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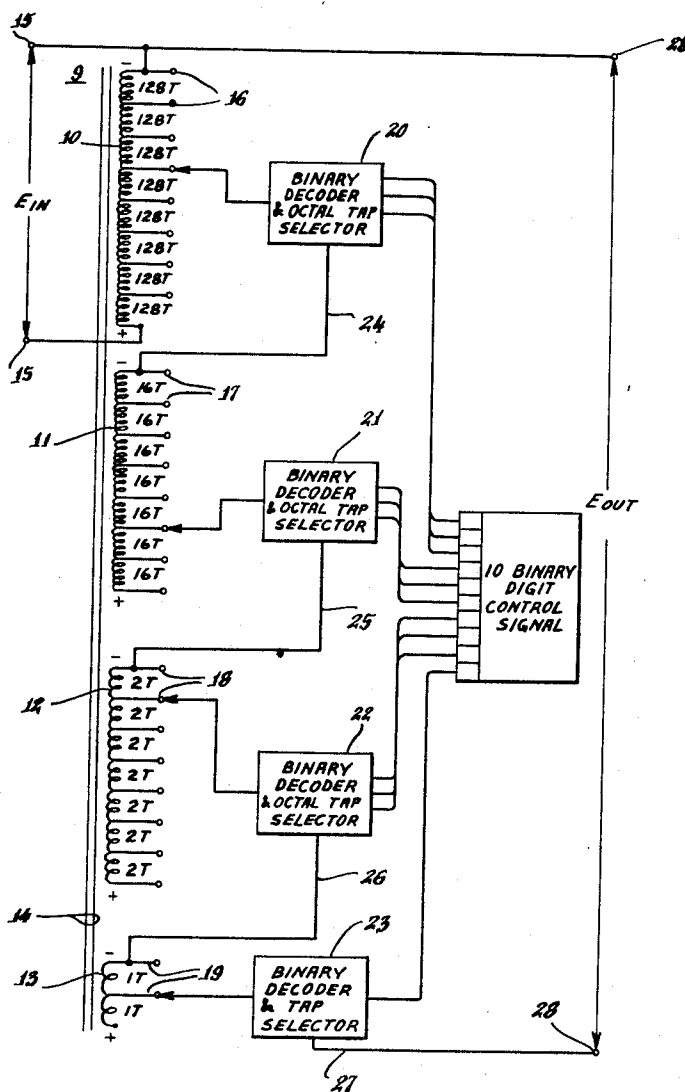
- [54] APPARATUS FOR CONVERTING BETWEEN
DIGITAL AND ANALOG INFORMATION
10 Claims, 2 Drawing Figs.**

- [52] U.S. Cl..... 340/347DA,
323/43.5 R
[51] Int. Cl..... H03k 13/04
[50] Field of Search..... 340/347;
336/150; 323/43.5

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| 3,244,966 | 4/1966 | Gertsch et al. | 336/150 X |

ABSTRACT: Apparatus for converting digital information to an analog voltage which includes a transformer having an ordered plurality of windings, all of which are magnetically flux linked and each of which corresponds to a digit of a digital number. Each winding is divided by output taps into a number of equal segments, the number being determined by the base of the digital number. The number of turns in the segments on each winding is determined by the power of the base represented by the digit to which the winding corresponds and by an arbitrary number of turns selected to correspond to the unit value of the digital number. Means are included for supplying an operating potential to one of the windings, preferably that having the largest number of turns. Switching means, adapted to be controlled by digital information, are provided for connecting one input tap on each winding to one end of an adjacent winding. Means for providing an output voltage are connected to one end of the driven winding and the last output tap. preferably the output is connected to the low voltage end of the driven winding and each tap is connected by the switching means to the low voltage end of the next less significant winding.



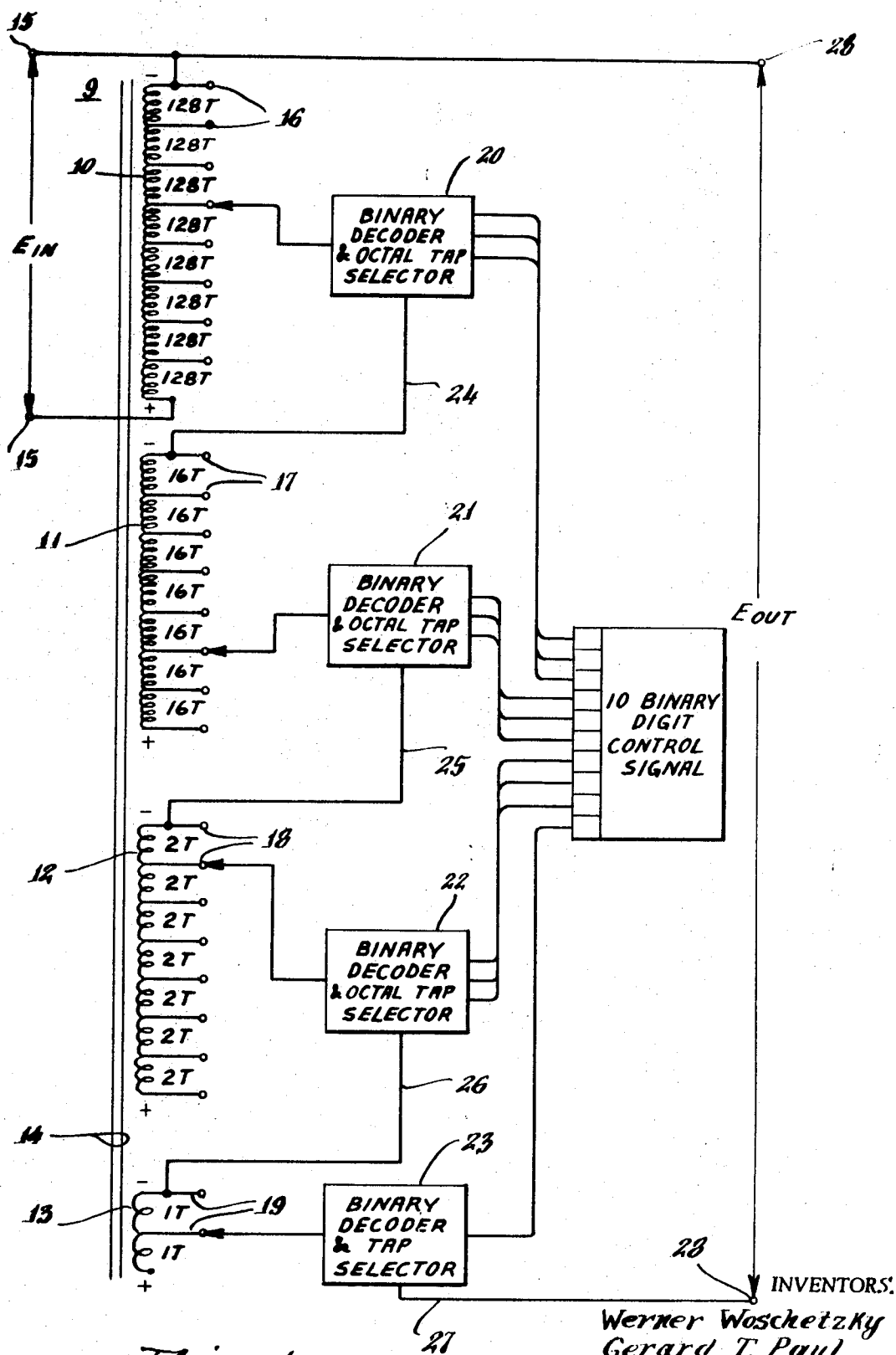


Fig. 1.

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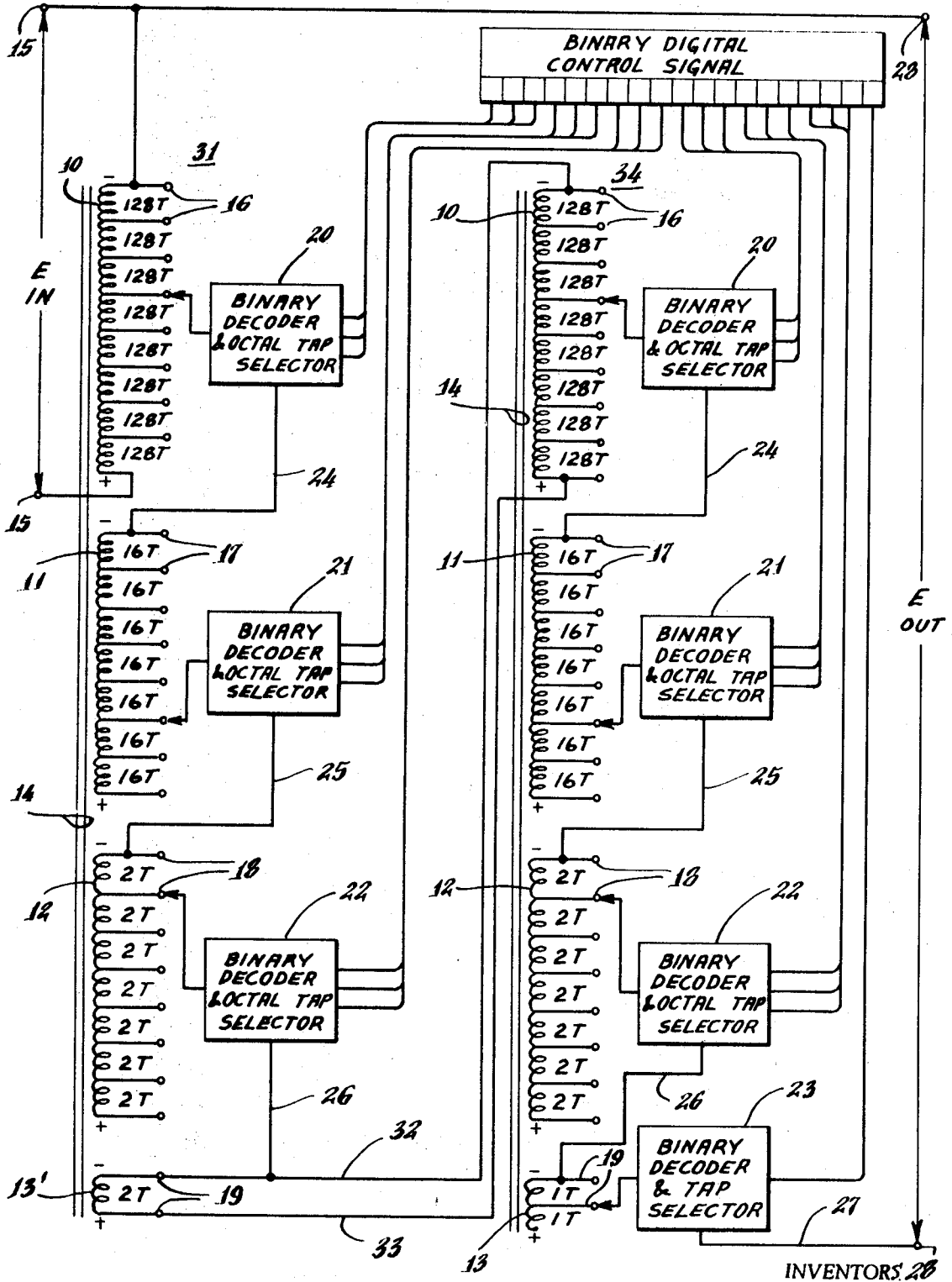


Fig. 2.

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APPARATUS FOR CONVERTING BETWEEN DIGITAL AND ANALOG INFORMATION

This invention relates to an improved digital-to-analog converter which is of reduced size and increased accuracy.

In the data processing field, much of the processing is performed by digital computers and, in order to convert the information produced by these systems into signals which can be used by output devices such as motors, conversion of the data from digital form to analog form must be accomplished. Since digital equipment produces very highly accurate results, the conversion means should produce a similarly accurate analog signal so that a part of the system capability is not wasted.

A particularly convenient method of accomplishing such a result is described in U.S. Pat. No. 3,179,875—Keats, wherein successive transformers are used in correspondence to the successive digits of a number, the outputs of each of the transformers being added electrically so that the result is an analog value corresponding to a digital control applied to the transformer. However, the system disclosed in this patent requires as many independent transformers to accomplish conversion of a multiple-digit number as there are digits in the number and is therefore subject to the disadvantages of large size and weight, and of increased possibility of failure due to the relatively large number of input and output connections to each transformer. Also, this system is subject to error due to the fact that each of the transformer cores used introduces its own loss or error factor.

It is the purpose of the present invention to provide a system which accomplishes a similar conversion from a digital input to an analog value without the attendant disadvantages.

The factors of size and weight are of particular significance in data processing equipment since each individual component, although small in and of itself, may be repeated thousands of times. This is particularly the case in systems designed for use in aircraft and spacecraft where size and weight are critical factors. Similar considerations, of course, apply to the input side of the digital computer where analog-to-digital converters are used.

Accordingly, it is an object of this invention to provide a new and improved device for converting between analog and digital information forms.

Another object of this invention is the provision of a new and improved device for conversion between analog and digital information which is of very high accuracy.

Another object of this invention is the provision of a new and improved device for converting between analog and digital information which is of reduced size and weight.

It is also an object of this invention to provide a converting device which is of simplified design and also of high accuracy.

Briefly, in accord with one embodiment of this invention, we provide means for converting digital information to an analog voltage which includes a transformer having an ordered plurality of windings, all of which are magnetically flux linked and each of which corresponds to a digit of a digital number. Each winding is divided by output taps into a number of equal segments, the number being determined by the base of the digital number. The number of turns in the segments on each winding is determined by the power of the base represented by the digit to which the winding corresponds and by an arbitrary number of turns selected to correspond to the unit value of the digital number. Means are included for supplying an operating potential to one of the windings, preferably that having the largest number of turns. Switching means, adapted to be controlled by digital information in electrical form, are provided for connecting one output tap on each winding to one end of an adjacent winding. Means for providing an output voltage are connected to one end of the driven winding and the last output tap. Preferably, the output is connected to the low voltage end of the driven winding and each tap is connected by the switching means to the low voltage end of the next less significant winding.

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in connection with the appended drawings in which:

FIG. 1 is a schematic representation of a preferred embodiment of this invention; and

FIG. 2 is a schematic representation of an alternative embodiment of this invention.

For clarity of description, the concept of this invention will first be discussed in terms of the base 10 number system. In any given number, each digit actually represents a multiplier of a corresponding power of 10. The last digit on the left of the decimal is a multiplier of 10^0 , the next digit to the left is a multiplier of 10^1 , etc. The present invention is based on the concept of providing a single core transformer having a plurality of windings, one for each digit in the digital number. Each winding has a series of outputs which are spaced in voltage level by an amount corresponding to the power of 10 represented by the associated digit. In other words, such a transformer has a first winding corresponding to the unit digit and this winding has 10 output taps, each one separated by a voltage value which has been selected to be the value for the number "1". Thus, by connecting successively to these taps, the voltages for the digits 0, 1, 2, ... 9 can be obtained. The second winding corresponds to the 10's digit and has 10 output taps separated by segments exactly 10 times as large as each of the segments of the first winding. Successive connection to these taps provides voltage levels corresponding to the digits 00, 10, 20, ... 90. Similarly, a third winding has segments 10 times as large as the segments of the second winding and the voltage values are also a factor of 10 larger. The present invention is further based on the concept of selecting a tap of the first winding of such a transformer according to the digit in the unit's place, selecting a tap on a second such winding according to the digit in the 10's place, etc. The voltages which exist at each of these locations are electrically summed and the output voltage is then the total of the respective multipliers of the unit voltages which have been selected by the digits of the input number.

FIG. 1 represents a specific and preferred embodiment of apparatus in accord with this invention which comprises a transformer 9 including a plurality of individual windings 10-13, each of which are wound on a single magnetic core schematically represented by the magnetic linkage lines 14. A selected input voltage E_{in} from a source (not shown) is applied to terminals 15 which are connected to the ends of winding 10. Due to the magnetic flux linkage provided by the core 14, a voltage is induced in each of the windings 11, 12 and 13. The relative direction of each of the windings is such as to provide the voltage polarities indicated in the figure.

Each of the windings 10-13 is divided into a plurality of equal segments by a series of output taps 16-19 and a selective switching means 20-23 is provided for each of the windings to provide for connection to a selected one of the taps on each of the windings. The output from each switching means is connected by wires 24-26 to one end of the adjacent winding, and, in the case of the last connection 27, to one of the output terminals 28. The other output terminal 28 is connected directly to one of the input terminals 15. It can thus be seen that the output voltage across terminals 28 is the sum of the voltages selected by the position of the respective switching means 20-23.

The first winding 10 is divided into eight equal segments of 128 turns each by eight output taps 16 while the windings 11 and 12 are divided into seven equal segments by eight output taps. These segments of winding 11 have 16 turns each while those of winding 12 have two turns each. An additional winding 13 is also provided which includes two turns and is separated into two segments by two output taps 19. In this embodiment, the unit value of the input signal, 1_{10} , has been selected to be equivalent to that voltage which exists across any two-turn segment. Thus, the output taps of winding 12

provide voltage values corresponding to the multipliers in the units place of the octal number: 0, 1, ... 6, 7; the taps of winding 11 provide voltage increments eight times larger, thus providing voltages for the multipliers in the 10's position: 00, 10, ... 60, 70; and the taps of winding 10 provide voltage increments eight times larger to correspond to the multipliers in the hundreds position: 000, 100, ... 600, 700. The last winding 13 provides for the addition of a voltage increment corresponding to 0.5_8 which is developed across one turn. If needed, a second turn on this winding can be used to add a unit increment so that the maximum output of the entire system can be rounded off from a value of 777_8 to 1000_8 if desired. The winding 10 preferably has a complete set of eight segments so that the full voltage corresponding to 1000_8 is applied across it.

The electrical input signal which is to be converted to an analog output may be in any digital form. In general, most present digital computers and other digital electronic systems produce binary digital information in electrical form. Since a unique correspondence can be defined between the possible values of a set of three binary digits and the values of a single octal digit, conversion between binary and octal number systems is common in computer systems. Accordingly, although any base may be used and any means such as a rotary switch may be provided for selecting one tap on each of the windings, it is preferred that a device such as the integrated circuit module identified as Model 3705 and described as an "MOS Monolithic 8 channel Multiplex Switch," manufactured and sold by the Fairchild Camera and Instrument Corporation, be used as the switching means 20-22. Each of these modules performs the required function of accepting a three-digit binary control signal and connecting one of eight inputs to an output according to the pattern of the control signal. It is, of course, understood that any system for uniquely selecting one of the output taps of each of the windings according to a set of possible digital input numbers could also be used.

In addition to the eight-position switching means associated with each winding 10-12, an additional switching means 23 comprises means for decoding a one-digit binary number and connecting one of the taps 19 to the output.

A binary digital input to the system of this invention thus comprises a 10-digit number wherein the first or most significant group of three digits controls switching means 20, the next group of three digits controls switching means 21, the next group of three controls switching means 22 and the last digit controls switching means 23. In operation, the three groups of three digits are equivalent to the number ABC_8 which is representative of the quantity:

$$A \times 8^2 + B \times 8^1 + C \times 8^0.$$

The first three digits are applied in parallel to switching means 20 and a tap is selected on a winding 10 which corresponds to the value of multiplier A. Since the segments of winding 10 are separated in voltage by values corresponding to 8^2 , the voltage at the output 24 has a value corresponding to the number $A00_8$. Similarly, an output tap on winding 11 is selected which corresponds to the multiplier B. Since the output from winding 10 is connected to the minimum voltage point on winding 11 and since the taps of winding 11 are separated in voltage by values corresponding to multiples of 8^1 , the voltage on output 24 and the voltage level corresponding to multiplier B are added and the voltage level at output 25 corresponds to the number $AB0_8$. In a similar manner, this output is connected to the low voltage end of winding 12 where it is added to the number of 8^0 increments selected by multiplier C. The voltage level at output 26 relative to the low voltage end of winding 10 is now that which corresponds to the number ABC_8 . Finally the switching means 23 and winding 13 are utilized in a similar manner to select either zero or a voltage value corresponding to 0.5_8 , according to the condition of the last digit. Thus the voltage of the final output 27 relative to the low voltage end of winding 10, where terminals 28 are connected, has a total value corresponding to that defined by the digital input signal.

The embodiment of this invention illustrated in FIG. 1 is of particular significance for several reasons. As previously noted, the equipment for binary to octal is readily available and it is customary, in computer technology, to work with octal numbers. Therefore, present systems readily accommodate this device. Furthermore, on the level of practical utilization, manufacturing convenience and space and weight considerations limit the core size which is normally fabricated to one which can accommodate only a limited number of turns. Usually, this number of turns is on the order of 3,000 or less. The total number of turns in the windings illustrated in FIG. 1 is 1152, comfortably within the preferred range. Despite this size limitation, the device is capable of converting octal numbers up to 1000_8 into corresponding analog voltages in increments of 0.5_8 . Another embodiment which would provide the same octal capacity in increments of 0.25_8 is that in which the unit voltage is developed across four turns so that windings 10-13 have, respectively, 256, 32, four and one turns per segment. This would also be within the 3000-turn limit. In some cases, in order to accommodate more turns in particular windings, it is useful to provide a number of segments proportional to the base rather than equal. For example, by adding a most significant winding having four segments in advance of winding 10, or by providing winding 10 with 16 segments, some additional capacity can be obtained without adding an excessive number of turns. Of course, if the additional size can be accommodated, a core which can accept more than 3000 turns is used, since there is no inherent limit on the expansion of the concept of this invention.

A further embodiment of this invention is illustrated in FIG. 2 wherein a longer series of binary digits is to be converted into an analog voltage. In this case, a first transformer 31 is provided which is similar to that described in FIG. 1 except that the last winding 13' is used as a secondary winding. Since this winding has the same number of turns as the segments of winding 12, the voltage induced in this secondary winding is the same as that across each segment of the least significant winding 12. This secondary voltage is then used as the input, via wires 32 and 33, to the most significant winding of a second transformer 34 which corresponds exactly to that shown in FIG. 1. Thus, if the segments of winding 12 correspond to digital increments of $1,000_8$, as may be accomplished, for example, by applying the voltage value for $1,000,000_8$ to winding 10, the second transformer 34 is excited by a voltage value corresponding to $1,000_8$ and the segments of its windings 10, 11 and 12 correspond respectively to voltage increments of 100_8 , 10_8 and 1_8 . Note that the unit of voltage for transformer 34 is two turns but that for transformer 31 it is one five-hundredth of a turn. This difference is not material since each transformer functions independently. As before, an additional winding 13 in transformer 34 may provide for adding an increment of 0.5_8 . In order to prevent error in the tap location on the most significant digits from being greater than this value, it is preferred that means for increasing the resolution, such as the Adjustable Transducer described and claimed in the copending application of L. B. Scott, Ser. No. 677,398, filed Oct. 23, 1967, now U.S. Pat. No. 3,505,591 and assigned to the assignee of this invention, be included.

The digital signal controlling such a system, represented schematically, consists of 19 binary digits which correspond to six octal digits plus the additional bit for adding 0.5_8 . The first three octal digits control the voltages selected in the first transformer 31 while the second three octal digits control the voltages selected in the second transformer. To accomplish summing in the manner previously described, the output wire 26 from transformer 31 is connected to the low voltage side of the most significant winding of the second transformer. Thus, the output taps selected on the second transformer add the voltage increments developed therein to the total level established by the first transformer.

While specific embodiments of this invention have been shown and described, it will be apparent to those skilled in the

art that many changes and modifications may be made without departing from this invention in its broader aspects. For example, the concept of this invention may also be utilized in an analog-to-digital converter by means of null circuits which signify when the output of a transformer of the base of described matches an analog input. Rotation of the successive digits through the possible values until a null signal is obtained thus provides a set of digits corresponding to the analog input.

Also, it is noted that the specific digital and octal systems mentioned are exemplary and not limiting. The concept of this invention may be applied to any digital input of any base. Other variations may include using a number of taps on a winding which is proportional to the base rather than equal, etc. It is therefore intended that the appended claims cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. Apparatus for converting between digital information and analog information comprising:
 - a transformer having an ordered plurality of magnetically flux-linked windings;
 - each of said windings corresponding to a digit of a digital number of a selected base;
 - each of said windings divided by a plurality of output taps into equal segments, the number of said segments being determined by the base of said digital number;
 - the number of turns in a segment on each of said windings being determined by the power of the base represented by the digit to which said winding corresponds and by an arbitrary number of turns selected to correspond to the unit value of said digital number;
 - means for supplying an alternating potential to one of said windings;
 - digitally controlled switching means responsive to a multidigit electrical control signal representative of a number of said selected base for coupling portions of each of said windings in series to provide a sum of the voltages developed in said portions; and
 - means for connecting said sum of voltages to an output.
2. Apparatus as claimed in claim 1, wherein said ordered plurality of windings are wound on a single core of magnetic material.
3. Apparatus as claimed in claim 1 wherein said switching means comprises means for connecting an output tap on each of said windings to the low voltage end of the next less significant winding in said ordered plurality; and
 - wherein said output is taken across an output tap on the last winding of said ordered plurality and the low voltage end of the first winding of said ordered plurality.
4. Apparatus as claimed in claim 1 wherein the number of turns in said segments is equal to the product of said number of turns selected to correspond to the unit value and said base of said digital number raised to the power represented by the digit to which said winding corresponds.
5. Apparatus as claimed in claim 4 wherein the number of output taps on each of said windings is equal to said base of said digital number.
6. Apparatus as claimed one/five-hundredth claim 5 wherein said switching means comprises means associated

with each of said windings controlled by one of a number of input patterns equal to said base for connecting one of said output taps to the next winding in said ordered plurality.

7. Apparatus as claimed in claim 6 wherein said connecting means is controlled by an input of three binary digital numbers.

8. Apparatus as claimed in claim 7 wherein:

said ordered plurality includes at least three windings;

said base of said digital number is eight;

the number of turns selected to correspond to said unit value is greater than one;

said transformer includes an additional winding for adding fractional parts of the unit values to said sum; and

said connecting means for said windings are controlled by an input comprising a plurality of binary digits.

9. Apparatus as claimed in claim 8 wherein said additional winding included in said transformer is magnetically flux-linked to said ordered plurality;

one end of said additional winding being connected to the selected output tap of the last of said ordered plurality of windings;

said additional winding having output taps at its low voltage end and at intervals of one turn from said low voltage end to provide for an additional increment of voltage corresponding to a fraction of the unit value in said output.

10. A system for converting digital information to an analog voltage comprising:

an ordered plurality of transformers;

each of said transformers having an ordered plurality of magnetically flux-linked windings;

each of said windings corresponding to a digit of a digital number of a selected base;

each of said windings divided by a plurality of output taps into equal segments, the number of said segments being determined by the base of said digital number;

the number of turns in a segment on each of said windings being determined by the power of the base represented by the digit to which said winding corresponds and by arbitrary number of turns selected to correspond to the unit value of said digital number;

means for supplying an alternating potential to one of said windings on a first of said transformers;

digitally controlled switching means responsive to a multidigit electrical signal representative of a number of said selected base for coupling portions of each of said windings in series to provide a sum of the voltages developed in said portions;

a secondary winding positioned in each superior transformer in said order for supplying power to each inferior transformer in said ordered plurality;

the selected output tap on the least significant winding on each superior transformer being connected to one end of the most significant winding on each inferior transformer; and

means for providing an output connected to one end of the most significant winding in the first transformer in said ordered plurality and to the selected output tap on the least significant winding of the last transformer in said ordered plurality.