

[54] CORRELATORS USING SHIFT
REGISTERS

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represented by the Secretary of the Navy

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328/37, 333/29
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[58] Field of Search 235/181, 150.4, 177; 333/18,
333/28, 29, 33, 70; 328/37; 340/347 DA

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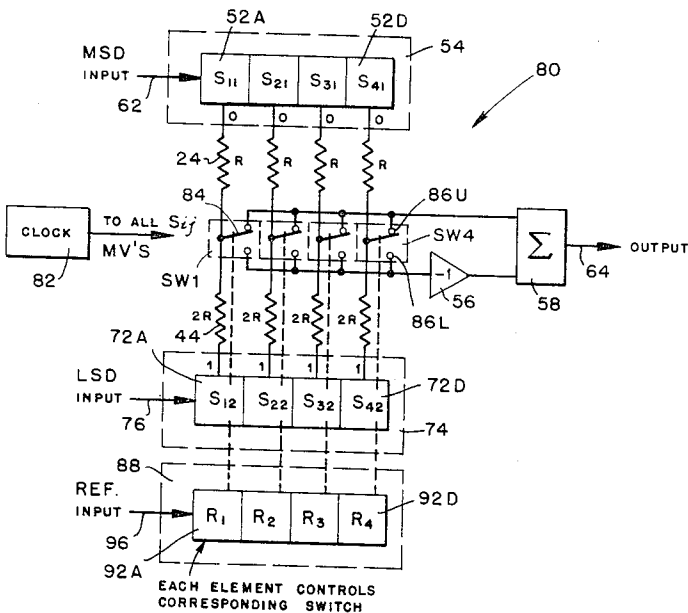
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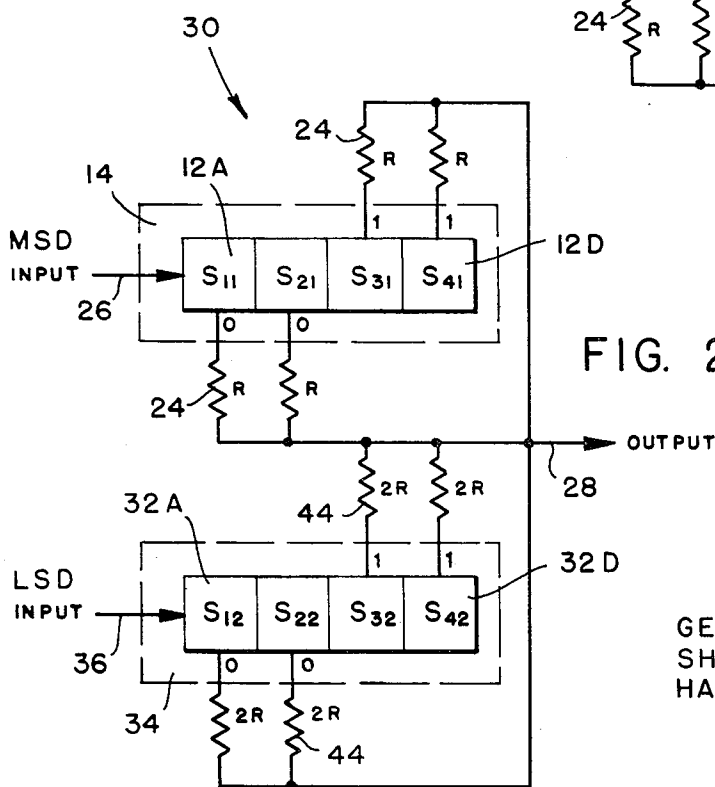
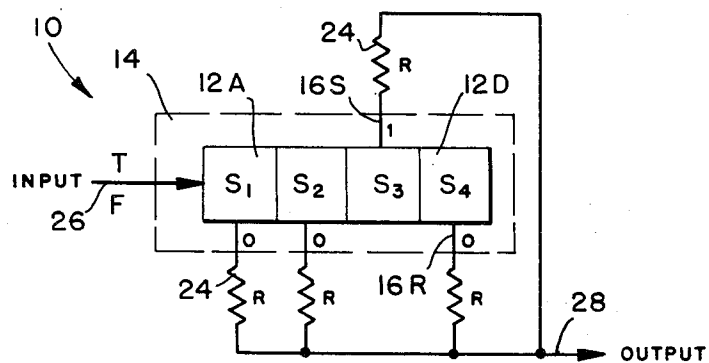
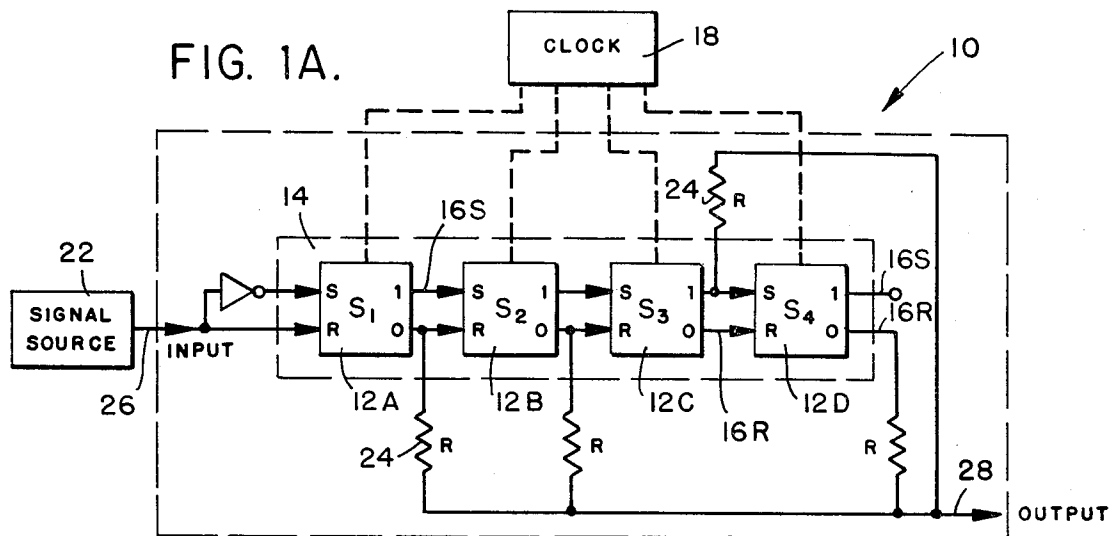
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[57] ABSTRACT

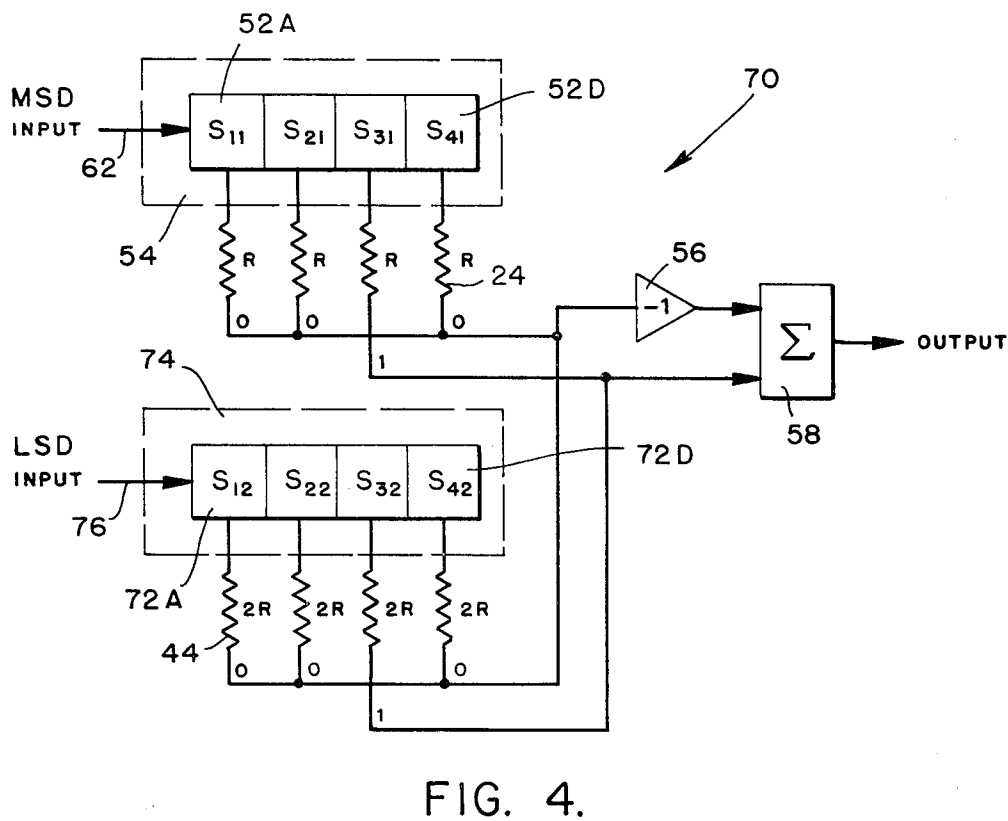
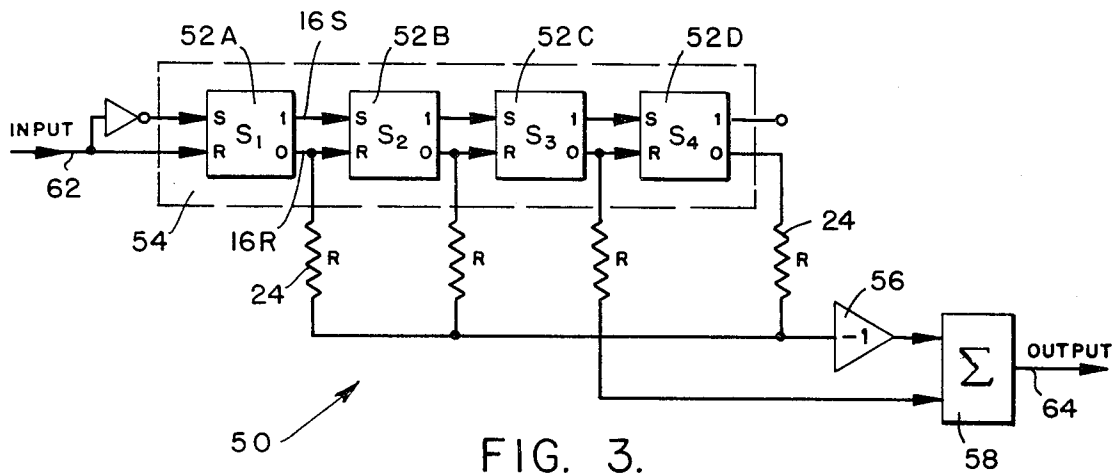
A correlator comprising a set of multivibrators which are seri-
ally connected to form a shift register, each multivibrator hav-
ing a set and a reset output lead, indicating its binary state.
Each multivibrator is connectable to a clocking source for
shifting the states of the multivibrators. One of the multivibra-
tors at one end of the series, the input multivibrator, is con-
nectable to a source of signals, generally bilevel signals or pul-
ses, each pulse having a predetermined time duration or a
multiple thereof. Means are operatively connected to the out-
put leads of the multivibrators for summing the outputs of the
multivibrators for each shift of binary states, the sum being a
maximum for a particular combination, or coding, of binary
states of the multivibrators of the shift register. The means
may comprise a plurality of output resistors, one for each mul-
tivibrator, each resistor having one end, the input end, con-
nected to one only of a set or reset output lead of a multivibra-
tor, the specific combination of connections being chosen in a
manner so that, with an applied input signal, a particular com-
bination of binary states of the multivibrators will result in a
maximum total output signal.

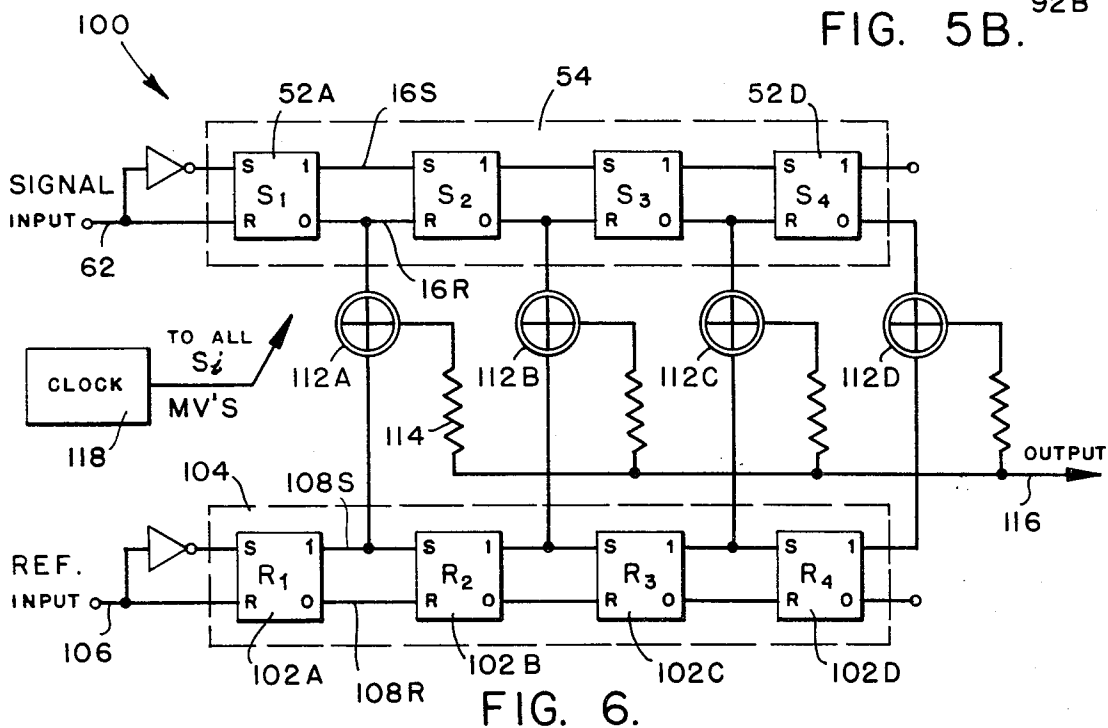
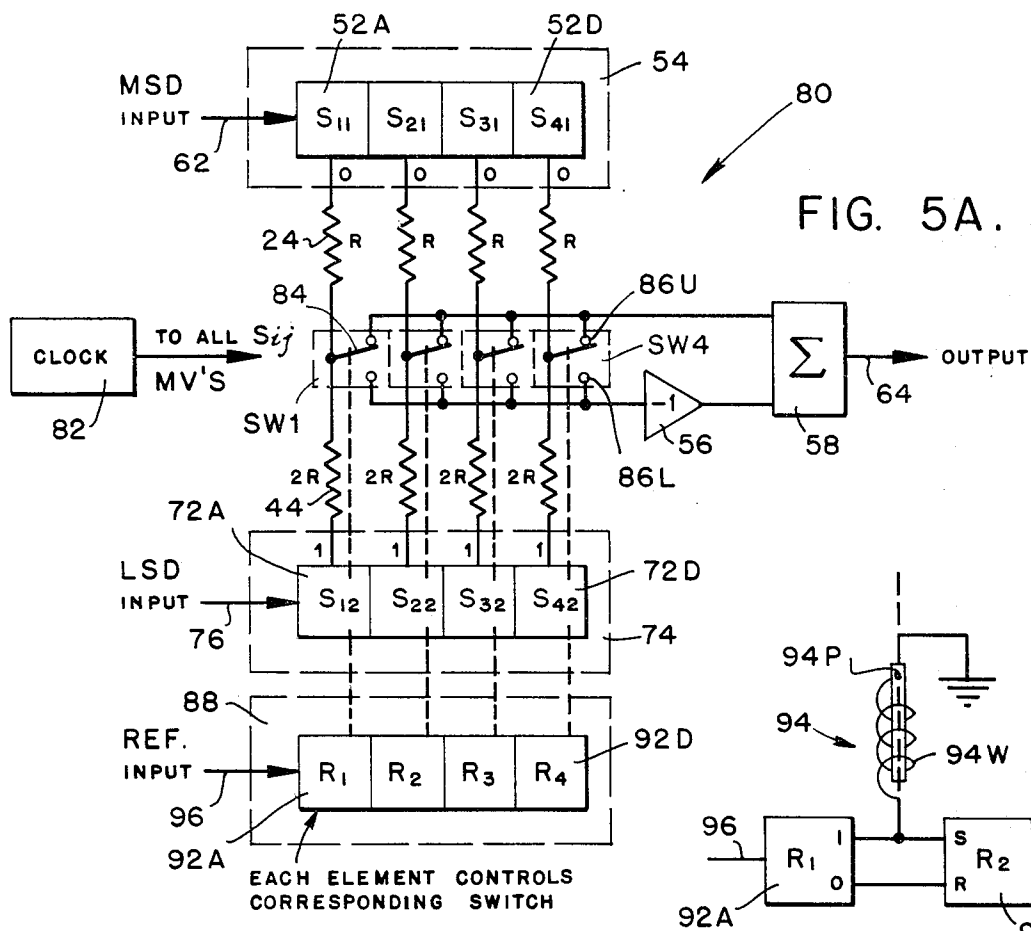
7 Claims, 10 Drawing Figures





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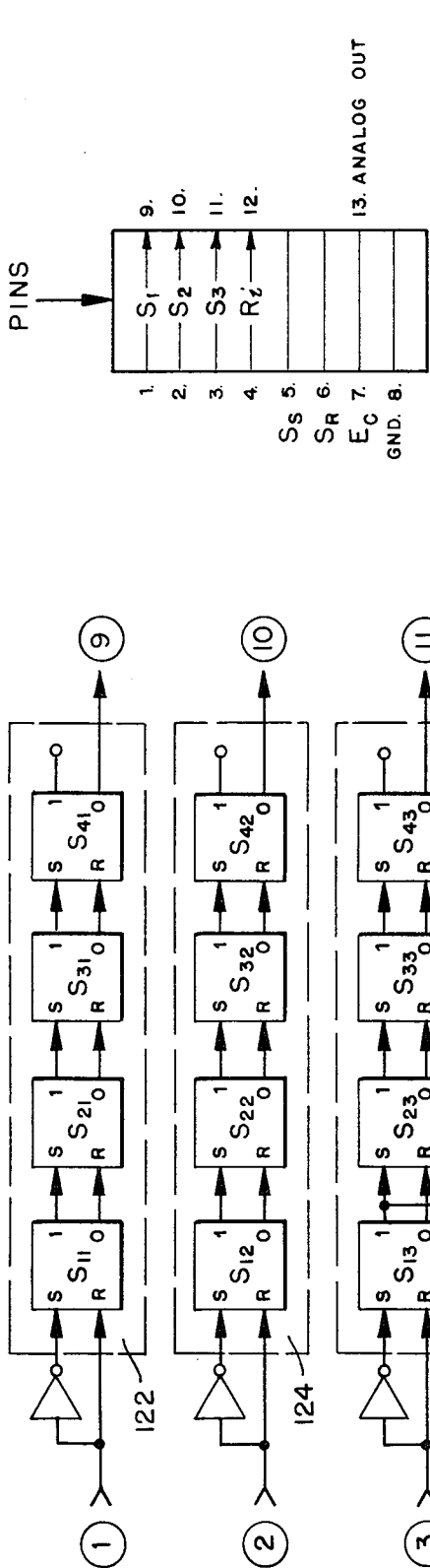


FIG. 7B.

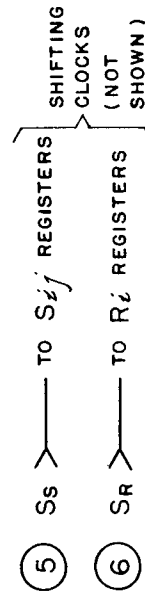
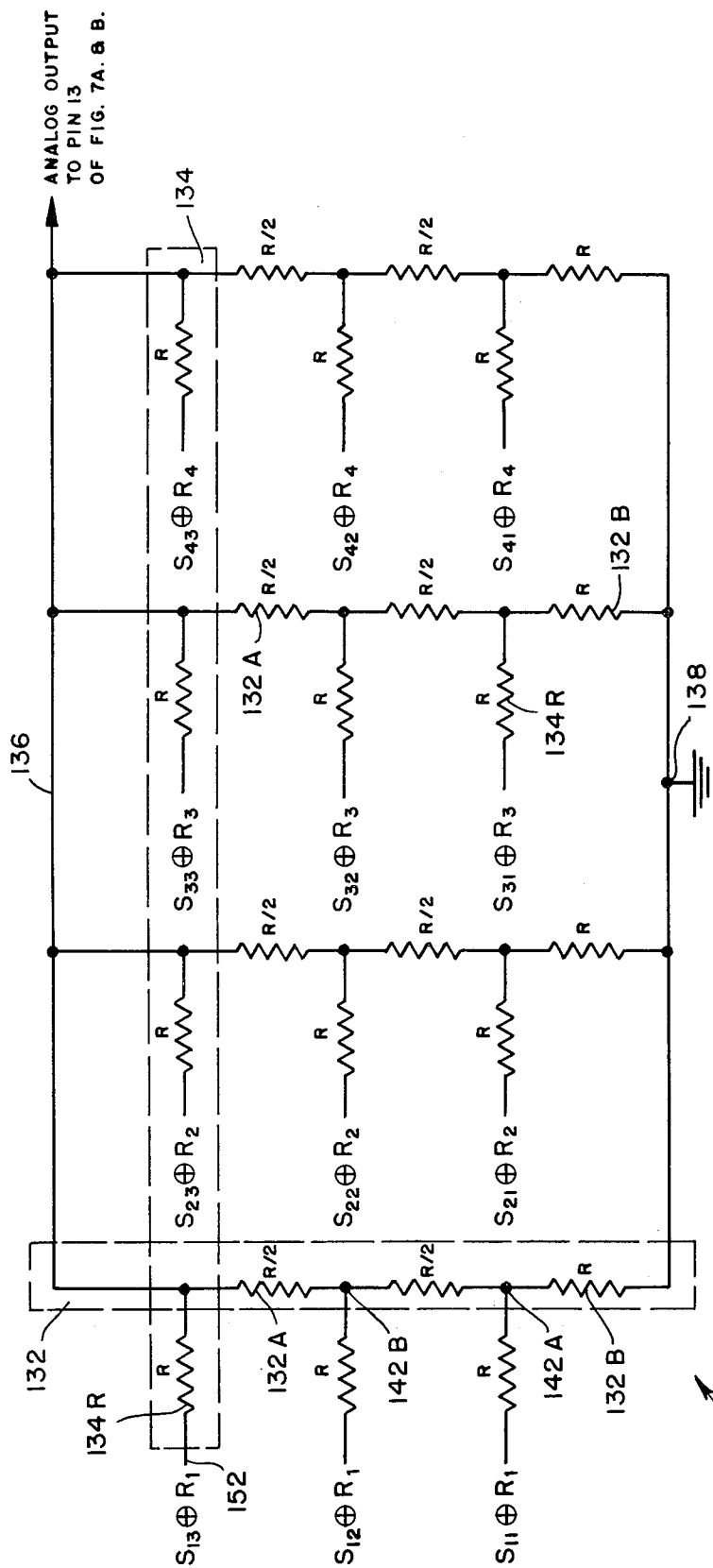


FIG. 7A.

NOTE: PART 120B OF CORRELATOR 120 IS SHOWN IN FIG. 8.



120 B
(PART OF 120)

$$S_{ij} \oplus R_i = S_{ij} \bar{R}_i + \bar{S}_{ij} R_i, 1 \leq i \leq I, 1 \leq j \leq J = A \text{ LOGICAL EXPRESSION}$$

THE TERMS $S_{ij} \oplus R_j$ SHOULD BE VOLTAGE SOURCES RELATIVE TO THE RESISTANCES R .

NOTE: PART 120A OF CORRELATOR 120 IS SHOWN IN FIG. 7A.

FIG. 8.

CORRELATORS USING SHIFT REGISTERS

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to correlators of various types utilizing shift registers as an essential element. The term "correlator" as used herein includes auto-correlators, cross-correlators, convolvers, and matched filters. Some of the embodiments utilize only one shift register, whereas other embodiments utilize two or more shift registers, each having the same number of multivibrators.

In the prior art, there are various types of correlators. Some use multiple filter sections, utilizing discrete filter elements. Recently developed matched filters utilize uniformly spaced magnetic interaction stations wherein tiny magnets are polarized, either electrically or permanently, in one of two opposite directions.

SUMMARY OF THE INVENTION

This invention relates to correlator-type devices in which at least one shift register is a key element. The multivibrators comprising the shift registers have accessible set or reset output leads, across which one of two output voltage levels may be developed and sensed. Where output resistors are used, the output voltages develop output currents across the output resistors, which currents may be summed. Where two shift-registers are used, the individual output voltages may be fed into modulo-two adders. The manner of connection of the resistors or modulo-two adders to the set and reset leads may be said to define a coding. If a sequence of pulses be made to traverse the multivibrators of the shift register, then for some unique combination of binary states of the multivibrators, a maximum output is obtainable. In order to clarify the meaning of the term "correlator" as used herein, it is intended to refer to a device which correlates one set of something, generally a stream of incoming pulses, with another set of something else, generally, a set of multivibrators, arranged or coded in a predetermined manner so as to match a particular sequence of pulses.

In some of the embodiments, the output resistors are connected to both the set and the reset leads of the multivibrators of the shift registers, while in other embodiments, the output resistors are connected to all set or all reset output leads. The fact that a choice of connections is available makes this type of correlator particularly adaptable to integrated circuitry, where for reasons of symmetry or otherwise the choice of connections may be restricted.

STATEMENT OF THE OBJECTS OF THE INVENTION

An object of the present invention is the provision of correlators whose primary elements are shift registers.

Another object is to provide a correlator structure utilizing any number of parallel shift registers, one for the most significant digit, another shift register for the least significant digit, and other shift registers for handling significant digits intermediate in value to these two.

Still another object is the provision of a correlator structure adaptable for implementation by integrated circuitry.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention, when considered in conjunction with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a detailed and FIG. 1B a simplified block diagram of a correlator involving one shift register with multivibrators wherein there are connections to both set and reset output leads.

FIG. 2 is a block diagram of a correlator comprising two shift registers, with the output resistors of one of the shift registers being a weighted multiple of the other, in this instance the weighting being by a factor of 2.

FIG. 3 is a block diagram of a simple correlator including one shift register, wherein the connections to the multivibrators are made only to reset leads of the shift register.

FIG. 4 is a block diagram of correlator using two shift registers, similar to the correlator shown in FIG. 2, except that all of the connections are made to the reset leads only of the multivibrators of both shift registers.

FIG. 5, comprising parts A and B, is a block diagram of a correlator utilizing two signal shift registers, comprising pairs of multivibrators, the outputs of each pair of which is controlled by a reference shift register.

FIG. 6 is a block diagram of a correlator using two shift registers having multivibrators whose outputs are summed by multivibrator pairs in modulo-two adders, the outputs of all adders being summed together.

FIG. 7 comprising parts A and B, and FIG. 8 in combination are block diagrams of a correlator having a plurality of signal shift registers and one reference shift register, the outputs of whose multivibrators, one signal multivibrator and one reference multivibrator at a time, are added in a modulo-two fashion to resistors of a multiple ladder network.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings, wherein like reference numerals designate like or corresponding parts throughout the several views, there is shown in FIG. 1 a correlator 10 comprising a set of multivibrators 12A through 12D which are serially connected to form a shift register 14. Each multivibrator 12A-12D has a set 16S and a reset 16R output lead, indicating its binary state, as shown by the 1 or 0 or the S and R alongside the set or reset lead, respectively.

To simplify FIG. 1B, only the set or reset leads actually used are shown in this figure, and they are shown connected to the middle of the MV's for clarity. The "S" in the multivibrator (MV) blocks designates that it is a signal MV, in contrast to MV's designated with an "R" for a reference MV, as shown in some of the later figures.

Each multivibrator 12A-12D is connectable to a clocking source or clock 18, for shifting the states of the multivibrators. One of the multivibrators at one end of the series, the input multivibrator, 12A is connectable to a source of signals 22, generally bilevel signals or pulses, each pulse having a predetermined time duration, related to the frequency of the clock 18, or a multiple thereof.

Means are operatively connected to the output leads 16S and 16R of the multivibrators 12A-12D for summing the outputs of the multivibrators for each shift of binary states, the sum being a maximum for a particular combination of binary states for the multivibrators of the shift register 14.

Speaking now in general terms of the inputs to and the outputs from the various correlators disclosed herein, there is an arbitrary stream of data coming into the input multivibrator, or input multivibrators if more than one. When the data stream matches the coding of the connections of the shift register, a large output is obtained. In effect, a cross-correlation is obtained between the coding of the structure and the data stream.

Generally, the type of output one is seeking is known in advance. It is also known in advance what the states of the multivibrators of the shift register must be in order to obtain a desired output.

In FIG. 1, the means comprises a plurality of output resistors 24, one for each multivibrator 12A-12D, each resistor having a resistance R and having one end, the input end, connected to one only of a set 16S or reset output lead 16R of a multivibrator, the specific combination of the connections of the resistors being chosen in a manner so that, with an applied input signal at lead 26, a particular combination of binary states of the multivibrators will result in a maximum total out-

put signal. The other ends, the output ends, of the output resistors 24 are connected together to form a common output lead 28.

The various configurations of this disclosure may also be used as matched filters. For example, if a single positive pulse be fed into the input 26 of FIG. 1, the output in time at output lead 28 would consist of two lower level signals, a high level signal, and then another lower level signal.

If a negative pulse be applied at the input 26, the output pulses would comprise, in the following time order, two high level signals, a low level signal and then another high level signal.

In FIG. 2 is shown a correlator 30, further comprising a second set of multivibrators 32A-32D, serially connected to form second shift register 34 substantially identical to the first-named set 12A-12D, the input multivibrator 32A of the set being adapted to be connected to an input signal at lead 36 independent of the first-named input signal 16.

A plurality of output resistors 44 is connected to the second shift register 34, one for each multivibrator of the second set of multivibrators 32A-32D. Each resistor 44 has its input end connected to a set or reset output lead (not shown) of a multivibrator of the second shift register 34, according to the combination of binary states of the multivibrators of the second shift register for which a maximum output signal may be obtained. Each of the resistors 44 of the second plurality of output resistors has a value of resistance 2R which is a multiple of the resistors of the first-named plurality of resistors 24.

The correlator 30 shown in FIG. 2 is adaptable for receiving a multilevel input signal, actually a two-level, input signal at leads 26 and 36, with fixed multilevel reference units, shift registers 14 and 34. Since the least significant digit (LSD), in the case of a two-level digital signal, has one-half the weight or significance of the most significant digit (MSD), the output resistors 44 for the LSD's have twice the resistance 2R of the resistors 24 in the output stages of the most significant digits, in order to contribute only one-half the current across them. It will be noted that the resistor configuration of FIG. 2 for shift register 14 is different from that for the same shift register shown in FIG. 1.

If the multilevel signal were a three level signal, the resistors in the LSD's would have a value of 4R compared to the value of 1R in the output resistors of the MSD's, while the resistors for the intermediate significant digits would each have a value of 2R.

The output leads of the first-named and second plurality of resistors 24 and 44 are connected together, with the result that independent pulses applied to the inputs 26 and 36 of each of the two sets of multivibrators 12A-12D and 32A-32D appear in the summed output signal at lead 28 with a desired relative weighting.

Whereas a clocking source is not shown in FIG. 2 and some of the other figures, it will be understood, of course, that in actual operation the various embodiments would have to be hooked up to a clocking source for properly shifting the binary states of the multivibrators.

Of course the correlator shown in FIG. 2 need not be limited to only two shift registers 14 and 34 with signal inputs 16 and 36 representing two significant digits, or even three shift registers. A correlator may readily be implemented comprising an additional N-2 number of sets of multivibrators, where N is a positive integer greater than 2, substantially identical to the first-named and the second set of multivibrators 12A-12D and 32A-32D of FIG. 2, an input multivibrator of each of which is adapted to be connected to an input signal independent of the input signal to the input multivibrator of any other set of multivibrators.

The additional N-2 shift registers have an N-2 number of pluralities of output resistors, one plurality for each set of multivibrators, with one resistor for each multivibrator. The resistance of each resistor of each of the N pluralities of resistors has a value of $2^n R$, where n has a range from 1 to N. Each resistor has its input end connected to a set or reset output lead of a multivibrator of its set, according to the combination of

binary states of the multivibrators of the additional N-2 shift registers for which it is desired that a maximum output signal be obtained for each of the N shift registers. The output leads of each of the resistors of the N pluralities of resistors are connected together, with the result that independent pulses applied to the input of each of the N sets of multivibrators appear in the output with a desired relative weighting.

In FIG. 3 is shown a correlator 50 wherein all of the input ends of the output resistors 24 are connected to only one of the set 16S or the reset 16R output leads of the multivibrators 52A-52D forming a shift register 54. In the embodiment shown, the connections are to the reset output leads 16R only. An inverter 56 has its input connected to the output end of those resistors 24 which are connected to multivibrators 52A, 52B and 52D. A summing circuit 58 has one of its inputs connected to the output of the inverter 56 and its other input connected to the output ends of those resistors 24 not connected to the input of the inverter, namely, the resistor connected to the reset lead 16R of multivibrator 52C.

The choice of whether the output ends of the resistors 24 are connected directly to the inverter 56 or to the summer 58 is dependent upon the specific combination of binary states of the multivibrators 52A-52D for which, with an applied input signal at lead 62, it is desired to get a maximum output signal at the output 64 of the summer.

A clock source is not shown in FIG. 3, but may be part of the embodiment 50.

FIG. 4 shows an embodiment of a correlator 70 similar to that shown in FIG. 3, but further comprising a second set of multivibrators 72A-72D, forming a shift register 74, substantially identical to the first-named set of multivibrators 52A-52D. An input multivibrator 72A at one end of the series is adapted to be connected to an input signal at lead 76, independent of the first-named input signal to lead 62. A second plurality of output resistors 44 includes one resistor, having a value of 2R, for each multivibrator 72A-72D of the second set, all of the input ends of the resistors of the second plurality being connected to only the set or only the reset output leads of each of the second set of multivibrators. In the embodiment 70 shown in FIG. 4, connections to the reset leads only are made. The inverter 56 may be connected to the output end of one or more resistors 44 of the second plurality of resistors, in this figure, those resistors connected to multivibrators 72A and 72C. The summing circuit 58 is connected directly to the output ends of those output resistors 44 of the second set of multivibrators 72B and 72D which are not connected to the input of inverter 56.

With respect to both FIGS. 2 and 4, the stream of bits entering the MSD shift register 14 or 54 has relationship to the stream of bits entering the LSD shift register 34 or 74. They are related by being the result of digitizing an original input signal, not shown. Both the MSD shift registers 14 and 54 and the LSD shift registers 34 and 74 are correlators in that they correlate the streams of incoming bits at the inputs 26, 36, 62 and 76 of the shift registers with the fixed pattern of the connections of the output resistors 24 and 44 connected to the shift registers.

FIGS. 5A and 5B in combination show a correlator 80 comprising two sets of multivibrators 52A-52D and 72A-72D, each of which are serially connected to form a shift register 54 and 74, each set having the same number of multivibrators. In general, each multivibrator of the two sets has a set and reset output lead, indicating its binary state. However, in the embodiment shown in FIG. 5A, only the reset connections indicated by the 0's at the input ends of the resistors 24 are connected to the multivibrators 52A-52D, and only the set connections indicated by the 1's at the input ends of the resistors 44 are connected to the multivibrators 72A-72D are shown. Each multivibrator of both sets 52A-52D and 72A-72D is adapted for connection to a clocking source 82 for shifting the states of the multivibrators. One of the multivibrators 52A and 72A at one end of the series of each of the two sets is connectable to a source of signals at input leads 62 and 76,

generally bilevel signals or pulses, having a predetermined time duration or a multiple thereof.

As in FIGS. 2 and 4, where two shift registers are involved, the correlator 80 in FIG. 5A utilizes two pluralities of resistors, one plurality for each set of the multivibrators, 52A-52D and 72A-72D, with one resistor, 24 or 44, having a value of R or 2R, for each multivibrator. Each resistor may be connected by its input end to a set or a reset output lead of a multivibrator of its own set, and by the output end to the output end of a resistor connected to an output set or reset lead of a corresponding multivibrator of the other set. In FIG. 5A, all of the resistors 24 belonging to the multivibrator set 52A-52D are connected to reset leads only, and all of the resistors 44 belonging to the multivibrator set 72A-72D are connected to set leads only. However, the connections of the resistors to set and reset leads could be interspersed, if desirable. The binary states that the multivibrators would have to assume to result in a maximum output signal at output lead 64 would also be changed.

The correlator 80 shown in FIG. 5A further comprises a set of single-pole double-throw switches SW1 through SW4, one switch for each pair of multivibrators from corresponding multivibrator sets, 52A-52D and 72A-72D. Each of the switch arms 84 is connected to the point joining two resistors 24 and 44 connected to corresponding multivibrators, 52A and 72A, for example. Corresponding contact points 86U (U for upper) and 86L, of each of the switches are connected together to form two sets of common contact points.

An inverter 56 has its input connected to one of the sets, the lower set, of common contact points 86L. A summing circuit 58 has two inputs, one input being connected to the other set of common contact points 86U, the other input being connected to the output of the inverter 56, for summing the currents developed across all of the resistors 24 and 44. A control means, for example electronic or electrical, may control the polarity, or setting, of the individual switch arms 84, so that, with input signals at input leads 62 and 76 at the input multivibrators 52A and 72A, a maximum sum signal 64 is obtainable at the output of the summer 58 when the settings of the switch arms matches a particular combination of binary states of both sets of multivibrators 52A-52D and 72A-72D, which combination may, of course, be determined.

In general, the resistance of each of the resistors of one plurality of resistors 44 connected to one of the sets of multivibrators 72A-72D has a weighted value with respect to the resistance of the other set of resistors 24. In the specific embodiment shown in FIG. 5A, the resistance 2R of each of the resistors 44 of one set is twice the resistance R of the resistors 24 of the other set.

In the correlator 80, the control means for controlling the position of the switch arms 84 comprises a control shift register 88, which may also be termed a reference shift register, having the same number of multivibrators 92A through 92D as there are switches SW1-SW4, and adapted for receiving a bilevel input signal. Each multivibrator 92A-92D has a set or reset output lead, at which a voltage at one of two voltage levels is available. As shown in FIG. 5B, only the set leads, labeled 1, are available for connection for this embodiment 80.

In FIG. 5A, the signals from corresponding multivibrators are summed together, since the two output resistors 24 and 44 from the multivibrators 52A-52D and 72A-72D are connected together at a switch arm 84. The corresponding multivibrator from the reference shift register then determines, since it controls the switch arm 84, whether this summed signal goes into the summer 56 inverted or uninverted.

The control means in the embodiment shown in FIG. 5A also includes a set of relays 94 of the same number as the number of switches SW1-SW4. One relay 94 is shown diagrammatically in FIG. 5B. The control winding 94W of each relay 94 is connected to a set output lead of a multivibrator 92A-92D of the control shift register 88, one of the voltage levels at the set output lead causing the switch arm 84 to be at

one of its two positions, the other voltage level causing the switch arm to be as its other position. The plunger 94P of each relay thereby controls the motion of the switch arm 84, with the result that the position of the switch arm of each switch SW1-SW4 is determined by the binary state of the multivibrator 92A-92D to whose set lead it is connected. It will be seen that each switch SW1-SW4 simultaneously senses the output of two corresponding multivibrators. For example, if the switch arm 84 of switch SW-1 makes contact with the lower switch contact 86L, then the output signals from both upper multivibrator 52A and lower multivibrator 72A enter the inverter 56, to be inverted when entering the summer 58.

In the usual application of the correlator 80, the control register has been set, by a signal to its input 96, to one of the two binary states.

If it be desired that additional significant digits are required, it may readily be seen that any number of additional signal shift registers may be added to the embodiment shown in FIG. 5, with the corresponding multivibrators connected, through output resistors having appropriate values of resistance, to corresponding switch arms. The reference register 88 would then cause each of the summed currents at the switch arm 84 to enter the summer 58 either inverted through inverter 56 or uninverted.

Instead of relays, analog solid state switches may be used.

FIG. 6 is a block diagram of another type of correlator 100, which, in addition to a signal shift register 54, comprising the set of multivibrators 52A to 52D, further comprises a second set of multivibrators 102A-102D, substantially identical to the first-named set, forming a reference shift register 104, and connectable to an independent source of signals at input lead 106. In general, the multivibrators 102A-102D of the reference shift register 104 would have available a set or a reset output lead 108S or 108R, but in FIG. 6, only the set output leads 108 are used.

In the embodiment 100 shown in FIG. 6, the totaling means comprises a set of modulo-two adders 112A-112D whose two inputs are the voltages available at the output leads of corresponding multivibrators, for example 52A and 102A. A set of output resistors 114 is connected at the output of the modulo-two adders 112A-112D, across which output current may be developed, the other end of each resistor being connected to a common output lead 116, so that when each set of multivibrators is connected to an input signal at leads 62 and 106, a maximum output may be determined when the binary states of the multivibrators 52A-52D of one set matches the binary states of the corresponding multivibrators 102A-102D of the other set. The correlator 100 may further comprise a clock 118 for shifting the states of the signal multivibrators 52A-52D.

The embodiment 100 shown in FIG. 6 differs in one important respect from the configurations 10 and 50 shown in FIGS. 1 and 3, in that in FIGS. 1 and 3 the reference configurations of the resistors 24 are fixed and cannot be changed except by rewiring them to form a new reference against which the incoming stream of bilevel signals at input multivibrators 12A and 52A is compared.

In the usual mode of operation of the correlator 100 shown in FIG. 6, the binary states of the multivibrators 102A-102D of the reference shift register 104 would remain fixed after the input signal at input lead 106 to the reference register has switched all its multivibrators to the chosen binary states, and do not shift with subsequent clocking pulses generated by the clock 118. The incoming reference signal at lead 106 is terminated, and all shifting of the reference multivibrators 102A-102D ceases until a new form of reference is desired, at which time a new sequence of bits is stored in the reference shift register 104. Of course, the clock 118 would continue to cause the multivibrators 52A-52D to continue shifting with each clock pulse.

However, the embodiment 100 shown in FIG. 6 may also be used in a manner in which there are incoming streams at the inputs 62 and 106 of both shift registers, the signal shift re-

gister 54 and the reference shift register 104. The output signal at lead 116 gives an indication of the number of matches of the bits in corresponding multivibrators 52A-52D and 102A-102D of each shift register 54 and 104.

Moreover, the modulo-two adders 112A-112D need not be connected as shown. For example, the modulo-two adders 112A-112D could be connected to the set output leads 16S of the multivibrators 52A-52D of the signal shift register 54, and the reset leads 108R of the multivibrators 102A-102D of the reference shift register 104. The binary states of the multivibrators 102A-102D of reference shift register 104 would remain as before to give the same output signal from the modulo-two adders 112A-112D.

Furthermore, all connections to the inputs of the modulo-two adders 112A-112D could be to the set output leads 16S and 108S only of the multivibrators 52A-52D and 104A-104D, or to the reset output leads 16R and 108R only, in which case the multivibrators 102A-102D of the reference shift register 104 would have to be set to the opposite binary states from that required in the embodiment shown in FIG. 6, to obtain the same output signal at lead 116.

Since the output of a modulo-two adder is the same whether both inputs to it are high-level signals or low-level signals, as long as both inputs to a modulo-two adder are connected to like output leads from the signal and reference shift registers, 54 and 104, the configuration would be similar to one where the input leads of the modulo-two adders are connected to multivibrator output leads of one kind only.

The fact that the modulo-two adders may be connected in various ways to detect the same binary combination of states may be of great importance when using chips or integrated circuitry, since the geometry of the chip may be such that only a certain one of the inter-connections is feasible or possible.

FIGS. 7A and 7B in combination are block diagrams of a correlator 120 comprising a plurality of shift registers 120A, shown in FIG. 7A, and a compound ladder network 120B, shown in FIG. 8. Interconnecting the circuitry shown in these two FIGS. 7 and 8 are logical circuitry in the form of modulo-two adders, defined by the logical expression shown in FIG. 8. One modulo-two adder 150 is shown in FIG. 7A in detail.

In more detail, FIG. 7A is a block diagram showing part of a correlator 120A comprising in the general case, a J number of rows of signal shift registers 122, 124 and 126, J being equal to 3 in this figure, each row containing an I number of serially connected multivibrators, I being equal to 4 in this figure, all the shift registers being arranged in I columns. Each multivibrator, labeled S_{ij} , has a set and reset output lead, at one of which appears one bilevel voltage, and at the other of which appears the other bilevel voltage, the voltages indicating the binary state of the respective multivibrator.

The plurality of shift registers 120A further comprises a reference shift register 128 substantially identical to one of the signal shift registers, 122-126, whose multivibrators are designated R_i . Each multivibrator of every shift register 122-128 is connectable to a clocking source, not shown, for shifting the states of the multivibrators. One of the multivibrators S_{11} , S_{12} , S_{13} and R_1 at one end of the series of each shift register 122-128 is connectable to a source of bilevel signals, or pulses, each pulse having a predetermined time duration or multiple thereof.

FIG. 8 is a block diagram of the other half of correlator 120, namely, a compound ladder arrangement 120B of resistors comprising, in the general case, an I number of columns of resistors, of which one column 132 is shown dotted, and a J number of rows of resistors, one row 134 of which is shown, also dotted. The columns of resistors are connected to common junction points or buses, 136 and 138, at both ends of the columns 132, one junction point 138 being a common ground point.

In the general case, each of the I columns 132 of resistors would consist of a series connection of J-1 resistors 132A having a value of R/2 ohms, and one resistor 132B at the common ground point end 138 having a value of R ohms. Each of the J

rows 134 of resistors 134R include I resistors, one for each column 132, each of the I×J (a number equal to the product of the number of columns 132 by the number of rows 134) row resistors having a value of R ohms, one end of one row resistor from all but one of the J rows being connected at a junction 142A or 142B of two columnar resistors, one end of each of the other row resistors from the other row being connected to the other, ungrounded junction point 136 of the columnar resistors.

Referring back to FIG. 7A, the correlator 120, in the general case, further comprises an I×J number of modulo-two adders 150, one of which is shown, whose inputs are the set or reset output leads of the signal and reference shift registers 122-128 as determined from the logical expression:

$$S_{ij} \oplus R_i = S_{ij}\bar{R}_i + \bar{S}_{ij}R_i, 1 \leq i \leq I, 1 \leq j \leq J$$

In this expression, the unbarred terms relate to the voltage level of the bilevel signal at, say, a set output lead, the barred terms relate to the negative of the voltage level of the bilevel signal at the set output lead, S_{ij} relates to the specific multivibrator of the signal shift registers 122-126 in the i th column and j th row, and R_i relates to the i th multivibrator of the reference shift register 128.

It is to be understood that instead of connecting the modulo-two adders 150 to the set leads as shown in FIG. 7A, they could be connected to the reset leads only, or even intermixed if inverters are interposed at the proper places.

In FIG. 7A, in the lower left-hand corner the modulo-two addition of, as an example, $S_{13} \oplus R_1$, is shown. By substituting $i = 1$ and $j = 3$ into the equation given in FIG. 8, and hereinabove, the logical expression becomes

$$S_{13} \oplus R_1 = S_{13}\bar{R}_1 + \bar{S}_{13}R_1$$

In order to define the terms of this equation for the specific case given, reference is directed to FIG. 7A, using connections to set leads only. The modulo-two addition of S_{13} and R_1 shows that the "1" or set output lead of the multivibrator labelled S_{13} is connected to the set output lead of the R_1 multivibrator. The modulo-two sum is obtained at output lead 152, shown in both FIGS. 7A and 8.

What is claimed is:

1. A correlator comprising:

- two sets of multivibrators, each of which are serially connected to form a shift register, each set having the same number of multivibrators;
- each multivibrator of the two sets having a set and a reset output lead, indicating its binary state;
- one of the multivibrators at one end of the series of each of the two sets being connectable to a source of signals, generally a stream of bilevel signals or pulses, having a predetermined time duration or a multiple thereof;
- each multivibrator of both sets being connectable to a clocking source for shifting the states of the multivibrators in synchronism with the streams of pulses;
- two pluralities of resistors, one plurality for each set of the multivibrators;
- one resistor for each multivibrator;
- each resistor being connected by its input end to a set or reset output lead of a multivibrator of its own set, and by the output end to the output end of a resistor which is connected to an output set or reset lead of a corresponding multivibrator of the other set;
- a set of single-pole double-throw switches, one switch for each pair of multivibrators from corresponding multivibrator sets;
- each of whose switch arms are connected to the point joining two resistors connected to corresponding multivibrators;
- corresponding contact points of each of the switches being connected together to form two sets of common contact points;
- an inverter whose input is connected to one of the sets of common contact points;

a summing circuit, having two inputs, one input being connected to the other set of common contact points, the other input being connected to the output of the inverter, for summing the currents developed across all of the resistors;

control means for controlling the polarity, or setting, of the individual switch arms, so that, with input signals at the input multivibrators, a maximum sum signal may be obtained at the output of the summer when the settings of the switch arms matches a particular combination of binary states of both sets of multivibrators.

2. A correlator according to claim 1, wherein the resistance of each of the resistors of one plurality of resistors connected to one of the sets of multivibrators has a weighted value with respect to the resistance of the other set of resistors.

3. A correlator according to claim 2, wherein the resistance of each of the resistors of one set is twice the resistance of the resistors of the other set.

4. A correlator according to claim 3, wherein the control means for controlling the position of the switch arms comprises:

a control shift register, having the same number of multivibrators as there are switches, and adapted for receiving a bilevel input signal;

each multivibrator having a set or reset output lead, at which a voltage at one of two voltage levels is available;

a set of relays of the same number as the number of switches;

the control winding of each relay being connected to a set or reset output lead of a multivibrator of the control shift register, one of the voltage levels at the set or reset output leads causing the switch arm to be at one of its two positions, the other voltage level causing the switch arm to be at its other position;

the plunger of each relay, actuated by current through the control winding of each relay, controlling the motion of a switch arm;

with the result that the position of the switch arm of each switch is determined by the binary state of the multivibrator to whose set or reset lead it is connected.

5. A correlator according to claim 4, wherein the control register ceases to shift after every multivibrator of the control register has been set, by a signal to its input, to one of the two binary states.

6. A correlator according to claim 5, wherein all of the input ends of the resistors of one of the pluralities of resistors are connected to only the set or to only the reset output leads of the multivibrator set to which they are connected; and

all of the resistors of the other plurality of resistors are con-

nected to only the set or to only the reset output leads of the multivibrator set to which they are connected.

7. A correlator comprising:

a J number of rows of signal shift registers, each row containing an I number of serially connected multivibrators, all the shift registers being arranged in I columns;

each multivibrator having a set and reset output lead, at one of which appears one bilevel voltage, and at the other of which appears the other bilevel voltage, the voltages indicating the binary state of the multivibrator;

a reference shift register, substantially identical to one of the signal shift registers;

one of the multivibrators at one end of the series of each shift register being connectable to a source of signals, generally a stream of bilevel signals, or pulses, each pulse having a predetermined time duration or multiple thereof;

each multivibrator of every signal and reference shift register being connectable to a clocking source for shifting the states of the multivibrators in synchronism with the streams of pulses;

a compound ladder arrangement of resistors comprising an I number of columns and a J number of rows of resistors;

the columns of resistors being connected to common junction points at both ends of the column, one junction point being a common ground point;

each of the I columns of resistors consisting of a series connection of J-I resistors having a value of R/2 ohms, and one resistor at the common ground point end having a value of R ohms;

each of the J rows of resistors including I resistors, one for each column, each of the I×J row resistors having a value of R ohms, one end of one row resistor from all but one of the J rows being connected at a junction of two columnar resistors, one end of each of the other row resistors from the other row being connected to the other, ungrounded, junction point of the columnar resistors;

an I×J number of modulo-two adders whose inputs are the set or reset output leads of the signal and reference shift registers as determined from the logical expression

$$S_{ij}\oplus R_i = S_{ij}\bar{R}_i + \bar{S}_{ij}R_i, 1 \leq i \leq I, 1 \leq j \leq J,$$

where

the unbarred terms relate to the voltage level of the bilevel signal at a set, or reset, output lead,

the barred terms relate to the negative of the voltage level of the bilevel signal at a set, or reset, output lead,

S_{ij} relates to the specific multivibrator of the signal shift register in the i th column and j th row, and

R_i relates to the i th multivibrator of the reference shift register.

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