Signal Sources and Interface Circuits

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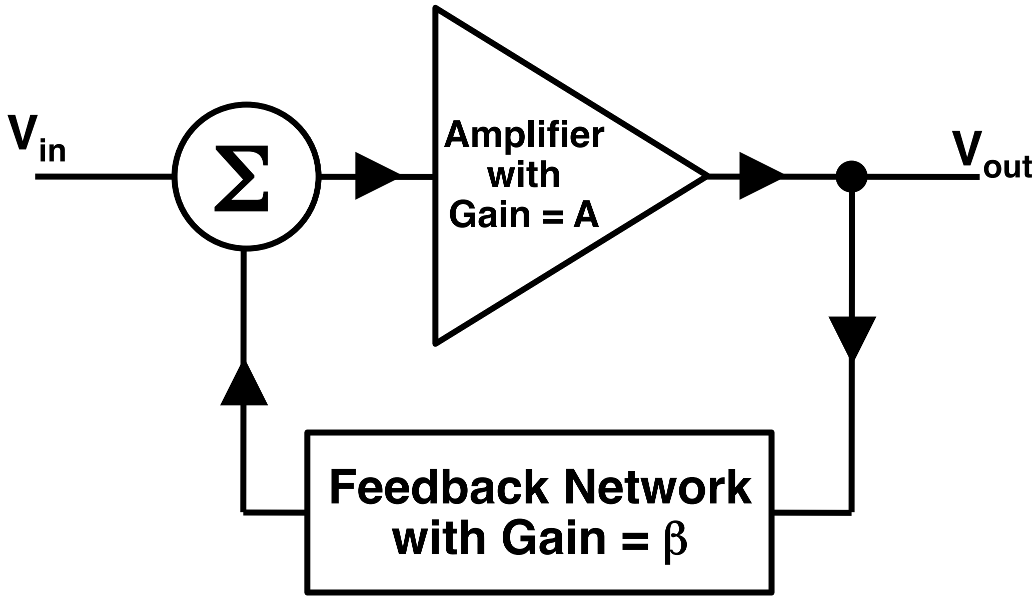
Linear Oscillators

- "Linear" oscillators are circuits that produce pure sinewave output signals.
- The basic concept is "placing" a single pole on the jω axis.
- To do this in a stable way, and with low distortion, is not trivial, and adding the ability to tune the sinewave with a linear oscillator is a definite challenge.
- Overcoming that challenge, with 1930's technology, was the catalyst that led to Hewlett-Packard's grow (the test equipment spin-off is now called Keysight).

LINEAR OSCILLATORS



Overall Gain

$$A_f(S) = \frac{A(S)}{1 - A(S)\beta(S)}$$

Amplifier Gain

Feedback Loop Gain

TO MAKE A_f INFINITY...

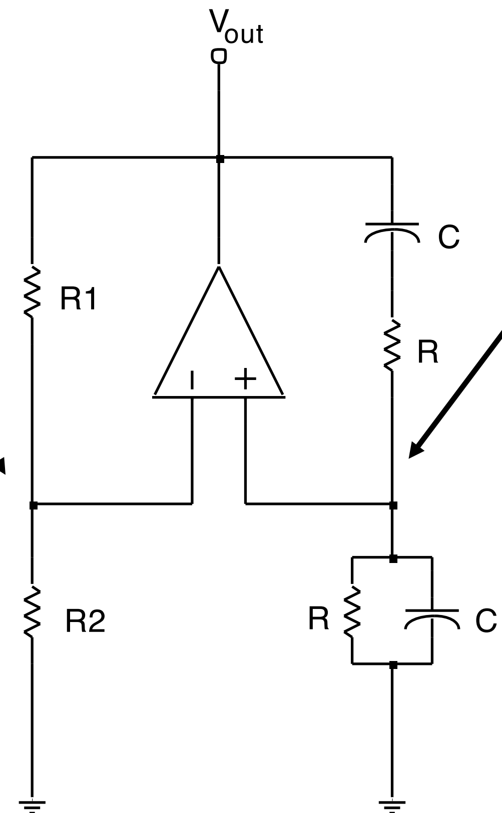
$$A(S)\beta(S) = 1$$

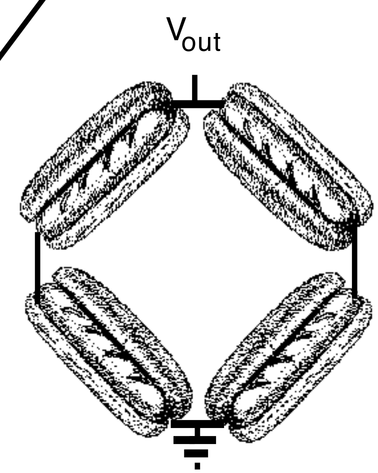
THE BARKHAUSEN CRITERION

THE WIEN BRIDGE OSCILLATOR

NEGATIVE FEEDBACK

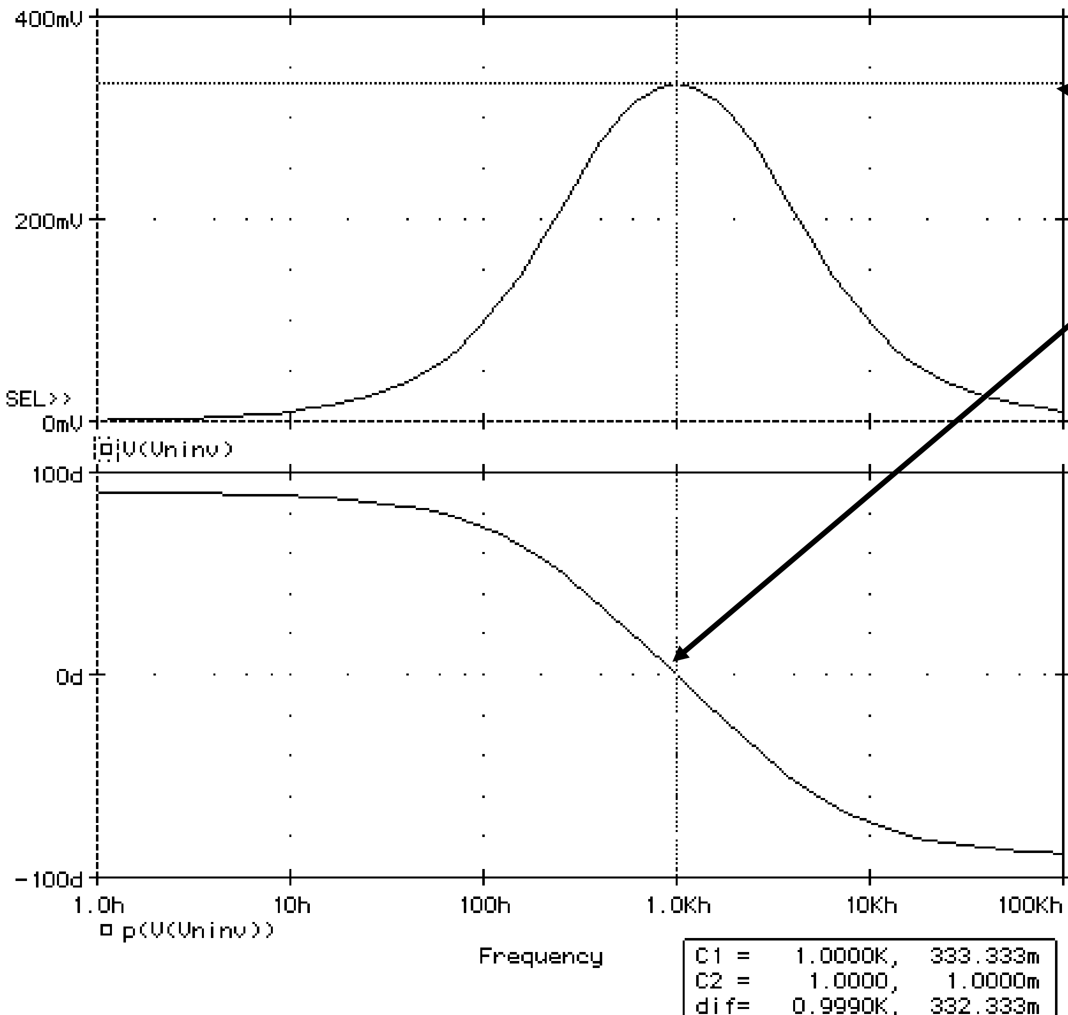
POSITIVE FEEDBACK

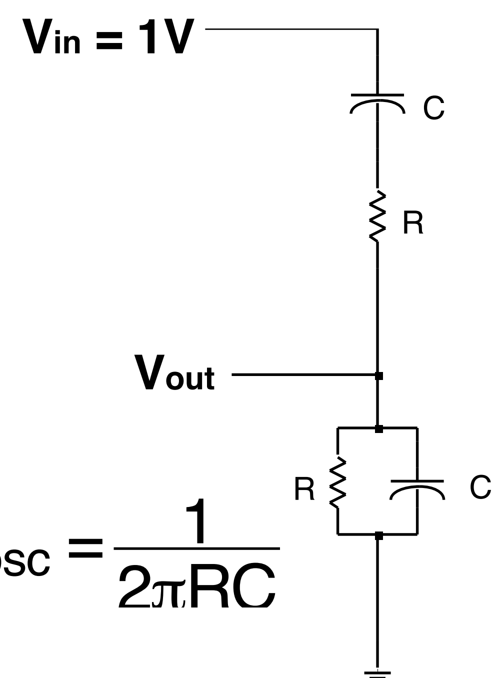




Wien, Max, "Measung der induction constanten mit dern Optischen Telephon," Ann. der Phys., Vol. 44, 1891, p. 704-7.

FREQUENCY RESPONSE OF POSITIVE FEEDBACK CIRCUIT

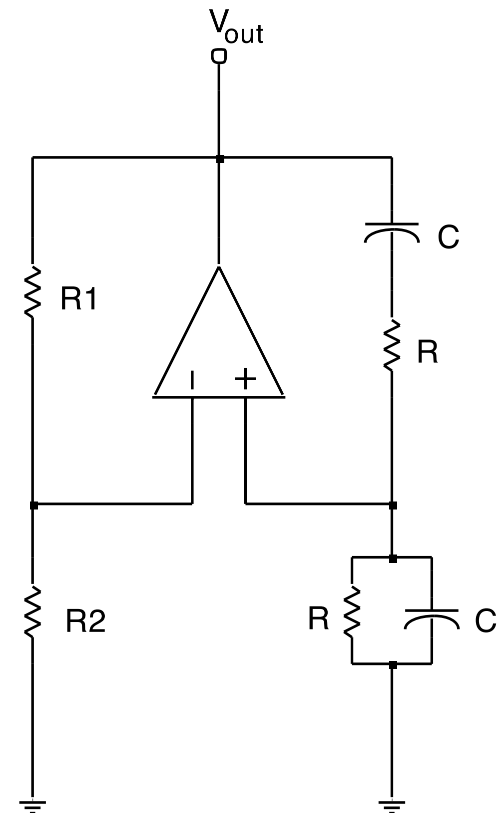


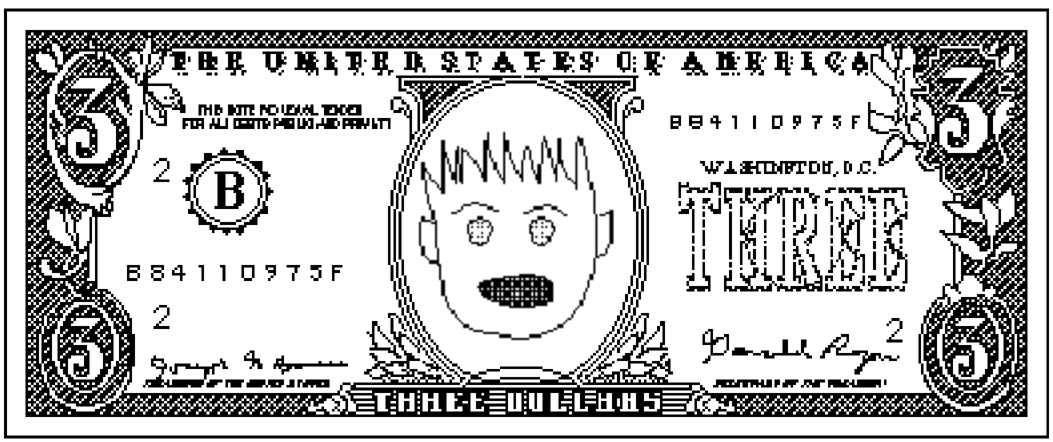


$$f_{osc} = \frac{1}{2\pi RC}$$

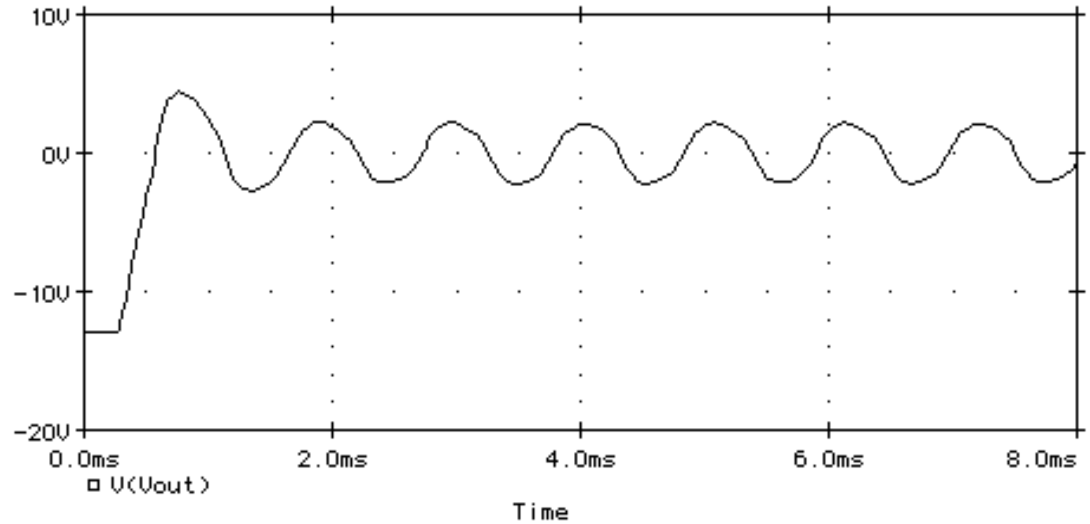
GAIN OF 3 ?

- SINCE THE POSITIVE FEEDBACK LOOP PROVIDES A GAIN OF 1/3 AT THE FREQUENCY OF OSCILLATION, THE BARKHAUSEN CRITERION REQUIRES THAT THE AMPLIFIER HAVE A GAIN OF 3...
- THE AMPLIFIER GAIN IS SET BY RESISTORS R1 AND R2...



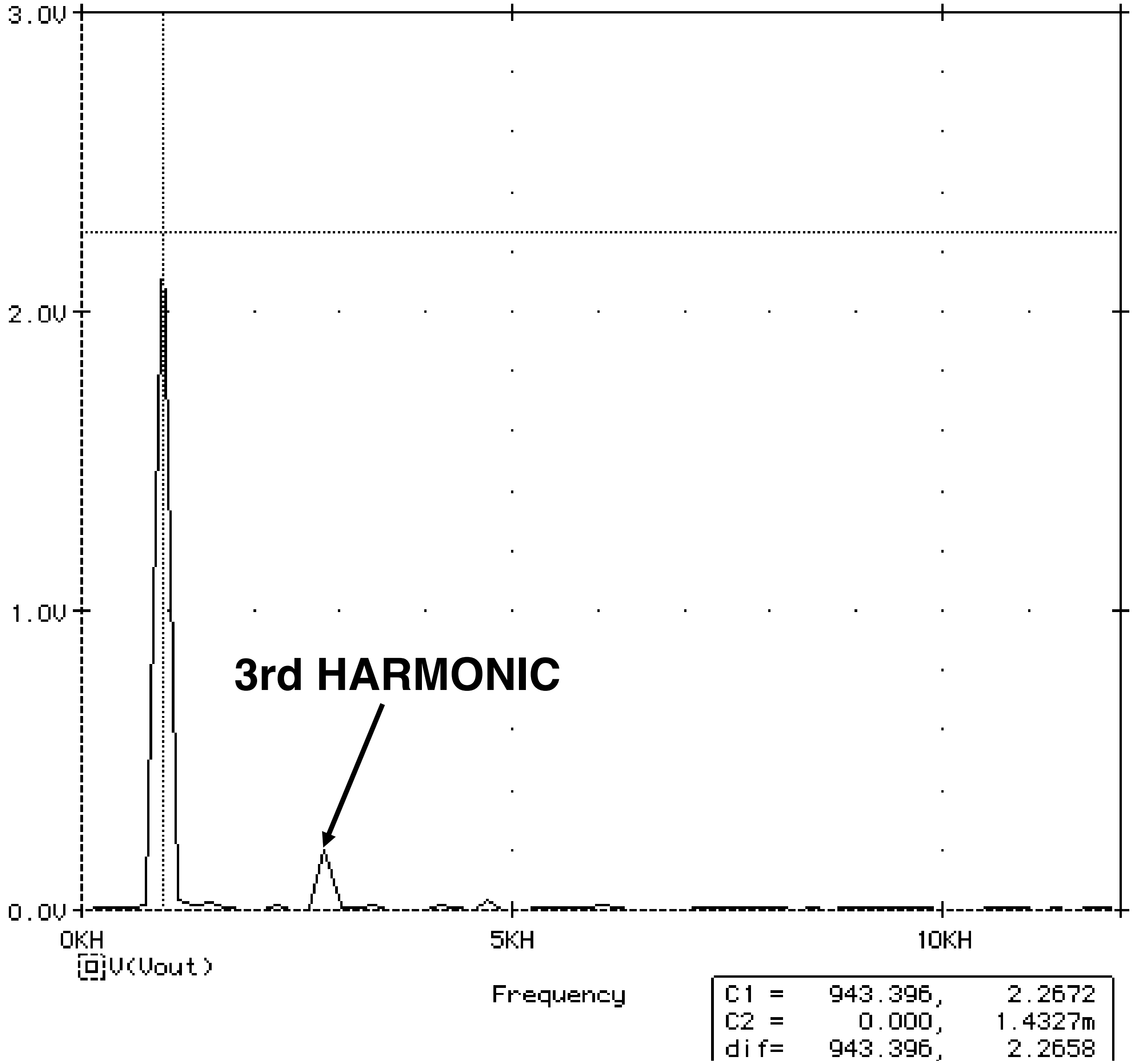


SIMULATED WIEN BRIDGE OSCILLATOR

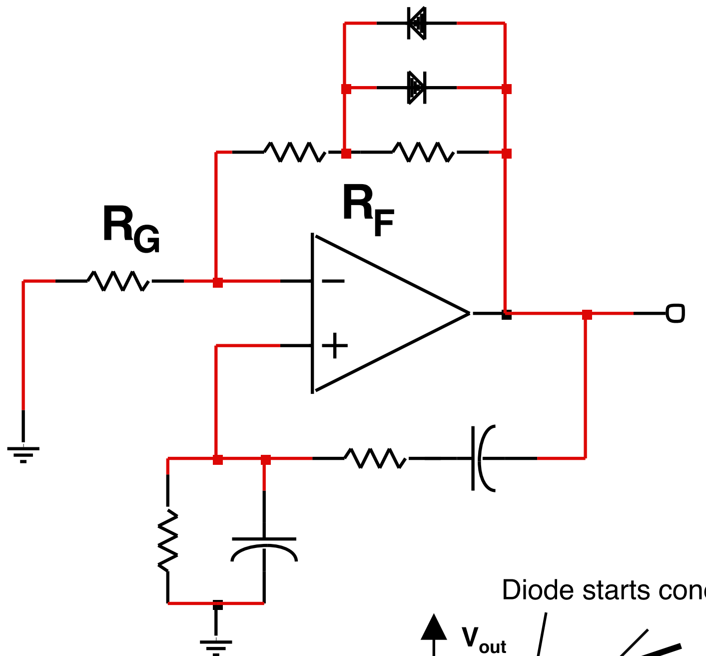


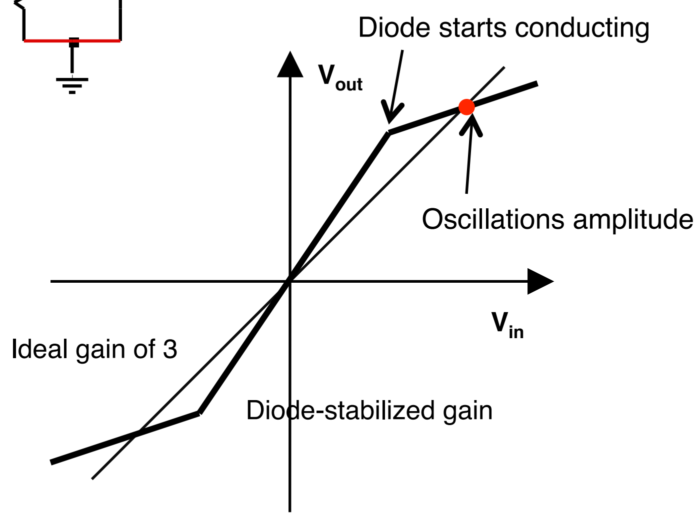

```
X1 Vninv Vinv 4 5 Vout UA741
Vplus 4 0 15V
Vminus 0 5 15V
R1 Vinv 0 ?
R2 Vinv 8 ?
C1 Vout 7 ?
R3 7 Vninv ?
C2 Vninv 0 ?
R4 Vninv 0 ?
Istart Vninv 0 pwl(0 1mA 10us 0V)
.model dmod D
.TRAN 100uS 8mS 0uS 100uS
.probe
.end
```


WIEN-BRIDGE PERFORMANCE



DIODE-STABILIZED WIEN BRIDGE OSCILLATOR





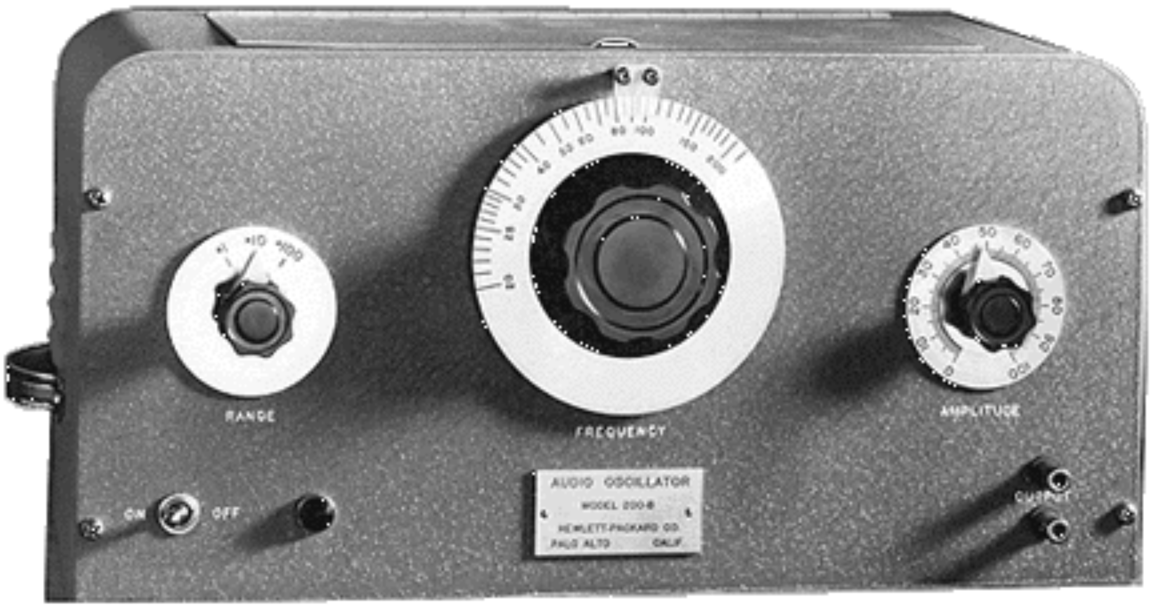
HOW DOES IT WORK?

- **WHEN OUTPUT AMPLITUDE GETS TOO LARGE, DIODES BEGIN TO CONDUCT**
- **DIODE CONDUCTION EFFECTIVELY REDUCES THE FEEDBACK RESISTANCE**
- **SINCE THE GAIN OF THE OP-AMP WITH NEGATIVE FEEDBACK IS:**

$$G = 1 + \frac{R_F}{R_G}$$

THIS STABILIZES THE OUTPUT AMPLITUDE!

HP200A Oscillator - The First HP Product



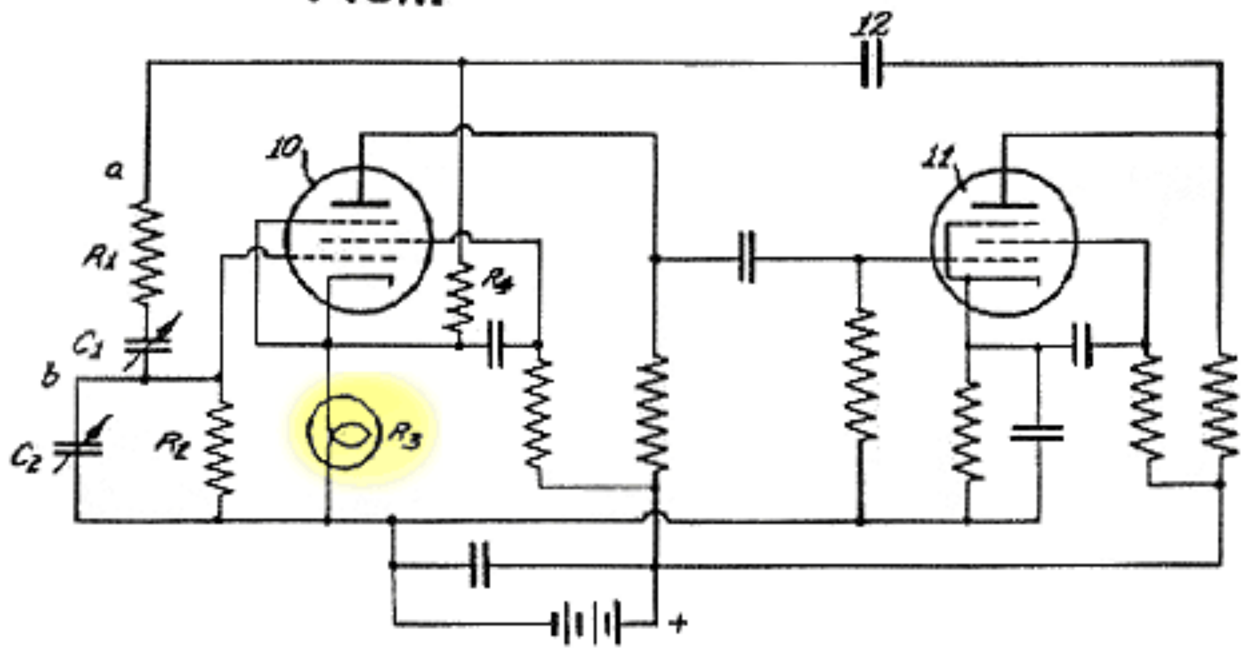
In 1939 William R. Hewlett applied for a patent with the United States Patent Office for his variable frequency oscillation generator, a resistance-capacitance tuned frequency audio oscillator. This instrument remained on the market in a succession of models until 1985. Prior to this invention, there was no simple and precise way of producing variable and stable signals in the low frequency range needed for measurements in acoustics, medicine, oil exploration, seismology, oceanography, structural vibration analysis, and many other fields whose natural processes involve these low frequencies.

Jan. 6, 1942. W. R. HEWLETT 2,268,872

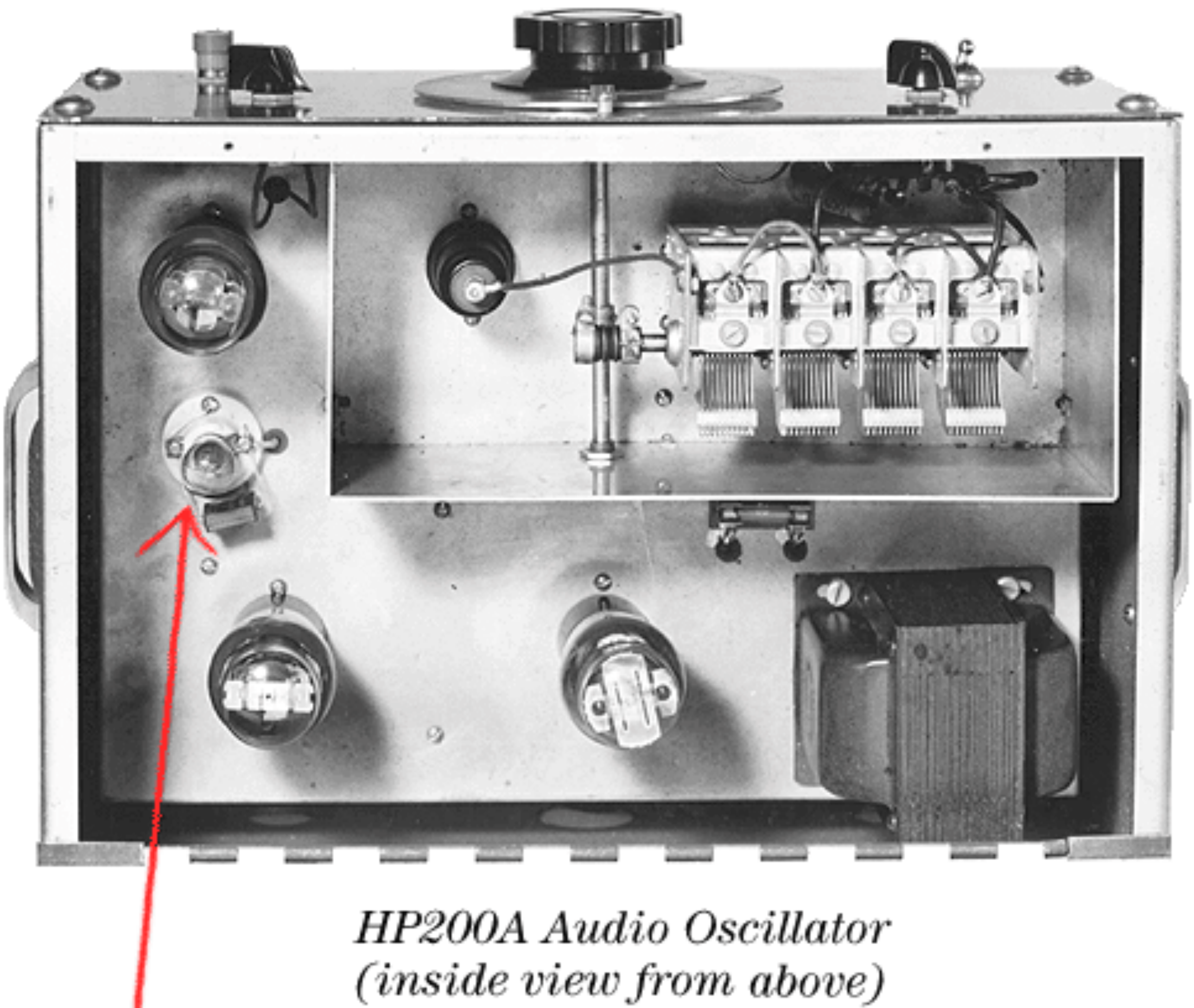
VARIABLE FREQUENCY OSCILLATION GENERATOR

Filed July 11, 1939

FIG. 1.



Schematic diagram for HP200A Audio Oscillator
(from original patent application)
A simple light bulb was used for Resistor R3



HP200A Audio Oscillator
(inside view from above)
A simple light bulb was used as a variable resistor

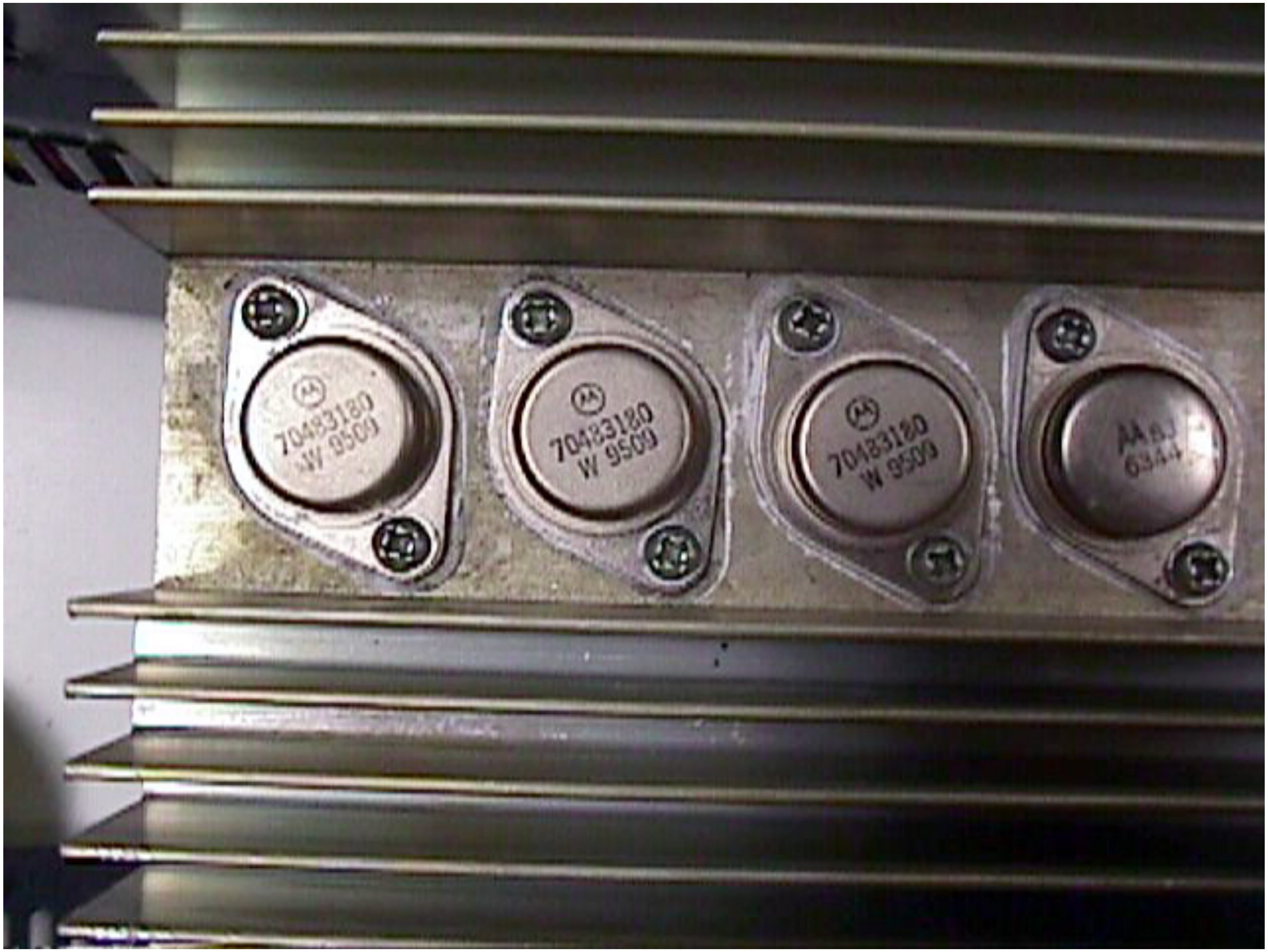
Interface Circuits

- Interface circuits “connect” between conventional electronic circuits (op-amps, logic, etc.) to the outside world.
- They include circuits to buffer, amplify, and process sensor signals - INPUT of information.
- Also, they can include circuits to drive actuators, relays, etc. - OUTPUT of information.
- In general, they translate between the “volts and milliamps” of conventional circuits and their equivalents within several orders of magnitude.

Power Driver Circuits

- There are a variety of devices that one might want to drive that require more current or higher voltages than inexpensive op-amps can produce.
- Of course, one solution is to purchase “specialty” op-amps with high current or high voltage outputs.
- However, it is very useful to know how to extend the capabilities of op-amp (and logic circuit) outputs to avoid this, particularly when the more expensive approach is not warranted.

Power Transistors/Heatsinks

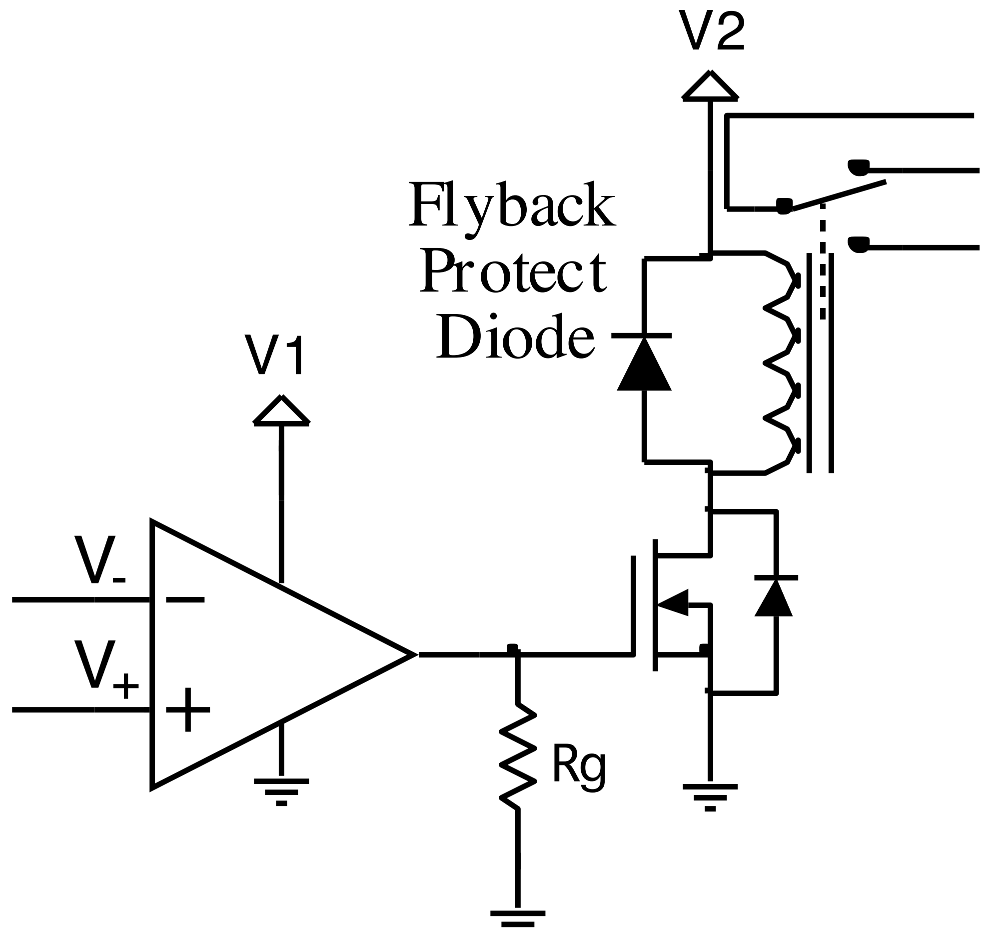


Unipolar Power Switches

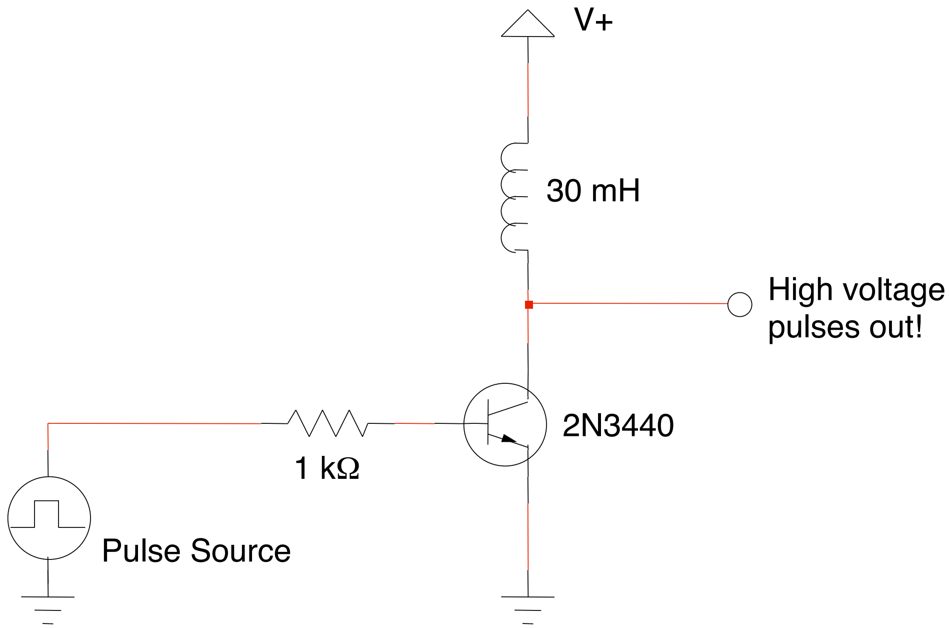
- For many output devices, one simply needs to switch a drive voltage on and off, not change polarity or amplitude.
- In this case, one can use a bipolar power transistor with sufficient current gain (or a Darlington configuration) or a power MOSFET.
- Today, the most efficient choice is usually the MOSFET.
- For the MOSFET the power dissipation is essentially $P_d = I^2 R_{dson}$ (R_{dson} is typically a few mOhms).
- In contrast, for a BJT in saturation, V_{CEsat} is typically around 0.2V, so $P_d \approx I\ (0.2V)$…

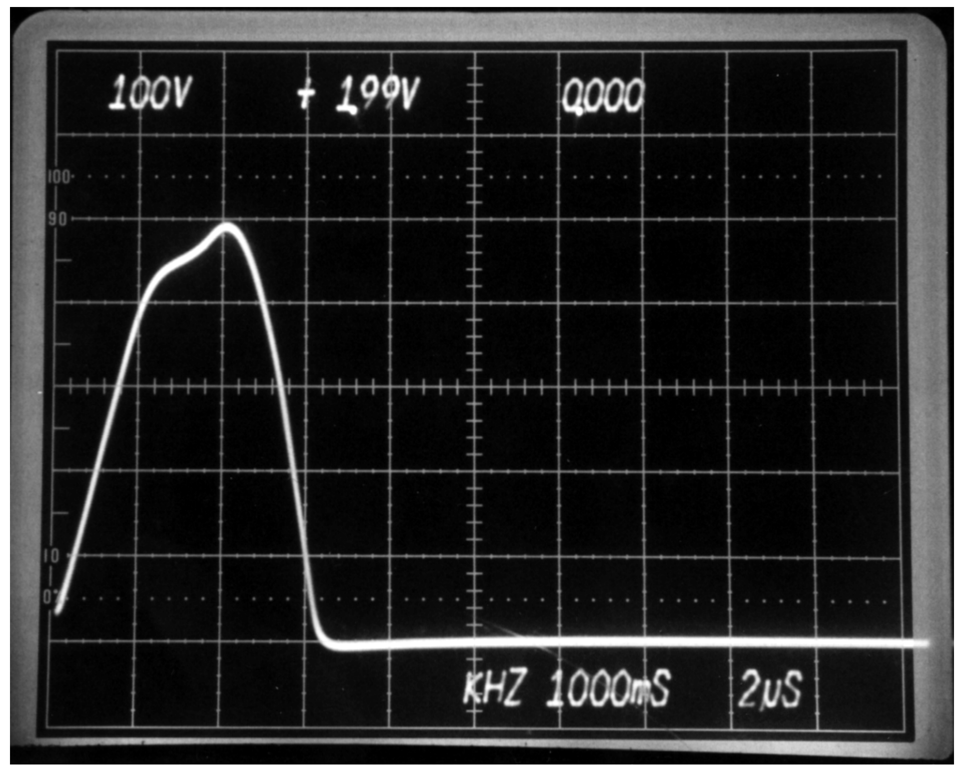
Basic Relay Switch

- Can use BJT or MOSFET.
- If loads are inductive, need flyback protect diode.
- Can drive directly from TTL/CMOS logic instead (want logic-drive MOSFET or BJT).
- Use current-limit resistor for BJT.



Why You Need Flyback Diodes





Demonstrates the large voltages developed when inductive current "flies back" after turn-off.

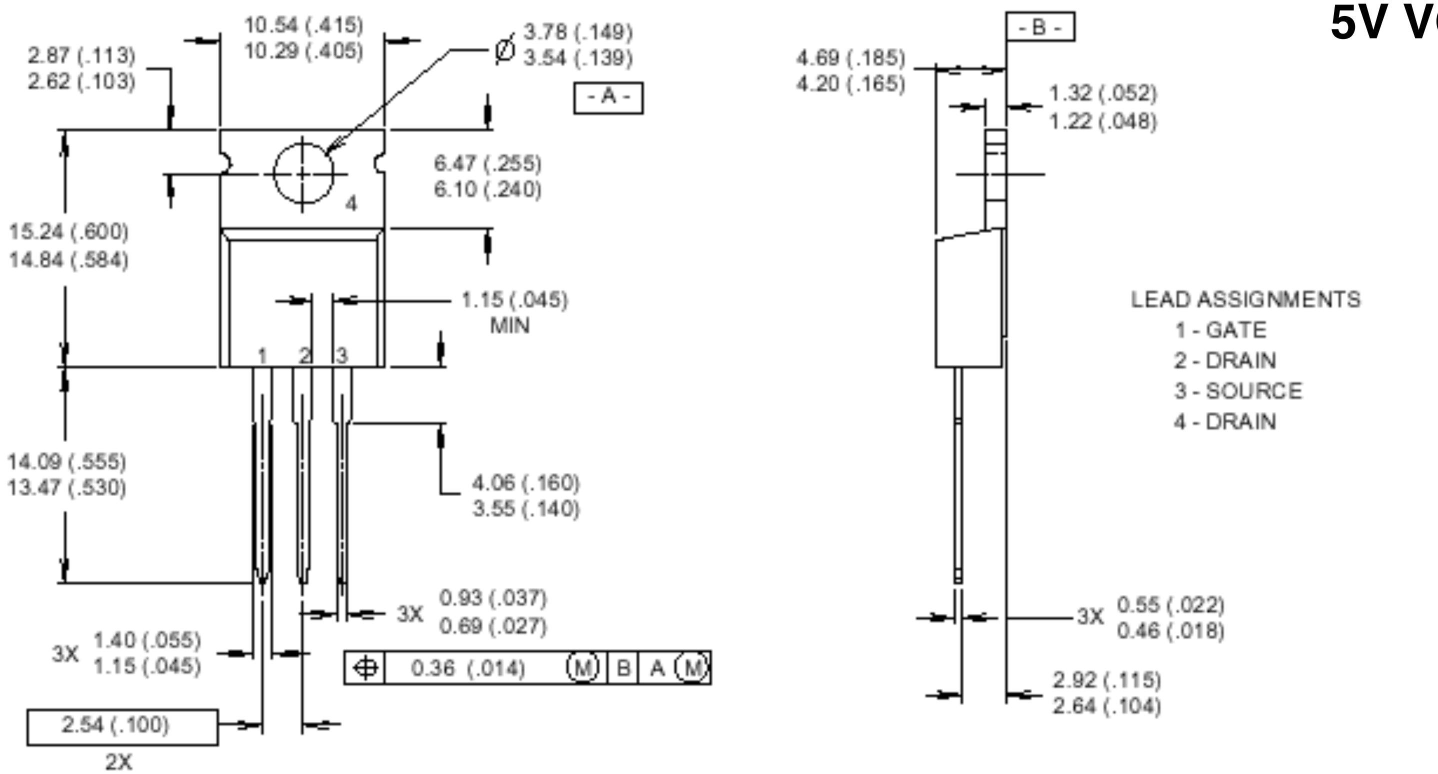
That pulse can destroy the transistor.

Typically a flyback diode is added.

IRLZ-34 Logic-Level MOSFET

60V, 30A, 0.05Ω

5V VGS



NOTES:

1 DIMENSIONING & TOLERANCING PER ANSI Y14.5M, 1982.

2 CONTROLLING DIMENSION : INCH

3 OUTLINE CONFORMS TO JEDEC OUTLINE TO-220-AB.

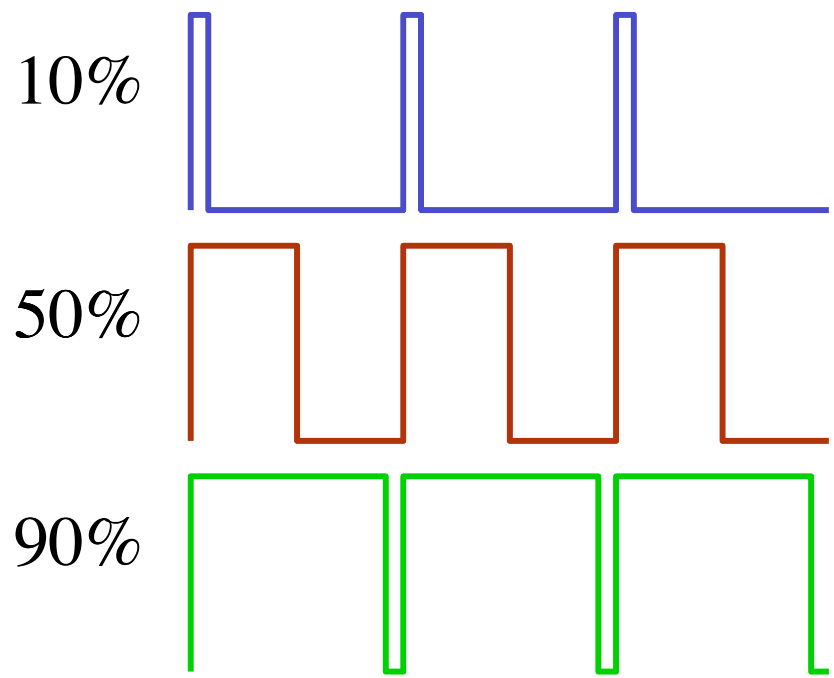
4 HEATSINK & LEAD MEASUREMENTS DO NOT INCLUDE BURRS.

$P_d = I^2R_{dson}$ For 30A, this is about 45W (BJT ≈ 6W).
For 1A, this is 50 mW, for BJT ≈ 200 mW.

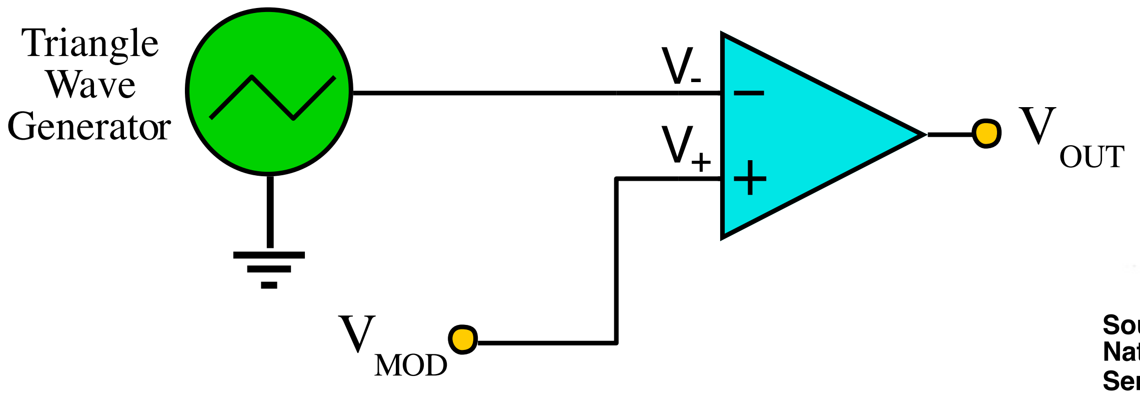

Relay

Pulse-Width Modulation

- **Pulse-width modulation, or PWM, offers a simple, DIGITAL output way of modulating power.**
- **The idea is to vary the duty cycle of pulses from zero to 100% and if the time constants of the device being driven are much longer than the pulse times, a low-pass filtered equivalent power is obtained.**



Random PWM Ideas



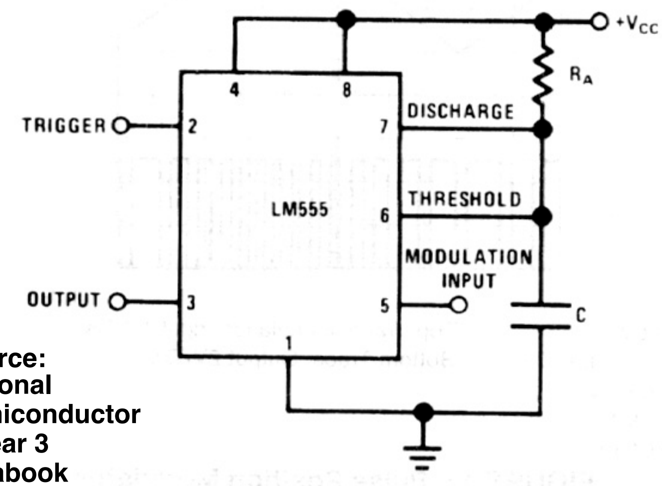
SG3525A/SG3527A

LM3524

Dedicated PWM Chips

PULSE WIDTH MODULATOR

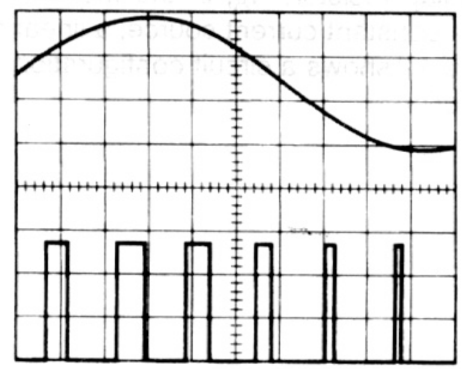
When the timer is connected in the monostable mode and triggered with a continuous pulse train, the output pulse width can be modulated by a signal applied to pin 5. *Figure 8* shows the circuit, and in *Figure 9* are some waveform examples.



Source: National Semiconductor Linear 3 Databook

TL/H/7851–12

FIGURE 8. Pulse Width Modulator

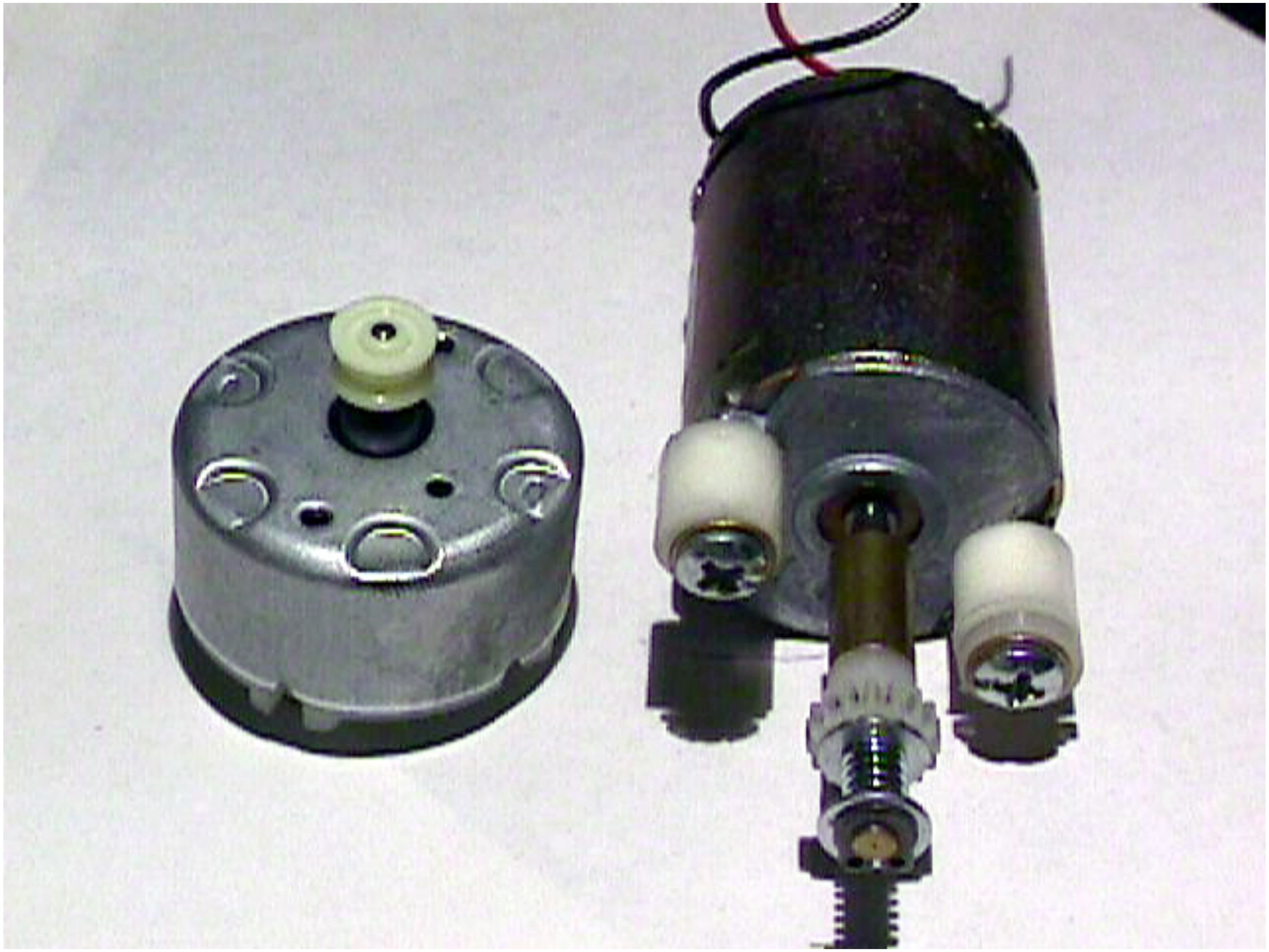


TL/H/7851–13

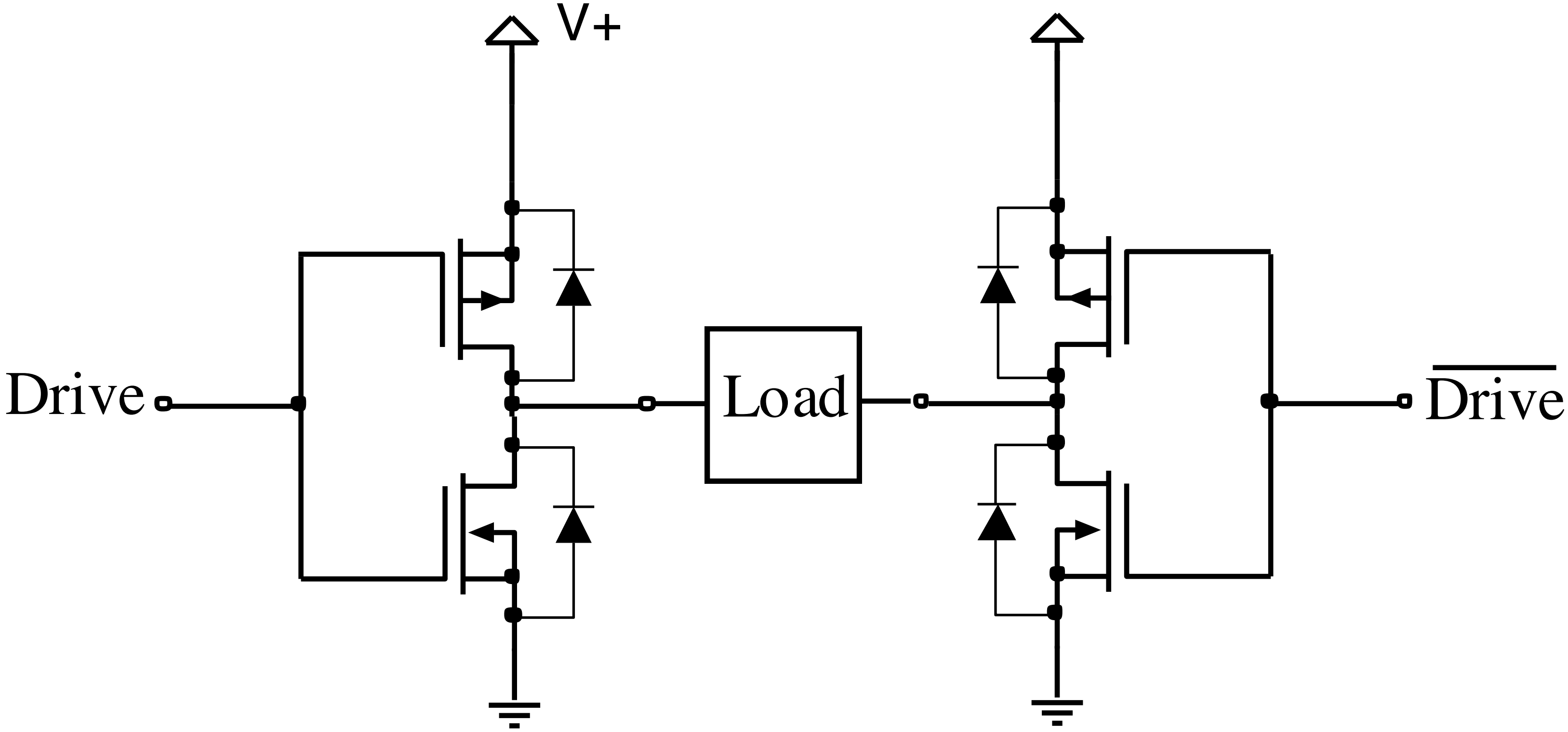
V_{CC} = 5V
TIME = 0.2 ms/DIV.
R_A = 9.1 kΩ
C = 0.01 μF

Top Trace: Modulation 1V/Div.
Bottom Trace: Capacitor Voltage 2V/Div.

DC Motors

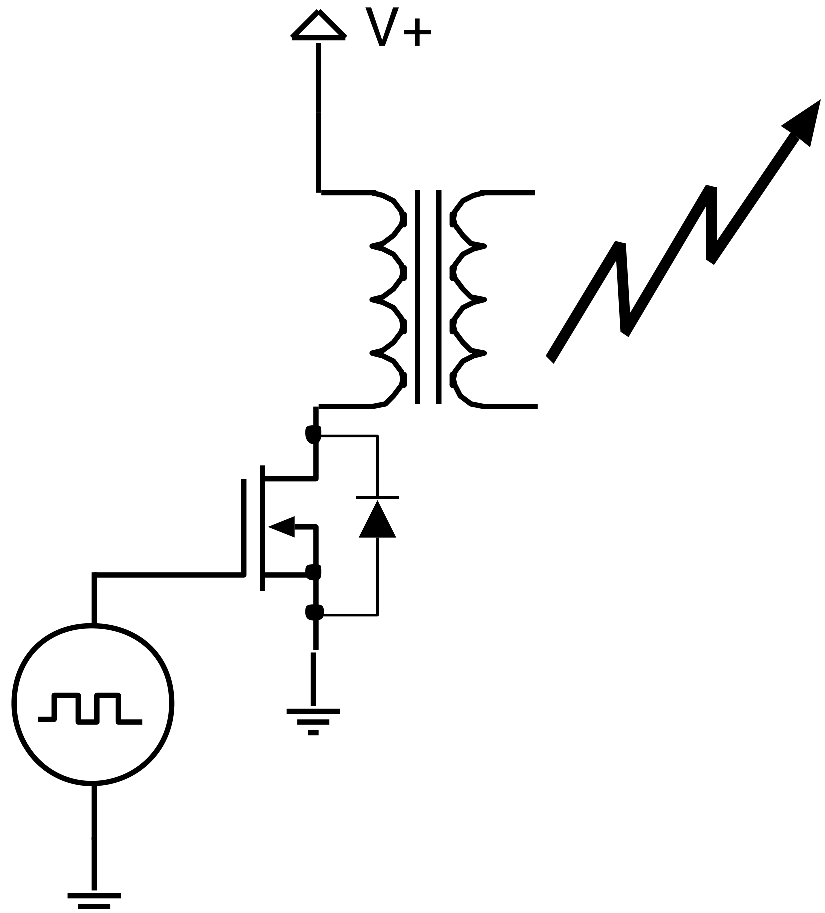


Bipolar Power Switches



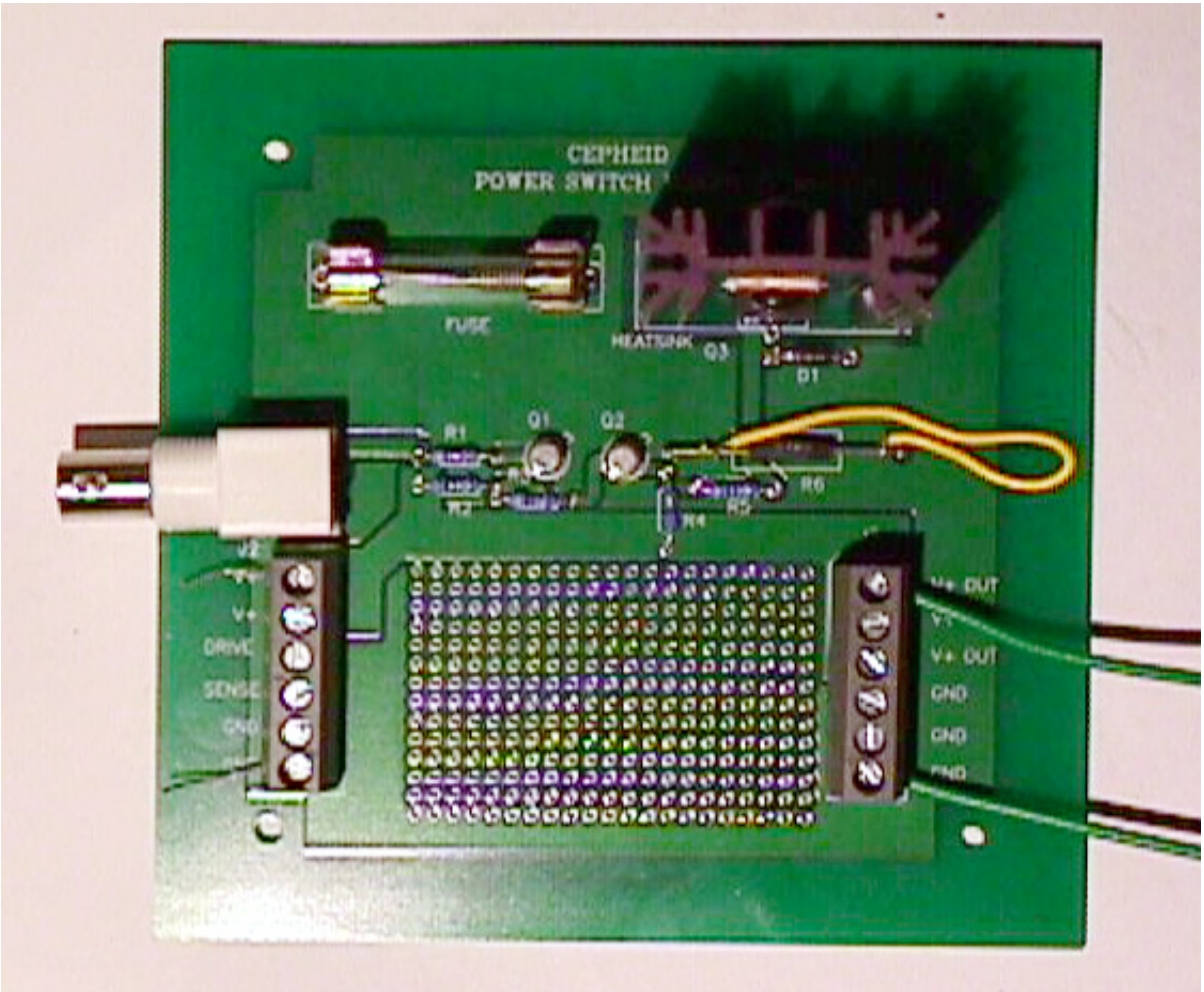
Power Inverters

- **Digital drive to transformer to generate higher or lower voltage.**
- **Can use to power fluorescent lights, AC appliances, or to generate higher DC voltages (need rectifier and filter).**
- **Can make negative supply rail.**

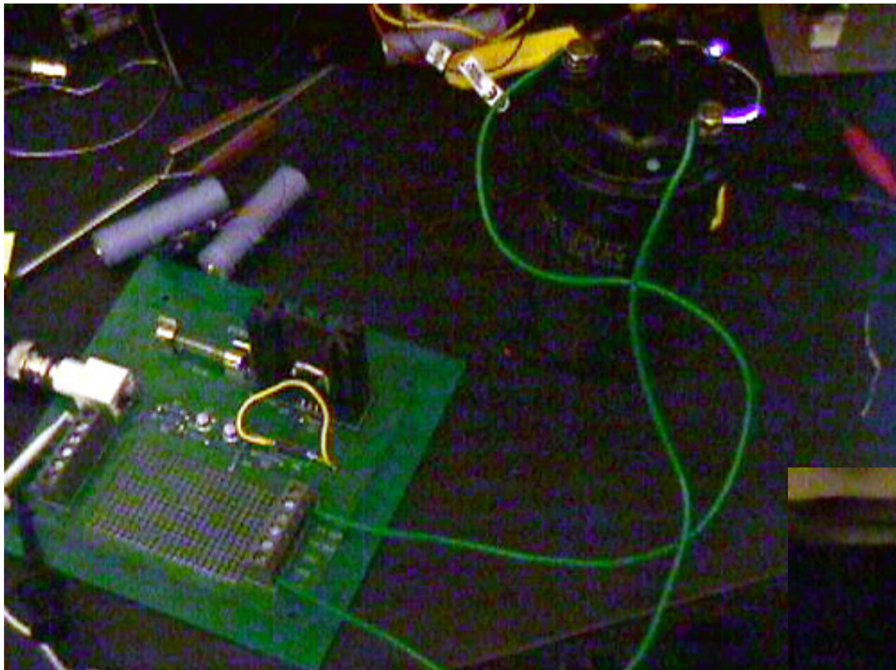


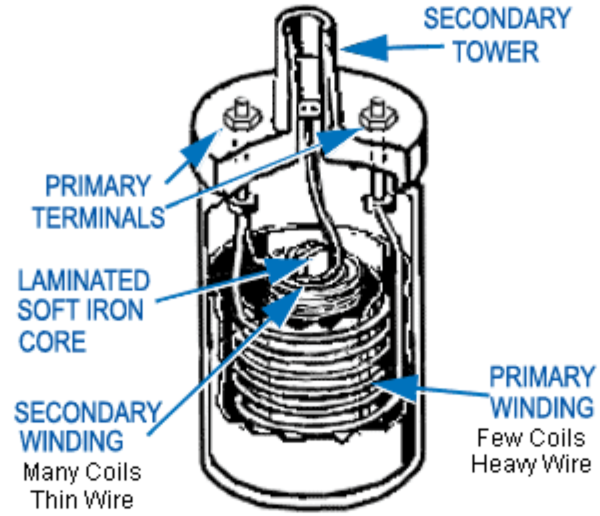
There are more efficient ways, but this illustrates the basic idea.

MOSFET Power Driver

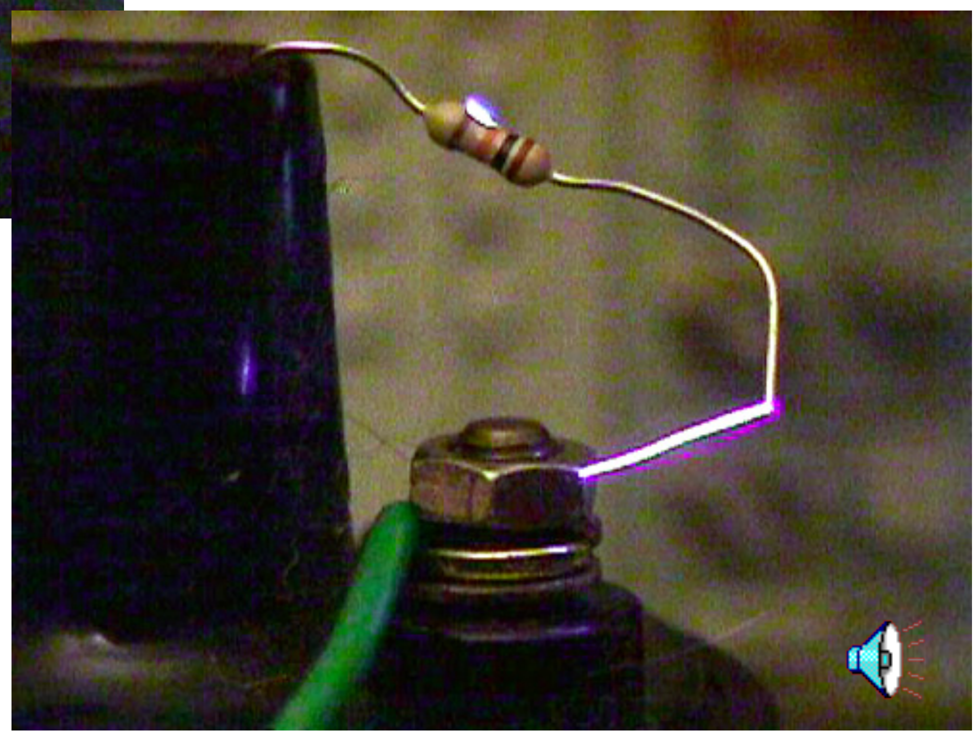


HV Inverter





http://www.familycar.com/Classroom/ignition.htm



Danger – if you do not know what you are doing with high voltage, DO NOT attempt this.

We accept no liability.

Power Voltage Sources

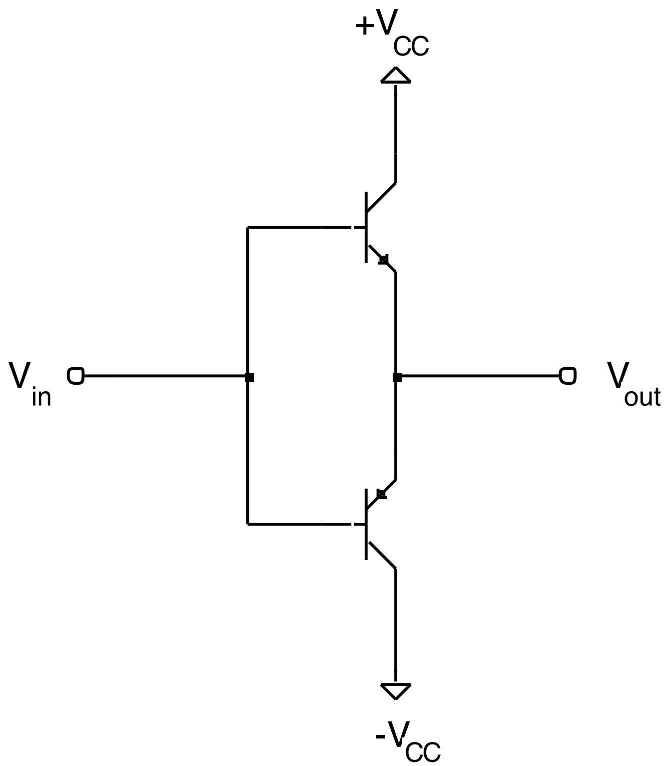
- In some cases, a "beefy" and variable voltage source is needed (e.g., audio power amplifiers, signal generator outputs, power supplies, etc.)
- In this case, one can either purchase power op-amps and use them in the standard configurations, or use power booster circuits with conventional, low-cost op-amps.

POWER AMPLIFIERS

- **Quite often, voltage swings and power levels needed exceed the capabilities of basic op-amps.**
- **This calls for external circuitry, and the next section is a discussion of such circuits – in particular the "push-pull" or Class AB amplifier.**
- **Key to this is the effects an op-amp can have on reducing distortion when external circuits are placed inside the op-amp's feedback loop.**

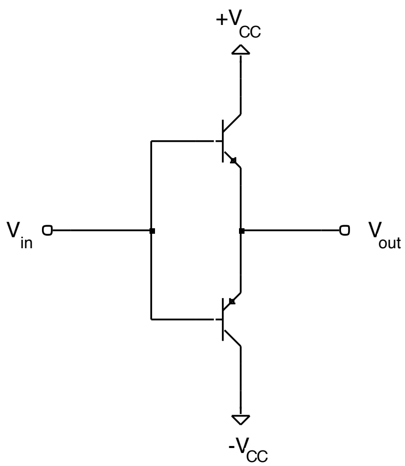
THE COMPLEMENTARY EMITTER FOLLOWER AMPLIFIER ("PUSH-PULL")

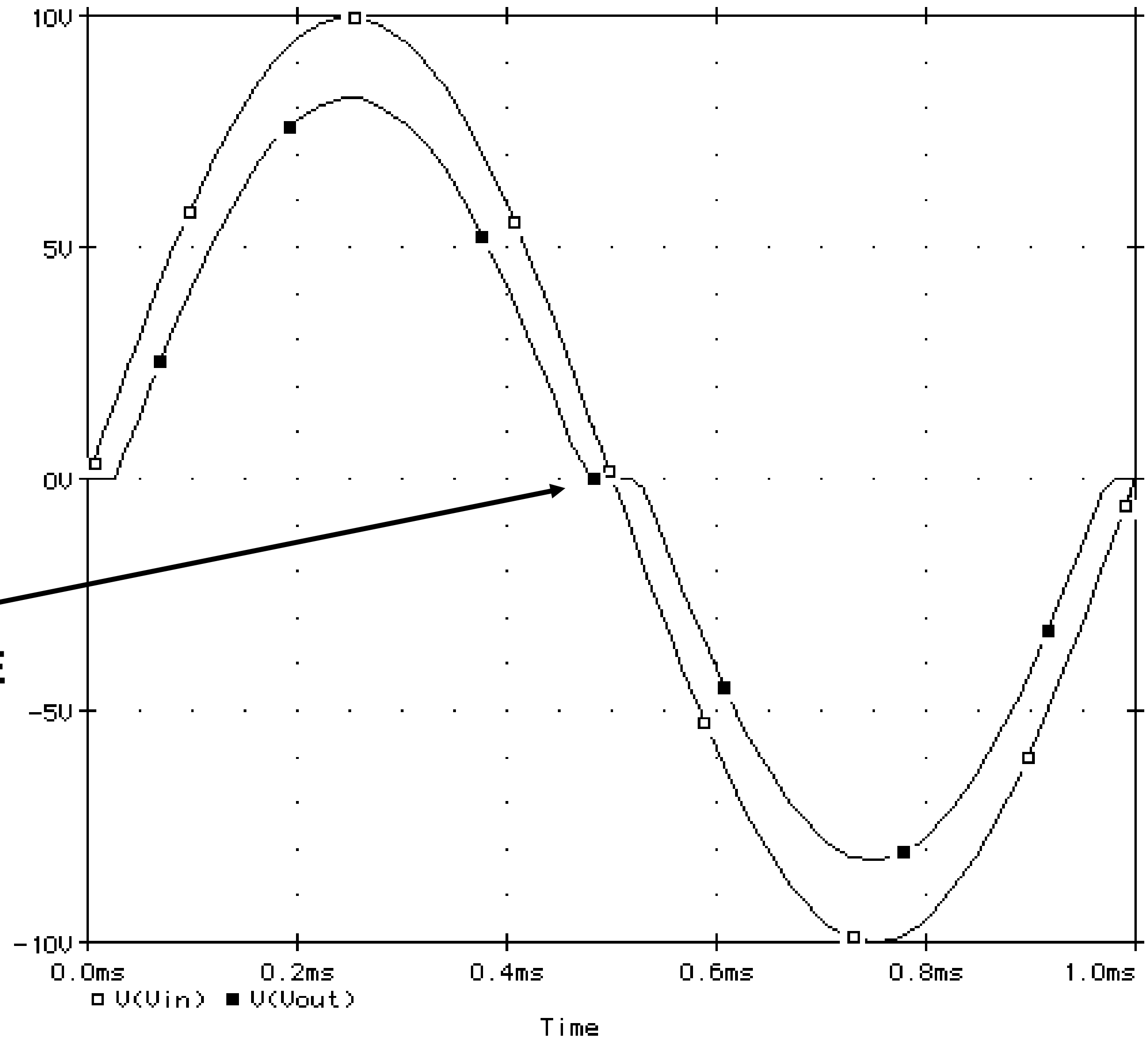
- A COMPLEMENTARY PAIR OF TRANSISTORS ARRANGED AS TWO EMITTER FOLLOWERS CAN PROVIDE LOTS OF POWER WITH INEXPENSIVE PARTS!
- VERY EFFICIENT (APPROXIMATELY 80%)
- CAN ALSO PROVIDE A DISTORTED SIGNAL DUE TO CROSSOVER DISTORTION…
- CAN DO THE SAME WITH MOSFETS



THIS IS A "CLASS AB" CIRCUIT

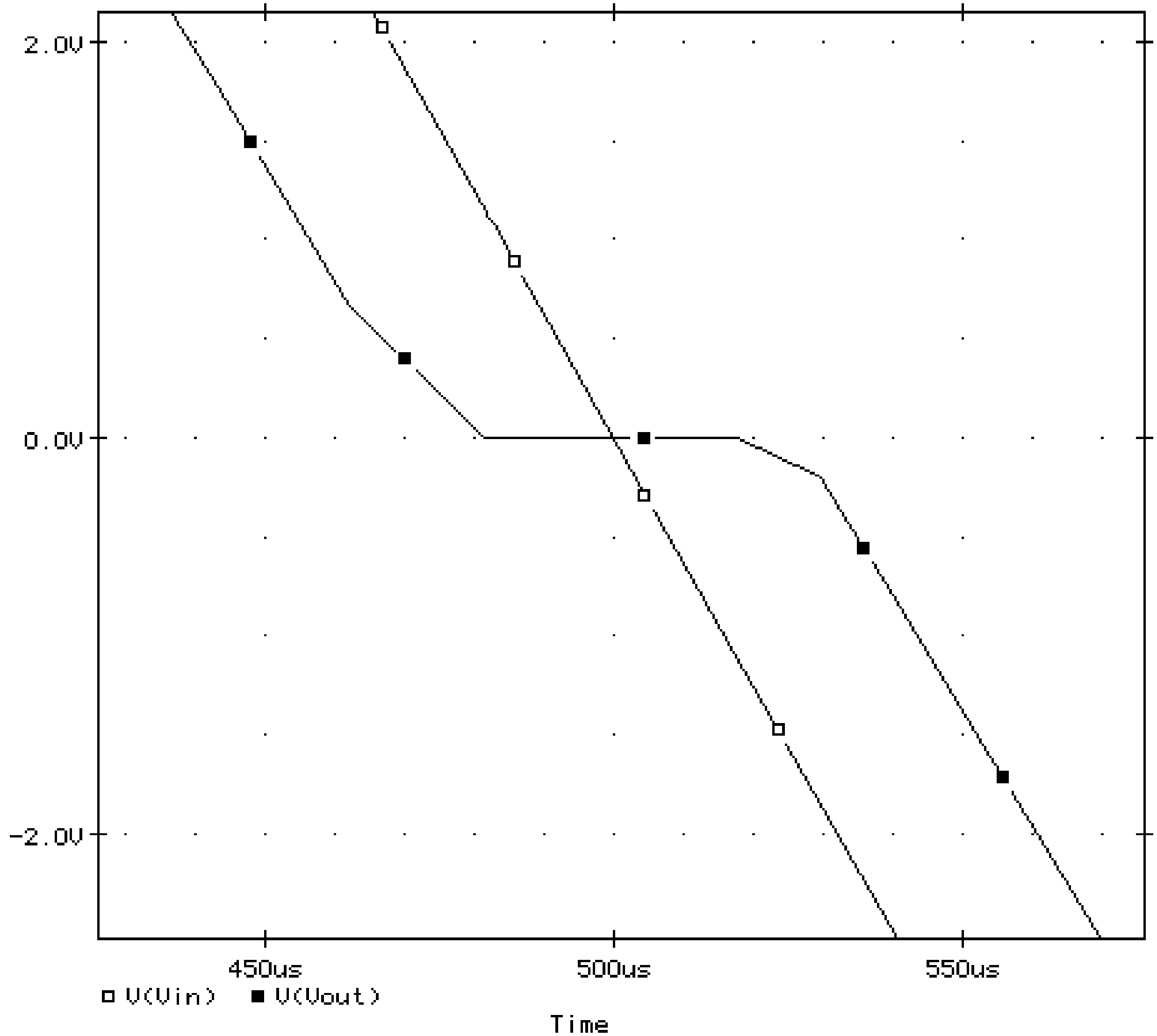
CROSSOVER DISTORTION



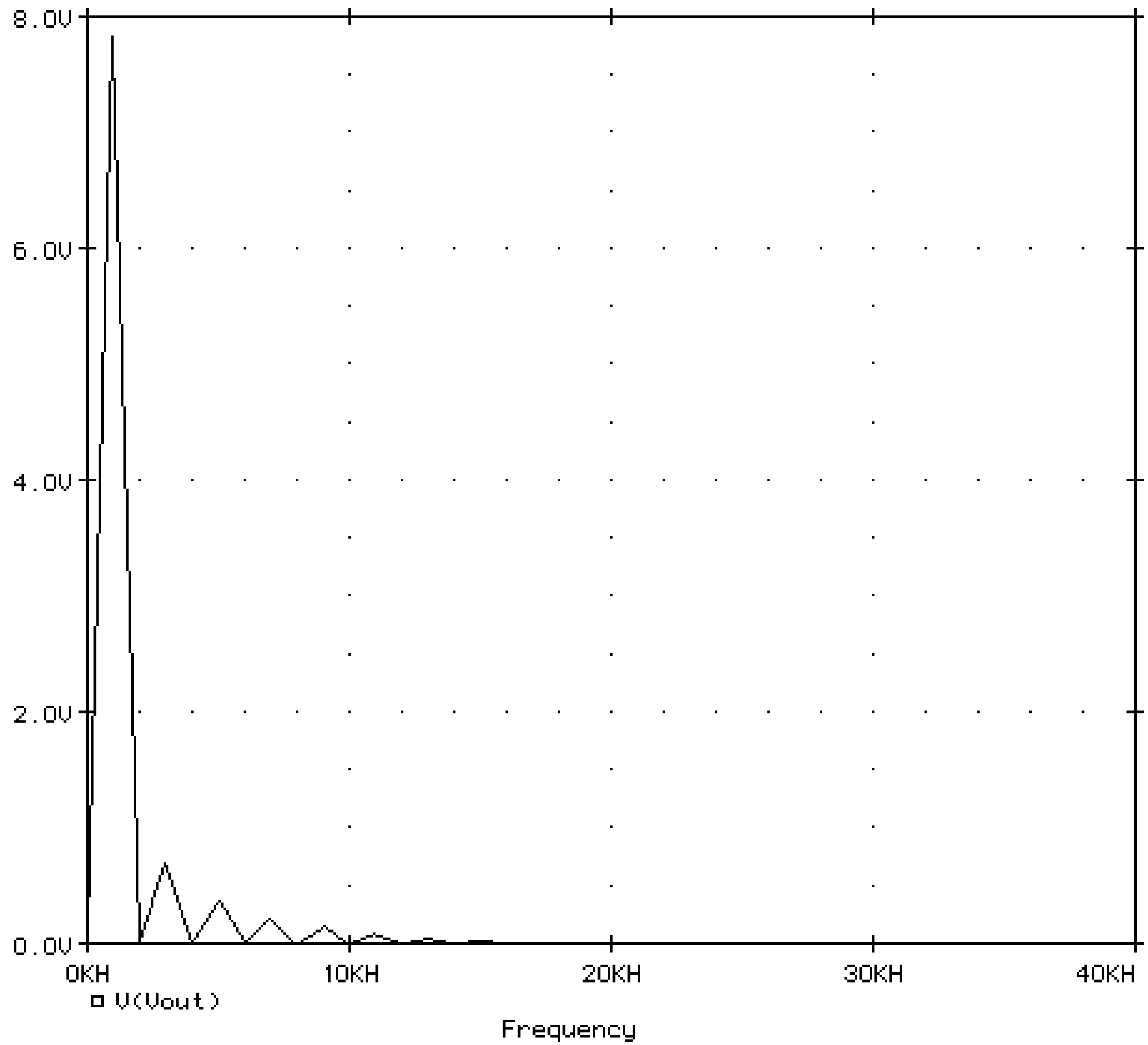


- THERE IS A +/- 0.7 V "DEADBAND" WITHIN WHICH THE NEITHER TRANSISTOR IS CONDUCTING...

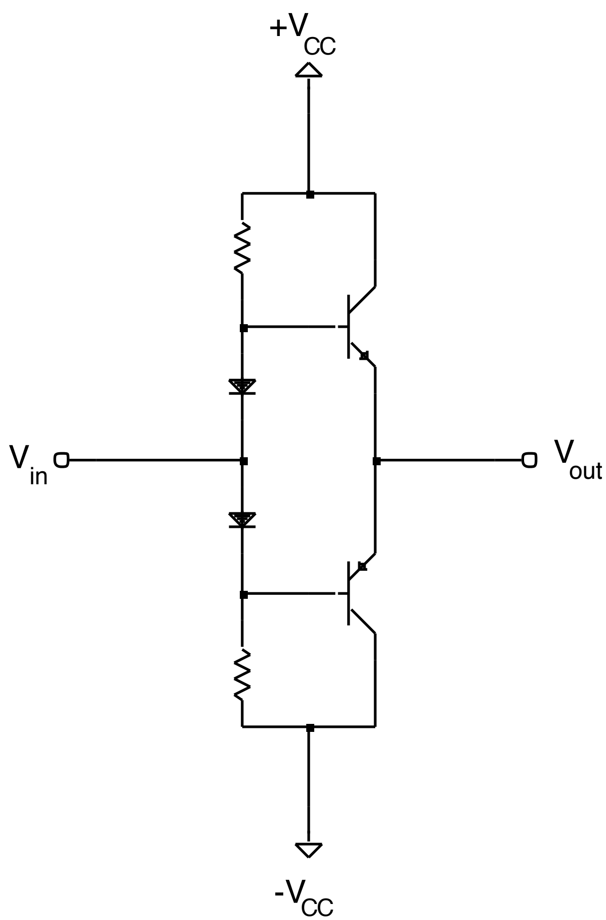
A CLOSE LOOK AT THE DISTORTION



OUTPUT SPECTRUM OF CLASS B AMPLIFIER WITH CROSSOVER DISTORTION



REDUCING CROSSOVER DISTORTION WITH BIASING DIODES...



THIS IS A "CLASS AB" CIRCUIT

HAYES & HOROWITZ SAY....

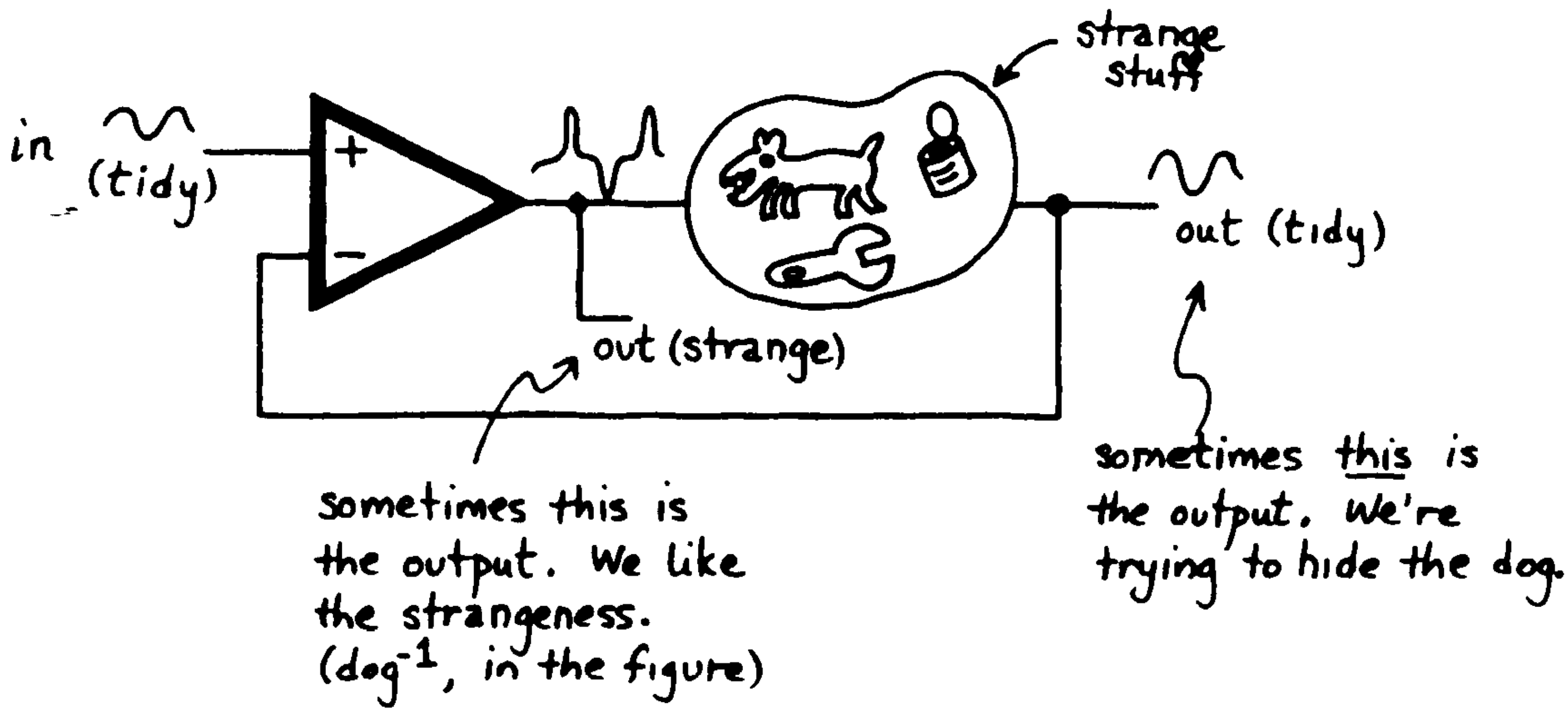
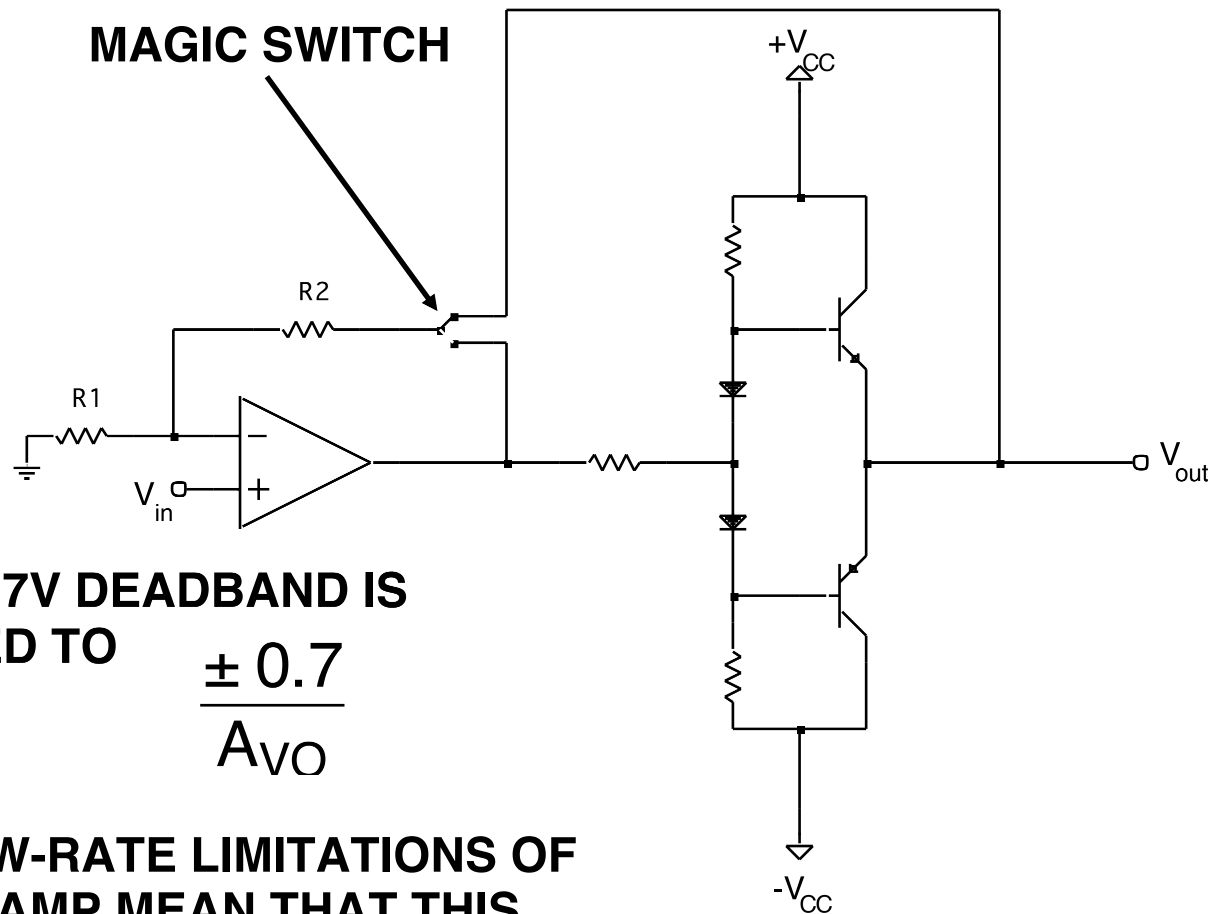


Figure N8.12: Op Amps can tidy up after strange stuff within the loop

BETTER PERFORMANCE WITH FEEDBACK!

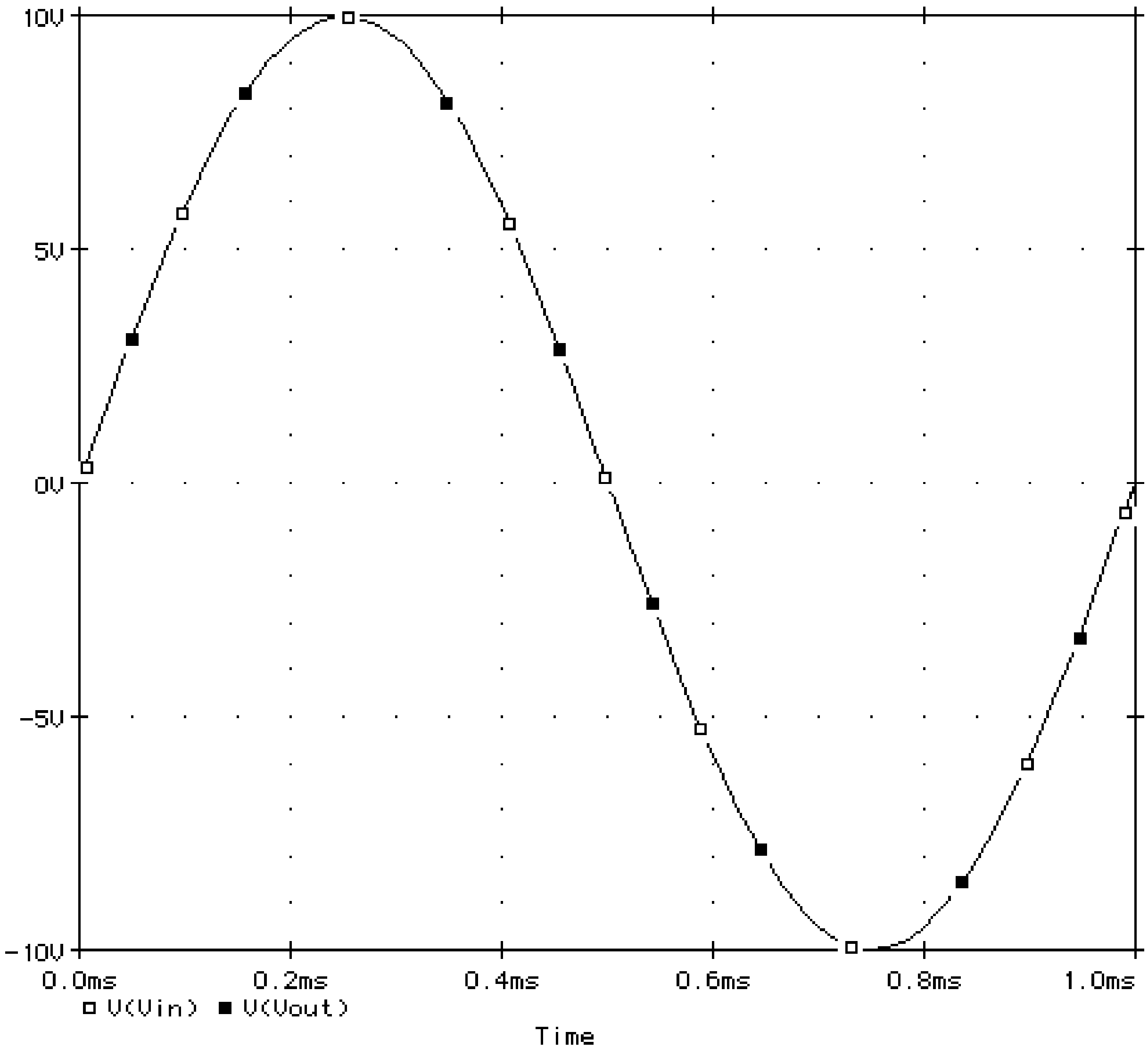
MAGIC SWITCH



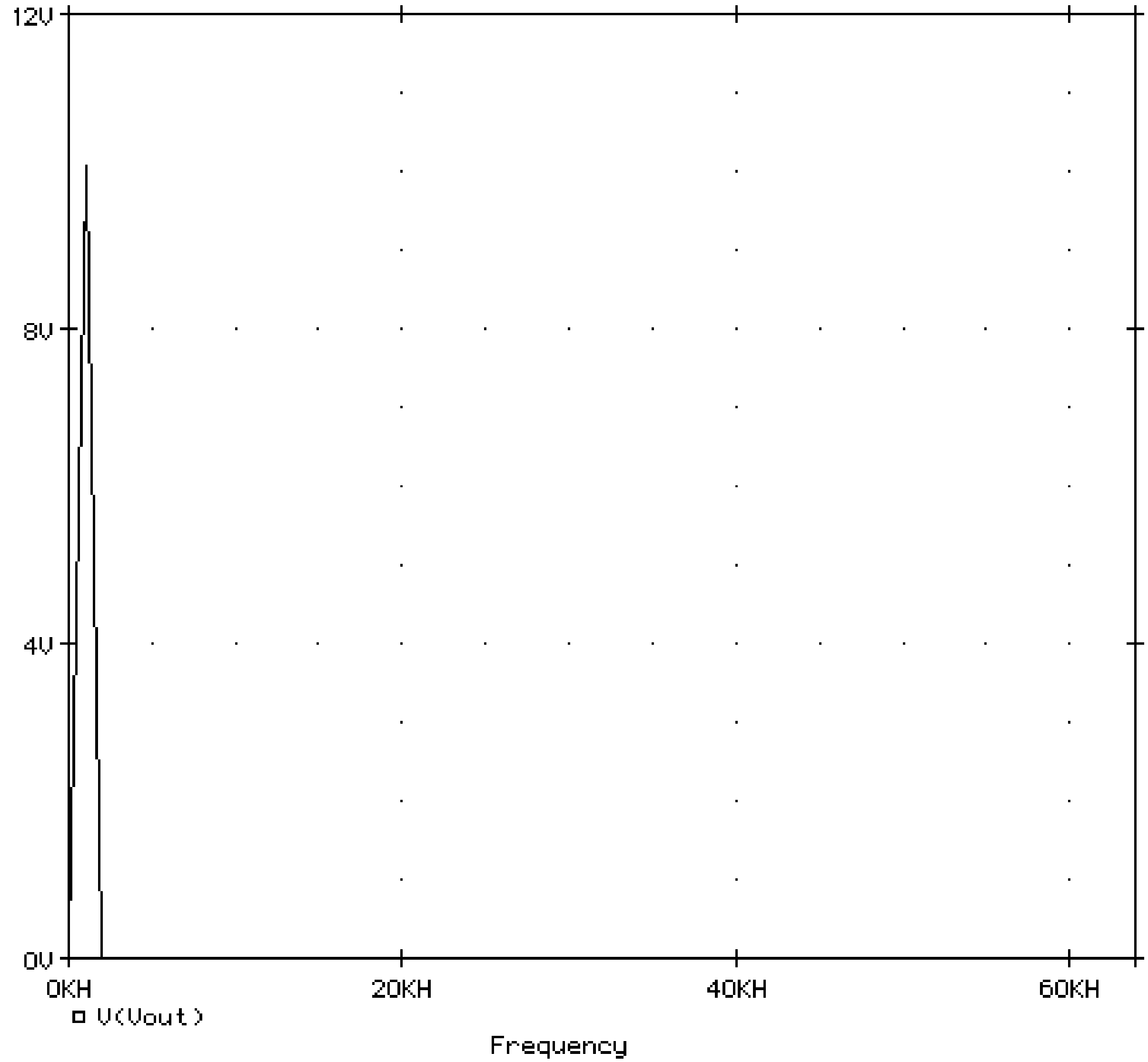
- THE +/- 0.7V DEADBAND IS REDUCED TO $\dfrac{\pm 0.7}{A_{VO}}$

- THE SLEW-RATE LIMITATIONS OF THE OP-AMP MEAN THAT THIS DEADBAND WILL STILL BE APPARENT AT HIGH FREQUENCIES....

SEE ANY DISTORTION?



OUTPUT SPECTRUM OF THE SAME PUSH-PULL AMPLIFIER WITH FEEDBACK



Modern Vacuum Tube Audio

Conrad-Johnson Premier 16LS

Vacuum Tube Preamplifier

A reference quality line-level tube preamplifier with the convenience of a remote control. Low output impedance enables this preamplifier to drive any interconnects without the loss of critical high frequencies. A top-rated preamp among audiophiles.

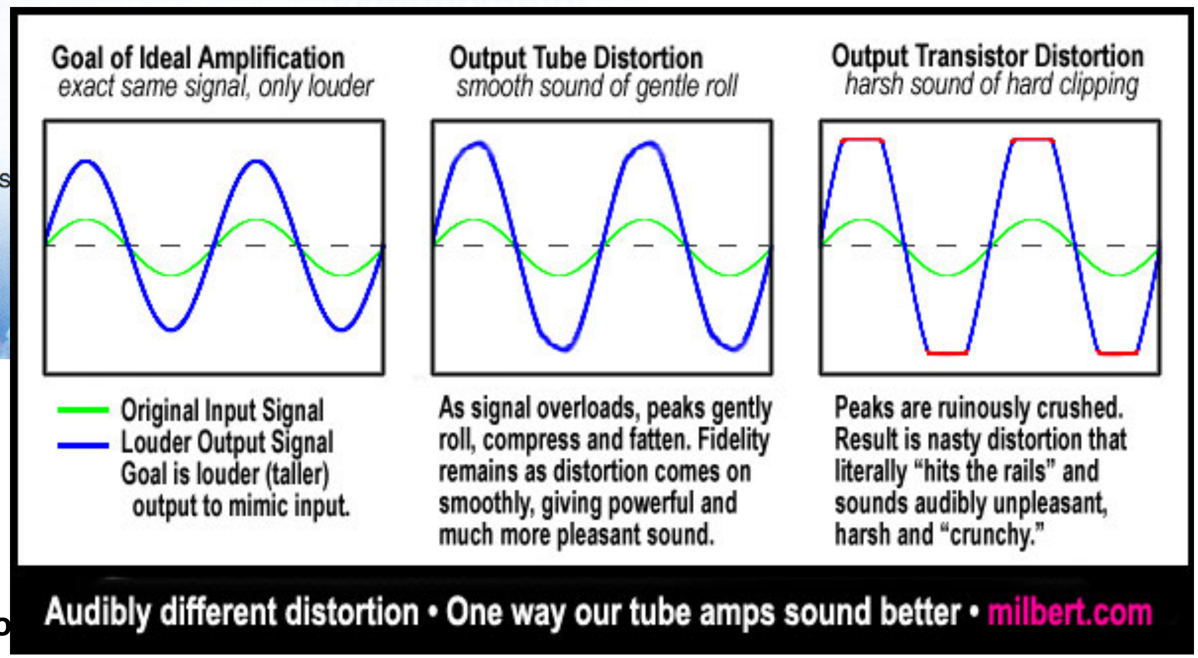
Conrad-Johnson Premier 12 Monoblocks

Vacuum Tube Power Amplifier

A purist tube power amplifier with superb presentation of tonal balance and timbre. Sound stage is wide and deep with no presence of electronic hardness or glare. Highly recommended for those who seek natural tonality and clarity without the listening fatigue.

From http://www.soundperfection.com/

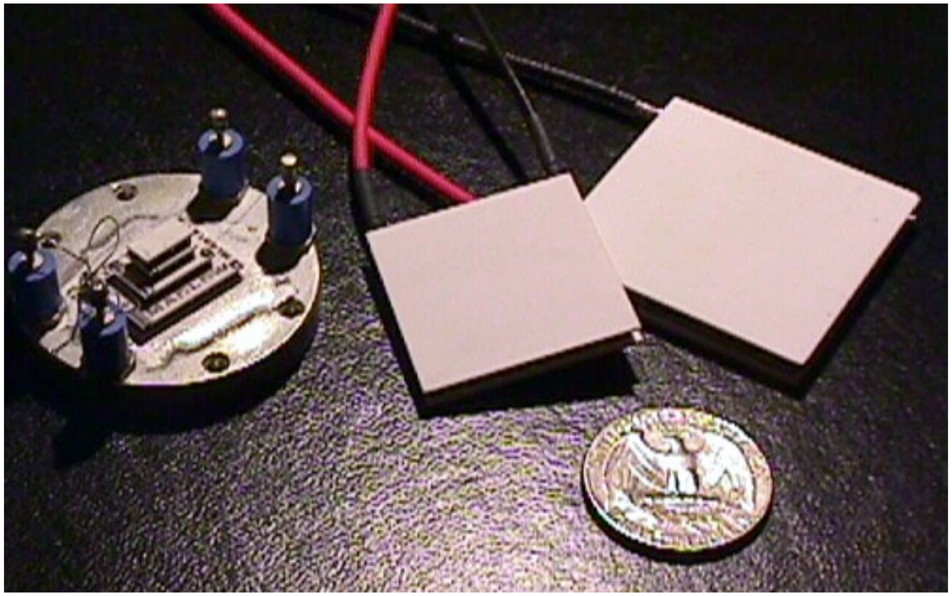
Why different? Distortion!

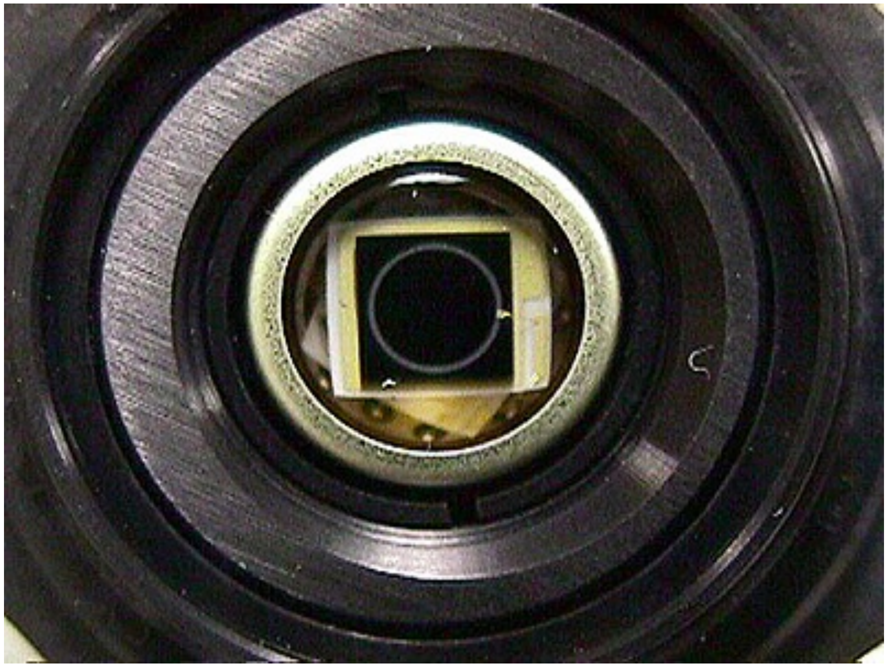


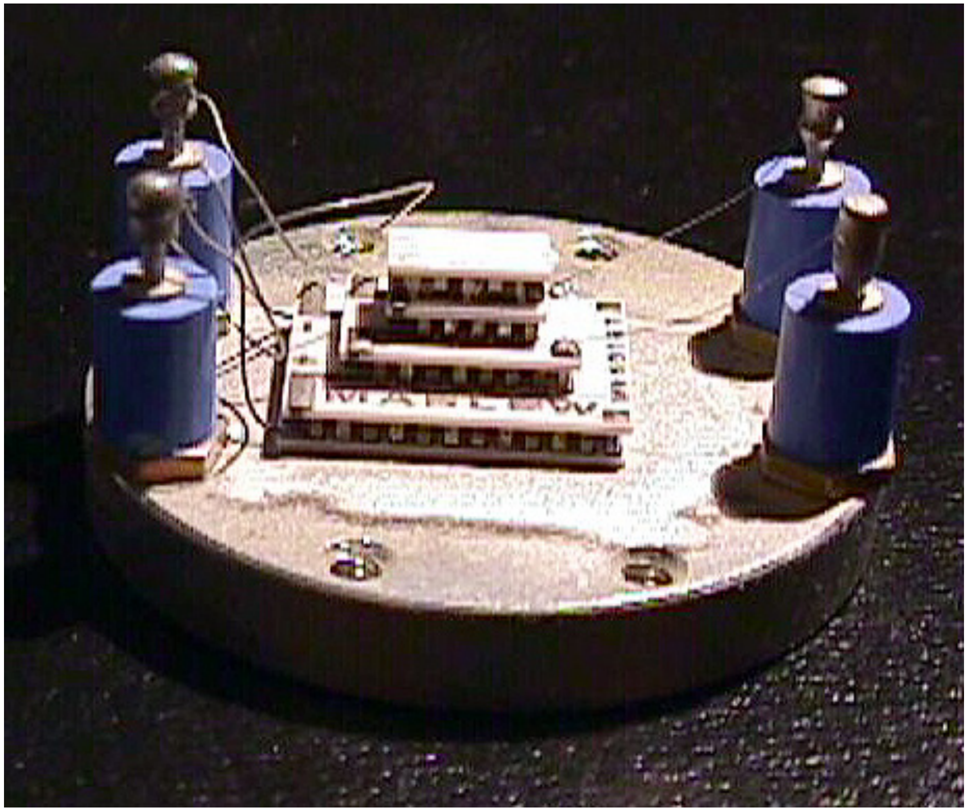
From milbert.com

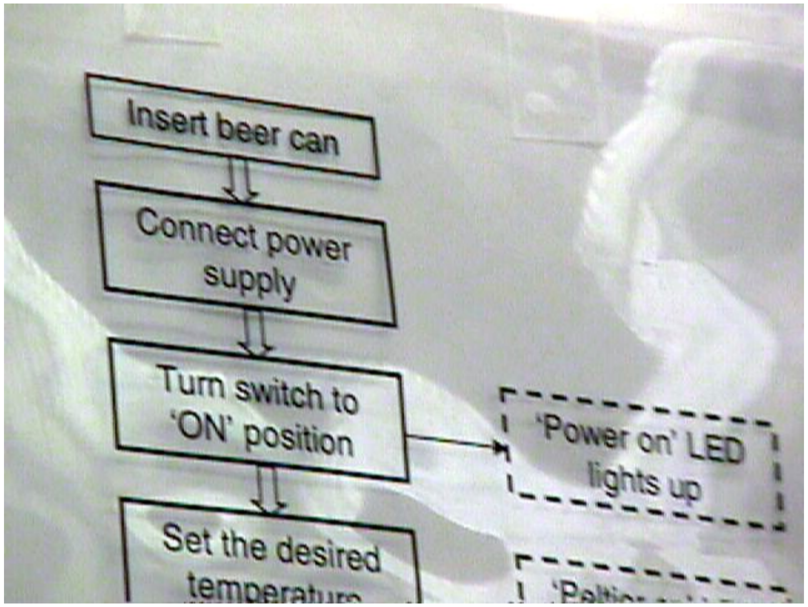
Peltier Devices

Cooling without pumps!

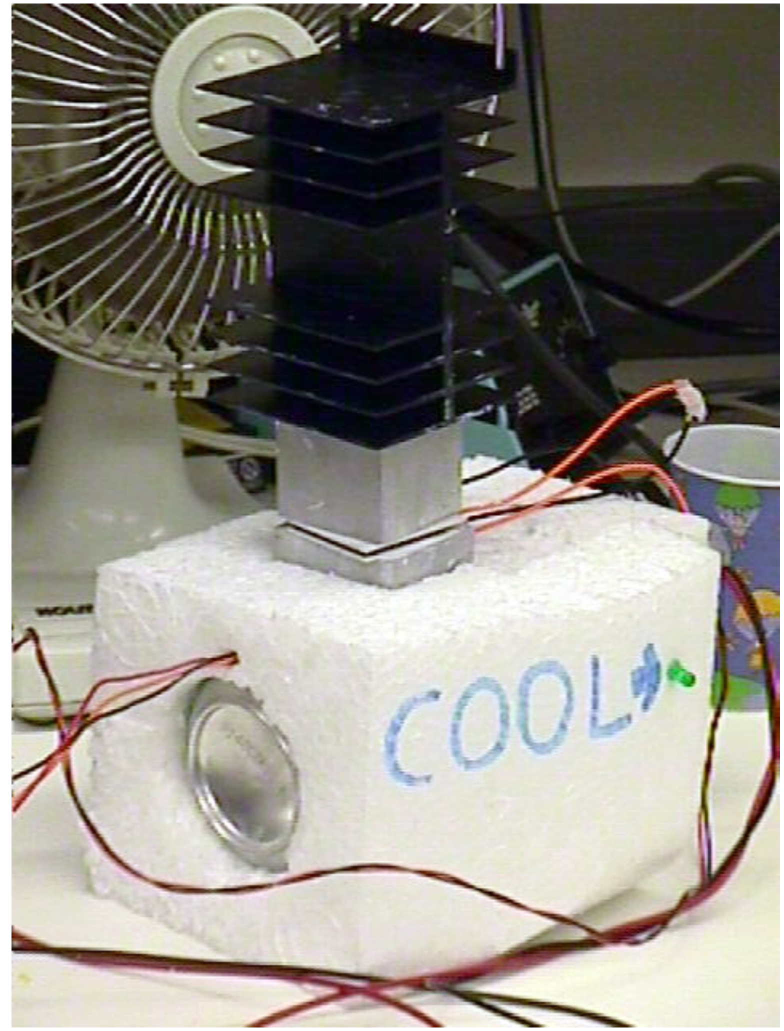


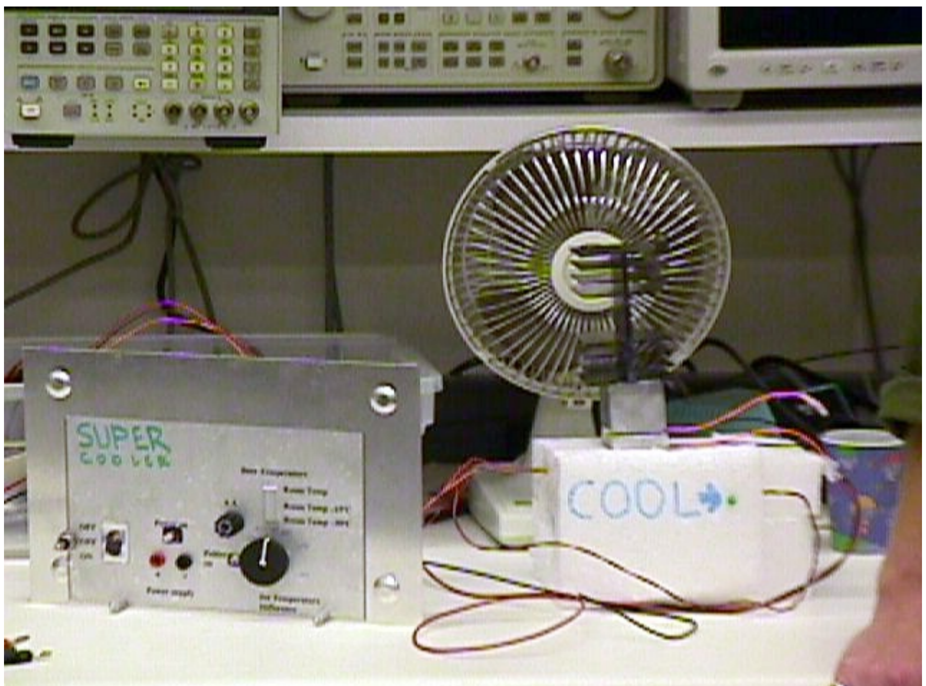


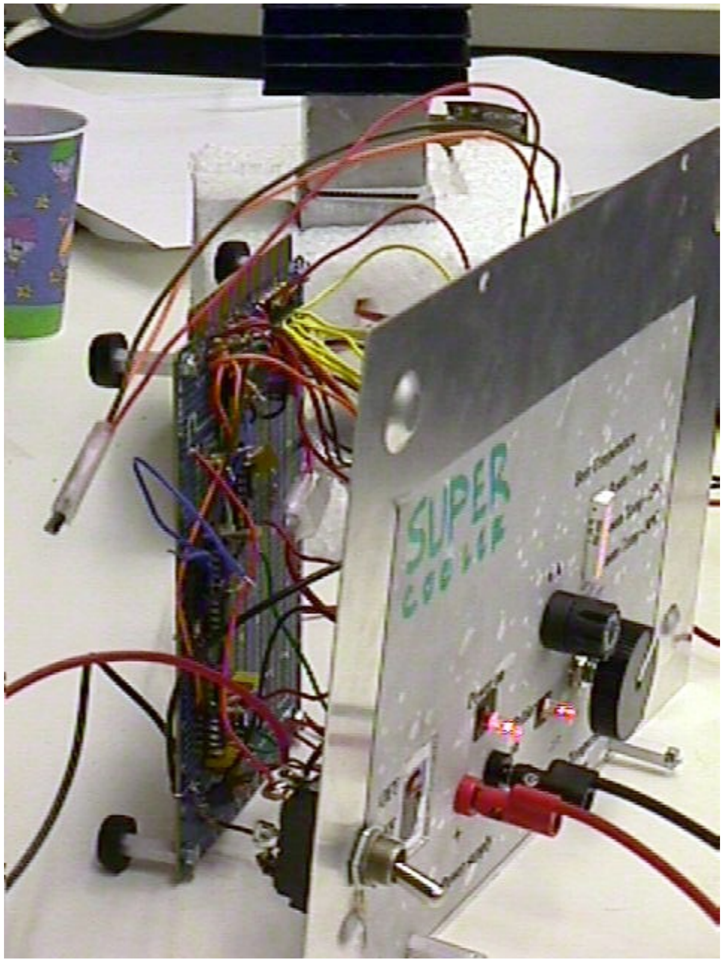




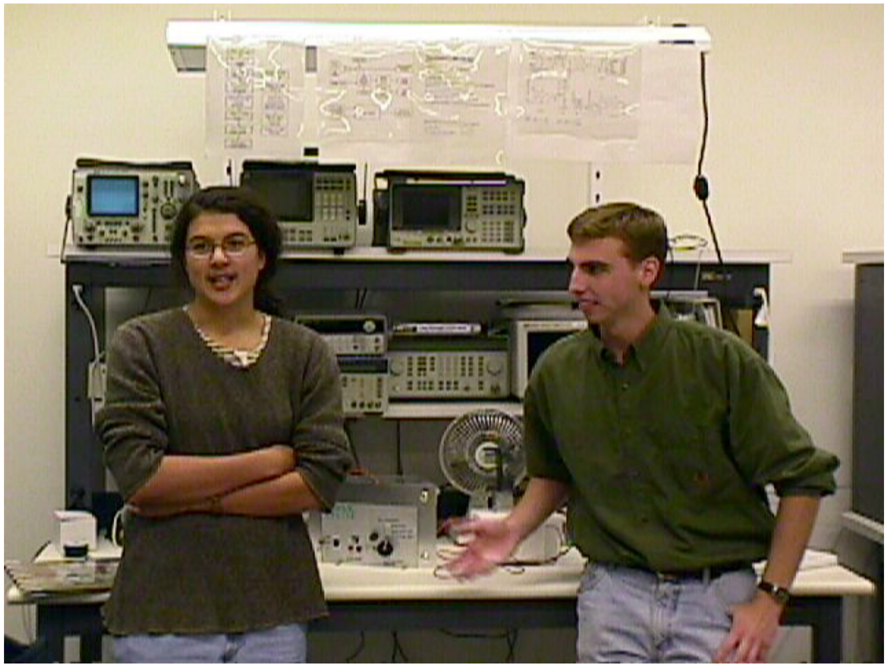
Drink Cooler #2



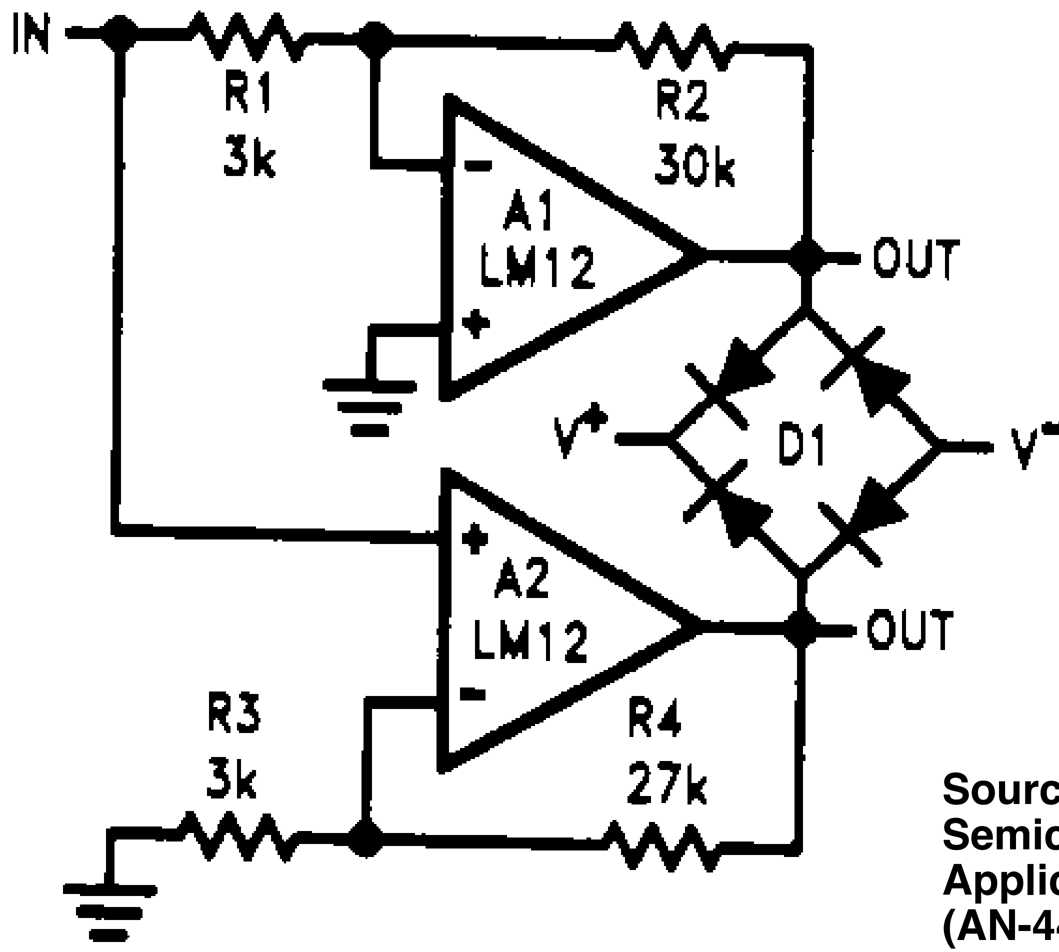





SUPER
COOLER
Beer Temperature
Room Temp
Room Temp -15°C
Room Temp -30°C
6 A
Power on
OFF
Peltier
+
Power supply



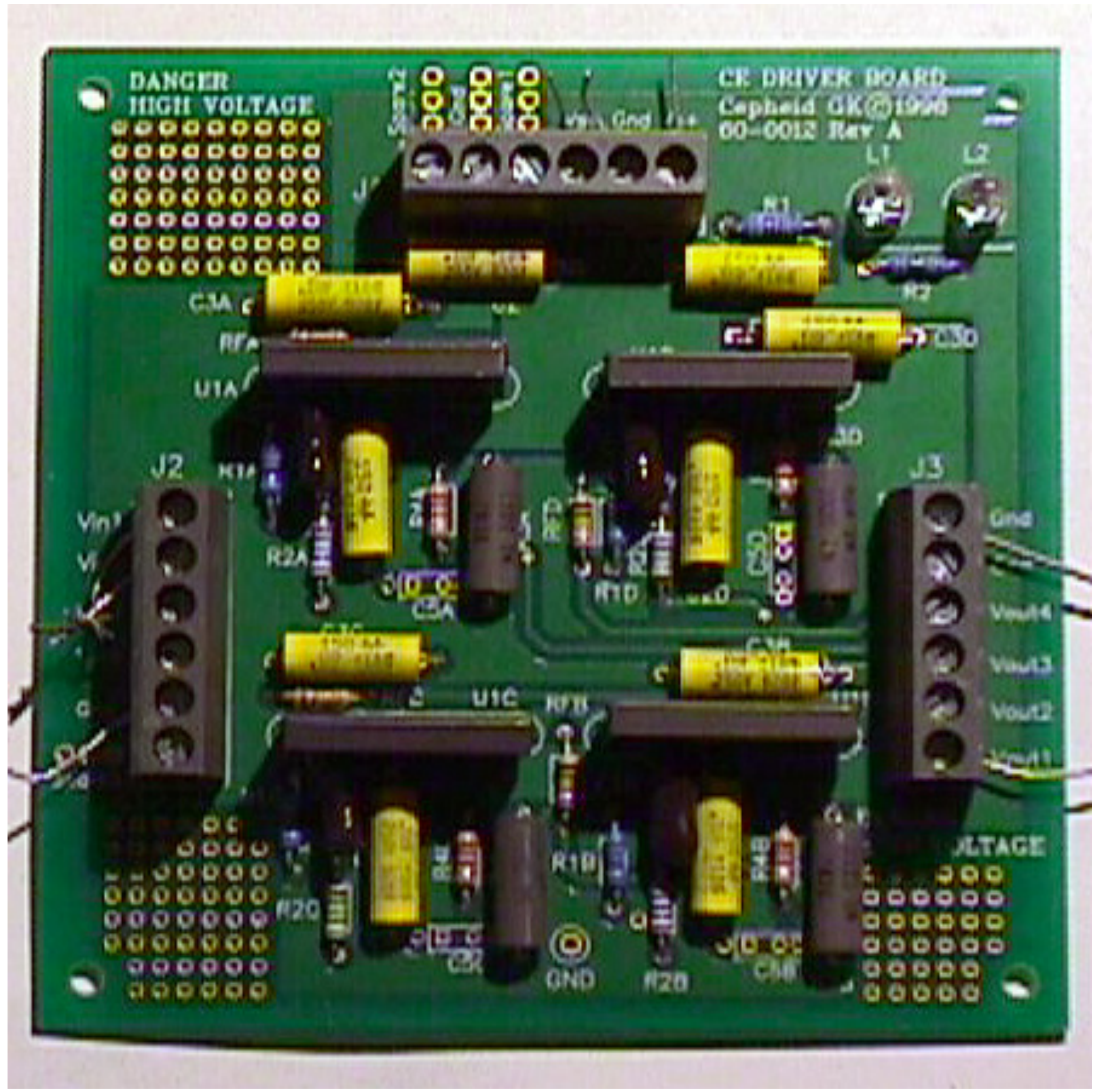
The Bridge Configuration



Source: National Semiconductor LM12 Application Note (AN-446).

High Voltage Amplifiers

- **For high voltage op-amp applications, recent price reductions in HV op-amps make it possible to use standard configurations easily.**
- **www.apexmicrotech.com is a good source of chips and application notes.**

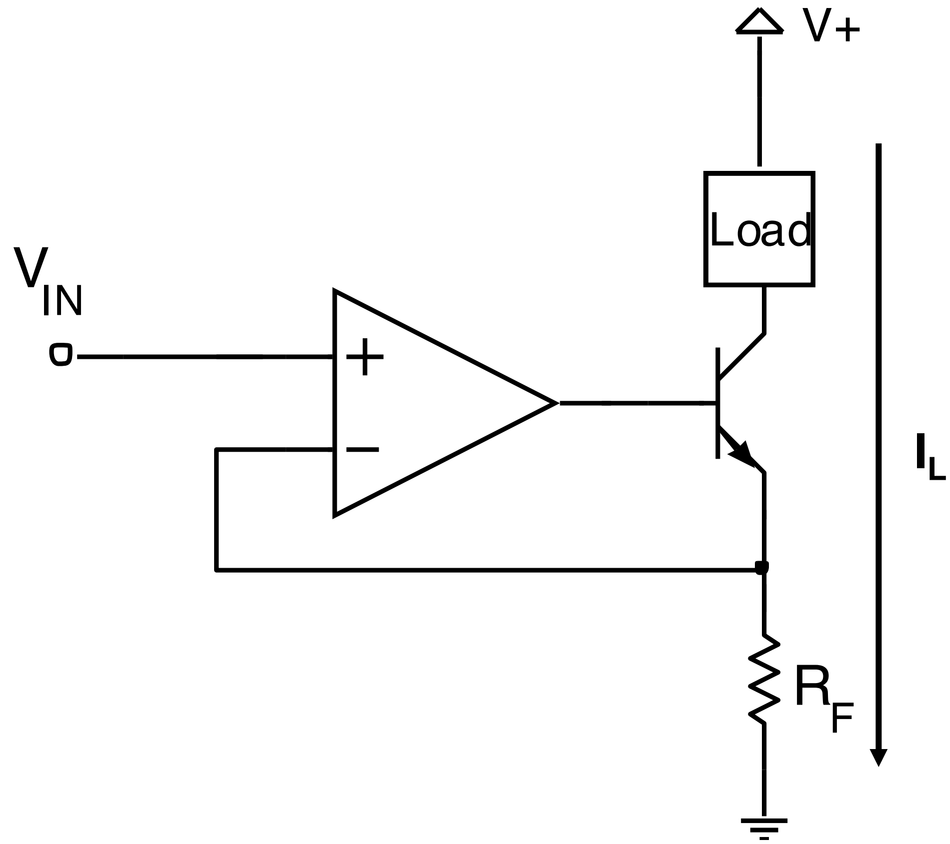


Current Sources/Sinks/Pumps

- Many transducers require current sources to drive them (e.g., electromagnetic coils in some settings, lasers, LEDs, etc.).
- There are several simple current driver circuits that use op-amps to provide closed-loop control, and the high output impedances required.
- The basic principle is to sense the sourced (or sunk) current and convert it into a signal for feedback purposes.
- If the desired currents exceed the capabilities of the op-amp, external "pass" transistors are used.

Classic Op-Amp Current Sink

$$I_L = \frac{V_{IN}}{R_F}$$




Beer-Locked-Loop

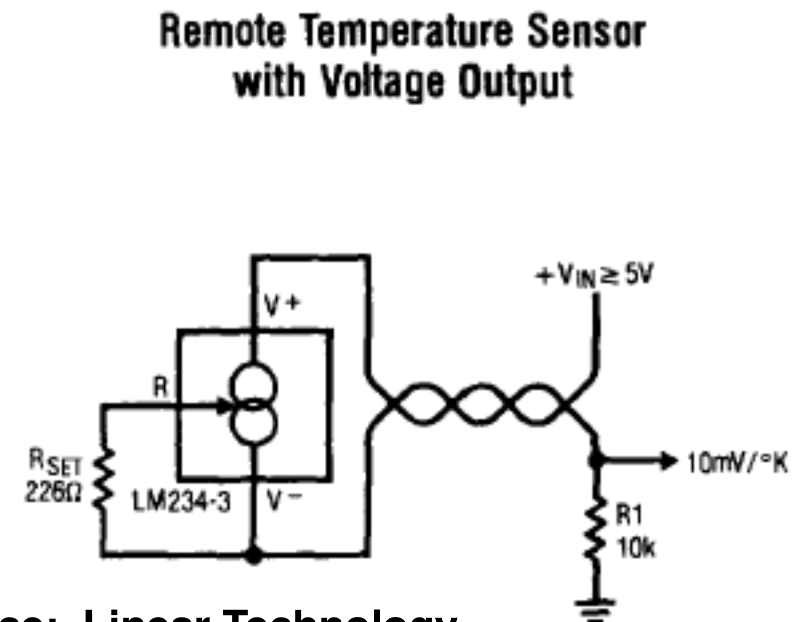
Types of Sensors

- Electromagnetic Coils (Lab 1)
- Strain Gauges
- Accelerometers
- Microphones
- Optical (covered elsewhere)
- Temperature Sensors

Sensor Signal Processing

- **Typical sensor signal processing involves (pre)amplification, filtering and sometimes some downstream functions.**
- **Downstream functions may include a comparator (decision) or A/D converter, sometimes preceded by a sample-and-hold circuit.**
- **In some cases (not covered in EE122), the sensor signal (before or after digitization) is transmitted to another location using telemetry.**

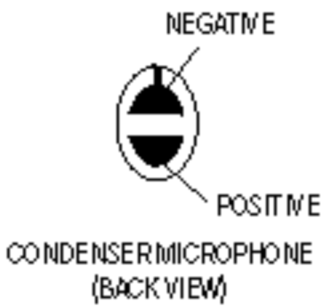
LM334 Temperature Sensor

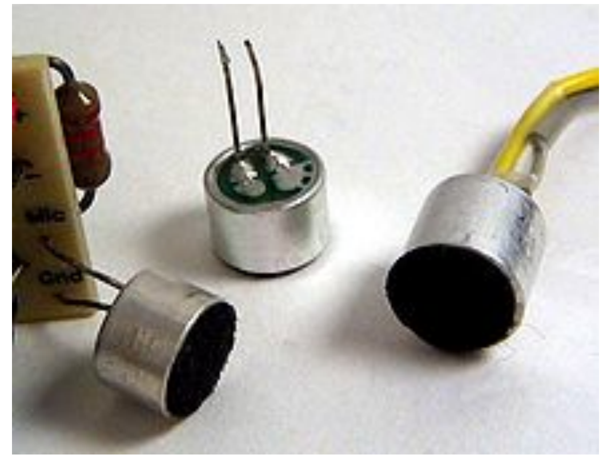


Source: Linear Technology
LM334 Datasheet.

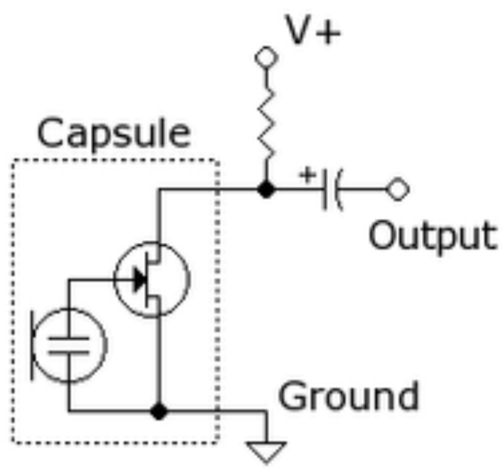
Note that current-output sensors allow quite long wire lengths, since they are pretty much insensitive to cable resistance.

Hooking Up Microphones





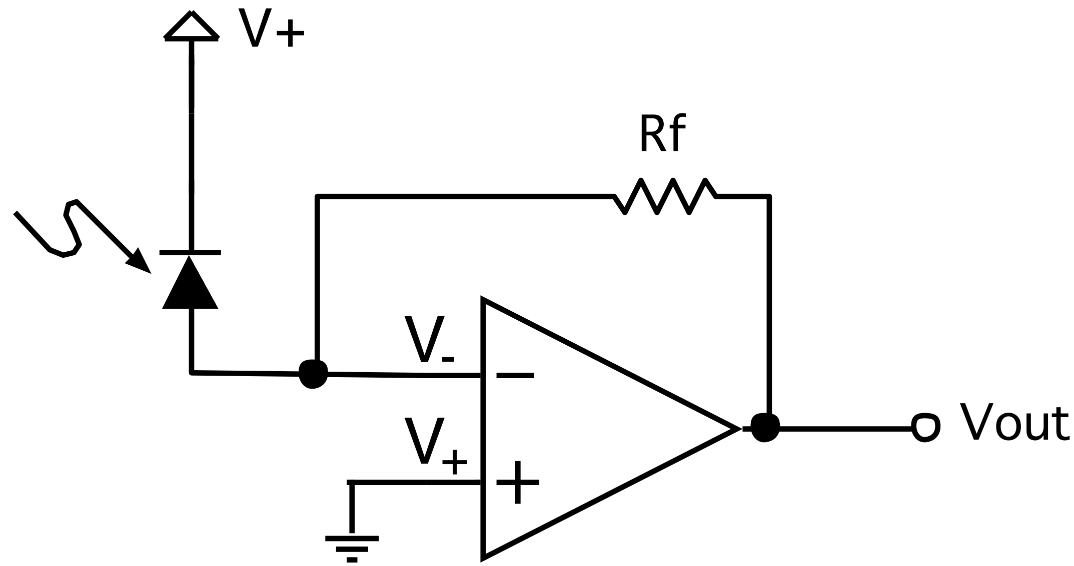
http://en.wikipedia.org/wiki/Electret_microphone



http://www.epanorama.net/circuits/microphone_powering.html

Transresistance Amplifiers

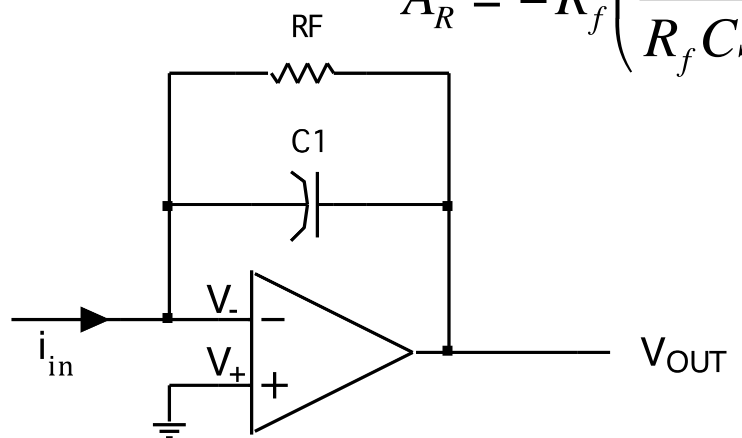
- **Transresistance amplifiers simply translate current from a sensor into an output voltage.**
- **They are just inverting amplifiers without the input resistor. The transresistance gain is given in OHMS.**

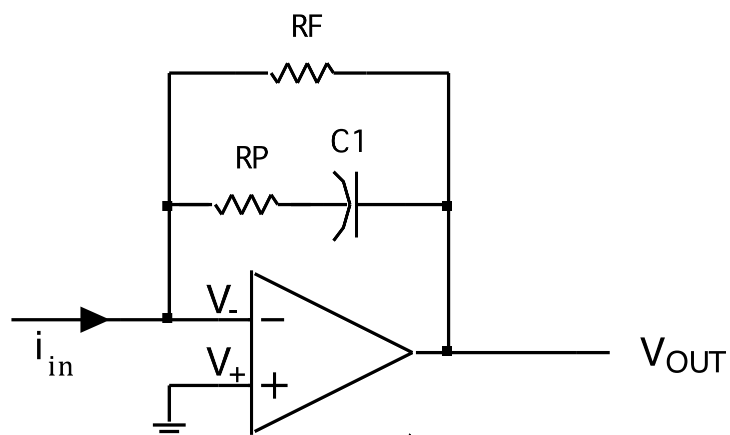


Transresistance Frequency Response

- Quite often, high DC gain is desired without much AC gain or controlled roll-off.
- These are two example approaches to achieve such characteristics.
- In practice the top circuit is most often used.

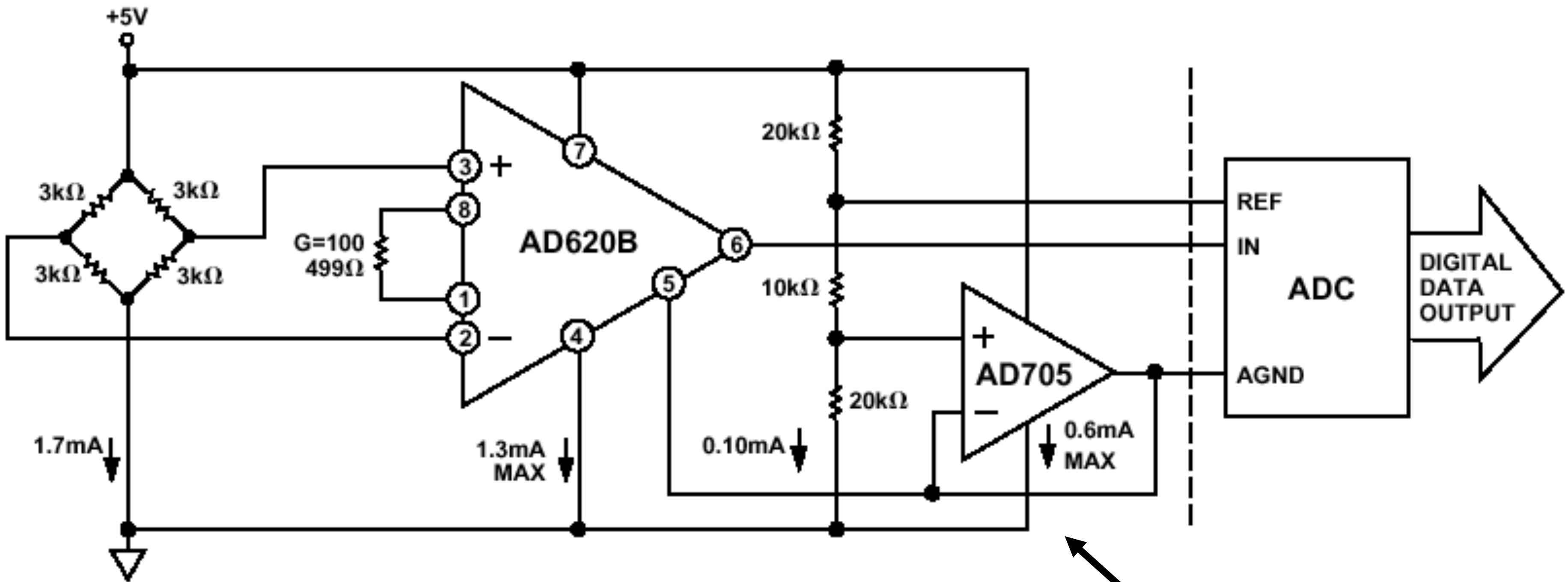
$$A_R = -R_f\left(\frac{1}{R_f CS + 1}\right)$$



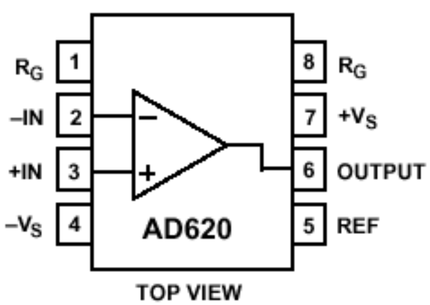


$$A_R = -\left(\frac{R_P R_f CS + R_f}{CS\left(R_f + R_P\right) + 1}\right)$$

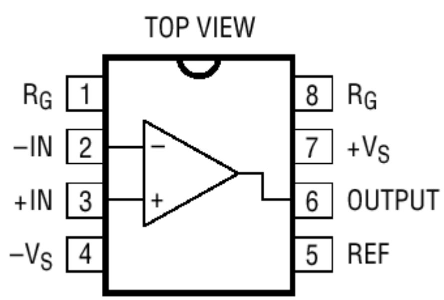
More on Instrumentation Amplifiers



Buffered voltage divider to set "ground."



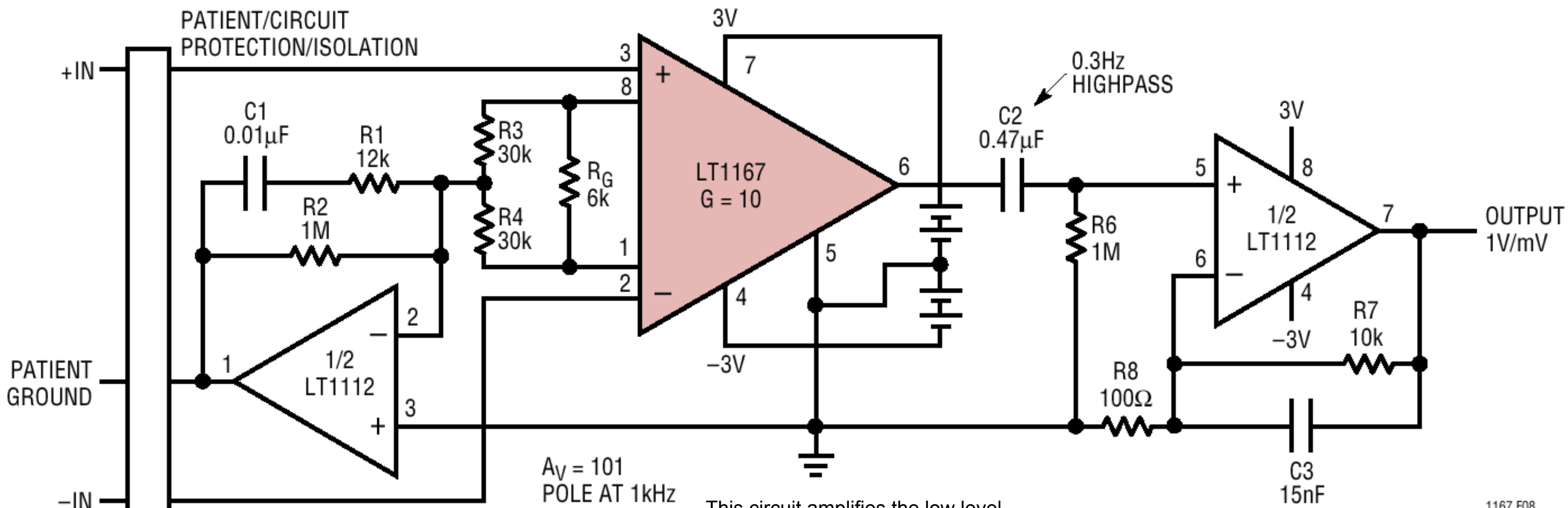
AD620



LT1167

Source: Analog Devices and Linear Technology Datasheets.

Nerve Impulse Amplifier



This circuit amplifies the low level nerve impulse signals received from a patient at Pins 2 and 3. RG and the parallel combination of R3 and R4 set a gain of ten. The potential on LT1112's Pin 1 creates a ground for the common mode signal. C1 was chosen to maintain thestabilityofthe patientground.TheLT1167's high CMRR ensures that the desired differential signal is amplified and unwanted common mode signals are attenuated. Since the DC portion of the signal is not important, R6 and C2 make up a 0.3Hz highpass filter. The AC signal at LT1112's Pin 5 is amplified by a gain of 101 set by (R7/R8) +1. The parallel combination of C3 and R7 form a lowpass filter that decreases this gain at frequencies above 1kHz. The ability to operate at ±3V on 0.9mA of supply current makes the LT1167 ideal for battery-powered applications. Total supply current for this application is 1.7mA. Proper safeguards, such as isolation, must be added to this circuit to protect the patient from possible harm.

Source: Linear Technology Datasheet.

Wright Field Fitness

Step aerobics with Michelle Tomko
Monday and Wednesday, 11:30 a.m. to 12:30 p.m.

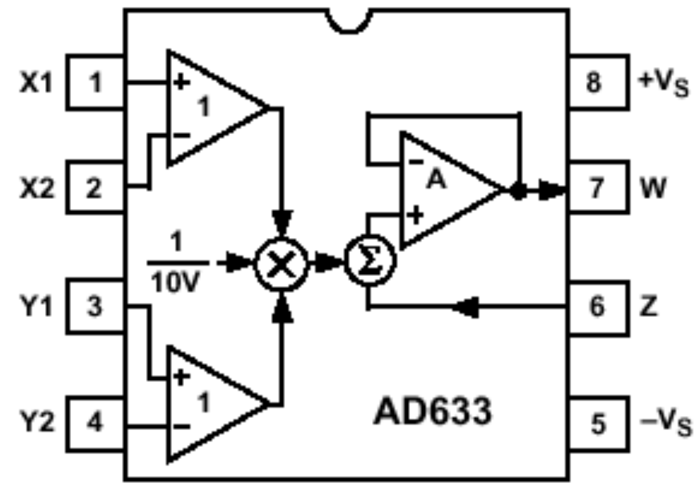
Step aerobics with Kym Kohut
Monday and Wednesday, 5-6 p.m.

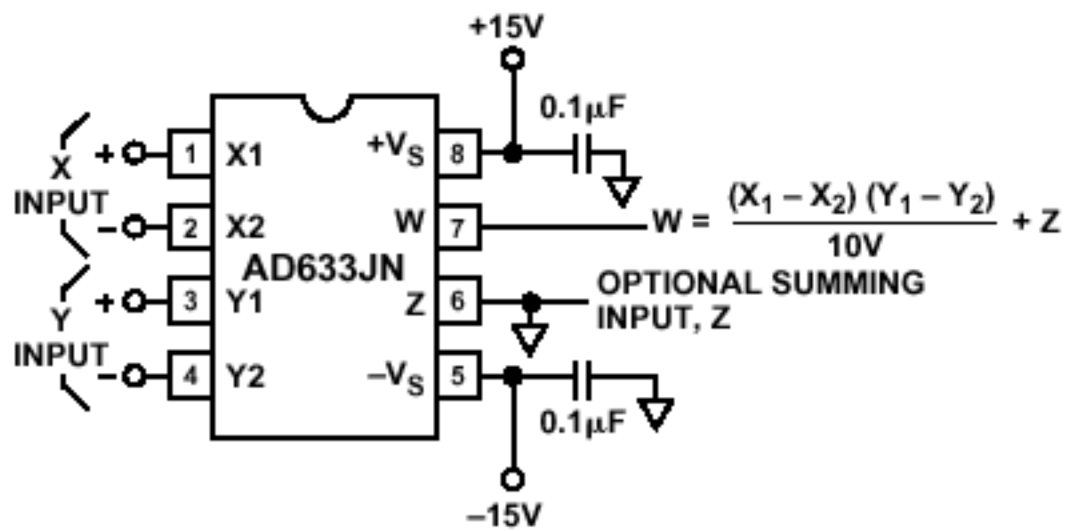
Cardio dick boxing with Kym Kohut
Friday, 11:30 a.m. to 12:30 p.m.

Boxercise with Laura Ortiz
Tuesday and Thursday, 6:10-7:10 p.m.

Analog Multipliers

- These devices can be used for modulation (AM), basic multiplication, and a variety of other functions.
- The AD633 is a particularly easy to use chip.

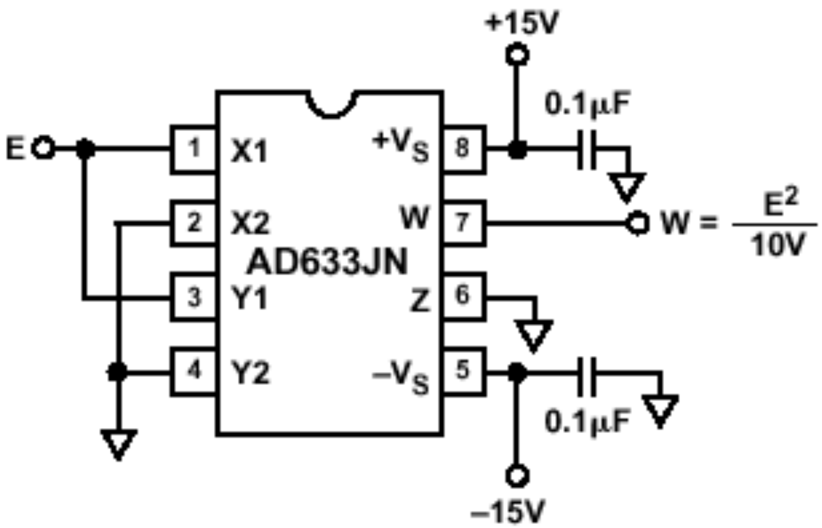




Source: Analog Devices Datasheet.

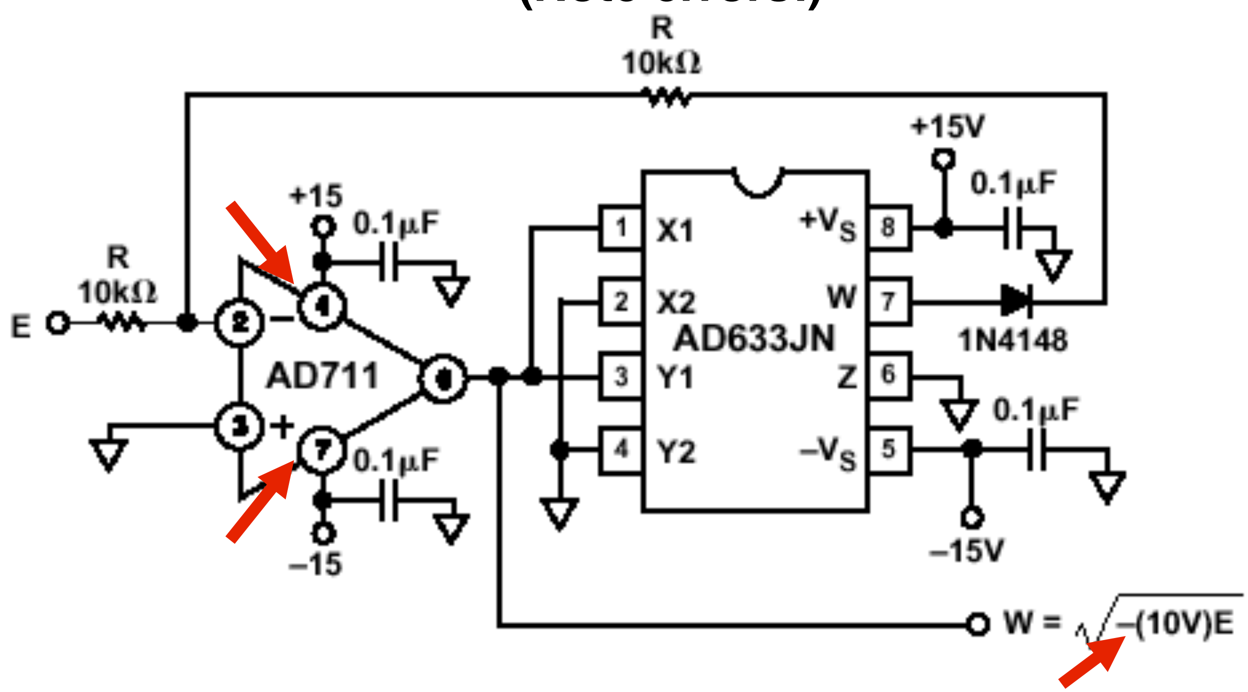
More AD633 Stuff

Squaring Circuit



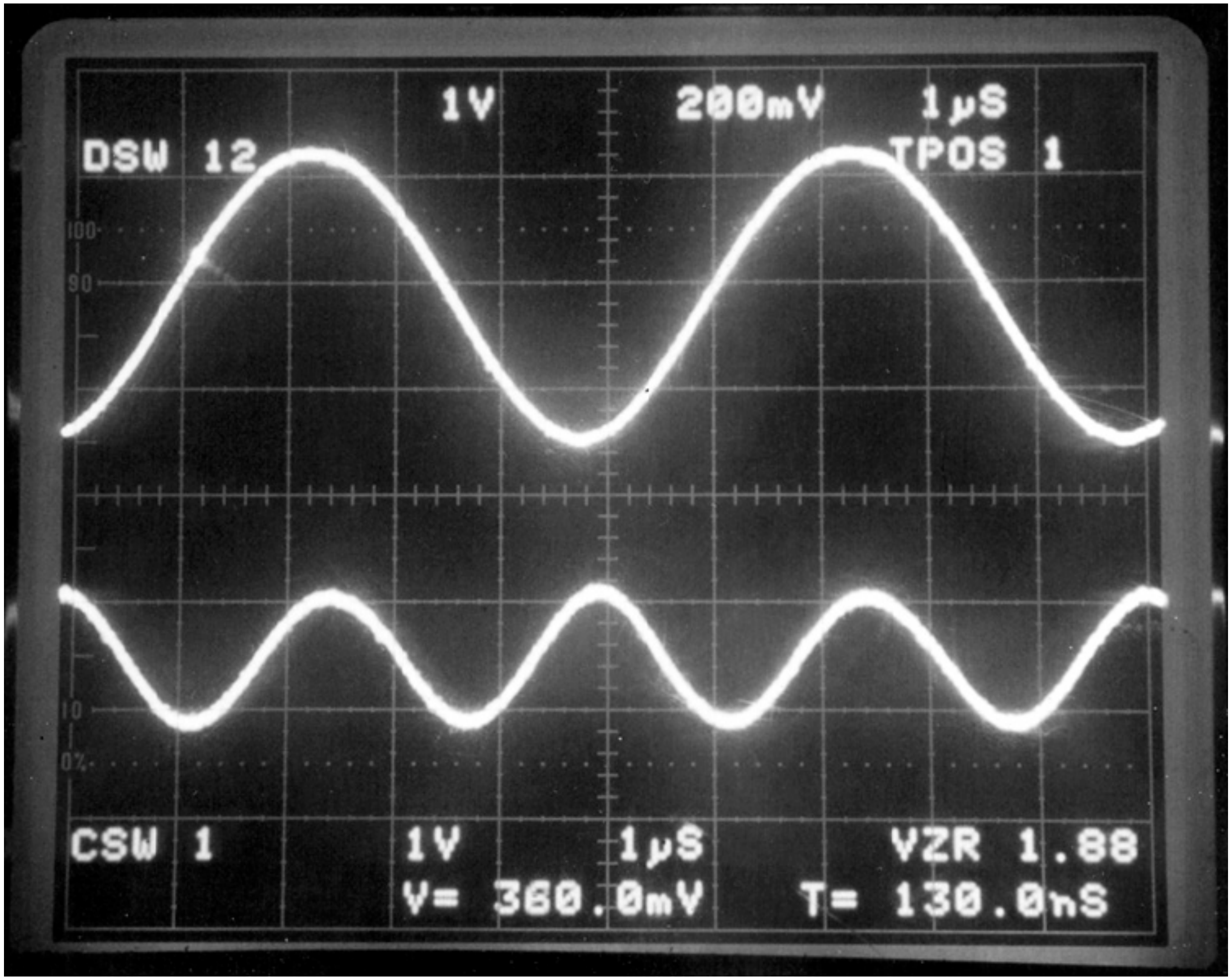
Square Root Circuit

(Note errors!)



Source: Analog Devices Datasheet.

Squarer



AD 633

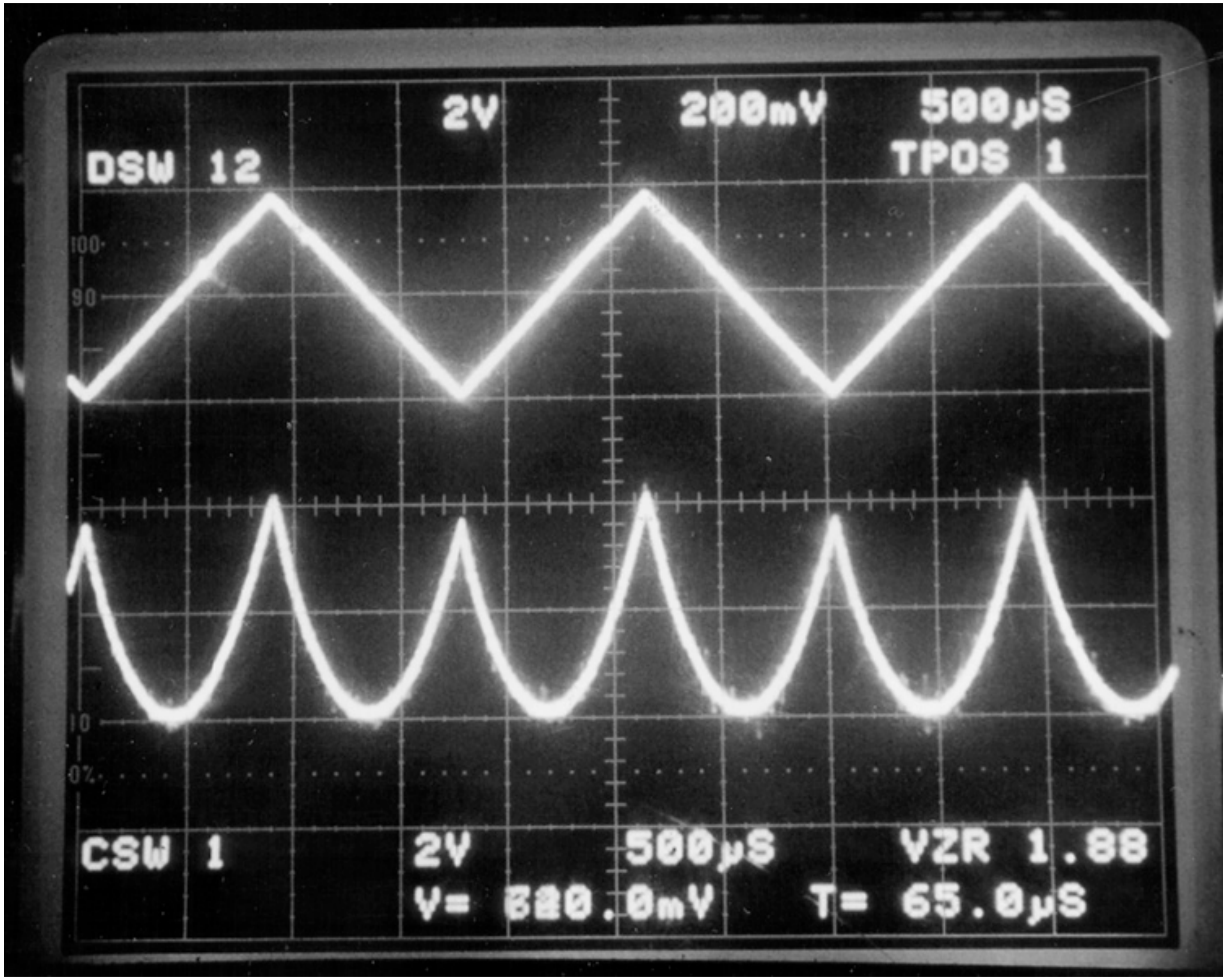
Vsupply = ± 15V

Input f = 200 kHz

Output f = 400 kHz

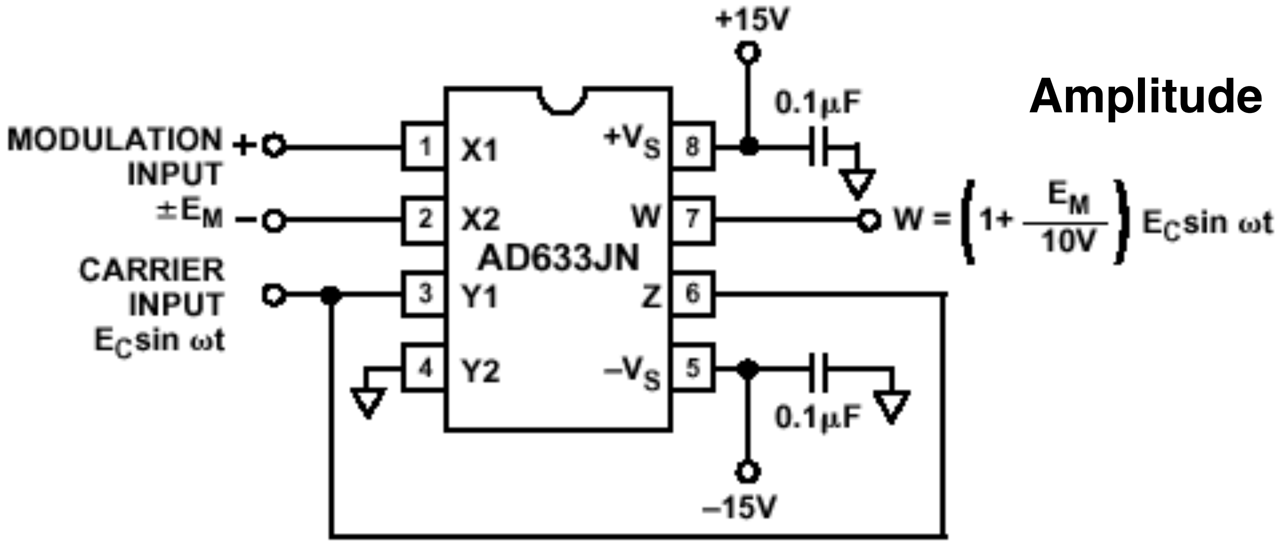
$$\sin^2(\omega t) = \frac{1}{2}\left(1 - \cos(2\omega t)\right)$$

Triangle Wave Input

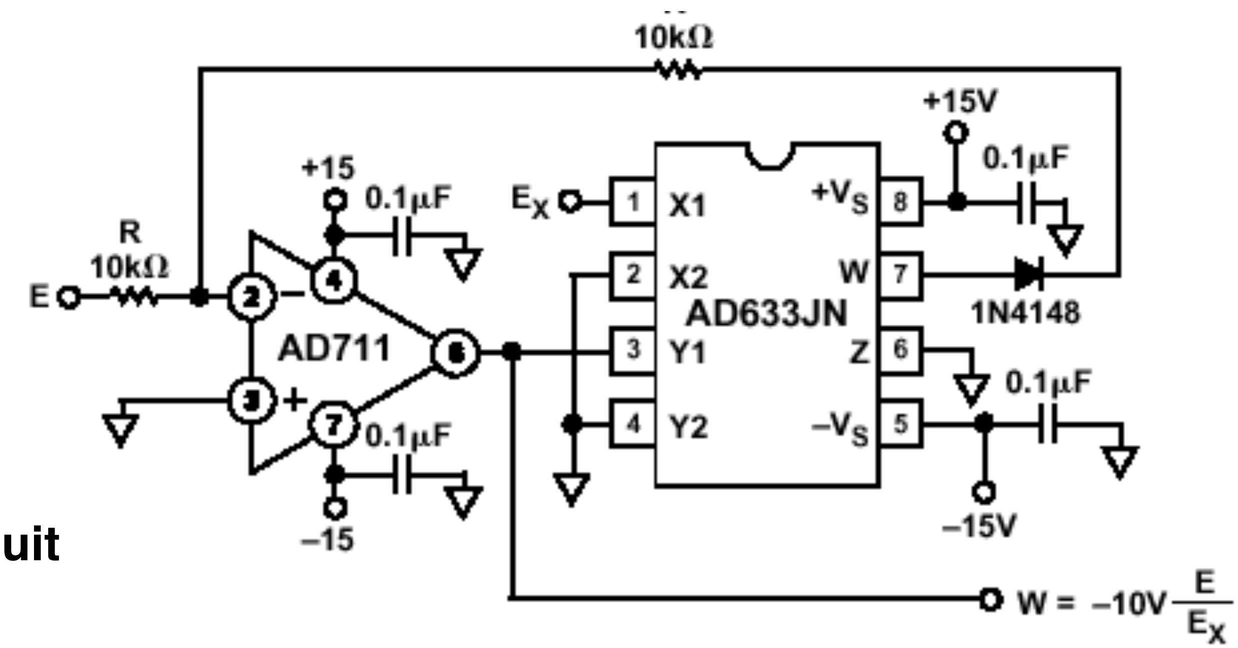


More AD633 Stuff

Amplitude Modulator

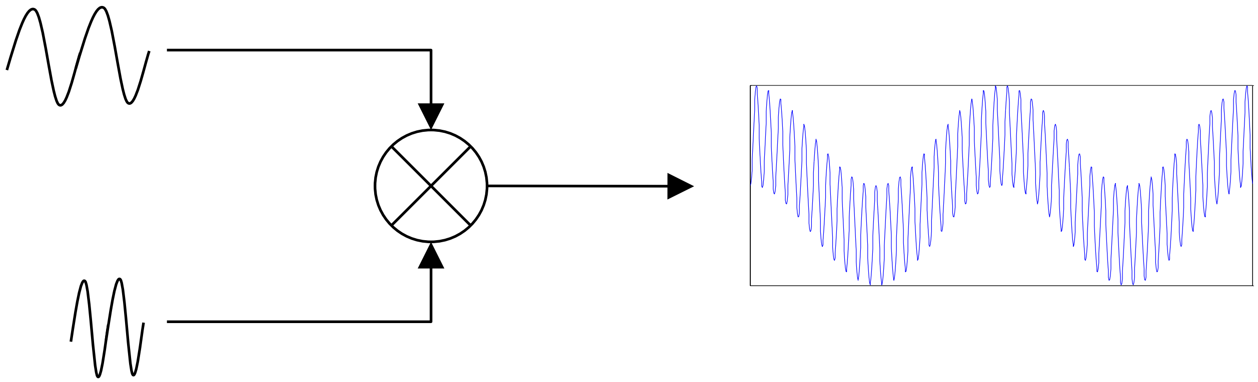


Source: Analog Devices Datasheet.



Divider Circuit

Multiplying Sinusoidal Waves (Mixers)



$$\cos\omega_1 t \cdot \cos\omega_2 t = \frac{1}{2}\cos(\omega_1+\omega_2)t + \frac{1}{2}\cos(\omega_1-\omega_2)t$$

Basis for:

- **modulation/demodulation**
- **phase detection**
- **lock-in amplifiers**
- **…**

Multipliers in Filters

Voltage Controlled Filter Circuits

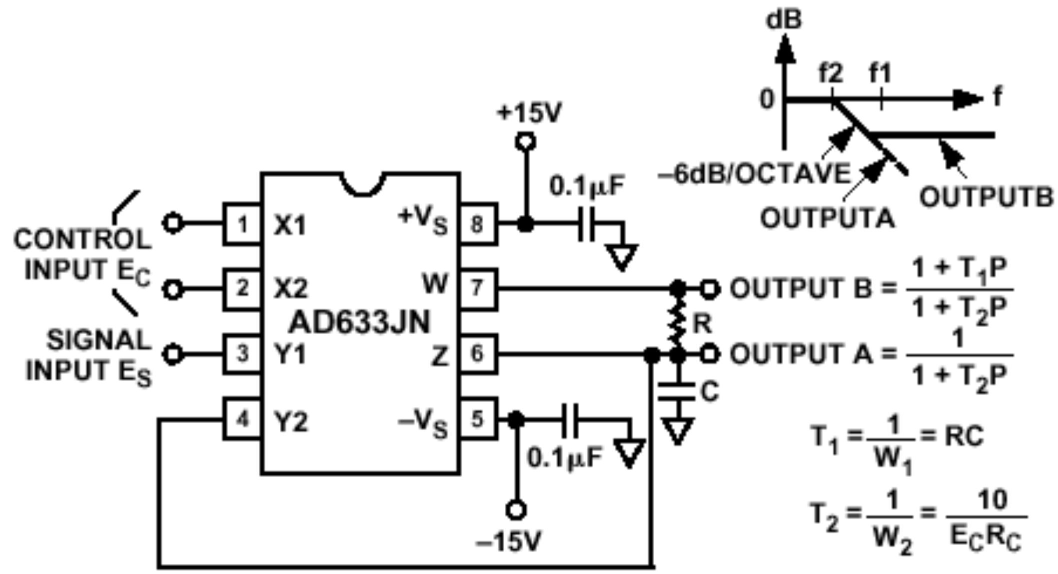


Figure 11. Voltage Controlled Low-Pass Filter

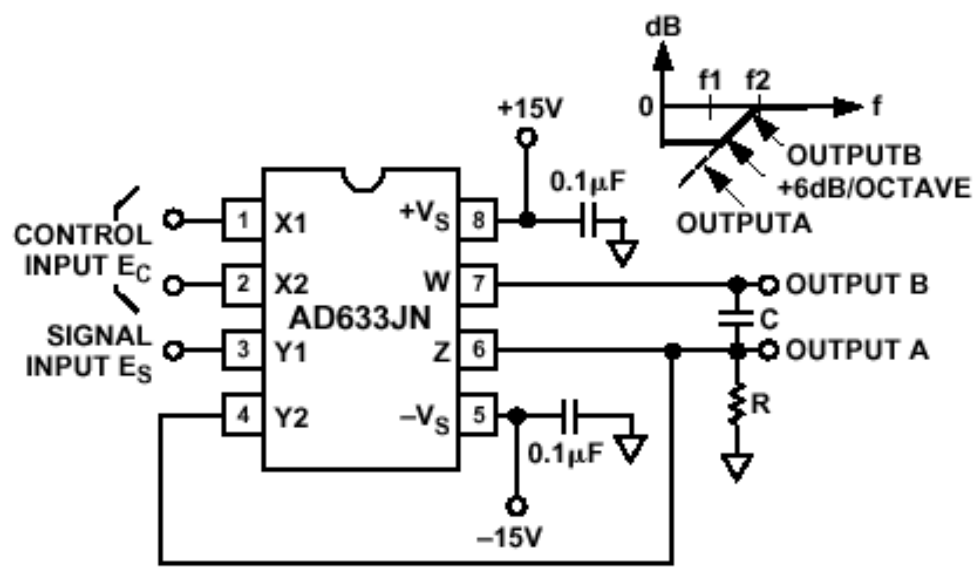
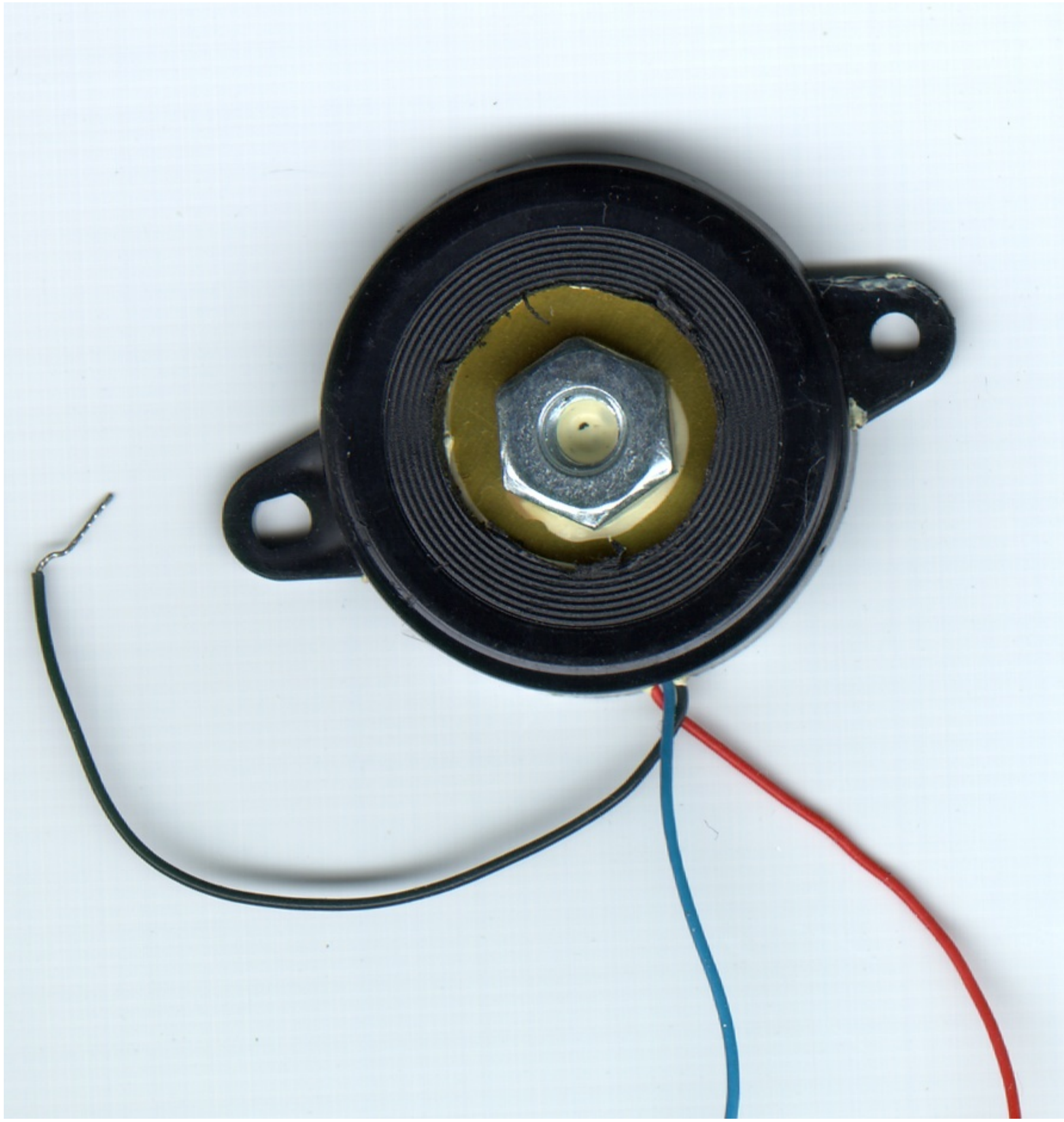


Figure 12. Voltage Controlled High-Pass Filter

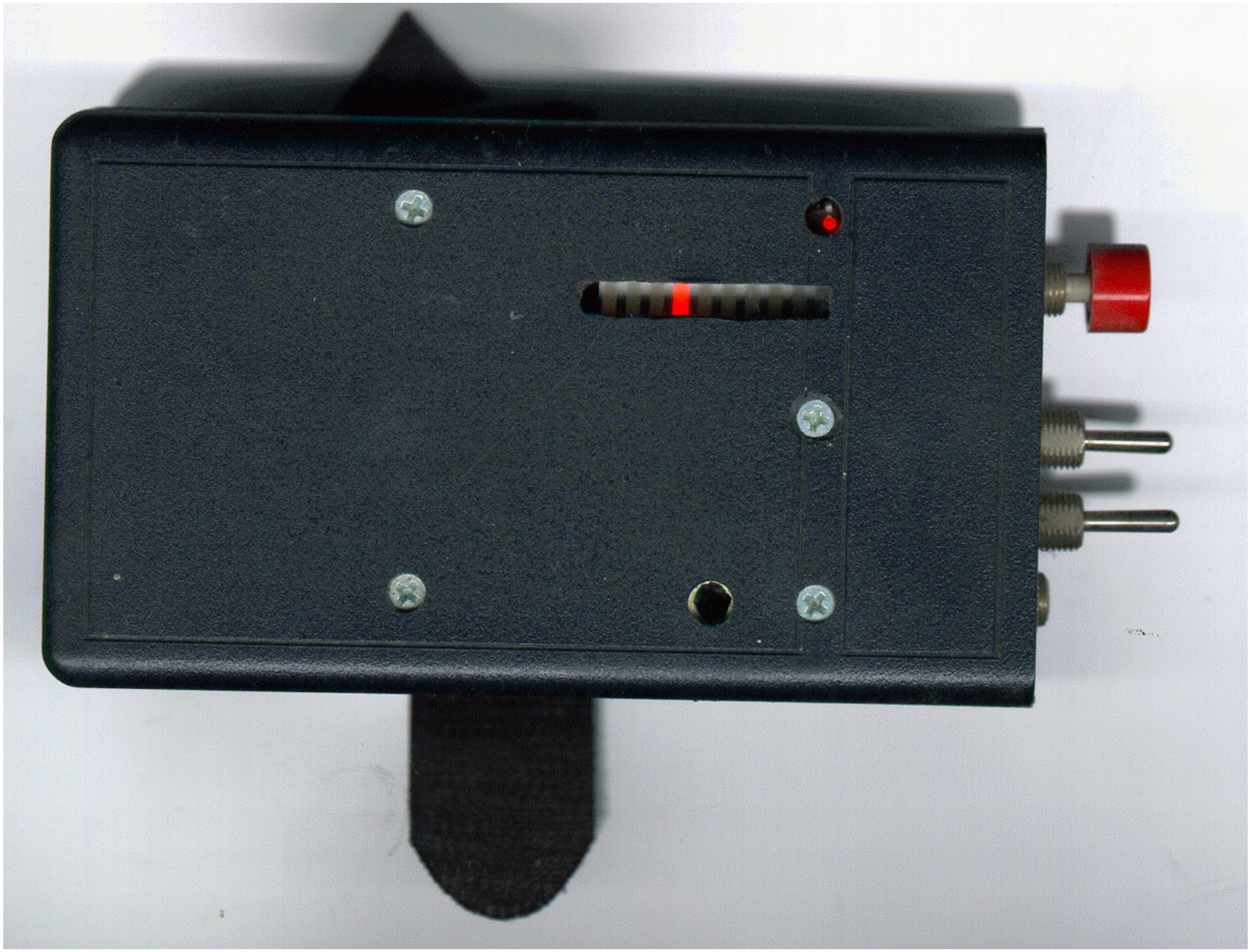
Source: Analog Devices Datasheet.

Example: Cheesy Accelerometer

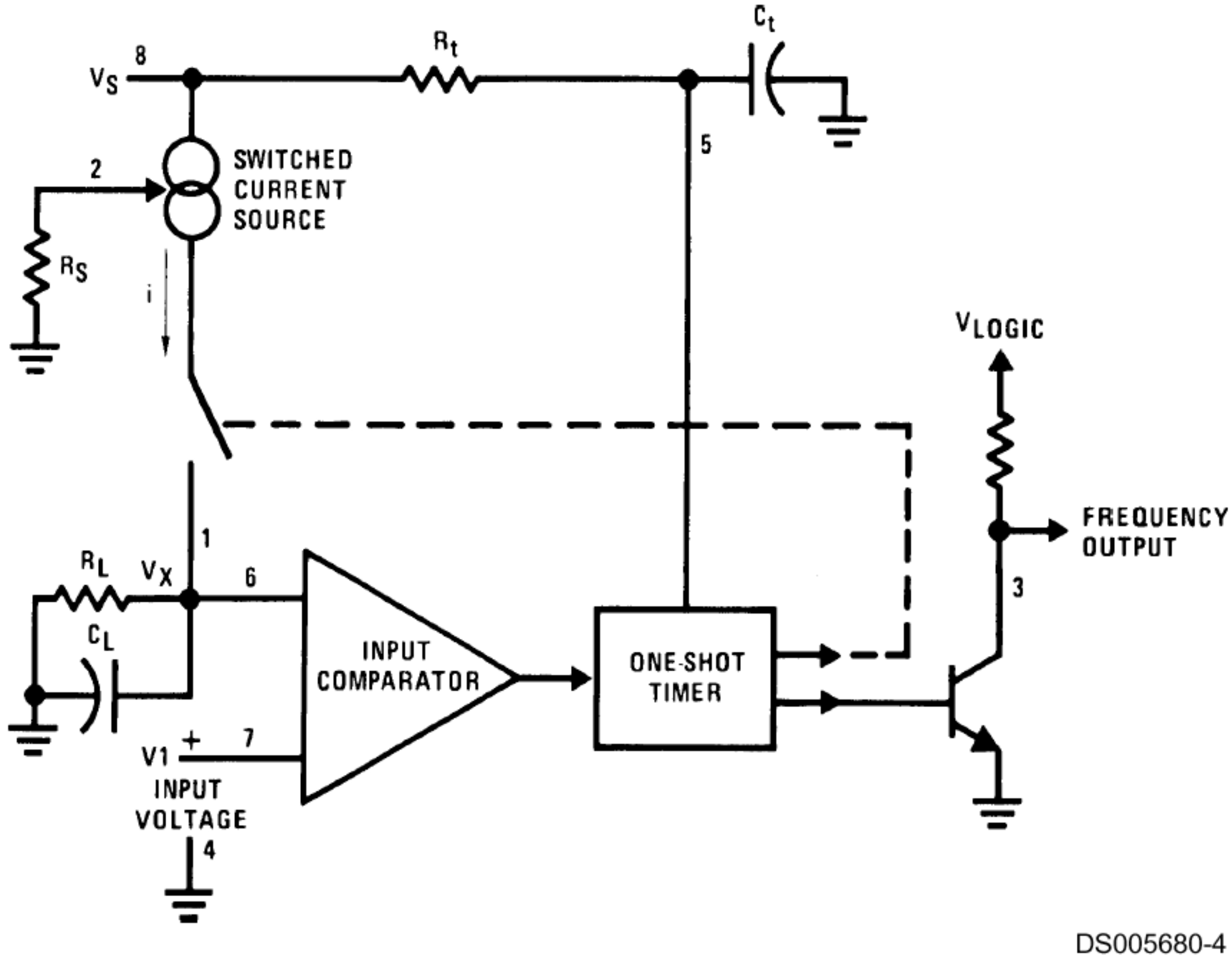
Gluing a 6-32 nut onto an inexpensive piezoelectric buzzer yields a cheesy, but functional accelerometer.



Cheesy Peak-Reading Accelerometer

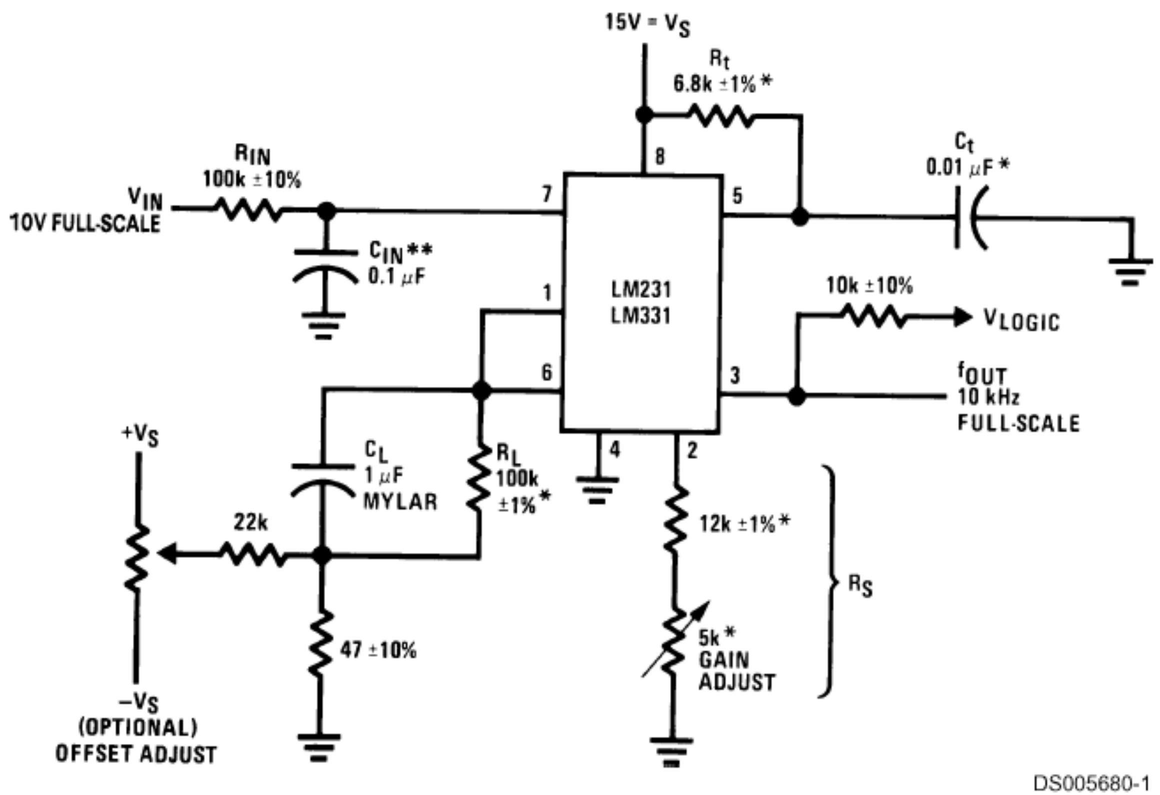


Voltage-to-Frequency Converters



Source: National Semiconductor LM331 Datasheet.

Voltage-to-Frequency Converters

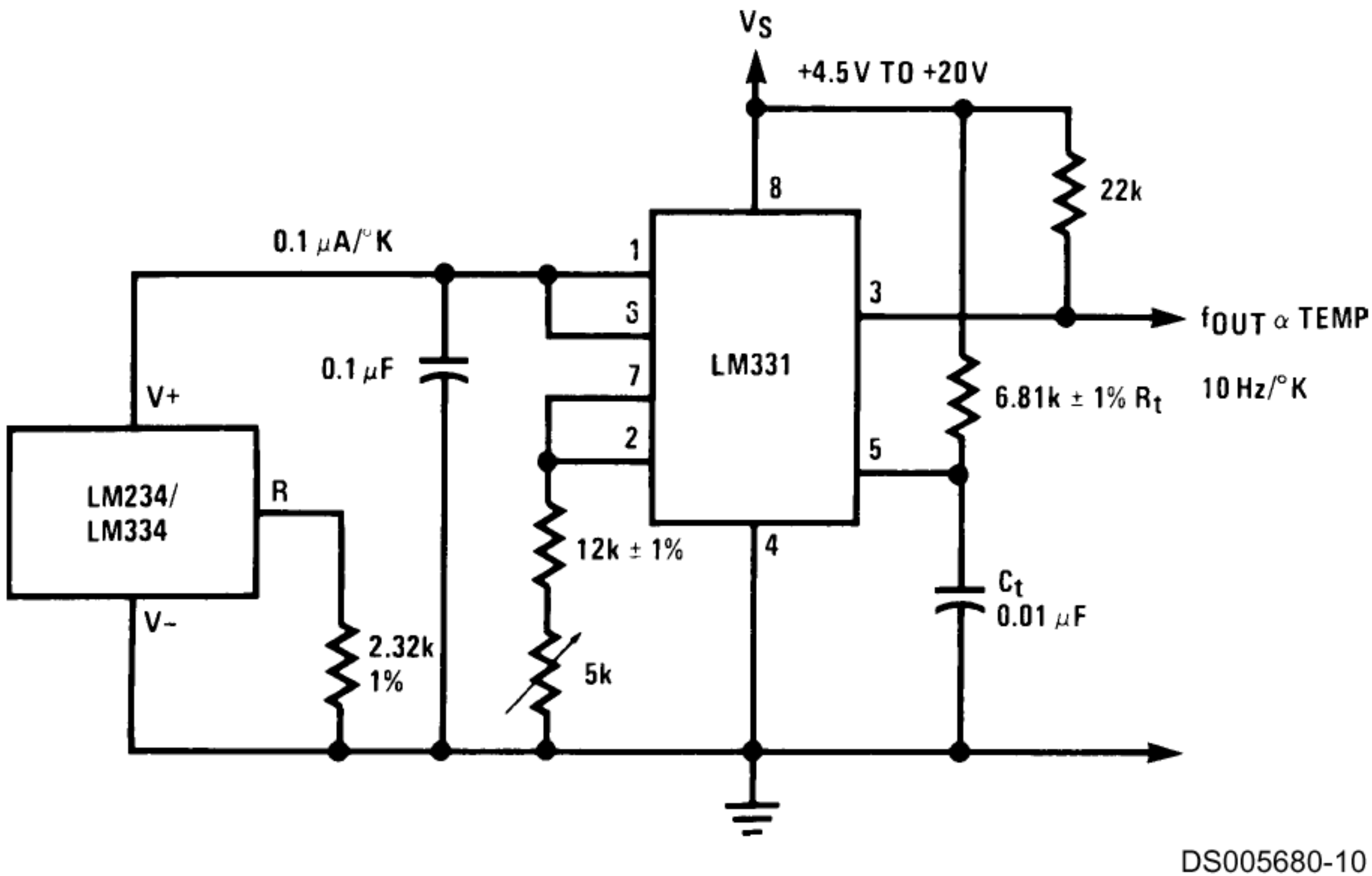


$$f_{OUT} = \frac{V_{IN}}{2.09\ V} \bullet \frac{R_S}{R_L} \bullet \frac{1}{R_t C_t}$$

*Use stable components with low temperature coefficients. See Typical Applications section.
**0.1μF or 1μF, See "Principles of Operation."

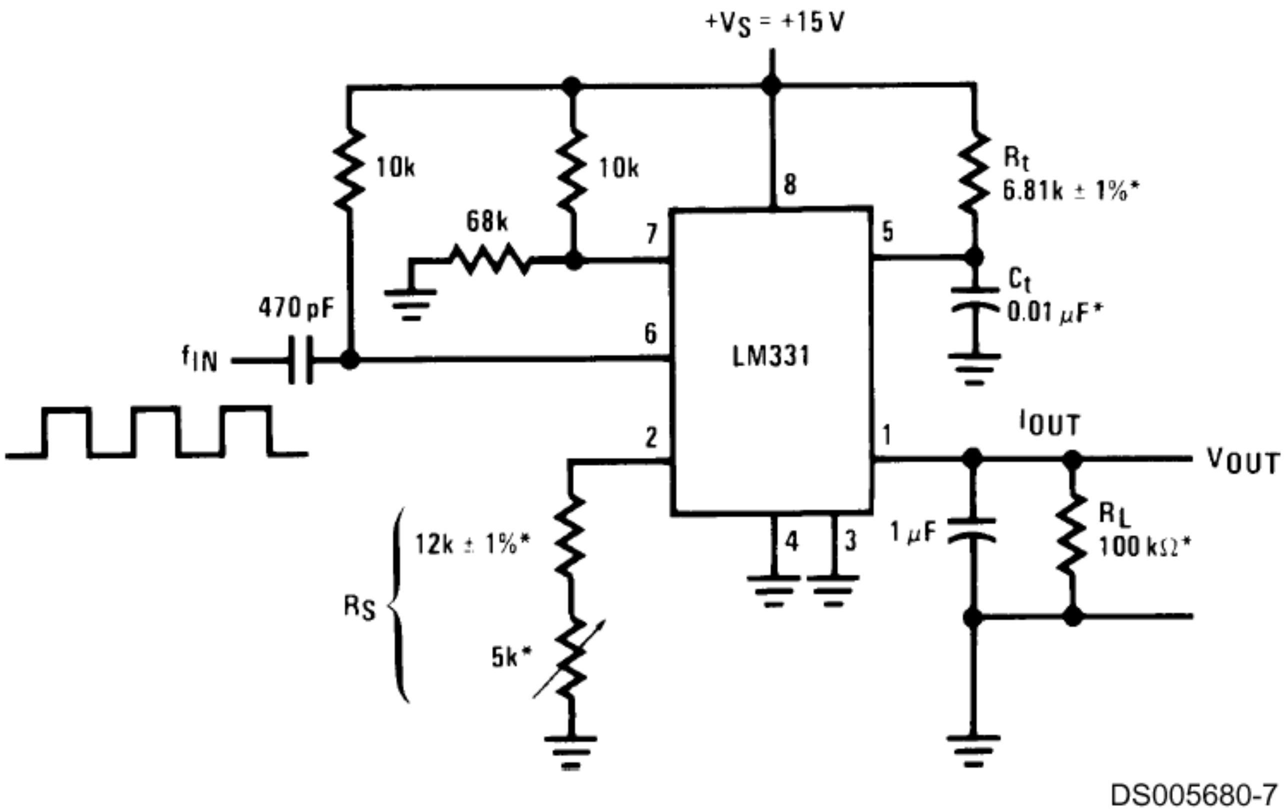
Source: National Semiconductor LM331 Datasheet.

Temperature-To-Frequency



Source: National Semiconductor LM331 Datasheet.

Frequency-to-Voltage Converters



$$V_{OUT} = f_{IN} \times 2.09V \times \frac{R_L}{R_S} \times (R_t C_t)$$

*Use stable components with low temperature coefficients.

Source: National Semiconductor LM331 Datasheet.

