Nov. 8, 1927. 1,648,145

H. NYQUIST

METHOD AND APPARATUS FOR COMPENSATING DISTORTION ON LONG LOADED LINES

Filed Nov. 2, 1923

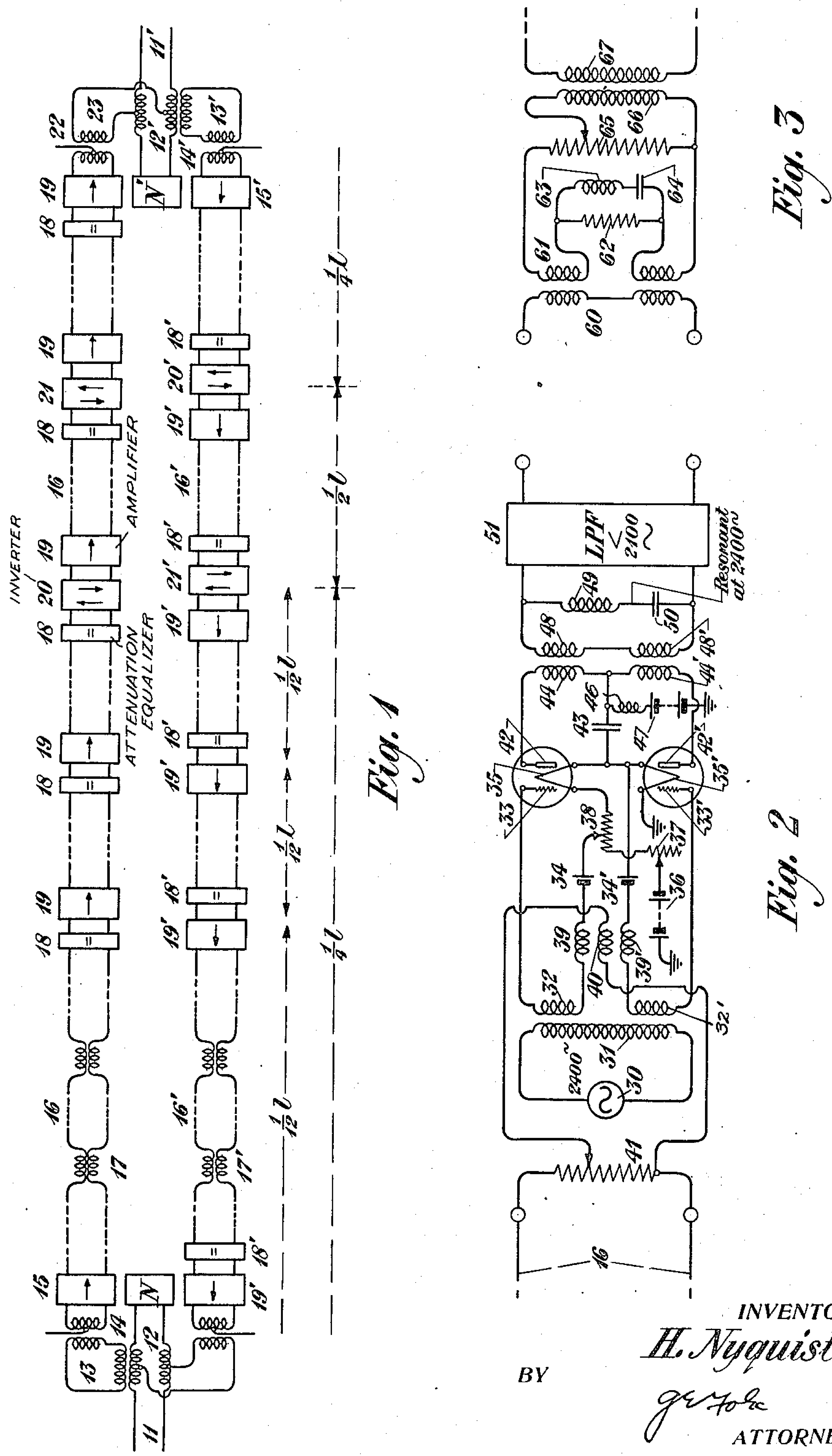

Fig. 1

Fig. 2

Fig. 3

INVENTOR

H. Nyquist

BY

ATTORNEY

Patented Nov. 8, 1927. 1,648,145

UNITED STATES PATENT OFFICE.

HARRY NYQUIST, OF JACKSON HEIGHTS, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

METHOD AND APPARATUS FOR COMPENSATING DISTORTION ON LONG LOADED LINES.

Application filed November 2, 1923. Serial No. 672,345.

An object of my invention is to provide apparatus and a method to compensate for the distortion on a long loaded line due to the differential retardation of the different frequencies of the voice range. Another object of my invention is to provide for compensating the differential retardation of a range of frequencies to be transmitted in case the transmission line has the property of retarding those frequencies unequally. Another object of my invention is to provide practicable means for inverting a range of frequencies. These and other objects of my invention will be made apparent in the following specification and claims taken with the accompanying drawings, in which I have illustrated an example of the invention which I now proceed to describe. It will be understood that the following specification relates more particularly to this embodiment of the invention and that its scope will be defined in the appended claims.

Referring to the drawings, Figure 1 is a diagram showing a four-wire transmission line adapted for operation according to the principles of my invention; Fig. 2 is a diagram of a frequency inverter and Fig. 3 is a diagram of an attenuation equalizer.

In this example which I proceed to disclose, the voice frequency range from zero up to nearly 2400 cycles per second is involved. To invert the frequencies of this range means to substitute for any frequency n a frequency of $2400-n$. Thus, a frequency of 900 cycles per second in the normal range becomes 1,500 cycles per second in the inverted range. Devices to accomplish this function are indicated symbolically at 20, 21, 20′ and 21′ in Fig. 1. These are shown in detail in Fig. 2, which will be described later, but for the present it will suffice to understand that for each frequency component n going into such a device as 20, there will come out of it a frequency $2400-n$.

The usual two-wire terminals of the four-wire line of Fig. 1 are shown at 11 and 11′. The input circuit 11 is balanced by the artificial line N across the three-winding transformer 12, and the input from the line 11 goes by the circuit 13 and repeating coils 14 to the amplifier or one-way repeater 15. The loaded line 16 comprises the spaced loading coils 17 and at suitable intervals attenuation equalizers 18 and repeaters 19 are located. In this example, with an assumed length l for the line, the attenuation equalizers 18 and repeaters 19 are placed at intervals of $l/12$.

At an interval of $l/4$ there is the usual attenuation equalizer and repeater combination 18, 19 with an interposed inverter 20. Then, for a length $l/2$ the loaded line 16 continues with attenuation equalizers and repeaters at intervals of $l/12$ until at $3l/4$ another inverter 21 is placed, and then the repeatered loaded line continues for the remaining $l/4$ in normal manner to the end at the two-wire terminals 11′. Connection is made through the repeating coil 22 and conductors 23 to the balanced points between the line 11′ and its network N′.

Thus, it will be seen that for transmission from 11 to 11′, the frequency range is normal for the first fourth of the way, inverted for the next half of the way and again normal for the remaining fourth of the way.

Primed numerals have been employed for the transmission from east to west, which corresponds to that from west to east and need not be described here in detail.

In a medium heavy loaded line the lower telephone frequencies will be propagated with a speed of about 10,000 miles per second, while frequencies of 2,000 cycles per second will be transmitted with a speed of about 9,000 miles per second. On a line 1000 miles long this differential speed will produce serious distortion at the receiving end. By inverting the frequencies over half the length of the line, such distortion will be effectively compensated.

The frequency inverter indicated symbolically at 20, 21, 20′ or 21′ is shown in the diagram of Fig. 2. Two audions are provided and the circuits of their respective grids 33 and 33′ comprise the respective secondary windings 32 and 32′. The corresponding primary winding 31 is energized by a source 30 of alternating current of 2400 cycles per second. The input of voice frequency range coming over the line 16 to the potentiometer 41 goes through the primary winding 40 associated with the respective secondary windings 39 and 39′ in the grid circuits. These grid circuits are connected to the filaments 35 and 35′ through the respective batteries 34 and 34′. A potentiometer 38 is provided for adjusting the balance between the two tubes. Filaments 35 and 35′ are glowed in series by current from the battery 36 through the rheostat 37. The audion plates 42 and 42′ are in parallel plate circuits on the battery 47 connected through the inductance 46. These plate circuits comprise the respective primary windings 44 and 44′ with the associated secondaries 48 and 48′. 49, 50 is a shunt, resonant at 2400 cycles, and 51 is a low-pass filter which cuts off transmission at about 2100 cycles. A suitable condenser 43 is interposed as shown across the plate circuits.

In the audion it is well understood that the effect on the plate circuits is due to the combined grid potential and plate potential. Let the factor by which the plate potential must be divided to make it coordinate with the grid potential be designated by μ, and let A represent this plate potential divided by μ minus the grid potential, which is negative. Let E stand for the voltage of the 2400 cycle current impressed on the grid. Let e be the voltage due to the input current impressed on the grid.

Then the current in the plate circuit of one audion may be represented with sufficient accuracy for the present purpose by the expression

$$(A+E+e)^2=A^2+E^2+e^2+2AE+2Ae+2Ee$$

also the current in the plate circuit of the other audion may be represented by

$$(A-E+e)^2=A^2+E^2+e^2-2AE+2Ae-2Ee.$$

Accordingly the resultant combined output will be the difference which is $4AE+4Ee$. The first term, $4AE$, represents the modulating frequency in the output and the second term, $4Ee$, represents the two side bands of frequency respectively higher and lower than the modulating frequency of 2400 cycles. This modulating frequency of 2400 cycles, represented by the term $4AE$, is removed, that is, shunted out, by the resonant branch 49, 50. The upper side band of frequency range above 2400 cycles is removed or shunted out by the low-pass filter 51 and there remains to be transmitted to the line 16 only the inverted voice frequency range below 2400 cycles.

The foregoing discussion has been based on the assumption that the two audions have identical amplification constants and identical internal impedance. If these conditions are realized only approximately it will still be possible to get a very good balance, provided the impedance of the output condenser 43 is low and provided that the respective output impedances in the plate circuits are made proportional to the amplification constants.

The attenuation equalizer represented symbolically at 18 in Fig. 1 is shown in more detail in Fig. 3. This is a well-known piece of apparatus and will be described only briefly. The transformer 60, 61 has a divided secondary in which the resistance 62 is interposed. This resistance 62 is shunted by a resonant combination 63, 64. For the ordinary voice range the resonance may appropriately be at about 2800 cycles. Thus, it will be seen that for high frequencies in the voice range the resistance 62 will be shunted by a low impedance path and will not be attenuated by the resistance 62, whereas, low frequencies in the voice range will be more attenuated by the resistance 62 and in this way the intensity over the voice range is substantially equalized. The output from the secondary 61 goes through the potentiometer 65 to the repeating coil 66, 67.

I claim:

1. A long loaded line and means to compensate the differential retardation for different frequencies comprising interposed frequency inverters spaced so that the frequencies are inverted along substantially half the length of the line and are normal along substantially the other half of the length of the line and normal at both ends of the line.

2. A transmission line having the normal property of causing distortion by differential retardation of the frequency components of a range of frequencies to be transmitted and means interposed in said line to invert said frequency range and means also interposed again to invert the frequency range and restore it to normal after transmission of the inverted range over substantially half the length of the line.

3. A long loaded line, repeaters therein, a frequency inverter at a distance of about one-fourth the line length from the sending end and another frequency inverter at a distance of about three-fourths the line length from the sending end whereby the different frequencies at the receiving end are in substantially the same phase relation as at the sending end.

4. A long loaded four-wire transmission line, one-way repeaters in each circuit-pair of conductors and two frequency inverters in each circuit-pair at a distance apart equal to about half the length of the line whereby transmission each way is with the normal frequency range about half-way and the inverted frequency range about half-way and distortion due to differential retardation is compensated.

5. The method of compensating differential retardation for different frequencies of a range in a long loaded line which consists in inverting the frequency range over about half the length of the line.

6. The method of compensating the differential retardation for different frequencies on a long loaded line which consists in

transmitting a fraction of the way with the normal frequency range, then inverting the frequencies of this range and transmitting about half the length of the line with the inverted frequency range, then again inverting the frequency range and thereby restoring it to normal and transmitting the remainder of the way with the normal frequency range.

In testimony whereof, I have signed my name to this specification this 1st day of November, 1923.

HARRY NYQUIST.