PULSE SHAPING CIRCUIT USING COMPLEMENTARY MOS DEVICES

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ABSTRACT
Disclosed is a pulse shaping circuit particularly constructed for use in driving the transducer coil of an electric wristwatch. The circuit comprises complementary P and N channel MOS transistors having their common gates connected in common to a MOS transistor switch for switching power through the load coil.

5 Claims, 9 Drawing Figures
This invention relates to a pulse shaping circuit using complementary MOSFET's and more particularly to a driver circuit for driving the transducer coil of an electronic watch.

Battery-powered wristwatches and other small portable timekeeping devices are well known and commercially available. One such device which has proven to be quite successful commercially is shown and described in assignee's U.S. Pat. No. Re. 26,187, reissued Apr. 4, 1967, to John A. Van Horn et al., for Electric Watch. Electric watches of this type employ a balance wheel and a hairspring driven by the interaction of a current-carrying coil and a magnetic field produced by small permanent magnets. Other types of mechanically regulated battery-operated wristwatches are also known.

Considerable effort has been directed toward the development of high accuracy wristwatches which do not employ electromechanical oscillators as the master speed reference. One such system is that shown and described in assignee's copending application Ser. No. 768,076, filed Oct. 16, 1968, which application is incorporated herein by reference.

That application provides a battery-operated wristwatch employing a purely electronic frequency standard. It utilizes a relatively high frequency oscillator and a low power integrated circuit frequency divider coupled to a display and time display actuator. The integrated circuit is so arranged that current flow through the circuit takes place only during circuit state transitions and not during the stable period between transitions. As a result, the watch can be constructed of relatively inexpensive components making the electronically controlled wristwatch commercially competitive with conventional spring-driven and electric watches.

The present invention is directed to a pulse shaping circuit and more particularly to a watch coil driver particularly adapted for use in an electronic wristwatch of the type shown and described in the above-mentioned copending application. Important features of the present invention include the provision of an electronic driver circuit which produces sharp, short squarewave pulses for switching a signal to the watch drive coil with very few elements of small size and weight so as to be usable in the small space available in a wristwatch and a circuit which provides a very high driving power so as to preserve the energy available from the small battery of a wristwatch. The drive circuit of the present invention comprises as an input stage a differentiator consisting of a simple R-C circuit for differentiating the input pulses derived from the frequency converter or divider of an electronic type watch. The differentiated pulses are applied to a complementary pair of MOSFET's which produce sharp square pulses in turn applied to a switching transistor also preferably in the form of an MOSFET. Periodic pulses are supplied from the battery through the switching transistor to a load coil which in the preferred embodiment constitutes the drive coil of an electronic watch transducer.

It is therefore one object of the present invention to provide an improved pulse shaping circuit for applying squarewave pulses to an output load.

Another object of the present invention is to provide an improved pulse shaping circuit particularly adapted for use as the drive circuit in an electronic watch.

Another object of the present invention is to provide a driver circuit for switching energy pulses to the drive coil of a watch transducer.

Another object of the present invention is to provide an improved pulse shaping circuit including a pair of complementary MOSFET's in combination with a R-C differentiator which may be manufactured using conventional techniques from integrated circuit components.

Another object of the present invention is to provide a switch driver circuit for electronic watches having rapid switching time and requiring little power or space.

These and further objects and advantages of the invention will be more apparent upon reference to the following specification, claims, and appended drawings, wherein:

FIG. 1 is a simplified overall block diagram of an electronic watch construction for which the novel pulse shaping circuit of the present invention is particularly adapted;

FIG. 2 is a detailed circuit diagram of a pulse shaping circuit constructed in accordance with this invention;

FIG. 3 is a circuit diagram of a modified pulse shaper or driver circuit according to this invention;

FIG. 4 shows a portion of the driver circuit of FIG. 1 with parts labeled for the purposes of explanation;

FIGS. 5A, 5B, and 5C are waveforms of voltage as a function of time at various locations in the driver circuit of FIG. 2;

FIG. 6 is a plot of both current and output voltage for the circuit of FIG. 2 as a function of transistor gate voltage; and

FIG. 7 is a plot of threshold voltage as a function of the circuit time constant.

Referring to the drawings, FIG. 1 is a simplified block diagram of an electronic watch construction generally indicated at 10. The watch comprises a frequency standard 12, preferably in the form of a crystal-controlled oscillator or free running multivibrator which produces output pulses at a frequency in the neighborhood of at least about 5 KHz. The output from oscillator 12 is applied by way of lead 14 to a multi-stage frequency divider 16 where the frequency of the signal is reduced to a value usable for driving the hands of a watch. The output from the frequency divider 16 is applied by way of lead 18 to a driver 20 which is a pulse shaper to shape the pulses and apply them to a transducer 22 which converts the electrical pulses into physical motion to actuate a watch display 24 which may typically be the watch hands rotating about the dial of a conventional watch face.

As disclosed in assignee's copending application, Ser. No. 768,076, filed Oct. 16, 1968, oscillator 12 and frequency divider 16 are preferably made from integrated circuit components utilizing complementary MOSFET transistors. The present invention is directed to a new and improved driver 20 shown in detail in FIG. 2, also formed from complementary MOSFET components which may be manufactured utilizing integrated circuit techniques which is completely compatible with the integrated circuit construction of the oscillator and divider. Referring to FIG. 2, the input from lead 18 of FIG. 1 is applied to the input terminal 26 of the driver in the form of squarewaves 28 as they are received from the frequency divider 16 of FIG. 1. Connected to the input terminal 26 is an integrator generally indicated at 30 comprising series capacitors 32 and shunt resistor 34. The voltage waveform appearing at the output of integrator 30, i.e., at the point labeled 2 in FIG. 2, is illustrated at 36.

The waveform 36 from the differentiator is applied to gates 38 and 40 of a pair of complementary MOSFET transistors, generally indicated at 42 and 44. Transistor 42 is a P-channel enhancement mode transistor having a source 46 and a drain 48 and transistor 44 is a complementary N-channel enhancement mode transistor having a source 50 and drain 52. The substrate of transistor 42 is connected to source 46 and the substrate of transistor 44 is connected to source 50 in a well-known manner. The two transistors 42 and 44 are connected in a more or less conventional inverter configuration with the common gates 38 and 40 and the common drains 48 and 52 so that the output waveform 54 appearing on output lead 56 connected to the transistor drains is inverted with respect to the input waveform 28. Source 46 of transistor 42 is connected to the positive side of a power supply, as indicated at 58, whereas source 50 of transistor 44 is returned to the other side of the power supply, as indicated by ground at 60.

Also connected to the positive side of the power supply terminal 58 by way of lead 62 is a transistor switch, generally indicated at 64, preferably in the form of an MOSFET 66 having a gate 68, source 70, and drain 72. Transistor 66 is preferably a P-channel enhancement mode transistor similar to transistor 42. Drain 72 of transistor 66 is returned to ground through a load which, in the preferred embodiment, takes the form of a wristwatch transducer coil 74. The voltage waveform of the pulses applied across coil 74 is illustrated at 76.
FIG. 3 shows a modified driver construction in accordance with the present invention and like parts bear like reference numerals in FIG. 3. Again, the input terminal 26 is connected through capacitor 32 to the gate of a pair of complementary transistors 42 and 44. However, in this embodiment, the gate of the two transistors is connected to the positive power supply terminal 58 through a resistor 78 which, in conjunction with capacitor 32, forms an integrator generally indicated at 80. The common drain connection 56 in FIG. 3 develops a non-inverted waveform illustrated at 82 which is applied to the gate of a MOSFET transistor 84. As illustrated in FIG. 3, transistor 84 may be either a P-channel or N-channel enhancement mode transistor, depending upon whether the load coil is connected between terminals 86 and 88 or between load terminal 90 and ground 92. If transistor 84 is a P-channel transistor, similar to transistor 66, then the load coil is connected across load terminals 86 and 88 and terminal 90 is returned directly to ground. If transistor 84 is an N-channel transistor, then terminals 86 and 88 are directly connected together and the load coil is connected between load terminal 90 and ground.

FIG. 4 is a diagram of the wave shape portion of the drive circuit of FIG. 2 and like parts bear like reference numerals. In FIG. 4, the input voltage to terminal 26 is labeled $V_{in}$ and the output voltage on lead 56 is labeled $V_{out}$. The power supply voltage is $+V$ volts and the threshold voltage to the transistor is given as $V_{th}$. Terminal 26 and ground form a pair of input terminals for the pulse shaper of FIG. 4 and terminal 56 and ground form a pair of output terminals for the shaper circuit.

FIGS. 5A, 5B, and 5C are enlarged views of the waveforms 28, 36, and 54, respectively, of FIG. 1. The input voltage normalized for a supply voltage of $+V$ volts is given by $V_{in}/V$ and is shown in FIG. 5A as having a positive squarewave with a half cycle from time $t_1$ to time $t_2$ and a positive excursion of approximately $+V$ volts. The gate voltage is shown at 36 in FIG. 5B and is given as $V_{in}/V$. The threshold level of the transducers is indicated by the dashed line 94, labeled $U_d$, and the differential switching voltage level is indicated at 96 and labeled $\Delta U_{th} / V$.

In FIG. 5C, the output voltage $V_{out}/V$ is indicated at 54 and the inverter or negative going voltage pulses have a pulse width of $T$ as indicated at 98.

FIG. 6 is a plot of the transfer characteristic of the pulse shaping portion of the circuit of FIG. 1 shown in FIG. 4 including the differentiator 30 and the inverter comprising MOS transistors 42 and 44. In FIG. 6, both output voltage $V_{out}/V$ as indicated at 100 and transistor current 1 are plotted as a function of gate voltage $V_{in}/V$. The current curve is indicated at 102 in FIG. 6, where the current is given by the vertical scale 104 in microamps.

Finally, FIG. 7 is a plot of the slope of the gate voltage $U_{g}/V$. Curve 106 in FIG. 7 is a plot of

$$U_{g} = \frac{1}{T} \theta$$

where $\theta = RC$. Curve 108 is a plot of

$$U_{g} = \frac{1}{\theta} e^{-\theta t}$$

and curve 110 is a plot of

$$U_{g} = \frac{1}{\theta}$$

As can be seen, this latter curve peaks or has a maximum at point 112 where $T = RC$.

If the circuit of FIG. 4 is provided with a supply voltage of $+V$ volts, and the transistors have a threshold voltage $U_{th} = U_d$, and further the input signal is a squarewave having a positive amplitude of approximately $V$, then when $V_{in}$ goes from $OV$ to $+V$, $U_{g}$ goes from $+V$ to $OV$ so as $U_{g} = \frac{1}{V} e^{-RC}$.

The width of the output pulse is given by

$$U_{e} = \frac{e}{2 \pi} \frac{1}{\theta}$$

which is maximum for $T = \theta$ (FIG. 3). The switching time of the output is given by the time that $U_{e} / V$ needs to go from $U_d$ to $U_d + \Delta U_{th} / V$ so that $\Delta U_{th} / V$ is the variation of the gate voltage we need to switch the inverter of FIGS. 1 and 2.

$$\Delta T = \frac{\theta}{U_{out}} \Delta U_{th} / V$$

$\Delta U_{th}$ is given by the transfer curve $V_{out}/V$ vs. $U_{g}/V$ (FIG. 2). We know that $\frac{U_{g}}{V}$ is maximum for $T = \theta$.

In the same way, we can determine the average current in the inverter when it switches with the curve $I$ versus $U_{g}$.

For instance, if $V = 3V$, $\Delta U_{th} = 0.05$ $V$

$$U_{out} = 1.17V$$

$$\Delta T = 10^{-3} \times 0.05 \times 46 \text{ ns} = 2.2 \text{ ns}$$

$R$ can be very large (greater than 10 MΩ).

As can be seen from the above, the present invention provides a novel pulse shaping circuit and more particularly a circuit particularly adapted for driving the transistor coil of an electrical or electronic watch. While the pulse shaping has been described in conjunction with a watch drive, it is understood that the pulse shaper can be used to drive the gate of one or many P or N channel MOS transistors working as a switch or as a preamplifier to drive a switch or may be used to drive the base of one or many P-N-P or N-P-N junction transistors working as a switch or as a preamplifier to drive a switch (with a resistance in the base circuit useful). In addition, the pulse shaper may be used to drive one or more other inverters in parallel or series or both. Each inverter works as a buffer and decreases the time switching of its own input signal until the physical limit of the device is reached. The device may drive MOS transistors with each MOS working as a common source or common gate with or without any feedback. If the output is applied to the base of an MOS, the MOS may...
work as a common source or common gate also with or without feedback. In the case of P-N-P or N-P-N junction transistor drives, each transistor works as a common emitter or common collector with or without feedback. Preferably one resistance is put in series with the base or bases to limit the base current if necessary. Important advantages of the pulse shaper and drive circuits of the present invention include the fact that they require very low input power, i.e., they have a high input impedance of many megohms which allows a small capacitance and very large resistance in the R-C differentiating circuit. The unit provides high power gain with high efficiency and independence of the input signal and of the load. A good squarewave is given by the circuit and the device can be used to drive any kind of drive power circuit. No variations occur in the output with temperature except for the limited R-C variation.

What is claimed and desired to be secured by United States Letters Patent is:

1. A pulse driving circuit comprising a pair of signal input terminals, a differentiator coupled across said input terminals, a load, a pair of power supply terminals, an electronic switch for coupling said load across said power supply terminals, and a pair of complementary MOS transistors coupling said differentiator to said switch for completing the circuit to said load in response to an input signal across said input terminals, said differentiator comprising a series capacitor and a shunt resistor, said load comprising a watch transducer coil.

2. A pulse driving circuit comprising a pair of signal input terminals, positive and negative power supply terminals, a P-channel MOS transistor having gate, source and drain electrodes, an N-channel MOS transistor having gate, source and drain electrodes, a capacitor coupling the gate electrodes of said transistors to one of said input terminals, a resistor coupling the gate electrodes of said transistors to the other of said input terminals, the source of said P-channel transistor being coupled to said positive power supply terminal, the source of said N-channel transistor being coupled to said negative power supply terminal, a solid state switch and load being connected in series across said power supply terminals, said switch having a control electrode, and means coupling the drains of said transistors to the control electrode of said switch, said switch comprising a P-channel MOS transistor, said control electrode comprising the transistor gate.

3. A circuit according to claim 2 wherein said load comprises an electrical wristwatch transducer coil.

4. A pulse driving circuit comprising a pair of signal input terminals, a differentiator coupled across said input terminals, a wristwatch transducer coil, a pair of power supply terminals, a solid state electronic switch for coupling said transducer coil across said power supply terminals, and a pair of complementary MOS transistors coupling said differentiator to said switch for completing the circuit to said transducer coil in response to an input signal across said input terminals.

5. A circuit according to claim 4 wherein said switch comprises an MOS transistor.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,657,568 Dated April 18, 1972

Inventor(s) Bruno Dargent

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Abstract, line 4, "connected in common" should read --connected to an R-C differentiator. The transistor drains are connected in common--.

In Column 1, line 56, "therefor" should read --therefore--.

Signed and sealed this 12th day of September 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR. ROBERT GOTTSCHALK
Attesting Officer Commissioner of Patents