractical by means of a low-pass filter effectively to separate the 3000 to 5000~ band from the others. But by first making the shift to a distant band and then back to an adjacent band, sharp discrimination by the filters is possible in each case, and a substantially pure output corresponding to the input is obtained. It will be seen that the general plan is to modulate a carrier frequency large in comparison with the input frequency or band of frequencies, and then to demodulate by a second carrier whose frequency is equal to that of the original carrier plus or minus the net frequency displacement which it is desired to effect. In other words, it may be said in this case that the most effective method of producing a small shift of a frequency band is to make a large shift and then a somewhat greater or smaller shift in the opposite direction, resulting in a differential small shift, as desired. In this way, at the various steps of modulation, the by-product harmonic terms and undesired side bands are readily separated out by suitable filters, since the various ranges of frequencies involved at each step are substantially non-overlapping and non-adjacent.

The method of Fig. 1 will be seen to involve the local generation of two carrier currents differing moderately in frequency, viz, in this particular case, 19000 and 21000~. These are generated by generating the intermediate or average frequency, viz, 20000~, and modulating it by a frequency equal to half the difference between the two desired frequencies. In this case it will be seen that half the difference between 19000~ and 21000~ is 1,000~. Even if there should be a little variation in the frequency of the generator F_1 so that its frequency varies a little from 20000~, nevertheless, if the frequency of the generator F_0 remains constant at 1000~, the two output frequencies 19000~ and 21000~ may vary a little but will keep the constant difference of 2000~.

Referring to Fig. 2, this illustrates a two way device by which alternating currents of 4000–6000~, coming from the west, are shifted to 3000–5000~, going east, and on the other hand, alternating currents of 3000–5000~ coming from the east are shifted to 4000–6000~ going west. The operation of the unit shown in Fig. 2 will be readily understood from the discussion that has been given of Fig. 1. Input currents from the west pass to the primary of the three winding transformer T_1 of well known design whose input and output branches are conjugate, so that currents in one such branch produce no substantial currents in the other. The currents from the west are assumed to lie in the range 4000–6000~ and go through the two band filters whose transmitting ranges are 4000 to 6000~, but these currents are blocked by the two band filters whose transmitting ranges are 14000 to 16000~. Accordingly, these frequencies 4000 to 6000~ go respectively to the audion grids and plates of the modulator M_1. But the audions being unilateral devices, the effect on the plates of the frequencies considered is nil. The modulator M_1 is connected with a 10000~ cycle generator and the frequencies 4000–6000~ on the grid side are modulated with the frequency 10000~, so that the output of the modulator M_1 comprises the frequencies 10000~, 4000–6000~ and 14000–16000~. Of these ranges, only that of 4000–6000~ is passed to the west by the upper left band filter, and only the last range, namely 14000–16000~, is passed to the east through the upper middle band filter of Fig. 2. This frequency range 14000–16000~ is blocked by the upper righthand band filter of range 3000–5000~. Accordingly it goes to the input of the modulator M_2 where it is combined with the locally generated frequency 11000~, giving an output of 11000~, 3000–5000~, and 25000–27000~. All of these ranges are blocked by the lower middle band filter of range 14000–16000~. Only the 3000–5000~ band is passed by the lower righthand band filter of Fig. 2. This frequency range is applied at the three-winding transformer T_2 at the neutral points so that it goes equally to the line to the east and to its balancing network, and not at all into the secondary circuit. Accordingly it will be seen that the 4000–6000~ range from the west is repeated to the east as a 3000–5000~ range. The full-line arrows indicate the course of the essential currents through the apparatus for this repeating operation. The dotted arrows indicate the repeating operation from east to west by which incoming currents of a frequency range 3000–5000~ are transformed to output currents of a range 4000–6000~. The repetition from east to west is the same in principle as from west to east and will be understood without further description.

Thus it will be seen that any frequency entering the circuit from the east within the range of 3000 to 5000~ will appear in the west increased by 1000~ and reciprocally, any frequency entering from the west within the range 4000 to 6000~ will appear in the east decreased by 1000~.

A use for a unit such as that shown in Fig. 2 is to install it at the ends of a line over which it is desired that telephone transmission shall be secret; thus, instead of an ordinary repeater station which repeats without changing the frequency, the repeater stations of Fig. 2 may be installed at the ends of a stretch of line. Assuming that voice frequency currents are put in at one end and are shifted by the device, their altered frequency on the stretch between the two stations will make them unintelligible for direct reception.

It would be still more effective to invert the frequencies and a unit that accomplishes this purpose is shown in Fig. 3. It will be seen that in general structure the arrangement is the same as for Fig. 2. Whereas in Fig. 2, the band filters transmitting from 14000 to 16000∼ are transmitting an upper side band; in Fig. 3 the band filters transmitting from 8000 to 10000∼ are transmitting a lower side band. The result is that the frequencies are inverted. For example, a frequency of 500∼ from the west goes to the modulator M_1 and appears in its output as a component, 9500∼, of the lower side band which goes through the band filter transmitting from 8000 to 10000∼. This 9500∼ frequency is combined in the modulator M_2 with the locally generated frequency 8000∼ and gives 1500∼ in the lower side band of the output of modulator M_2. This is passed by the lower righthand band filter whose range is 0 to 2000∼ and appears in the line east as a frequency of 1500∼. In short, any frequency n∼ between 0 and 2000∼ in the line west gives an output frequency of $(2000-n)$∼ in the line east, and vice versa. Accordingly, the substitution of two repeater stations like Fig. 3 for the ordinary repeater stations in a long transmission line secures the result that between those stations all the voice currents will be of inverted frequency and quite unintelligible for direct reception.

It has been suggested to attain secrecy by transmitting with the voice currents a pure tone loud enough to drown out the voice and to separate this tone from the voice currents at the receiving end. However, it is difficult to separate out the pure tone lying within this frequency range without suppressing a whole range of adjacent frequencies and seriously distorting the voice currents. By my method for example, a pure tone of 400∼ might be put on the line with the voice currents so that anywhere on the line, by direct reception, this tone would competely mask the voice currents. At the receiving station the received currents would be displaced down 400∼, thus causing the 400∼ loud tone current to appear at approximately 0∼. It could then be easily filtered out and the frequency range shifted back by 400∼, giving the voice frequency range substantially unimpaired as transmitted at the outset.

It is known that loaded cables have a tendency to attenuate high frequencies relatively more than low frequencies, so that transmission of a wide frequency range over a loaded cable may be impractical on this account. A much wider range can be transmitted on an open wire line because the attenuation does not fall off with increasing frequency so rapidly in that case. It is common that a long distance transmission will be partly by cable in a region of dense traffic and partly by open wire in an outlying region. The direct connection of a cable in series with an open wire therefore cuts down the capacity of the open wire to the frequency range which may be transmitted over the cable. In Fig. 4, I have shown an arrangement by which one open wire line can be made to serve for connection in series with each of two cables. This figure illustrates a carrier current telegraph system with six channels each way on an open wire line connected serially to each of two cables, each cable having three channels corresponding to three of the six of the open wire line. In Fig. 4, the rectangles marked "(Fig. 1)" represent the system of Fig. 1 by which one-way frequency shift is obtained. The respective numerals in these rectangles, viz, −300∼, −1200∼, +1500∼, and +3400∼, indicate the resultant frequency shift. In this connection it will be understood that the corresponding numeral for Fig. 1 would be −2000∼. It will be seen that from west to east on the open wire line there are six carrier current frequencies ranging by 300∼ intervals from 3300 to 4800∼. These are separated into two groups by the band filters BF_1 and BF_2. Then the frequencies are shifted down as indicated and as already mentioned, and each group of three carrier frequencies is put on a respective cable, each group comprising 3000, 3300 and 3600∼. Other frequencies namely 4000, 4300 and 4600∼, come in over the cables from east to west and go through the band filters BF_3 and BF_4 to the devices like Fig. 1, where the frequencies are raised by 1500∼ for the group from cable No. 1, and by 3400∼ for the group from cable No. 2. This gives the set of six west-bound carrier frequencies, ranging by 300 cycle intervals, from 6500 to 8000∼. Thus it will be seen that the greater frequency range of the open wire line as compared with the cable is utilized by making one open wire line serve in series with each of a plurality of cables.

In cases for which it is desired to transmit voice currents over a line of limited frequency range, my invention may be employed to divide the voice range up and apportion the parts thereof to conductors each having a frequency range sufficient to carry its respective portion. It is well known that transmission through ocean cables is possible only for the relatively low frequencies involved in telegraphy and not for the higher frequencies involved in voice currents. Referring to Fig. 5, suppose that there are five lines, L_1, L_2, L_3, L_4 and L_5, each of which will carry effectively a frequency range of only 0 to 400∼, and that it is desired to transmit between their common terminals a voice frequency range of 0 to 2000∼. At one end a set of five band filters will separate the voice frequencies into five consecutive bands, each of range 400. These various frequency ranges will then be depressed by the devices of Fig. 1, and by amounts indicated by the numerals −400∼, −800∼, etc., so that the output frequency ranges for each of the five devices will be from 0 to 400∼. These ranges will be transmitted over the five respective lines and at the other end the respective frequency ranges will be increased by +400∼, +800∼, etc., and then recombined to give a correct voice frequency range.

With the simplest types of carrier modulating circuits difficulty has been experienced in using carrier frequencies lower than about 4000∼. In this case, the harmonics of the voice frequency ange, produced by the normal action of the modulating circuits, are transmitted in the carrier band itself, 4,000 to 6,000∼, and cause effective noise and quality distortion in the demodulating circuit at the receiving end. For such low carrier frequencies, and even lower carrier frequencies, when desired, it will be seen that my system will be advantageous. Such low carrier frequencies might be useful for loaded cable. A carrier telegraph channel might be operated at say 2500∼ for the carrier frequency in addition to a voice range channel.

The amount of amplifying gain at voice frequencies is often limited by the incidental noise produced in the vacuum tube circuits, as, for example, by the vibration of the vacuum tube grid. By introducing the amplification in the high frequency part of the circuit much of this trouble may be avoided. Accordingly, it may be desirable to shift the frequencies to a high frequency merely to secure this advantage in cases where no ultimate frequency displacement is desired.

I claim:

1. The method of producing a modulation of a comparatively low frequency by a range of frequencies without intermediate transmission, which consists in modulating a comparatively high frequency by such range and then directly demodulating by a frequency differing from said high frequency by the desired frequency.

2. The method of shifting a frequency band at a single station by a comparatively small frequency displacement, which consists in first shifting it by a wide frequency displacement and then at the same station shifting it back to the desired degree of displacement.

3. The method of producing a comparatively small displacement of a frequency band, which consists in shifting it by modulation over a comparatively wide displacement, then filtering out undesired frequency bands, then directly at the same station shifting back to the desired point of displacement by another modulation, and again filtering out undesired frequencies.

4. The method of shifting the frequency range of a wave by a comparatively small frequency displacement, which consists in modulating it with one comparatively large frequency and then demodulating with another frequency differing therefrom by the ultimate displacement desired, and generating the two modulating frequencies by modulating their average with half their difference.

5. The method of repeating a frequency range which consists in shifting such range by a comparatively large frequency displacement, and directly at the same station shifting back by a range differing slightly from the first range, and transmitting the resultant frequency range.

6. A two-way repeater comprising means both to transmit and receive throughout one frequency range on one side, means both to transmit and receive throughout one different frequency range on the other side, and means to shift the frequency up one way and down the other way from one said range to the other, the said two ranges being near together in frequency, so as to effect transmission on each side each way within and throughout the respective frequency ranges.

7. A two-way repeater comprising two three-winding transformers, two opposite modulators, one to step a frequency up by a certain number of cycles and the other to step it down by a number of cycles slightly different, respective generators of different frequency for these two modulators, and filters connected for two-way transmission whereby the transmission on one side of the repeater both ways is at a slightly different frequency than on the other side of the repeater both ways.

8. A two-way repeater comprising two three-winding transformers, two opposite modulators, one to step a frequency up by a comparatively wide frequency range and the other to step it back by a range nearly but not quite the same, respective generators for the two modulators each of frequency high compared to the frequencies in said transformers but the two generators being of slightly different frequency, and filters connected for two-way transmission whereby the transmission both ways on one side of the repeater is at a frequency slightly different from the transmission both ways on the other side of the repeater.

9. A frequency inverter comprising means to shift an input frequency range to a comparatively distant range and means at the same station to shift it directly back to give an output not far from the original range, said means being adapted to invert the frequencies between the input and output.

10. A two-way frequency inverter comprising two three-winding transformers, and means to shift an input frequency range at either transformer to a comparatively distant range and then back not far from the original range but inverted at the other transformer.

11. The method of transmitting a band of waves over a conducting path which offers an excessive attenuation to the higher frequency components thereof, which method comprises reducing the frequencies of all the components to frequencies well within the efficient transmission range of said path.

12. The method of transmitting a band of waves lying between two definite frequency limits over a conductor within the transmission range of which one of said limits does not fall, which method comprises reducing the frequencies of each component of said band by a predetermined amount to cause said frequency limits to fall within said transmission range, transmitting said reduced frequency band over said conductor and thereafter increasing the frequency of each of the transmitted components by the same predetermined amount by which it was reduced before transmission.

13. The method of transmitting between two points a band of waves of broader frequency extent than the transmission range of a practical transmission circuit which can be used to connect said points, comprising separating said band into a plurality of nonoverlapping frequency sub-bands of narrower extent, transmitting each of said sub-bands over an individual transmission circuit, connecting said two points, receiving said sub-bands, and re-assembling them to produce said original band of waves.

14. The method of transmitting between two points a band of waves of greater frequency extent than the practical transmission range of a circuit that may be used to connect said points, comprising dividing said band into a plurality of non-overlapping frequency bands, reducing the component frequencies of each of said plurality of bands, transmitting each of said reduced frequency bands over an individual circuit connecting said points, restoring each of said transmitted bands to its original frequency position, and re-assembling said restored frequency bands to reproduce the original band.

15. The method of transmitting over a conductor waves having components higher than the practical upper frequency transmission limit of said conductor, which comprises so combining said waves with a wave of a single frequency as to reduce the component frequencies by said single frequency, transmitting said wave of reduced frequency components over said conductor, and thereafter so combining said transmitted wave with a wave of said single frequency as to increase the component frequencies of the transmitted wave to their original magnitudes.

16. A transmission system for transmitting a band of waves over a conducting path which offers excessive attenuation to the higher frequency components thereof, comprising means for reducing the frequencies of all of the components of said band to frequencies well within the efficient transmission range of said path, and transmitting said reduced frequency components over said path.

17. A system for transmitting a band of waves lying between two definite frequency limits over a conductor within the transmission range of which one of said limits does not fall, which comprises means for reducing the frequency of each component of said band by a predetermined amount to cause said frequency limits to fall within said transmission range, means for transmitting said reduced frequency band over said conductor to a distant station, and means at said station for increasing the frequency of each of the transmitted components by the same predetermined amount by which it was reduced before transmission.

18. A system for transmitting between two points a band of waves of broader frequency extent than the practical transmission range of a circuit which can be used to connect said points, comprising means for separating said band of waves into a plurality of non-overlapping frequency sub-bands of narrower extent, an individual transmission circuit for each of said sub-bands connecting said two points, means for supplying each sub-band to its individual transmission circuit, means for receiving said sub-bands at a distant point, and means for re-assembling them to produce said original band of waves.

19. A system for transmitting between two points a band of waves of greater frequency extent than the practical transmission range of a circuit that may be used to connect said points, comprising means for dividing said band into a plurality of non-overlapping frequency bands, means for reducing the component frequencies of each of said plurality of bands, means for transmitting each of said reduced frequency bands over an individual circuit, means for restoring each of said transmitted bands to its original frequency position, and means for re-assembling said restored frequency bands to reproduce the original band.

20. A system for transmitting over a conductor waves having components higher

than the practical upper frequency transmission limit of said conductor, which comprises means for combining said waves with a wave of a single frequency to reduce the component frequencies by said single frequency, means for transmitting said wave of reduced frequency components over said conductor, and means for combining said wave after transmission with a wave of said single frequency to increase the component frequencies thereof to their original frequency magnitudes.

In testimony whereof, I have signed my name to this specification this 26th day of January, 1922.

HERMAN A. AFFEL.