June 8, 1965 W. PALMER 3,188,626

ANALOGUE-TO-DIGITAL-CONVERTER

Filed Sept. 15, 1961 2 Sheets-Sheet 1

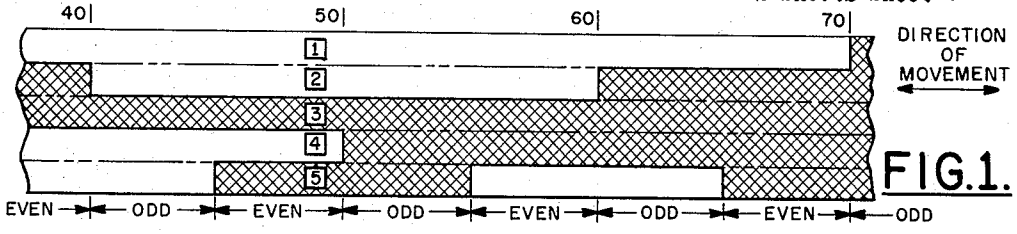



FIG.1.

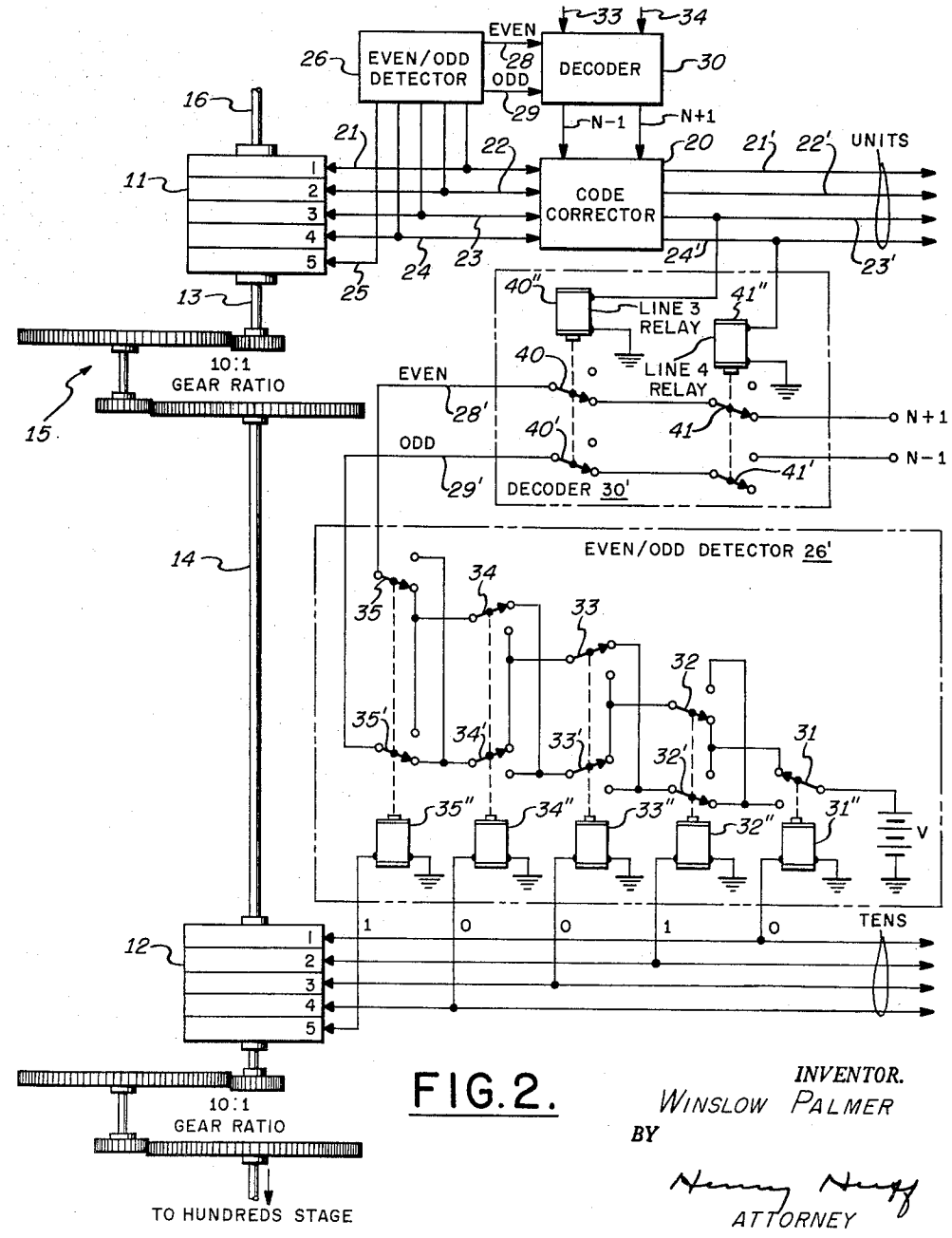



FIG.2.

INVENTOR.
WINSLOW PALMER
BY
ATTORNEY

June 8, 1965 W. PALMER 3,188,626

ANALOGUE-TO-DIGITAL-CONVERTER

Filed Sept. 15, 1961 2 Sheets-Sheet 2

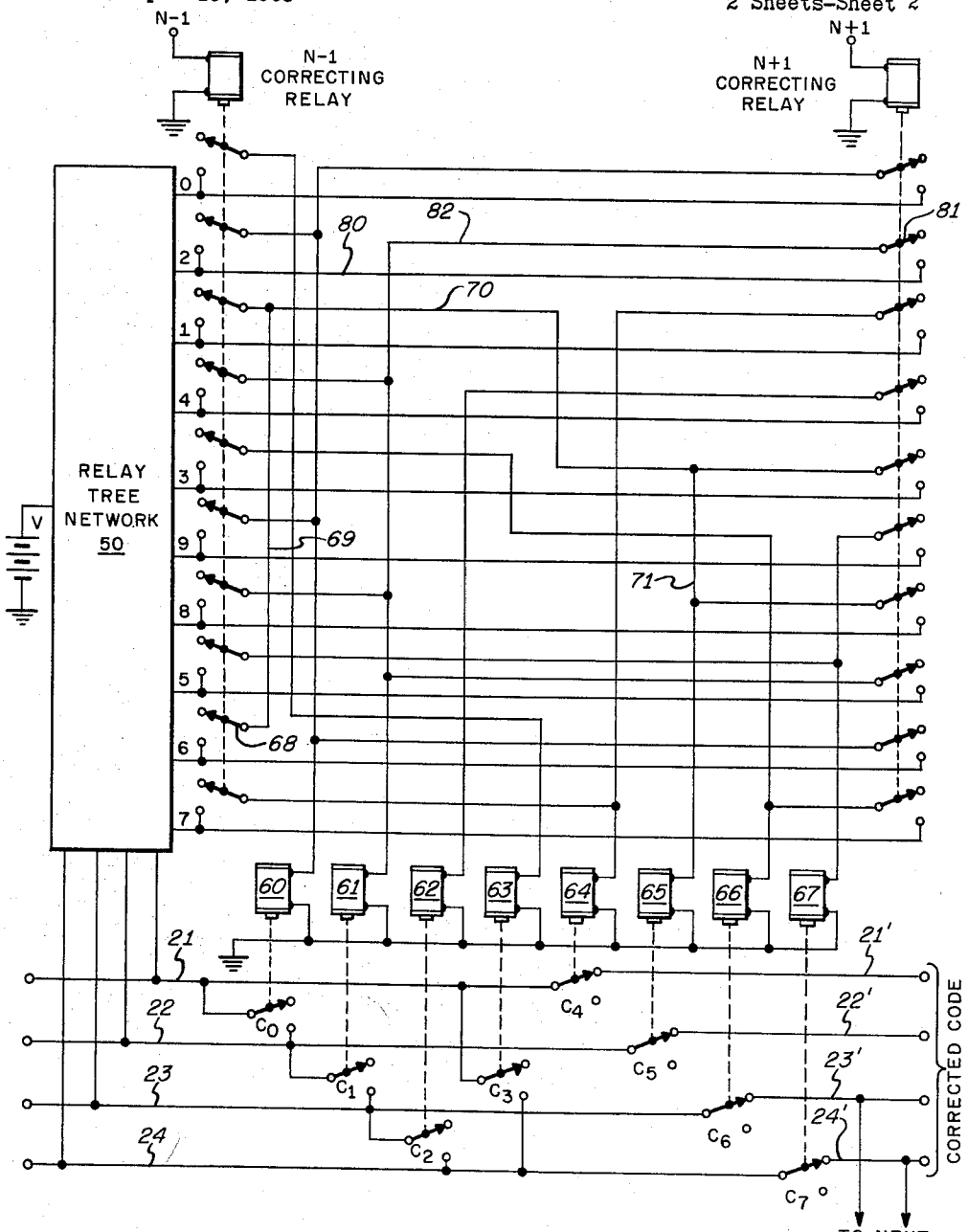



FIG. 3.

INVENTOR.
WINSLOW PALMER
BY
ATTORNEY

United States Patent Office

3,188,626

Patented June 8, 1965



3,188,626

# ANALOGUE-TO-DIGITAL-CONVERTER

Winslow Palmer, Amityville, N.Y., assignor to Sperry Rand Corporation, Great Neck, N.Y., a corporation of Delaware

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5 Claims. (Cl. 340—347)

This invention relates to a multispeed analogue-to-digital converter for converting a mechanical movement to a digital code, and more particularly to such a converter having a self-correcting feature for producing a correct output code irrespective of backlash or play in the linkages of the multispeed system.

A common method of converting the angle of a rotatable shaft to a digital code, for example, is to connect a digitally coded wheel to the shaft and provide means for reading off the character of the code at a fixed position with respect to the rotatable wheel. It has been found impractical to use the pattern of the conventional binary code on the wheel because the transfer between successive characters on the code wheel requires simultaneously making and breaking of a number of contacts, or other sensing means, and because it is physically impossible to exactly align the contact members, a character entirely different from that of the desired code may be transmitted during transfer from one digit to the next. To overcome this difficulty, the Gray code has been used on the code wheel. This is a cyclic or unit-distance binary code wherein each character of the code differs from the preceding and succeeding characters by a change in only one digit position. This eliminates the possibility of error due to minor misalignment of the contacting members, but in order to obtain appreciable resolution with the Gray code a multispeed system must be used. Because of backlash and play in the linkages of the multispeed system, however, alignment errors may arise because a higher speed code wheel in the linkage may transfer from one character to the next higher or lower character before or after one of the lower speed code wheels makes a corresponding transfer from one character to the next.

It therefore is an object of this invention to provide a multispeed analogue-to-digital converter which overcomes the above-mentioned difficulty.

Another object of this invention is to provide a self-correcting multispeed analogue-to-digital converter for providing a correctly coded digital signal irrespective of non-synchronous operation of the code wheels in the system.

A further object of this invention is to provide a multispeed analogue-to-digital converter for providing an unambiguous coded output signal representing the position of a mechanical member.

In describing the present invention, consideration first will be given to the unique code which I employ on each code wheel of the multispeed system. The basic code consists of ten characters of four binary digits each. These ten characters represent the ten decimal digits of a coded binary notation. In order to aid in determining when the code pattern on a wheel has changed from one character to the next higher or lower character during rotation of the wheel, each character is represented in the code pattern on the wheel by two sub-characters which represent the lower half and upper half of the value of the character. The sub-characters have an additional binary digit



added to the four digits of the basic code, and the code, both before and after adding this additional digit, is cyclic or unit-distance in nature, that is, each sub-character differs from the adjacent characters by a change in only one digit position. The code is set forth below, wherein rows 1–4 constitute the basic code and row 5 contains the added digit of each sub-character.

| 11 | 11 | 00 | 00 | 00 | 00 | 00 | 11 | 11 | 11 | 11 | 11 | 00 | 00 | 00 | 00 | 00 | 11 | 11 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00 | 11 | 11 | 11 | 00 | 00 | 11 | 11 | 11 | 00 | 00 | 11 | 11 | 11 | 00 | 00 | 11 | 11 | 11 | 00 |
| 00 | 00 | 00 | 11 | 11 | 11 | 11 | 11 | 00 | 00 | 00 | 00 | 00 | 11 | 11 | 11 | 11 | 11 | 00 | 00 |
| 00 | 00 | 00 | 00 | 11 | 11 | 11 | 11 | 11 | 00 | 00 | 00 | 00 | 00 | 11 | 11 | 11 | 11 | 11 | 11 |
| 01 | 10 | 01 | 10 | 01 | 10 | 01 | 10 | 01 | 10 | 01 | 10 | 01 | 10 | 01 | 10 | 01 | 10 | 01 | 10 |
| 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E | 0E |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

It may be seen from the code that the added digits in the fifth row alternate in binary value and are arranged so that the sum of the five digits of the sub-characters representing the lower half of each character is odd and the sum of the digits of the sub-characters representing the upper half of each character is even. It also may be seen that the change between characters from a lower value to a higher value is accompanied by a change of the sum of the corresponding coded binary digits from even to odd. This change in the sum of the digits from even to odd occurs only when the code changes to the next higher character, and both these events necessarily occur simultaneously. Another feature of this code, the importance of which will become evident from the discussion below, is that the binary digits in rows 3 and 4 form a binary pair having the value 0, 0 for the characters 0 through 2, the value 1, 0 for the characters 3 and 4, the value 1, 1 for characters 5 through 7 and 0, 1 for characters 8 and 9. It will be seen that the combinations of these binary pairs for the characters 0, 1 and 8, 9 are unique because these same combinations do not appear in the 3 and 4 digit positions throughout the remainder of the code. Therefore, these unique combinations are restricted to the position on the code wheel immediately adjacent where the code pattern repeats, and may be used to aid in determining when the characters in the code pattern on the wheel have changed from 9 to 0, or vice-versa.

The invention will be further described by referring to the accompanying drawings wherein:

FIG. 1 is a linear representation of a portion of the pattern of the code set forth in the above table;

FIG. 2 is a simplified diagram, partially in block form, illustrating the converter of this invention; and

FIG. 3 is a simplified diagram, partially in block form, illustrating in more detail the error correcting portion of the converter.

FIG. 1 is a simplified representation of a portion of the code pattern on the tens code wheel showing the code pattern from approximately **40** through **70**. For simplicity, this representation is linear. Its adaptation to a flat disc-shaped code wheel is obvious. The shaded portion of the pattern may be conductive material and the remainder may be an insulating material, in which case the sensing elements **1–5**, illustrated by the small squares, may be brush contacts. Sensing elements **1–5** sense the binary values of the correspondingly-numbered digit positions. Alternatively, the shaded portion may be opaque to light and the remaining portion of the pattern may be transparent, in which case sensing elements **1–5** may be photo cells. This invention is not limited to the particular code wheel arrangement discussed herein, and any known arrangement may be used for establishing a code pattern on a translatable member, and any compatible sensing means may be employed without departing from the teachings of this invention.

A schematic representation of the converter, partially in block form, is illustrated in FIG. 2, and shows but two code wheels stages, the units and tens stages of the multi-

speed system. Successive stages would be identical to the tens stage. Code wheels **11** and **12**, each having fixed thereon a pattern of the code set forth above, are coupled together by means of mechanical linkages **13** and **14** and a gear train **15** having a gear ratio 10:1 so that wheel **12** makes one-tenth of a revolution for each revolution of wheel **11**. The rotatable shaft whose angular position is to be converted to a digital code is coupled to linkage **16**.

The binary values of each of the five digit positions of the code pattern on code wheel **11** are sensed and corresponding signals are respectively coupled over leads **21–25** to even/odd detector **26** which produces a first output signal on lead **28** when an even number of binary ones, for example, are present in a sensed sub-character of the code, and produces a second output signal on lead **29** when there are an odd number of binary ones in the digits of the sensed sub-character. The even and odd output signals on leads **28** and **29** are coupled to decoder **30** and the other two input leads **33** and **34** to decoder **30** respectively couple the signals from the third and fourth digit positions from the next-higher-speed code wheel, not illustrated. Decoder **30** operates in response to its input signals to produce signals on either of two output leads $N-1$ or $N+1$ only when either one of two combinations of input signals are present. Decoder **30** operates to produce an output on lead $N+1$ only when an even signal is coupled from lead **28** and the signals on leads **33** and **34** from the third and fourth digit positions of the preceding code wheel both are zeros, and produces an output on lead $N-1$ only when an odd signal is present on lead **29** and the respective signals on leads **33** and **34** are 0 and 1. The operation of decoder **30** may be represented by the following Table I:

*Table I*

| Preceding Code Wheel | | Even/Odd | Read |
|---|---|---|---|
| Digit 3 | Digit 4 | | |
| 0 | 0 | Even | N+1 |
| 0 | 0 | Odd | N |
| 1 | 0 | Even | N |
| 1 | 0 | Odd | N |
| 1 | 1 | Even | N |
| 1 | 1 | Odd | N |
| 0 | 1 | Even | N |
| 0 | 1 | Odd | N−1 |

The signals on input leads **33** and **34** are indicative of whether or not the pattern on the preceding wheel has just changed from the character 9 to the character 0, or vice versa, or lies some distance therebetween. As may be seen from the code table above, this results from the unique arrangement of the binary digits in the third and fourth digit positions of the code. The binary pair of the third and fourth digit positions will be 0, 0 for the zero and first characters, and will be 0, 1 only for the eighth and ninth characters. Also, an even number will be present on lead **28** only if the character sensed on code wheel **11** has not yet changed from 9 to 0, and an odd signal on lead **29** will be present only if the character sensed on code wheel **11** already has transferred from 9 to 0. Because a unique combination of input signals is coupled to the decoder **30** when the character sensed on the next-higer-speed code wheel has changed from 9 to 0 but code wheel **11** has not so changed, and because a different unique combination of inputs is present when the reverse situation is true, logical networks may be constructed to produce respective output signals only upon the occurrence of these two unique combinations of input signals. Thus, in accordance with Table I, an output signal on lead $N+1$ indicates that the next higher character is the correct character which should be read, and an output signal on the $N-1$ lead indicates that the next lower character is the correct character which should be read. If neither the $N+1$ or $N-1$ leads are energized, the character being sensed on the code wheel **11** is correct. Now it may be seen that a means has been provided for determining whether or not successive code wheels in the multispeed system transfer simultaneously, and the $N+1$ and $N-1$ output signals also provide information which indicates the relative order of transfer of the two successive wheels in the system.



The signals representing the binary values of the four digit positions of the sensed character also are coupled on leads **21–24** to code corrector **20** along with the code correcting signals on leads $N-1$ and $N+1$. Code corrector **20** operates in response to these code correcting signals to correct the digit signals on leads **21–24** if they are in error so that the correct code is coupled out on leads **21'–24'**.

The even/odd detector is illustrated in schematic form in block **26'** in the tens stage of FIG. 2 and is comprised of a network of relay-actuated switches **31–35** and **32'–35'**. Switch **31** is a single-pole double-throw relay and the remainder of the network is comprised of double-pole double-throw relays. Each relay is normally closed on its upper contact, and closes on its lower contact only when a binary one is coupled to its respective energizing winding designated by a corresponding double-primed numeral. A source of potential V is coupled to relay **31**, and depending upon the state of energization of the relays, is coupled out on either the even line **28'** or the odd line **29'**. As an example of the operation of even/odd detector **26'**, assume that the code of the sub-character presently being sensed on code wheel **12** is 0, 1, 0, 0, 1, the code of the upper half of the decimal code 2 (see the code table above). In FIG. 2 the switches of the detector are illustrated as closed on the appropriate contact when energized in response to this assumed combination of binary digits from code wheel **12**. Following through the continuity of the switching network in the condition illustrated, it is seen that voltage source V is coupled through the upper contact of switch **31**, through switches **32**, **33'**, **34** and **35** to the even line **28'**. This is the correct output since there are two binary ones in the assumed input code.

The decoder **30'** also is comprised of a relay-actuated switching network comprised of switches **40**, **40'** and **41**, **41'**, actuated respectively by windings **40''** and **41''** which are energized only by binary ones being coupled thereto from the third and fourth digit positions of the correctly coded digit signals at the output of code corrector **20**. Switches **40**, **40'** both are normally closed and switches **41** and **41'** are respectively normally closed and normally open.

Before describing the operation of the decoder **30'**, it should be remembered that the only time that an error or ambiguity in a multispeed system will arise is when successive wheels are to simultaneously change to the adjacent decimal digit, or character, i.e. the unit wheel changes from 9 to 0 and the tens wheel is to simultaneously change from 50 to 60. As an example of the operation of the decoder **30'**, assume that zeros are coupled to relay windings **40''** and **41''**, respectively, from the third and fourth digit positions of preceding code wheel **11**. Also assume that a signal is coupled from even/odd detector **26'** to decoder **30'** on even line **28'**. Referring now to the code table above, it will be seen that the binary pair 0,0 is present in the third and fourth digit position of the code for the characters 0 and 1, and therefore code wheel **11** must have transferred from the character 9 to 0. Similarly the sum of the binary digits from the even/odd detector **26'** is even, so it is seen that code wheel **12** must now be on the upper half of the sub-character of the decimal digit 9, that is, has not yet changed from 50 to 60. With these respective inputs applied to decoder **30'**, odd line **29'** is unenergized so that no outputs can appear on the $N-1$ output line. Even line **28'** is energized and both switches **40** and **41** are closed so that a signal appears on the output line $N+1$, indicating that the tens code wheel should have transferred but has not yet done so.

The only other possible combination of inputs which will produce an output from decoder **30** is represented in the bottom row of Table I. That is, a binary zero and a binary 1, respectively, from the third and fourth digit positions on preceding code wheel **11**, and a signal on odd line **29'** from the even/odd detector **26'**. In this instance, both relays **40'** and **41'** are closed and a signal will appear on the output line $N-1$. The even line **28'** will not be energized and no signal will appear on output line $N+1$. In referring again back to the code table, it will be seen that this latter situation arises when the character being sensed from the preceding code wheel **11** has not yet transferred from the decimal digit 9 to the decimal digit 0, and the code wheel **12** already has transferred to its next decimal digit, as evidenced by the odd signal from detector **26'**. It may be seen by trial that none of the other possible combinations set forth in Table I will produce a signal on either the $N+1$ or $N-1$ output lines of decoder **30'**.

The method used to correct the code depends to some extent upon the manner in which the code wheels operate. If it is assumed that the pattern on the code wheels is of conductive material and that contact is made from a source of potential through the pattern to an output line when that line is to be energized, and leaves the line open when no output is required on the line, then the codes representing the characters can be changed by opening the appropriate lead by means of a relay to switch an energized line to an unenergized line, and a presently unenergized line can be energized by connecting it to a presently energized line.

The following Table II shows which digit positions change in the characters of the code when the characters change in value.

*Table II*

| Character Decimal Digit | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Line | | | | | | | | | | |
| 21 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 22 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 |
| 23 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |

The dash lines indicate on which lead the change of energization takes place when a character changes in value to the next higher or lower valued character. Thus, for example, if the character being sensed is 6, and if the output from decoder **30** indicates that the next lower character should be read ($N-1$), then line **22** should be opened to change this output from 1 to 0. If decoder **30** indicates that the next higher character should be lead ($N+1$), then line **21** should be energized. The necessary inter-connections between lines for increasing and decreasing the value of a presently sensed character are set forth in the following Table III wherein the numerals connected by a dash indicate that lines having those numbers are to be connected together and the numerals within the parentheses indicate that the lines having those numbers are to be opened.

*Table III*

| Character | N+1 Connection | N−1 |
|---|---|---|
| 0 | 21—22 | 21—24 |
| 1 | (21) | (22) |
| 2 | 22—23 | 21—22 |
| 3 | (22) | (23) |
| 4 | 23—24 | 22—23 |
| 5 | 22—23 | (24) |
| 6 | 21—22 | (22) |
| 7 | (23) | (21) |
| 8 | (22) | 22—23 |
| 9 | (24) | 21—22 |

In order to apply the appropriate correction it is necessary first to recognize which character is being sensed. Referring now to FIG. 3, a schematic illustration of code corrector **20**, the code of the particular character being transmitted is recognized by means of a relay tree network



**50** which connects a source of potential V to a respective one of the output terminals 0–9 depending upon the particular combination of the binary digits of the sensed character on the lines **21–24**. The relay tree **50** may be of the type described on pages 108 and 109 of Automatic Digital Calculators, by Booth and Booth, published by Butterworths Scientific Publications, London, 1953. In the event that the code of the character being sensed is incorrect, a correcting signal $N+1$ or $N-1$ from decoder **30** energizes a respective $N+1$ or $N-1$ correcting relay so that the associated normally-open contacts of the energized relay are closed. Continuity then is established from voltage source V to one of the relay windings **60–67** so that one of the relay contacts $C_0$–$C_7$ is energized in accordance with Table III to open one of the output lines **21'–24'**, or to cross-connect an unenergized line to an energized line.

As an example of the operation of the code correcting circuit of FIG. 3, assume that the code for the character 6(0, 1, 1, 1) presently is being sensed and corresponding binary digit signals are present on the input lines **21–24**. Also assume that the $N-1$ correcting relay is energized, indicating that the code is to be corrected to indicate the character 5. With these conditions present, output terminal **6** of relay tree **50** will be energized and connection will be made through contact **68**, leads **69–71** to code correcting relay **65** which opens normally-closed contact $C_5$ to deenergize output line **22'**. The code on the output lines **21'–24'** now is 0, 0, 1, 1 which is the code for character 5, this showing that the desired correction has been made.

As a further example of the operation of the correcting circuit of FIG. 3, assume tha the character presently being sensed on the code wheel is decimal digit 2 so that the binary digits on input lines **21–24** are 0, 1, 0, 0, respectively. Also assume that the $N+1$ correcting relay is energized to close its associated normally-opened contacts. The $N+1$ output from decoder **30** being energized indicates that the input code is incorrect and the value of the character now being read is to be increased by one. Relay tree **50** operates in response to the digit signals on lines **21–24** to connect the voltage source V to output terminal **2** of the relay tree, through lead **80**, contact **81**, lead **82** to the relay winding **61** which closes the normally-opened contact $C_1$. The closing of contact $C_1$ connects lines **22–23** together, and since line **22** is energized, it also energizes line **23**. The digits on output lines **21'–24'** then are 0, 1, 1, 0, the code for the decimal digit 3. Thus the correcting circuit of FIG. 3 has performed its desired function.

When the correct input code is coupled on input lines **21–24**, the $N+1$ and $N-1$ correcting relays both will be unenergized and their associated relays will remain open. Therefore, normally open contact $C_0$–$C_3$ will remain open, and normally-closed contacts $C_4$–$C_7$ will remain closed and the input signal will be coupled directly through to output lines **21'–24'**.

It is believed to be obvious that the practice of my invention is not limited to the particular types of relay networks illustrated. Different logical networks employing different elements may be employed with equal facility. It also is to be understood that the practice of my invention is not limited to translatable members such as rotatable code wheels, but may be practiced with translatable members having different relative motion, such as linear.

While I have described my invention in its preferred embodiment, it is to be understood that the words which I have used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of my invention in its broader aspects.

What I claim is:

1. A multispeed analogue-to-digital converter comprised of a plurality of translatable members coupled to-

gether so that the speed of translation of successively coupled members is related by the factor N, each member having thereon a cyclic binary code pattern comprised of N characters of Y digits, each character being represented on said pattern by two adjacently positioned sub-characters of $Y+1$ digits and each pair of corresponding sub-characters being of opposite binary values in their $Y+1$ digit positions in a manner to preserve the cyclic nature of the code, said code being further characterized by having a first unique combination of binary values in two digit positions of the first character of said code and a second unique combination of binary values in the same two digit positions of the Nth character of said code, said two unique combinations being restricted, respectively, to the immediate vicinity of said first and Nth characters of the code, means associated with each translatable member for sensing at any position of said member the sub-character of the code present at a reference position and for producing corresponding signals representing the binary digits of the sensed sub-character, means responsive to said sub-character binary digit signals from each sensing means for producing a first signal when an even number of said digit signals from the respective means are of a given binary value and for producing a second signal when an odd number of said digit signals are of said given binary value, correcting signal producing means associated with each member responsive to said first and second signals and responsive to correct signals from said two digit positions of the next-higher-speed member for producing a first correcting signal when said first signal is coupled thereto and the first unique combination is present in the correct signals from said two digit positions of the next-higher-speed member and for producing a second correcting signal when said second signal is coupled thereto and said second unique combination is present in the correct signals from said two digit positions of the next-higher-speed member, and code correcting means for each member coupled to receive the sensed digit signals from the associated sensing means and responsive to the first correcting signal associated with each respective member to change the value of one of said digit signals to increase by one the value of the character represented by said sensed digit signals and responsive to the second associated correcting signal to change a different one of said digit signals to decrease by one the value of the character represented by said sensed digit signals.

2. An analogue-to-digital converter comprising a plurality of linked code wheels wherein the rotational speed of successively linked wheels is related by the factor N, a pattern of a cyclic code fixed to each of said wheels, said code being composed of N characters of Y binary digits each and each character being represented on said pattern by two adjacently positioned sub-characters of $Y+1$ binary digits each, the sub-characters corresponding to a character being oppositely valued in their $Y+1$ digit positions in a manner to preserve the cyclic nature of the code, said code being further characterized by having a first combination of binary digits in at least two given digit poistions of the first character and a second combination of binary digits in the same given digit positions of the last character, said two combinations being unique in the code only in the respective immediate regions of the first and last characters of the code, means for sensing on each wheel the sub-character which is at a respective reference position and for producing signals corresponding to the sensed binary digits, detector means associated with each wheel operating in response to the digit position signals from its respective wheel for producing either a first or a second signal when the sensed binary digits contain, respectively, either an even or an odd number of signals corresponding to a given binary value, decoder means for each wheel coupled to receive said first and second signals from a respective detector and to receive the correct combination of binary digit signals from said two given digit positions from the next-higher-speed wheel and operating in response thereto to produce a first correcting signal when said first signal and the first unique combination of binary digit signals are coupled thereto and to produce a second correcting signal when said second signal and the second unique combination of binary digit signals are coupled thereto, and code correcting means coupled to receive the sensed signals from the Y digit positions from each wheel and the corresponding correcting signals and operating to change said sensed signals to represent the next-higher-valued character when said first correcting signal is present and to represent the next-lower-valued character when said second correcting signal is present.



3. The combination claimed in claim 1 wherein said code correcting means is comprised of means for producing a respective identifying signal corresponding to the code of the Y binary digit position signals coupled thereto and is further comprised of means operating in response to a correcting signal and a respective identifying signal to change the binary value of one of said digit position signals to indicate an adjacent character in the code in accordance with the correcting signal.

4. In an analogue-to-digital converter the combination of a plurality of rotatable code wheels linked together so that the rotational speeds of successively linked wheels are related by the factor N, each wheel having thereon a continuous pattern of a cyclic code comprised of N characters of Y digits, wherein each character is represented on said pattern by two adjacently positioned sub-characters of $Y+1$ digits and each pair of corresponding sub-characters are oppositely valued in their $Y+1$ digit positions in a manner to preserve between sub-characters the cyclic nature of the code, sensing means for each code wheel for producing respective signals representing the value of each digit of the sub-character present at a respective reference position, means associated with each wheel and responsive to the sensed digit signals from the wheels for producing a first signal when an even number of the sensed digits are of a given binary value and for producing a second signal when an odd number of the digits are of said given binary value, means for coupling correct digit signals from two digit positions of the sensed sub-character from the next-higher-speed wheel, said two digit positions of the sub-characters from the next-higher-order wheel having different combinations of binary values for the first and the Nth characters of the code and the combinations being present in the pattern in said two digit positions only in the immediate vicinity of the first and Nth characters of the code, means responsive to the first and second signals from a given wheel and said two digit signals from the next-higher-speed wheel for producing a first correcting signal when said next-higher-speed wheel has rotated so that the character sensed thereon has changed from the Nth to the first character but the sensed character on the given wheel has not so changed and for producing a second correcting signal when the sensed character on the given wheel but not the next-higher-speed wheel has so changed, means for increasing by one the value of the sensed character from said given wheel in response to said first correcting signal and for decreasing by one the value of the sensed character from said given wheel in response to said second correcting signal.

5. In an analogue-to-digital converter the combination of a plurality of rotatable code wheels linked together so that the rotational speeds of successively linked wheels are related by a factor N, each of said wheels having fixed thereon a pattern of a cyclic code of N characters each comprised of Y binary digits, each character being represented on said pattern by a pair of adjacently positioned sub-characters, each sub-character further including an additional binary digit and the additional digits of a pair of corresponding sub-characters being of opposite binary values and arranged in said pattern in

a manner to preserve between successive sub-characters the cyclic nature of said code, sensing means for each wheel for producing signals representing the values of the respective digits of the sub-character of the code present at a reference position, means respectively responsive to the sensed digit signals from each wheel except the highest speed wheel for producing a first signal when an odd number of said sensed digits are of a given binary value and for producing a second signal when an even number of said digits are of said given binary value, means for monitoring at least two of the Y digit positions on the next-higher-speed code wheel, said monitored digit positions having different combinations of binary values for the first and Nth characters of said code, said combinations being present in the pattern only in the immediate regions of the first and Nth characters, means operating in response to said first and second signals and in response to correct signals representing said two monitored digits from said next-higher-speed wheel for producing a first correcting signal when the sensed character on a given wheel changes from the Nth to the first character but the next-higher-speed wheel does not so change and for producing a second correcting signal when the order of change of said two wheels between the Nth and first characters is reversed, means responsive to said correcting signals for decreasing by one the value of the sensed character on said given wheel upon the occurrence of the first correcting signal and for increasing by one the value of the sensed character upon the occurrence of the second of said correcting signals.



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MALCOLM A. MORRISON, *Primary Examiner.*