Electronics
Controlling Power to Output Transducers

Terry Sturtevant

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Basic Rule of Control

Control usually involves three things:
1. a fixed power supply
2. a load to which we want to control the power
3. a control element to which we will send signals to control the power to the load.

These will be arranged in a voltage divider.

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These will be arranged in a voltage divider.
C.E. is the control element. Load could be a motor, solenoid, relay coil, etc.
“C.E.” is the control element.
“C.E.” is the control element.
“Load” could be a motor, solenoid, relay coil, etc.
Low power devices
Low power devices

These devices require low power.
Low power devices

These devices require *low power*. Low power is typically $\lesssim 1W$. 
Low power devices

These devices require *low power*. Low power is typically $\lesssim 1\text{W}$.

- meter
Low power devices

These devices require *low power*. Low power is typically $\lesssim 1W$.

- meter
- oscilloscope
Low power devices

These devices require *low power*. Low power is typically $\lesssim 1\text{W}$.

- meter
- oscilloscope

These devices produce *information*.
High power devices

These devices require high power. High power is typically \( \gtrsim 1 \) W.

- Lights
- Solenoids

These devices produce action. An operational amplifier is a voltage device; it can't produce more than a few mW of power.
High power devices

These devices require *high power*.
High power devices

These devices require *high power*. High power is typically $\geq 1\, \text{W}$. 
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- lights
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- lights
- solenoids
High power devices

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- lights
- solenoids

These devices produce \textit{action}.
High power devices

These devices require *high power*. High power is typically \( \geq 1\, \text{W} \).
- lights
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These devices produce *action*. An operational amplifier is a *voltage* device; it can’t produce more than a few mW of power.
Types of control

- on/off like a switch
- proportional like a rheostat or potentiometer
Types of control

- on/off
Types of control

- on/off
  like a switch
Types of control

- on/off
  - like a switch
- proportional
Types of control

- on/off
  like a switch
- proportional
  like a rheostat or potentiometer
Control trade-offs

There are trade-offs involved in choosing a type of control. Efficiency on/off is 100% efficient, proportional is less efficient. Noise on/off produces more noise, proportional produces less noise. There is a trade-off between efficiency and noise.
Control trade-offs

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Control trade-offs

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- efficiency
Control trade-offs

There are trade-offs involved in choosing a type of control.

- efficiency

  - on/off is 100% efficient

  - proportional is less efficient

- noise

  - on/off produces more noise

  - proportional produces less noise

There is a trade-off between efficiency and noise.
Control trade-offs

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As previously noted, any device used for control is basically used in a voltage divider using
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- and the load.
As previously noted, any device used for control is basically used in a voltage divider using:

- the supply voltage,
- the control device,
- and the load.

The order of the control element and the load in the voltage divider has some effects on the circuit operation.
Relay

A relay is based on a solenoid, and has four types of pins:
- coil
- common
- NO; normally open (possibly)
- NC; normally closed (possibly)
Relay

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A relay is based on a solenoid, and has four types of pins:

- coil
- common
- **NO**; normally open (possibly)
A relay is based on a solenoid, and has four types of pins:

- **coil**
- **common**
- **NO**: normally open (possibly)
- **NC**: normally closed (possibly)
Relay **OFF**

![Relay Circuit Diagram](image)

- **NC**: Common
- **NO**: Open
Relay ON

NC
common

NO
An internal spring returns the solenoid to its original position when power is removed from the coil.
Since a relay is inductive, all of the precautions for an inductive device must be taken.
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The relay can be inserted on either side of the load in a voltage divider.
The relay can be inserted on either side of the load in a voltage divider.

\[ V_{\text{in}} \quad V_{\text{supply}} \quad V_{\text{out}} \]
The relay can be inserted on either side of the load in a voltage divider.
Transistors

There are several types of transistor; each is a three terminal device. The most common types of transistors are BJTs and FETs. Transistors are often used in voltage dividers to act as variable resistors.
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- Transistors are often used in voltage dividers to act as variable resistors.
Metal Oxide Semiconductor Field Effect Transistors
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A MOSFET (or Metal Oxide Semiconductor Field Effect Transistor) is a three terminal device.
Metal Oxide Semiconductor Field Effect Transistors

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- drain
Metal Oxide Semiconductor Field Effect Transistors

A MOSFET (or Metal Oxide Semiconductor Field Effect Transistor) is a three terminal device.

- drain
- source
Metal Oxide Semiconductor Field Effect Transistors

A MOSFET (or Metal Oxide Semiconductor Field Effect Transistor) is a three terminal device.

- drain
- source
- gate
FET symbol
FET symbol

drain
FET symbol

\[ \text{drain} \]
\[ \text{source} \]
FET symbol

gate \[ \rightarrow \] drain

source
FET operation

- FETS are *voltage* amplifiers; a small *gate voltage* controls a much larger *drain/source current*. 
FET operation

- FETS are *voltage* amplifiers; a small *gate voltage* controls a much larger *drain/source current*.

Actually it’s the voltage between the gate and the source which matters.
D and E MOSFETs

There are two kinds of MOSFET:
- **Enhancement mode (E type)**
  - When $V_{gs}$ is below $V_{th}$, $I_D = 0$
  - As $V_{gs}$ increases above $V_{th}$, $I_D$ increases.
- **Depletion mode (D type)**
  - To get $I_D$ to zero, a negative $V_{gs}$ off must be applied.

Actually, all MOSFETs operate in enhancement mode. It's just that some only operate in that mode. Which kind you want depends on whether or not you want some current to flow with no applied gate-source voltage.
D and E MOSFETs

There are two kinds of MOSFET
D and E MOSFETs

There are two kinds of MOSFET

- enhancement mode (E type)
D and E MOSFETs

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Actually, all MOSFETs operate in enhancement mode. It’s just that some only operate in that mode. Which kind you want depends on whether or not you want some current to flow with no applied gate-source voltage.
### Basic Rule of Control

- Types of output transducers
- Types of control
- Devices for control
- Other considerations

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<td>TRIAC</td>
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#### Devices for control

- Relay
- Transistors
- MOSFET
- BJT
- TRIAC

#### Other considerations

- D (depletion mode) MOSFET

![Diagram of D (depletion mode) MOSFET](image)

**D (depletion mode) MOSFET**
D (depletion mode) MOSFET output
E (enhancement mode) MOSFET
E (enhancement mode) MOSFET output
E (enhancement mode) MOSFET output zoomed in
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$$V_{supply}$$

$$V_{gs}$$

$$V_{o}$$

$I \approx 0$ if $V_{gs} \lesssim V_{th}$

E (enhancement mode) FET
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\[ V_{supply} \]

\[ V_{gs} \]

\[ V_o = V_{DS} \]

E (enhancement mode) FET
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\[ V_{gs} = 0 \]

\[ V_o \approx V_{supply} \text{ if } V_{gs} < V_{th} \]

E (enhancement mode) FET
E (enhancement mode) FET

\[ V_o = V_{DS} < V_{supply} \text{ if } V_{gs} \gtrsim V_{th} \]
Basic Rule of Control

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\[ V_{o} = V_{DS} \rightarrow 0 \text{ if } V_{gs} >> V_{th} \]

E (enhancement mode) FET
FETs are *voltage* amplifiers; a small *gate-source* voltage controls a much larger *drain/source* current.
• FETS are *voltage* amplifiers; a small *gate-source* voltage controls a much larger *drain/source* current.

• *You do not use a gate resistor with an FET!*
- FETS are *voltage* amplifiers; a small *gate-source* voltage controls a much larger *drain/source* current.

- *You do not use a gate resistor with an FET!*

- All FETs work in *enhancement* mode; some also work in *depletion* mode.
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\[ V_{\text{supply}} \]

\[ V_{gs} = 0 \]

gate

\[ V_o = V_{DS} > 0 \text{ if } V_{gs} = 0 \]

D (depletion mode) FET
$I \approx 0 \text{ if } V_{gs} \lesssim V_{gs_{off}} < 0$

$V_{gs}$ has to be negative to turn off.

D (depletion mode) FET
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\[ V_{o} = V_{DS} < V_{\text{supply}} \text{ if } V_{gs} \gtrsim 0 \]

D (depletion mode) FET
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\[ V_{supply} \]

\[ V_{gs} \gg 0 \]

\[ V_o = V_{DS} \rightarrow 0 \text{ if } V_{gs} \gg 0 \]

D (depletion mode) FET
The MOSFET, like the relay, can be placed in either position of a voltage divider.
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Bipolar Junction Transistors

A BJT (or Bipolar Junction Transistor) is a three terminal current device. The terminals are collector, emitter, base. The current from the collector to the emitter is controlled by the current into the base.
Bipolar Junction Transistors

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Bipolar Junction Transistors

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Bipolar Junction Transistors

A BJT (or Bipolar Junction Transistor) is a three terminal *current* device. The terminals are

- collector
Bipolar Junction Transistors

A BJT (or Bipolar Junction Transistor) is a three terminal current device. The terminals are

- collector
- emitter
Bipolar Junction Transistors

A BJT (or Bipolar Junction Transistor) is a three terminal *current* device. The terminals are:

- collector
- emitter
- base
Bipolar Junction Transistors

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- collector
- emitter
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The current from the collector to the emitter is controlled by the *current* into the base.
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collector
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collector
emitter
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collector
emitter
BJT operation

BJTs are current amplifiers; a small base current controls a much larger collector/emitter current. You should always have a base resistor with a BJT!
BJT operation

- BJTs are *current* amplifiers;
BJT operation

- BJTs are *current* amplifiers; a small *base* current controls a much larger *collector/emitter* current.
BJT operation

- BJTs are *current* amplifiers; a small *base* current controls a much larger *collector/emitter* current.
- *You should always have a base resistor with a BJT!*
V_o \approx V_s \text{ if } V_i \lesssim 0.7

I_c \approx 0 \text{ if } V_i \lesssim 0.7
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\[ V_s \]

\[ V_i \lesssim 0.7 \]

\[ V_o \approx V_s \text{ if } V_i \lesssim 0.7 \]

\[ I_c \approx 0 \text{ if } V_i \lesssim 0.7 \]
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\[ V_i > 0.7 \]

\[ V_o = V_s - I_c R \text{ if } V_i > 0.7 \]

\[ I_c \propto I_b \text{ if } V_i > 0.7 \]
Like the previous devices, either position in a voltage divider can be used.
Like the previous devices, either position in a voltage divider can be used.
Like the previous devices, either position in a voltage divider can be used.
Like the previous devices, either position in a voltage divider can be used.

![Diagram of a voltage divider with input $V_{in}$, output $V_{out}$, and supply $V_{supply}$]
TRIAC

A TRIAC is a three terminal ac voltage device. The terminals are main terminal 1, main terminal 2, and gate. A triac will begin to conduct when it receives a voltage pulse on the gate. It will continue to conduct until the current is zero.
TRIAC

A TRIAC is a three terminal *ac voltage* device.
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A TRIAC is a three terminal *ac voltage* device. The terminals are

- main terminal 1
A TRIAC is a three terminal *ac voltage* device. The terminals are
- main terminal 1
- main terminal 2
A TRIAC is a three terminal *ac voltage* device. The terminals are

- main terminal 1
- main terminal 2
- gate
A TRIAC is a three terminal *ac voltage* device. The terminals are
- main terminal 1
- main terminal 2
- gate

A triac will begin to conduct when it receives a voltage pulse on the *gate*. 
A TRIAC is a three terminal *ac voltage* device. The terminals are
- main terminal 1
- main terminal 2
- gate

A triac will begin to conduct when it receives a voltage pulse on the *gate*. It will continue to conduct until the *current* is zero.
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### Types of control

- Relay
- Transistors
- MOSFET
- BJT
- TRIAC

---

**Diagram:**

![Circuit Diagram](image)

---

Electronics Controlling Power to Output Transducers
It can operate in two modes.
It can operate in two modes.

- burst
It can operate in two modes.

- burst
- delayed trigger
In burst mode, trigger pulses are only given at the beginning of half-cycles.
In *burst* mode, trigger pulses are only given at the beginning of half-cycles.
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This is a typical circuit to control a triac in burst mode.

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Electronics Controlling Power to Output Transducers
This is a typical circuit to control a triac in burst mode.
In delayed trigger mode, trigger pulses are delayed after the beginning of half-cycles to produce power for only a part of each half cycle.
In *delayed trigger* mode, trigger pulses are delayed after the beginning of half-cycles to produce power for only a part of each half cycle.
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This is a typical circuit to control a triac in delayed trigger mode.

Terry Sturtevant
Electronics Controlling Power to Output Transducers
This is a typical circuit to control a triac in delayed trigger mode.
Using TTL gates for control
Using TTL gates for control

- “Extra” current from TTL
Using TTL gates for control

- “Extra” current from TTL
- sink instead of source
Using TTL gates for control

- “Extra” current from TTL
- sink instead of source
- 0.4mA vs. 8 mA (LS)
Current sourcing
Current sourcing

![Diagram of current sourcing](image-url)
Current sourcing

$I_{OH} \leq 0.4\text{mA}$
Current sinking
Current sinking

\[ V_{CC} \]
Current sinking

\[ V_{CC} \]

\[ I_{OL} \leq 8.0\text{mA} \]
Using a TTL gate to sink instead of source allows 20x the current!