# Power Supplies, Power Converters, Useful Signal Sources

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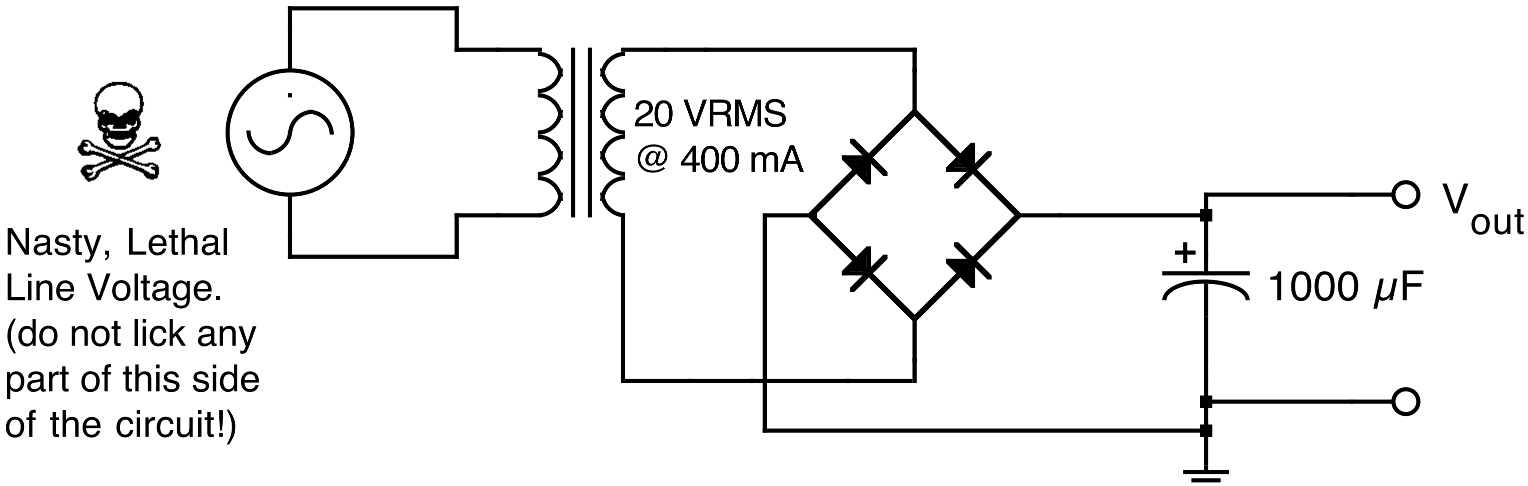
# Power Supplies

- **Linear supplies - sine wave input, step down (or up) transformer, rectification, filtering and (if necessary) regulation.**
  - Simple in implementation.
  - Can be heavy (transformer iron!).
  - Generally low noise.
- **Switching supplies - feedback-controlled transfer of energy packets from a supply (sometimes rectified straight from the line) to a load.**
  - Much higher power density.
  - Higher complexity.
  - Can be noisier than linear supplies.

# THE UNREGULATED POWER SUPPLY

- **This is the basic "linear" power supply.**
- **The input transformer typically "steps-down" the input voltage.**
- **The diode bridge rectifies the AC output of the transformer.**
- **The filter capacitor tries to make the output DC.**




**PROBLEMS:**

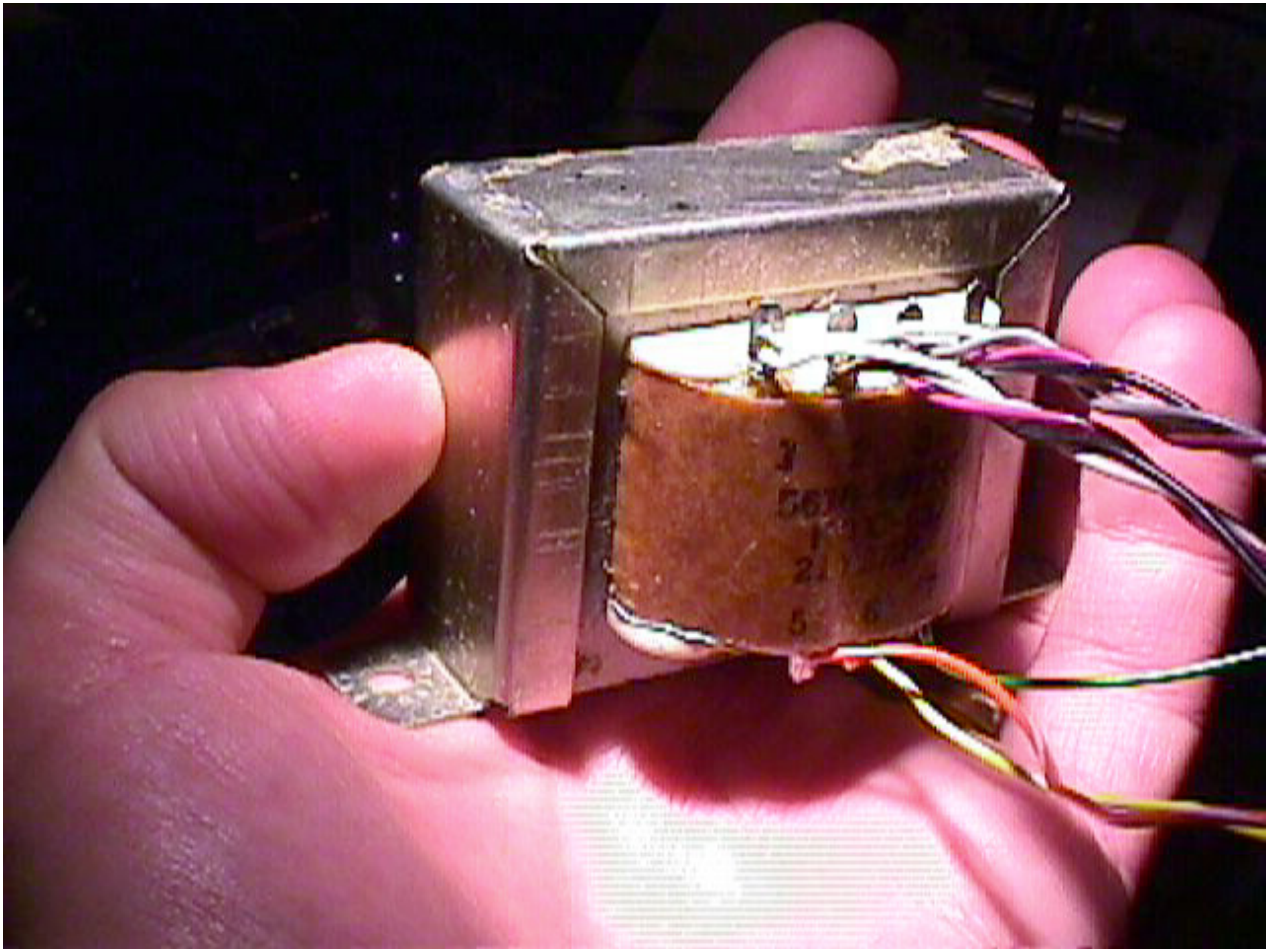
- **The output isn't "perfect" DC.**
- **The output is (as the name implies) UNREGULATED.**

$$V_{DC} = \frac{2V_{PEAK}}{\pi} = 0.637V_{PEAK} = 0.9V_{RMS}$$

$$V_{PEAK} = \sqrt{2}V_{RMS}$$

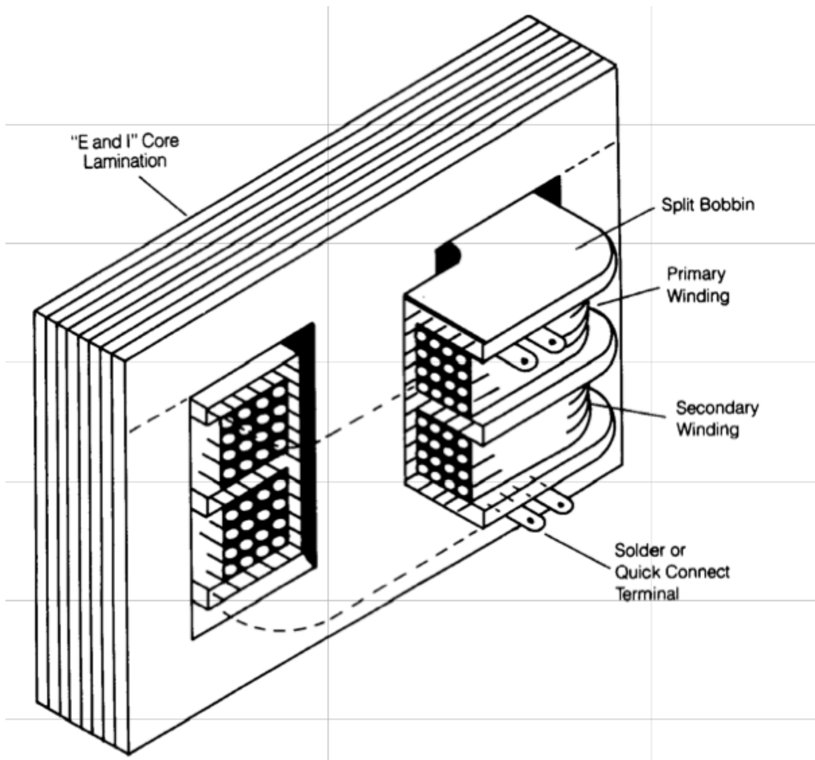
  

# Transformer



# THE TRANSFORMER

**Alternating magnetic fields in the core, created from AC voltage applied to the primary winding, are available at the secondary winding at a voltage determined by the ratio of the primary to secondary windings.**



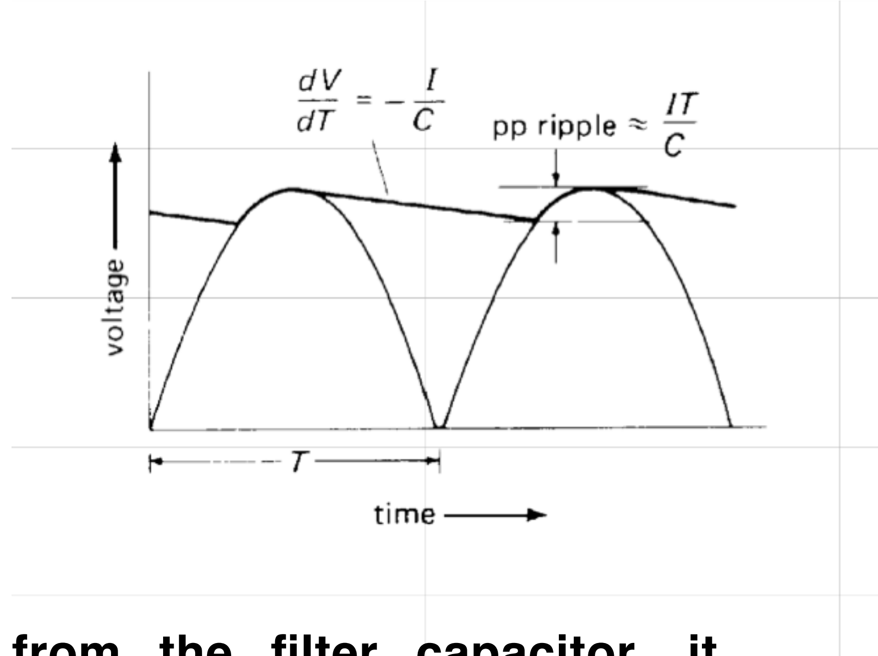

  

# "Wall Wart" AC Adapters

**Old fashioned wall warts are linear power supplies, which are not very efficient. Newer ones are switching supplies (more efficient) – see below.**

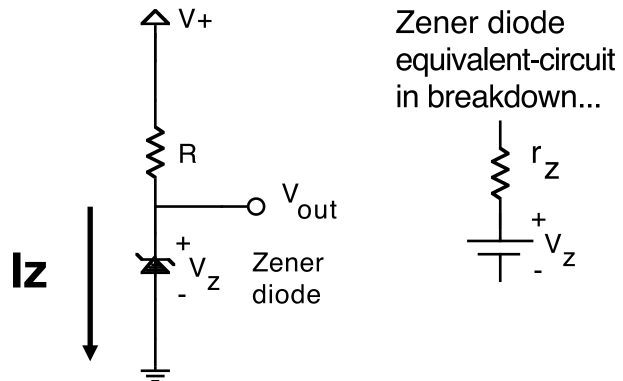
  

# RIPPLE

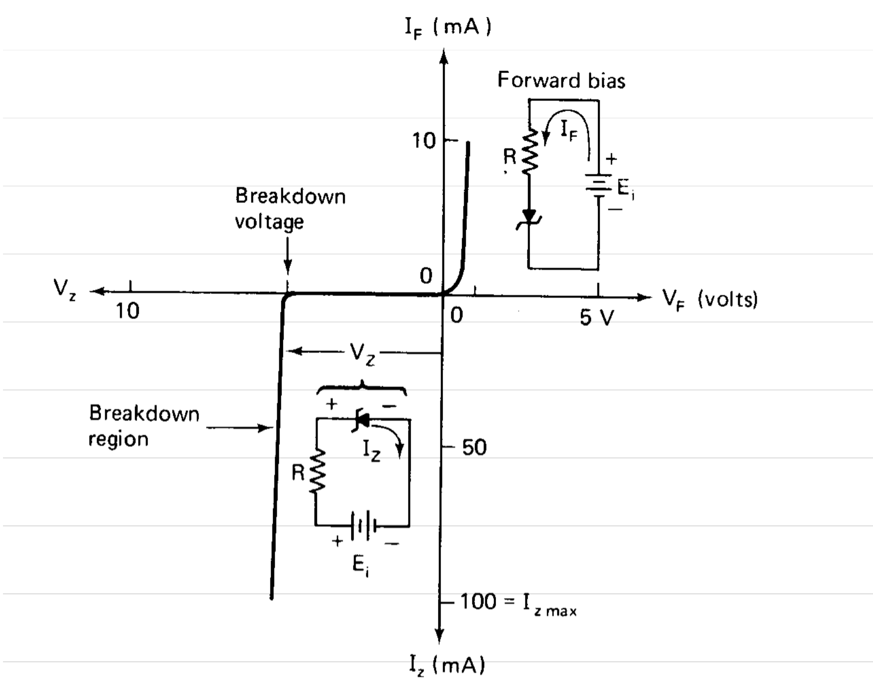

- As current is withdrawn from the filter capacitor, it discharges somewhat when its input voltage (from the rectifier bridge) is low.
- Since most loads are roughly constant current, you see a "ramp-like" ripple voltage at the output.
- The amplitude of the ripple varies significantly with the load current. WHY?
- Rule of thumb: > 1000 $\mu$F/ampere (more even better, but can be bulky and costly).

# THE ZENER DIODE REGULATOR




$$I_{zMAX} = \frac{P_{dMAX}}{V_z}$$

$$I_{total} = \frac{V_{supply} - (V_z + r_z I_z)}{R}$$




- **Good for low currents.**
- **Choose a Zener diode that can handle the power dissipation required to deliver the current you need.**
- **Potential problems: noise, drift with temperature...**

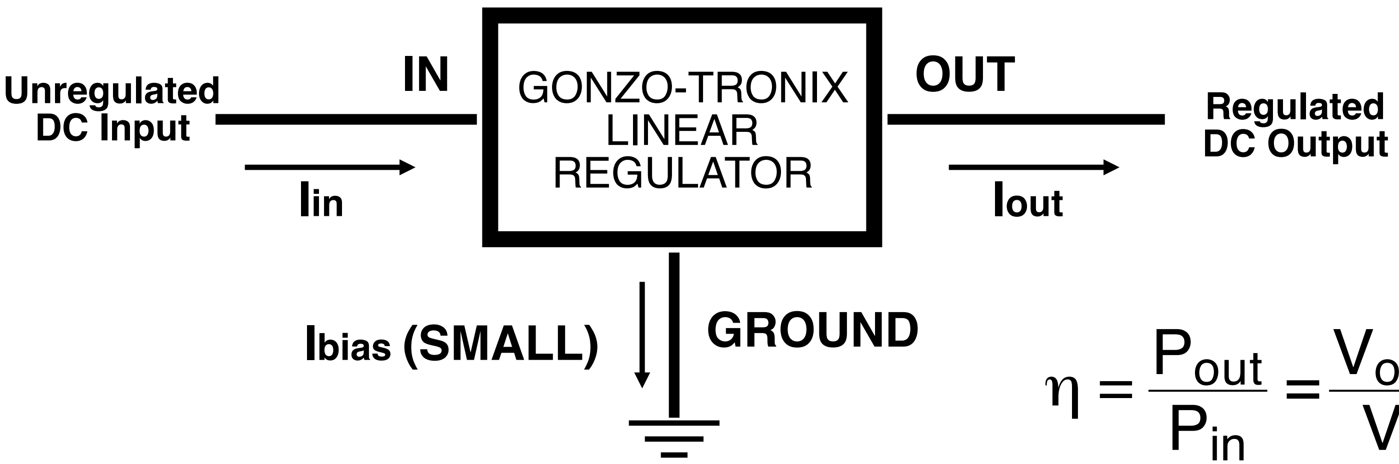
# Linear Regulators

**Basically a FEEDBACK CONTROLLED RESISTIVE DIVIDER that maintains a constant output voltage for a range of load currents...**

**They are relatively noise-free, but are somewhat inefficient...**

**Most require a voltage drop across them (typically at least 3 V) to operate.**

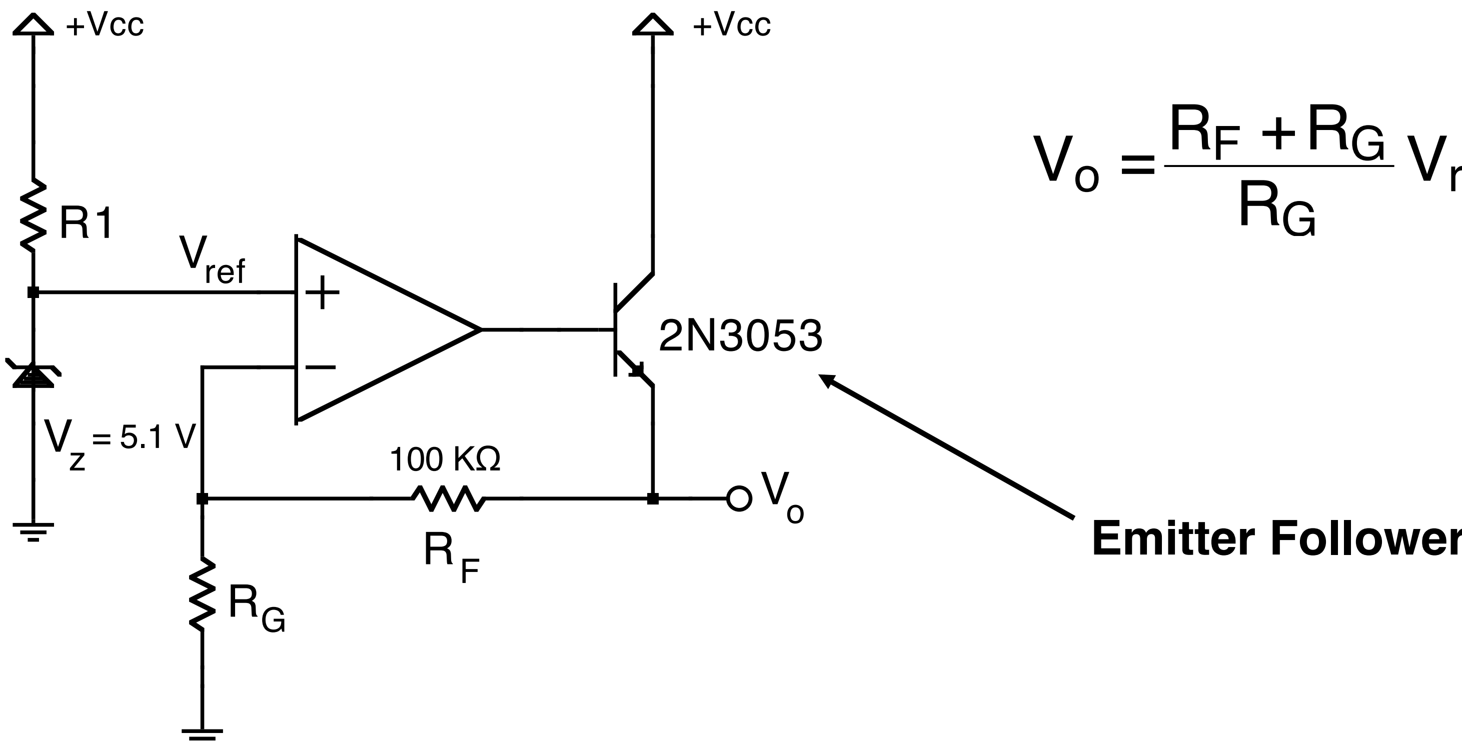
**Popular single-chip versions have only three terminals:**




$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{out}I_{out}}{V_{in}I_{in}} \approx \frac{V_{out}}{V_{in}}$$

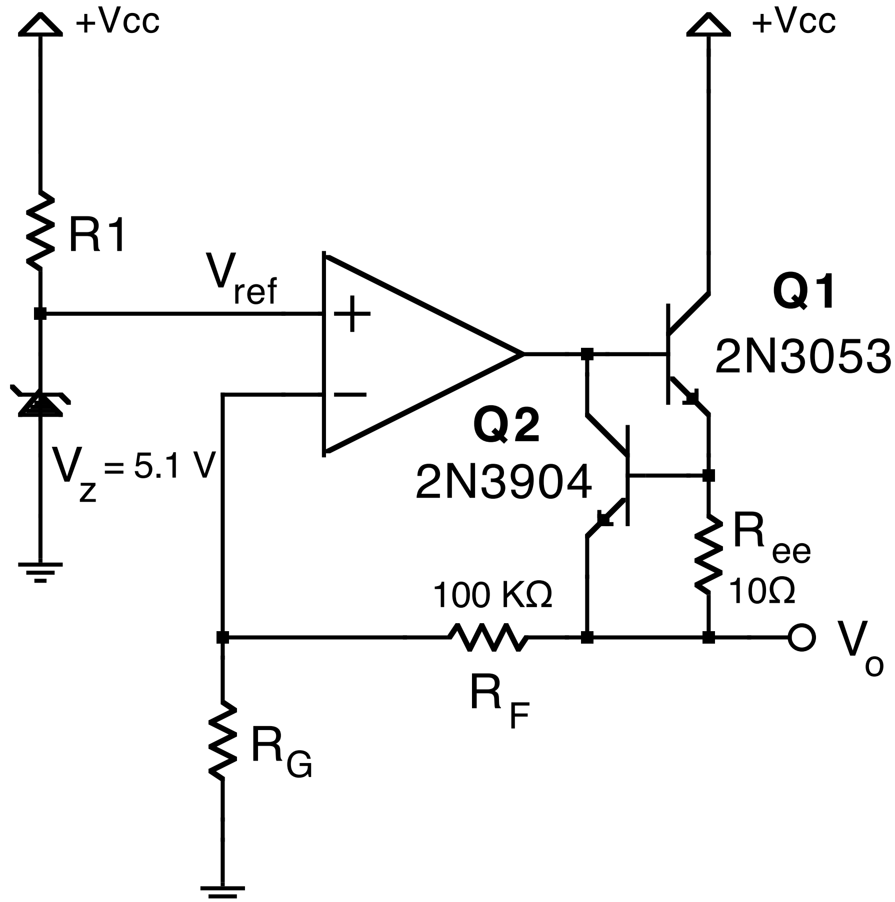
# Op-Amp Voltage Regulator With Pass Transistor




$$V_o = \frac{R_F + R_G}{R_G} V_{ref}$$

# Op-Amp Voltage Regulator With Current-Limit Circuitry

**As the foldback transistor (Q2) "steals" base current from Q1, the current is limited... ultimately, if the output is shorted, the short-circuit current of the op-amp limits the output current.**



# Switching Regulators

- Here the basic principle is to use an energy storage element (typically an INDUCTOR, but it can be a CAPACITOR) to shuttle energy between a source (unregulated) and a load (regulated).

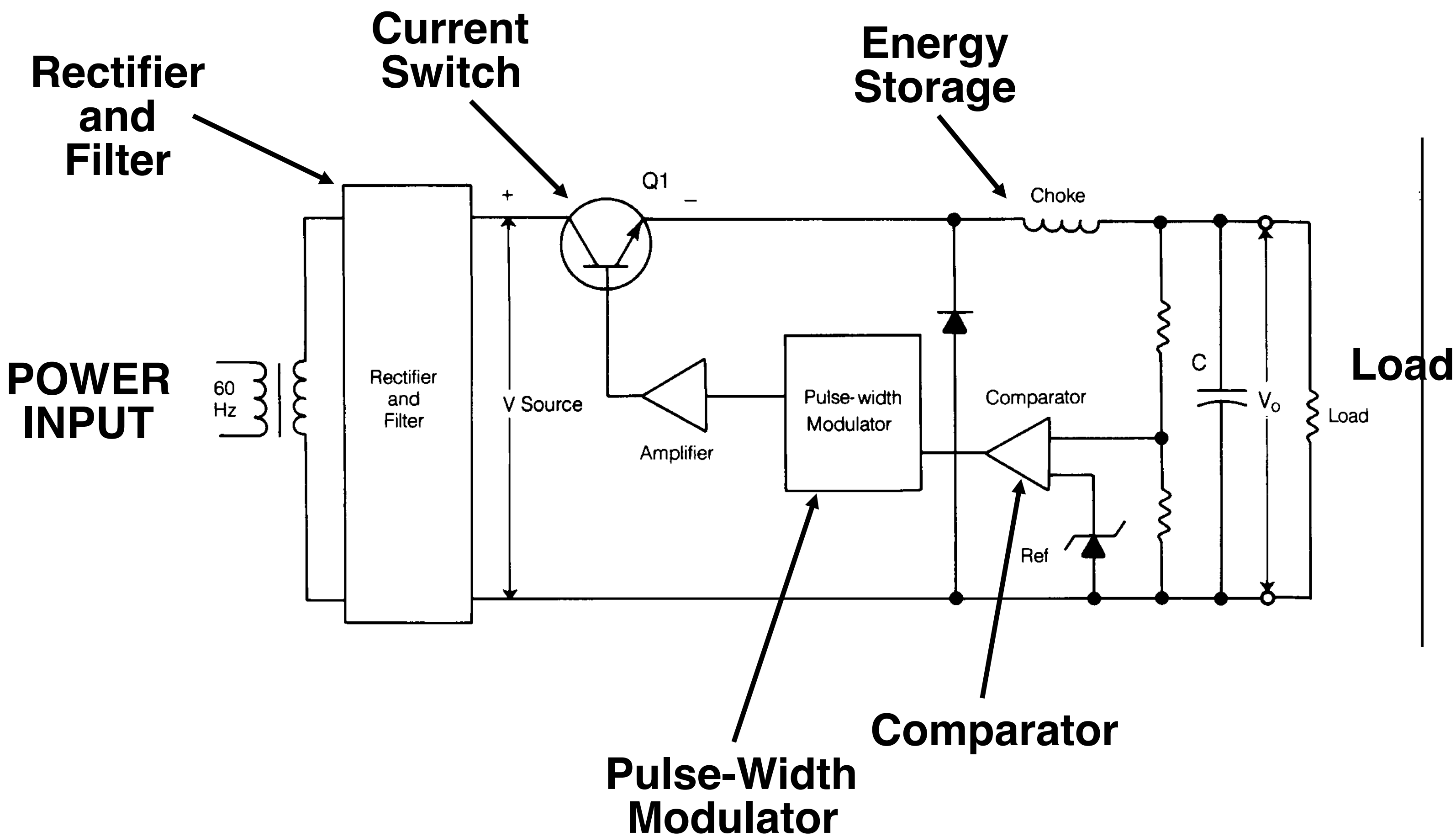
- The amount of energy in each "PACKET" that is shuttled is varied OR the rate of packet transfer is varied using FEEDBACK to maintain a constant output voltage.

- ADVANTAGES over linear regulators: LIGHTER (do not need heavy transformers), CHEAPER (transformers are expensive), SMALLER (transformers are BIG)

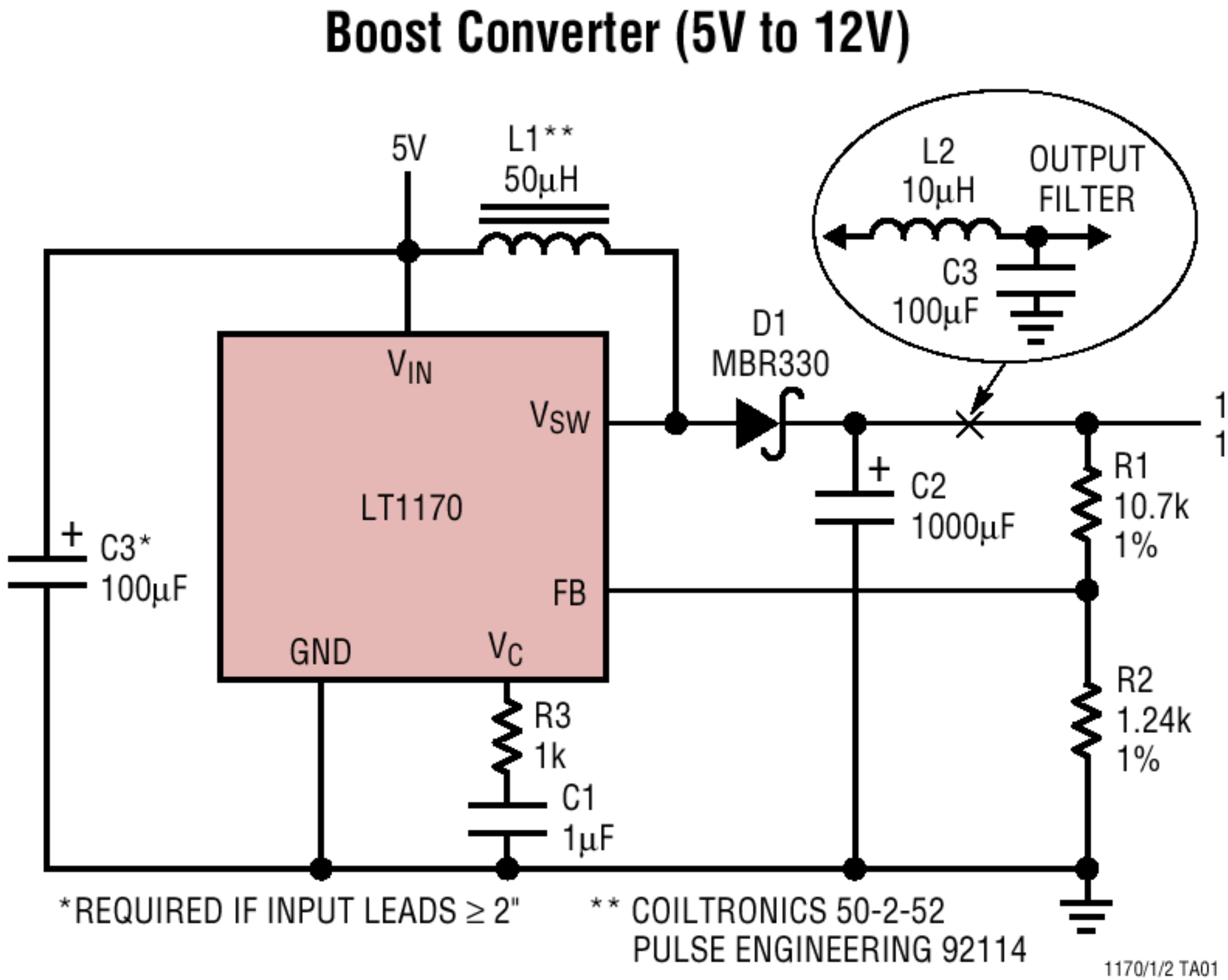
- DISADVANTAGES: NOISIER (due to high-frequency switching), MORE COMPLEX (and thus less reliable), HIGH VOLTAGES may be present!

# Block Diagram of a "Switcher"



# Simple Switcher:  LT1070

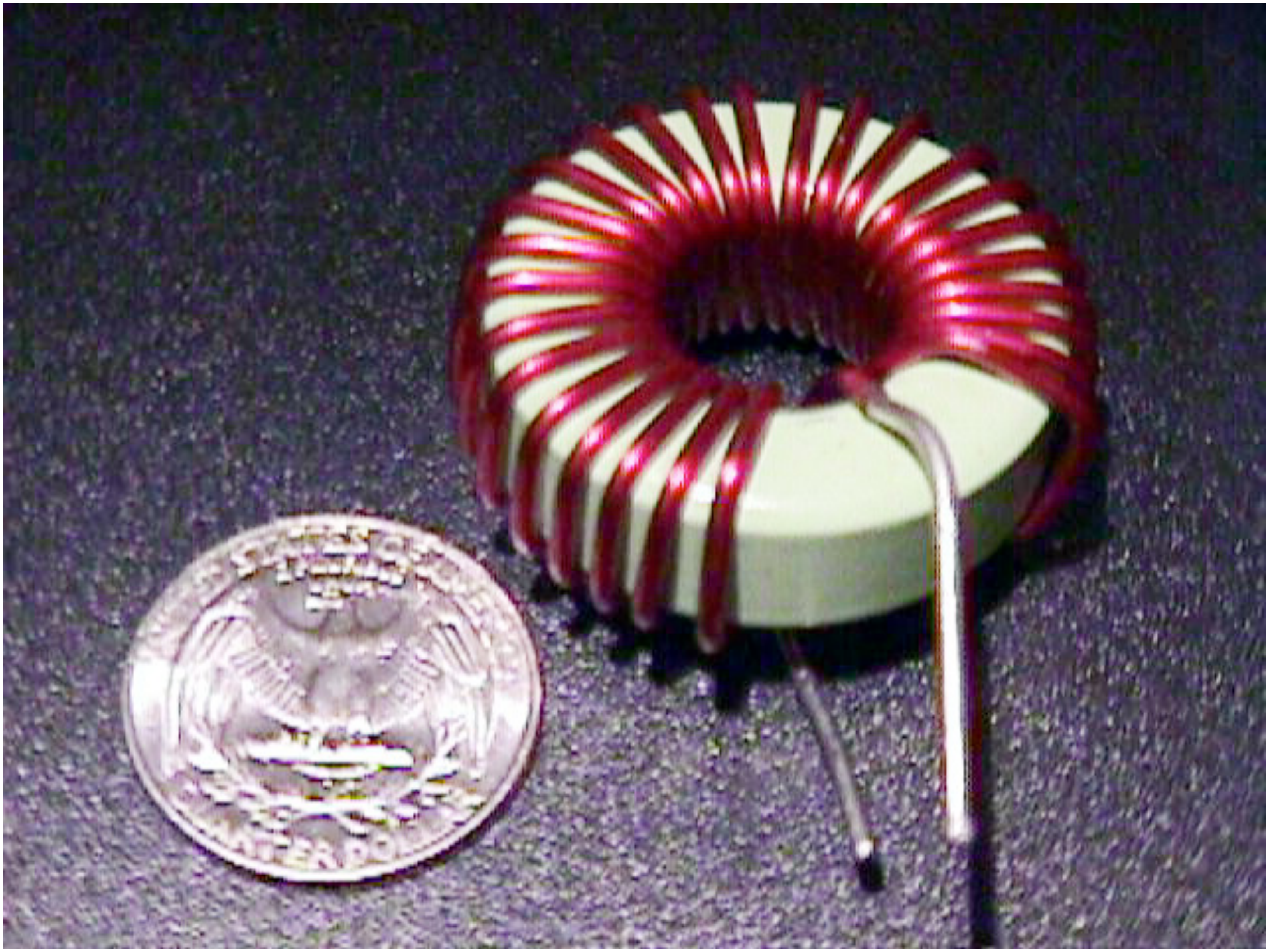



**Source:  Linear Technology LT1170 datasheet.**

# Typical Switcher Module

# Inductors for Switchers

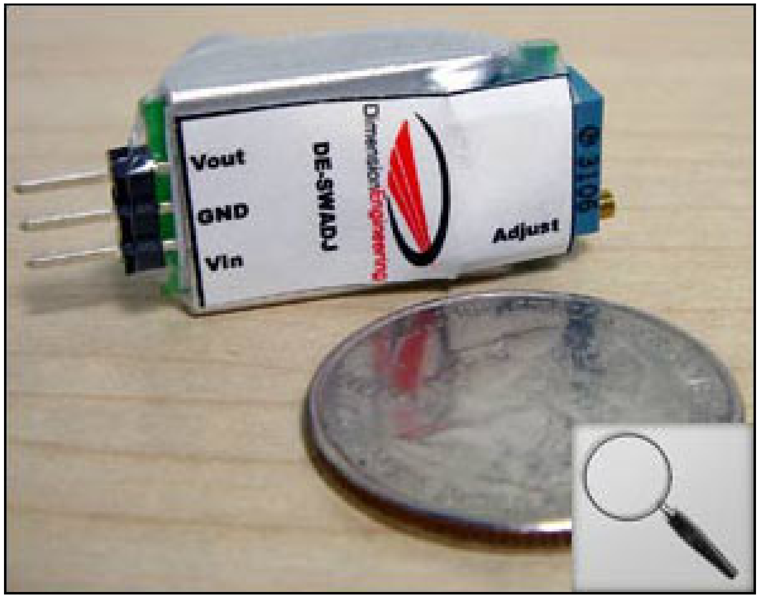


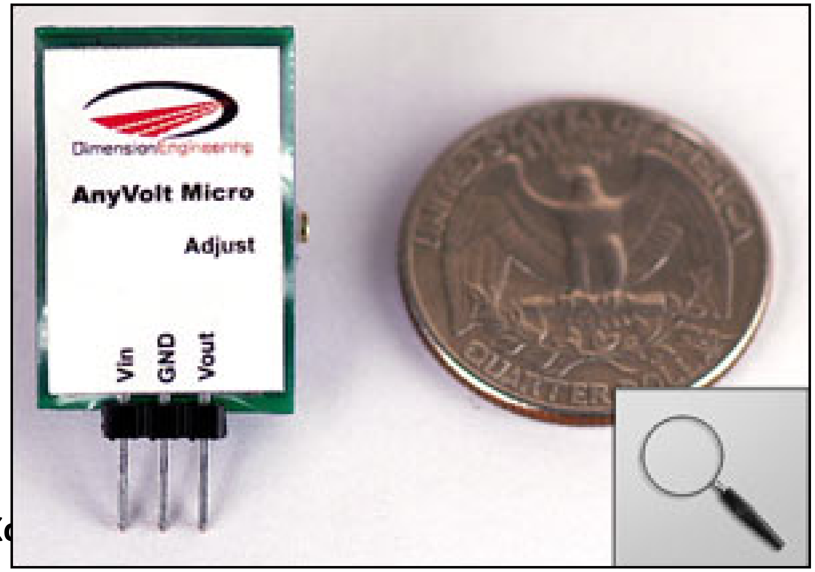
# Switching Regulators

- "Three-terminal" switchers are available that wire up just like linear regulators.

- Some, like those from Dimension Engineering, are adjustable and are available as buck (step-down), boost (step-up), buck-boost (down or up) and inverting (generates negative rail from single positive rail).

- http://www.dimensionengineering.com/



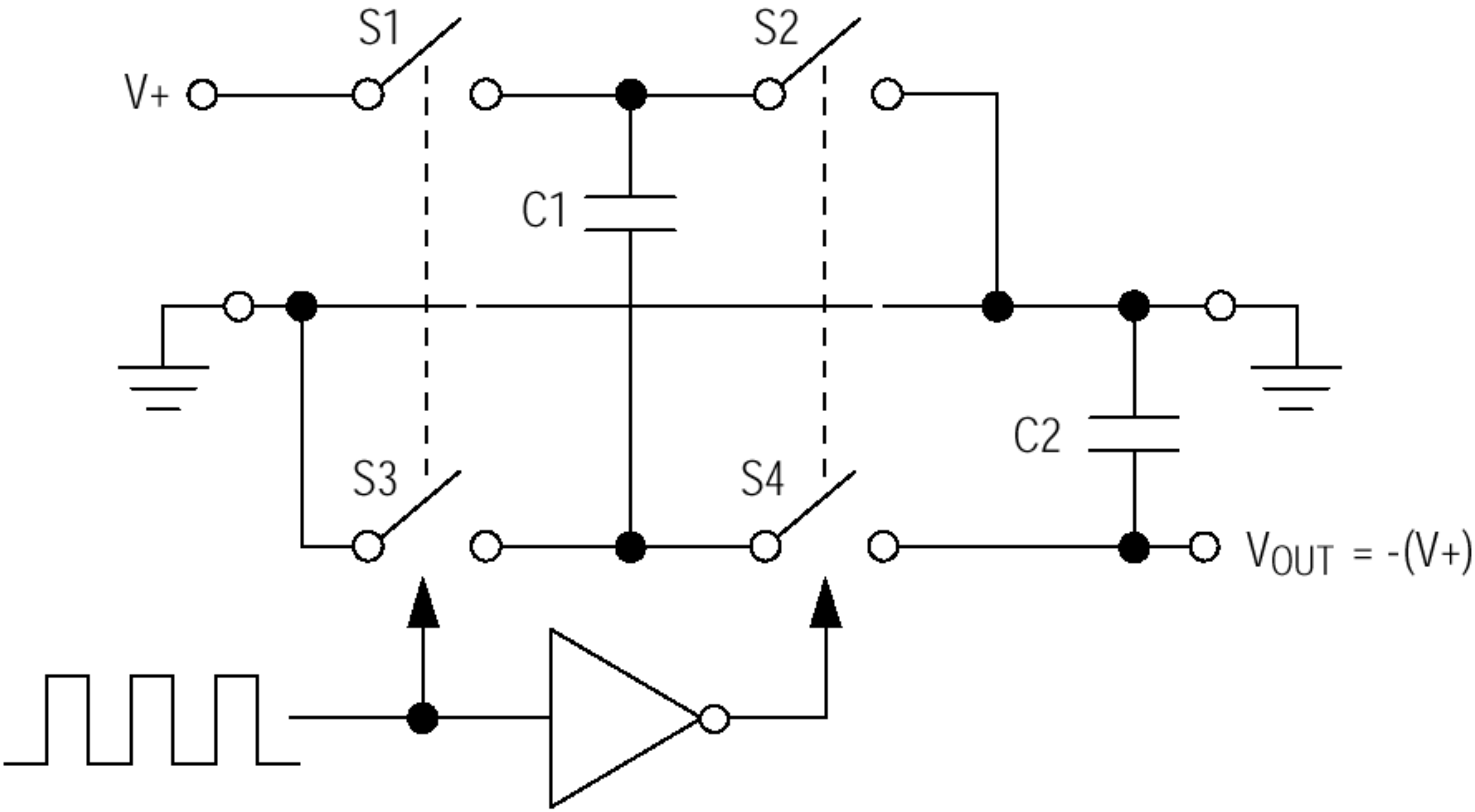

 

# Power Converter Modules

# Example: Implantable Cardiac Defibrillator


  Courtesy of Medtronic, Inc. 

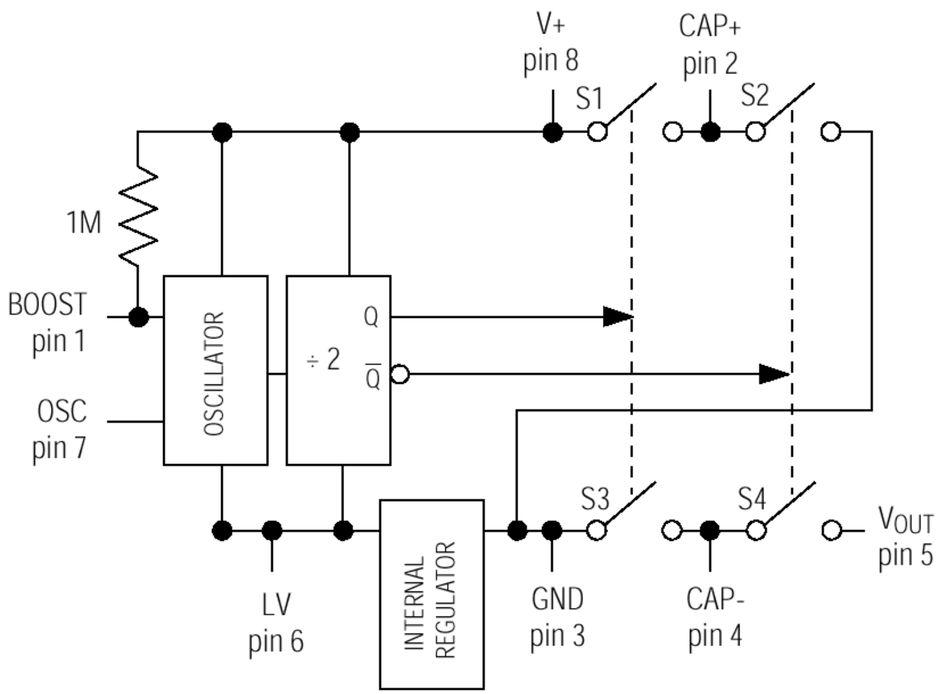
# Capacitive Power Converters




**Source: Maxim MAX1044/ICL7660 datasheet.**

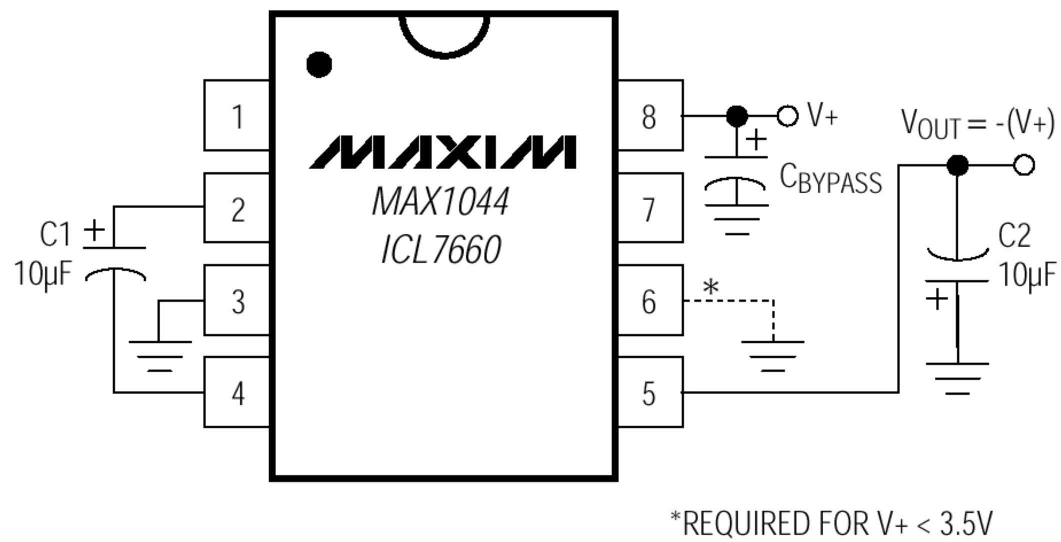
  

# MAX1044/ICL7660




**These, and variants, are useful for small current applications (tens of mA).**

**Electromagnetic energy storage is more common, but capacitive approaches can be scaled up also...** (See: https://www.analog.com/en/design-notes/high-efficiency-high-density-switched-capacitor-converter-for-high-power-applications.html)




**Source: Maxim MAX1044/ICL7660 datasheet.**

# Adjustable Bench Power Supply

- **Can use adjustable regulators to build a bench-type power supply (commercial version shown).**
- **Typically, they provide a dual-rail adjustable output and a logic-level (+5V) output.**

# Batteries (Primary)


**Secondary (rechargeable) batteries not covered here.**

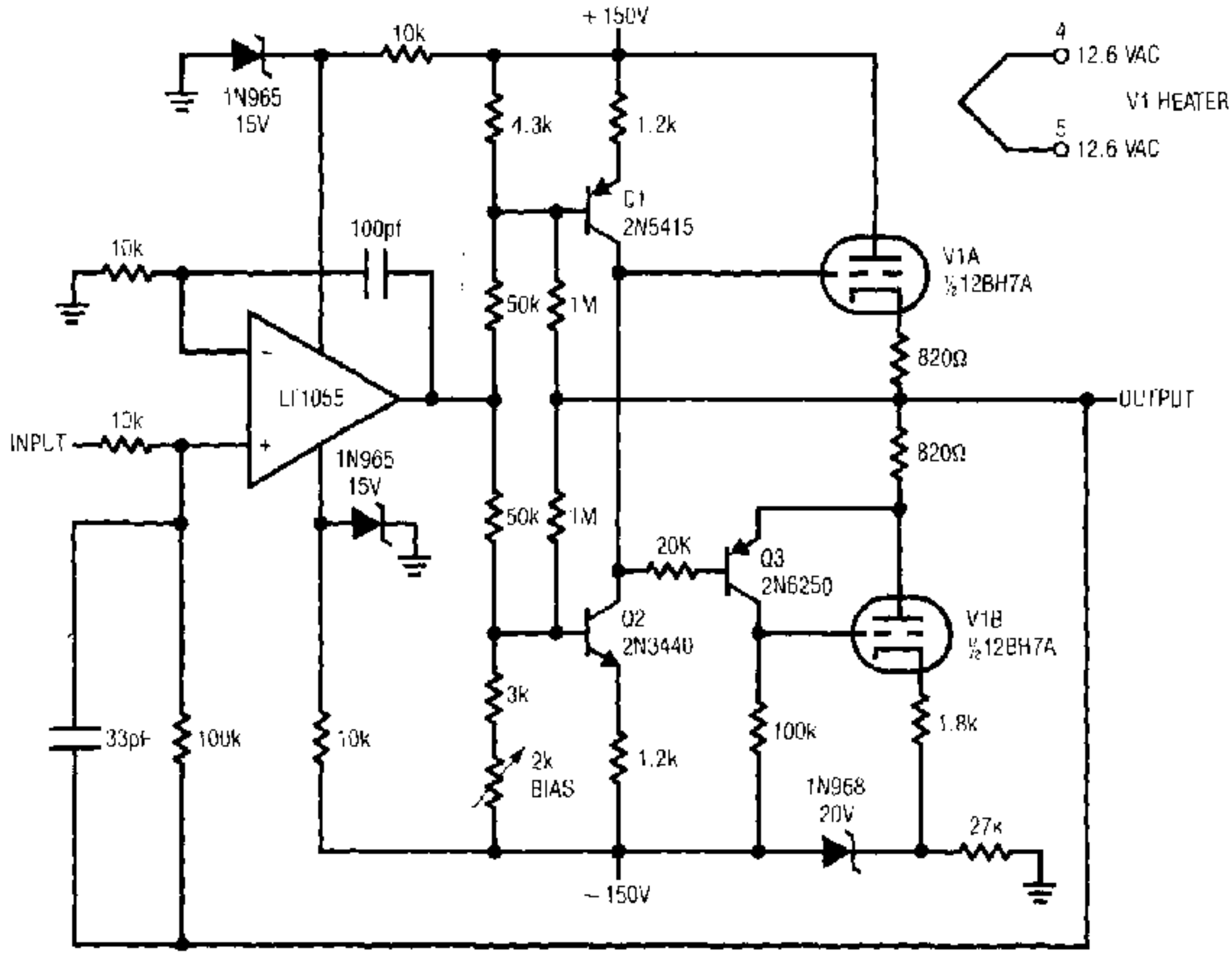

Made in Russia
FOREVER
FLASHLIGHT

# Interesting Signal Generation Circuits

IATIONAL
UNION
U

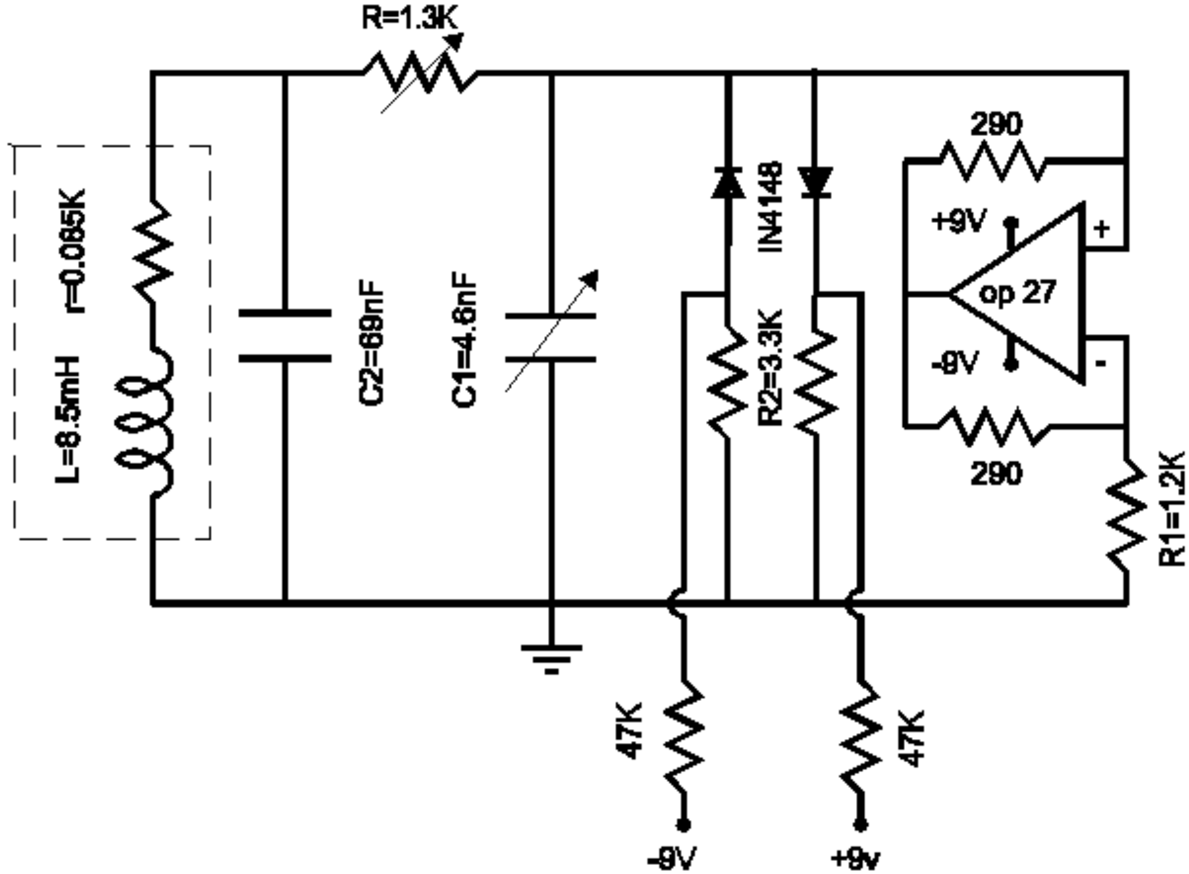

  

# Vacuum Tube Op-Amp Output




Source: Linear Technology AN-18.

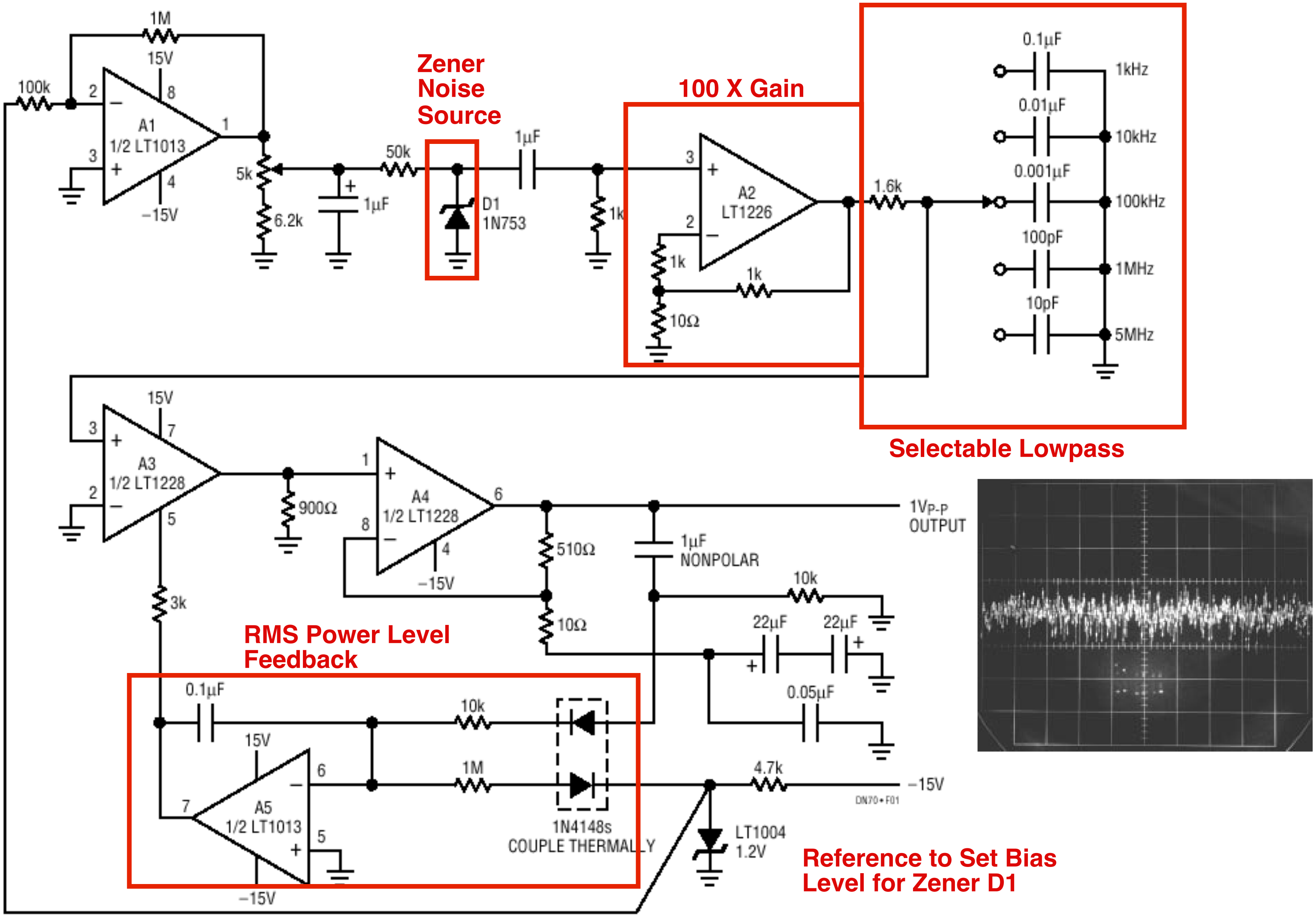
# Chua's Chaotic Circuit




**To see chaotic behavior, plot the voltage measured across *C1* against the voltage measured across *C2* (an *X-Y* oscilloscope with probes connected across these capacitors). The transition to chaotic dynamics can be found by *carefully* decreasing *R* or *C1*, (e.g. decrease *R* in steps of 0.01 to 1.2K). Source: http://www.cmp.caltech.edu/~mcc/chaos_new/Chua.html**

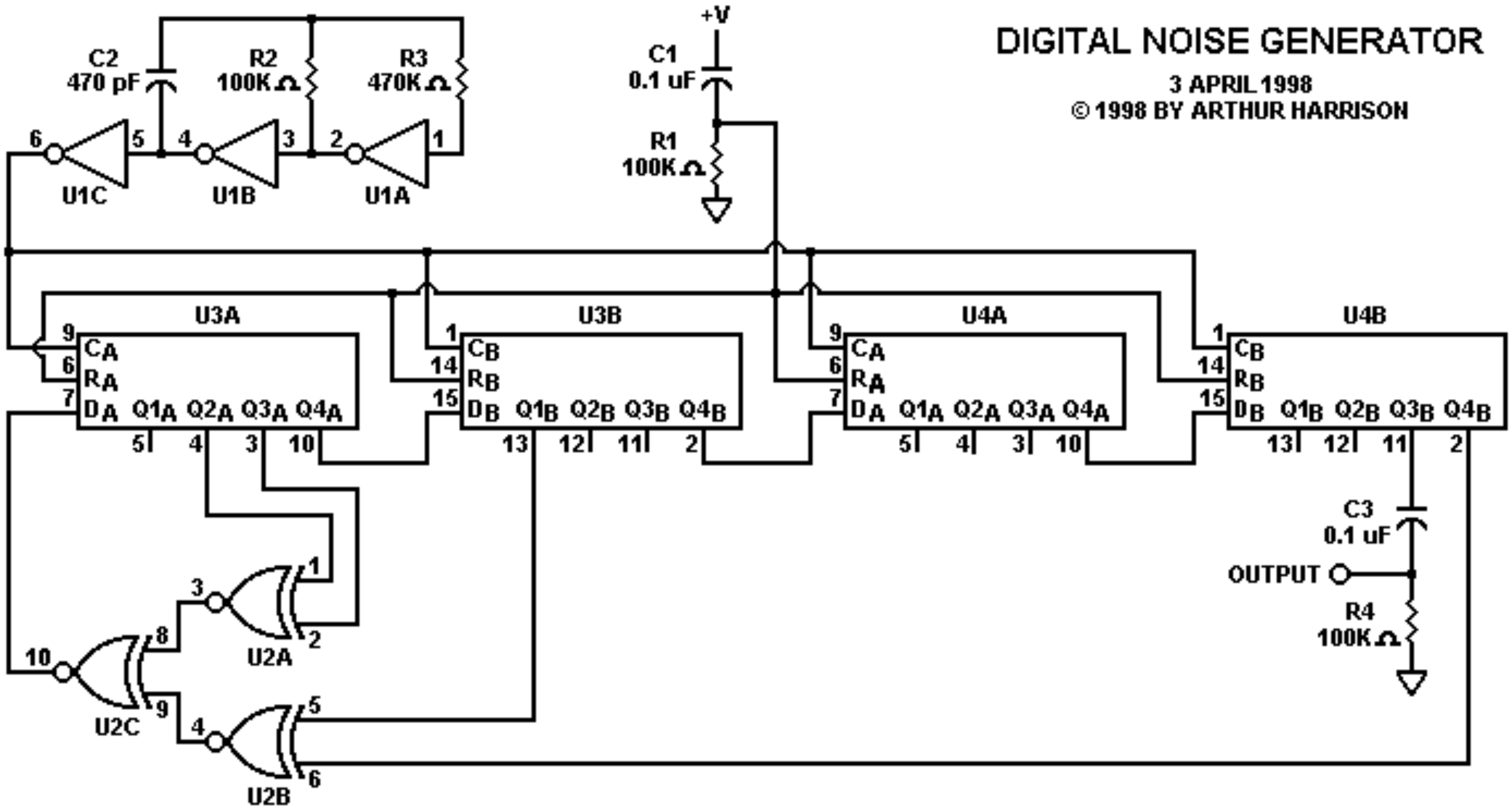
# The First 8-Bit Micro On A Chip

# Broadband Noise Generator




Source: Linear Technology DN-70.

# Digital Noise Generator Example

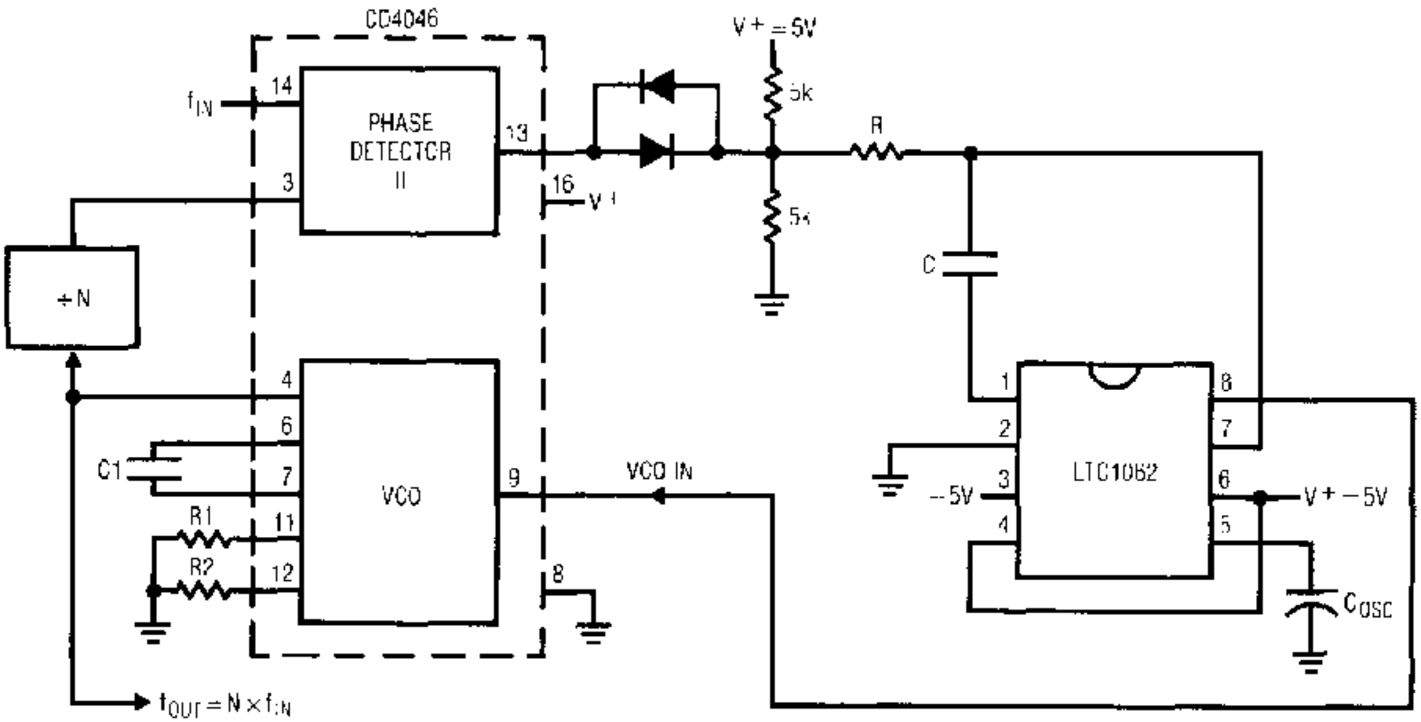



| INTEGRATED CIRCUIT TYPE DESIGNATIONS AND POWER CONNECTIONS | | | | |
|---|---|---|---|---|
| DESIGNATION | TYPE | +V | GROUND | GROUND UNUSED INPUTS |
| U1 | CD4069UBE | 14 | 7 | 9, 11, 13 |
| U2 | CD4077BE | 14 | 7 | 12, 13 |
| U3, U4 | CD4015BE | 16 | 8 | — |

NOTES:
1. +V = 5 TO 12 VOLTS
2. DECOUPLE ALL ICS WITH 0.1 uF CERAMIC CAPACITORS

**Source:** http://home.att.net/~theremin1/circuitlibrary/digitalnoisegen.html

# Quick Look:  Phase-Locked Loops




Source: Linear Technology AN-24.

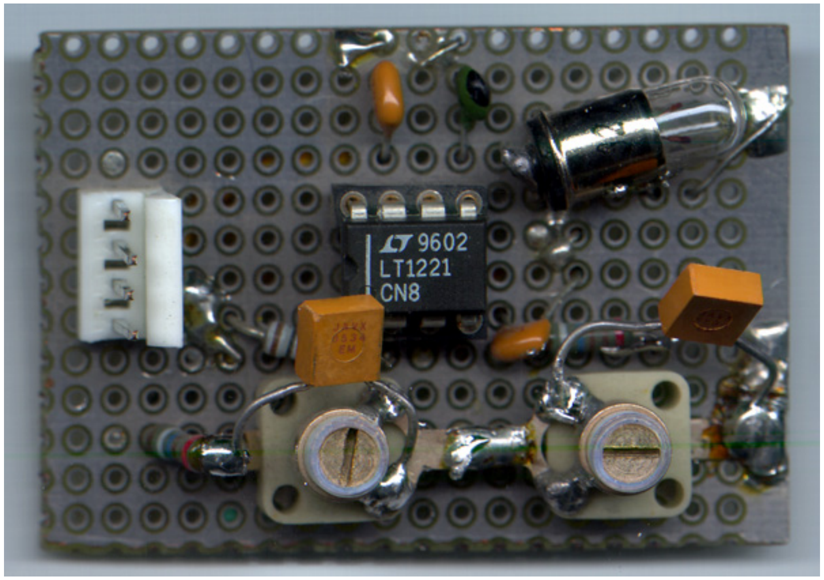
# More Oscillator Circuits

# Cool Ways to Make Sinewaves

- **Wein Bridge variants.**
  - **Quartz crystal.**
  - **Stabilization schemes.**
- **Look-Up-Table + D/A Converter.**
- **Direct Digital Synthesis (accumulator + look-up-table + D/A converter).**
- **Filtered squarewaves.**

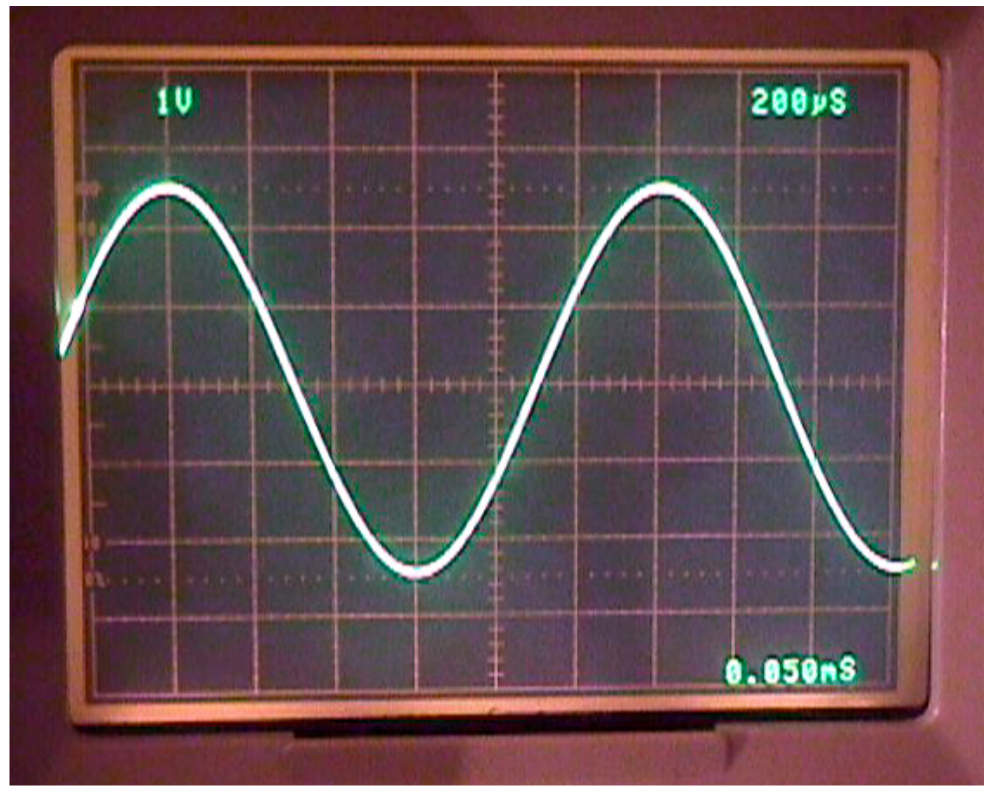
# Lamp-Stabilized Wein Bridge




**Just like HP!**



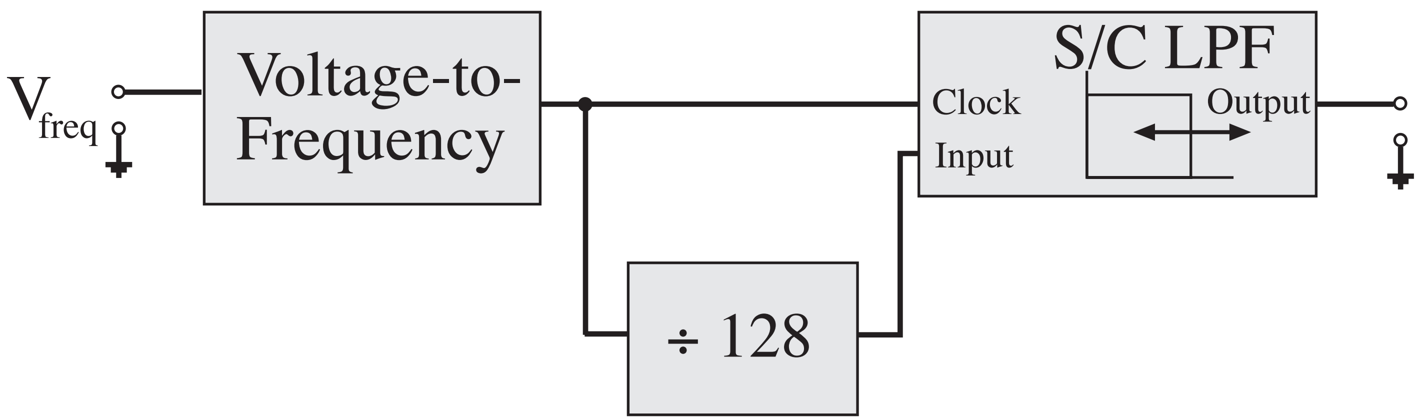
**Low distortion!**



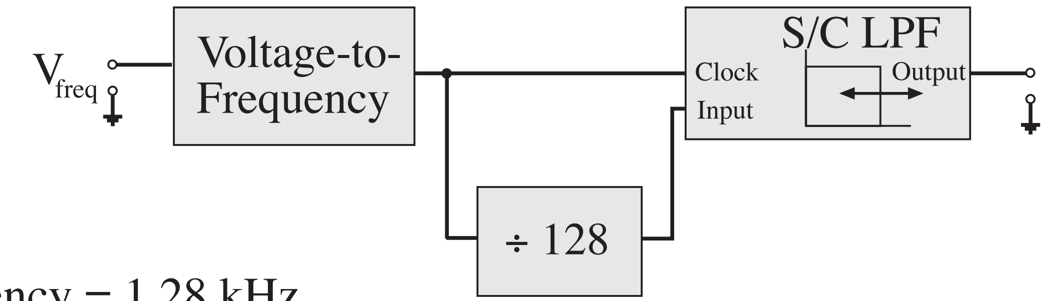

  

# Sines from Filtered Squarewaves

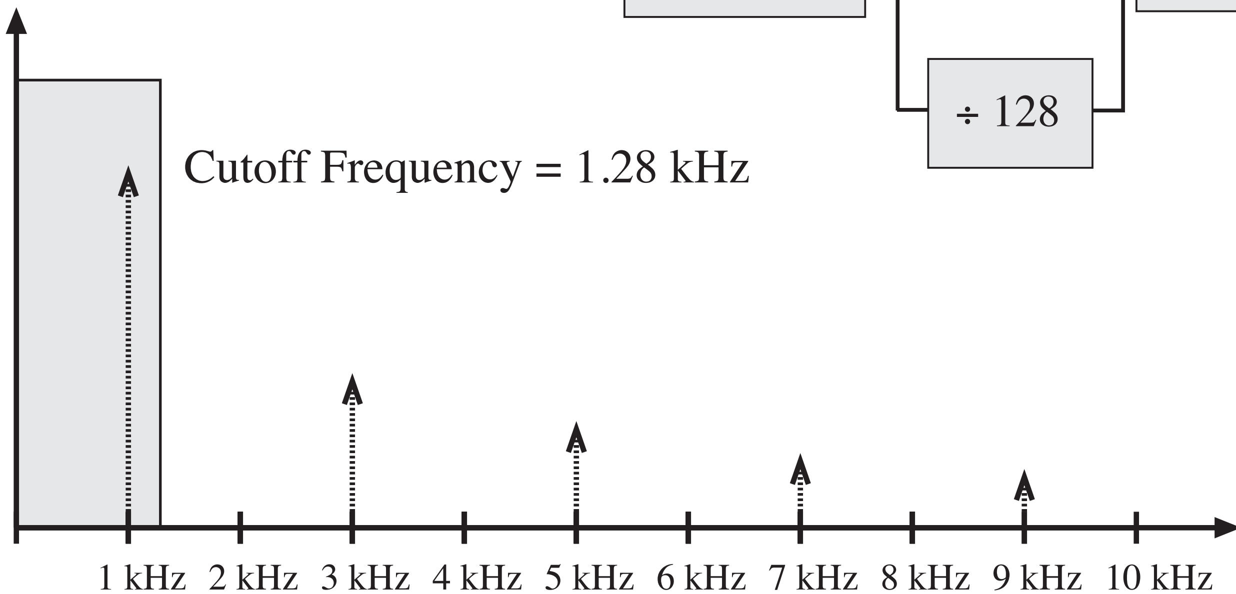
- Sweepable design - switched capacitor filter automatically tracks squarewave frequency and filters all but the fundamental frequency.
- The result is clean sinewaves.



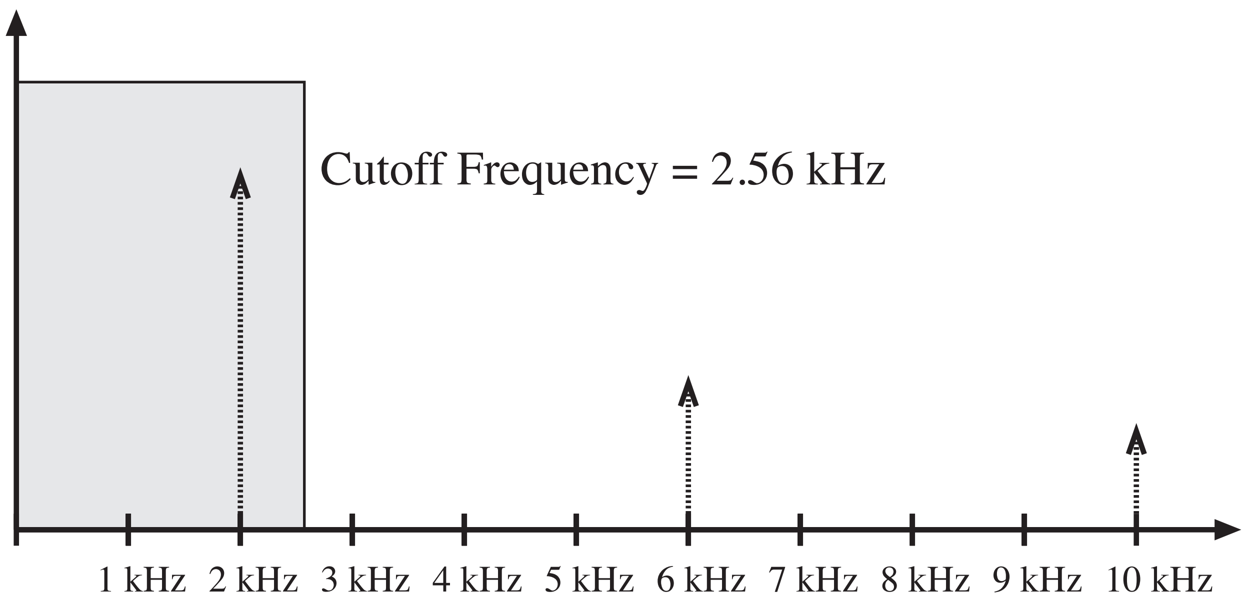
# How it Works



$V_{freq}$
Voltage-to-Frequency
S/C LPF
Clock Input
Output
÷ 128

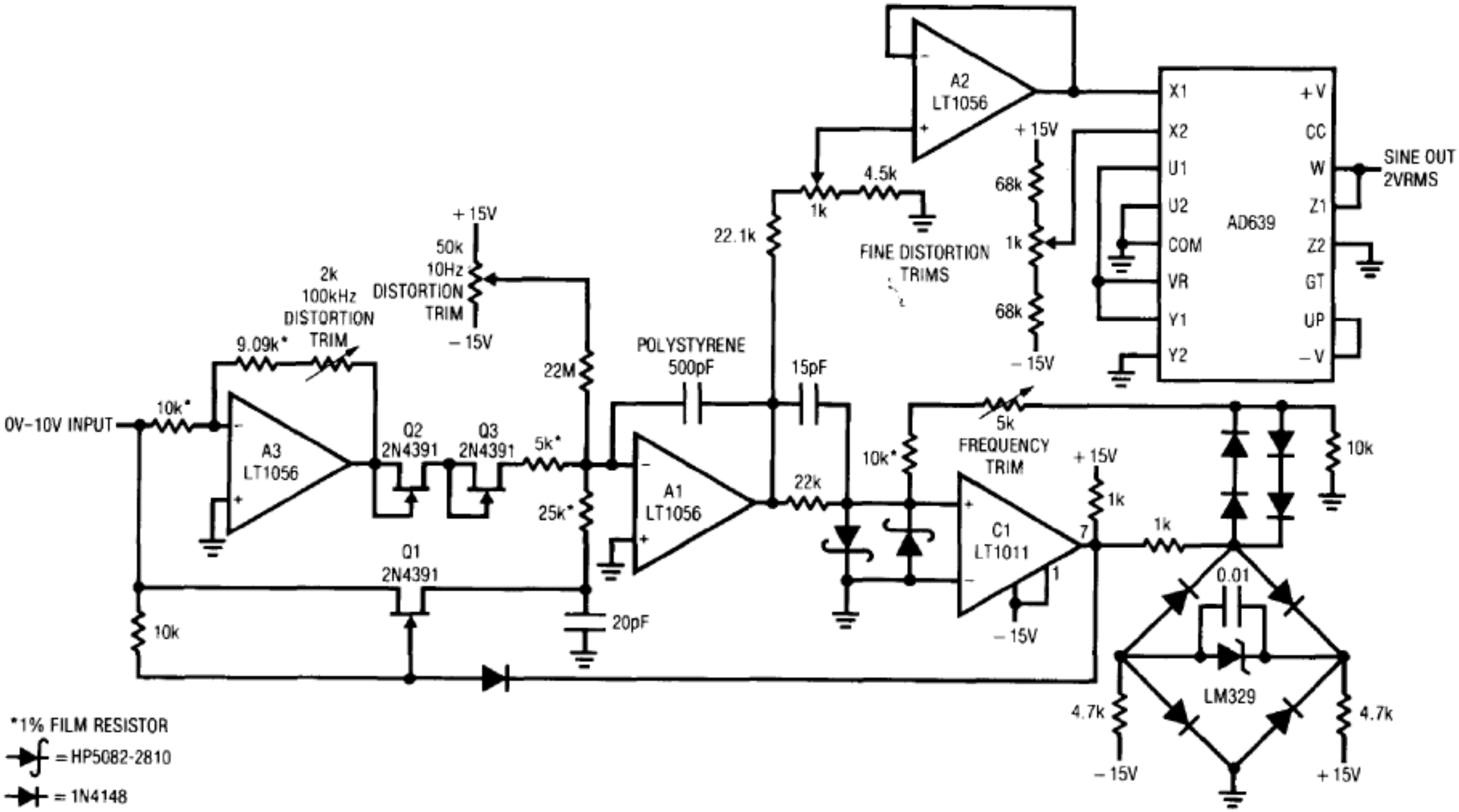



Cutoff Frequency = 1.28 kHz
1 kHz 2 kHz 3 kHz 4 kHz 5 kHz 6 kHz 7 kHz 8 kHz 9 kHz 10 kHz

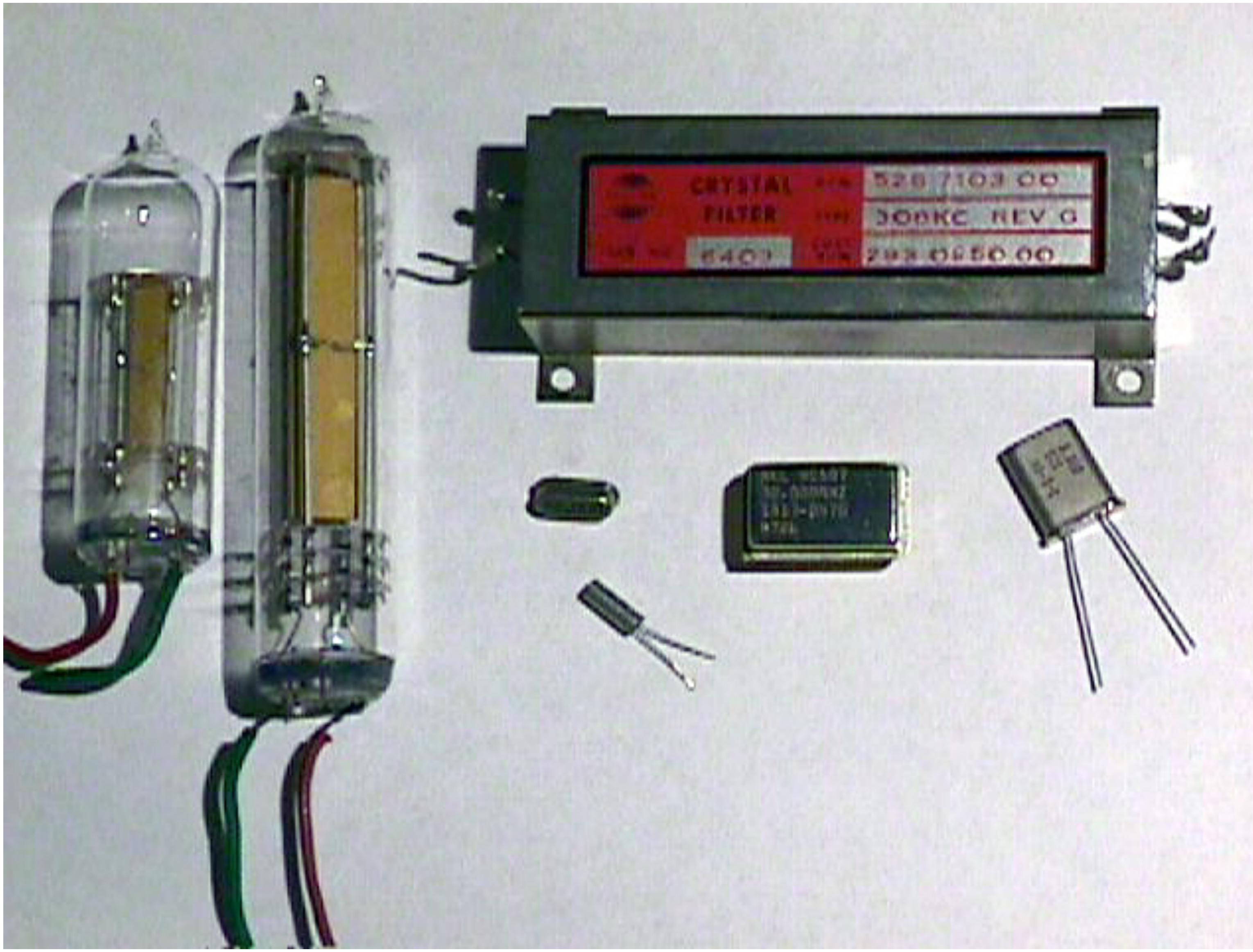
Cutoff Frequency = 2.56 kHz
1 kHz 2 kHz 3 kHz 4 kHz 5 kHz 6 kHz 7 kHz 8 kHz 9 kHz 10 kHz

# Sinewave V-to-F Converter




**Source: Linear Technology AN-14.**

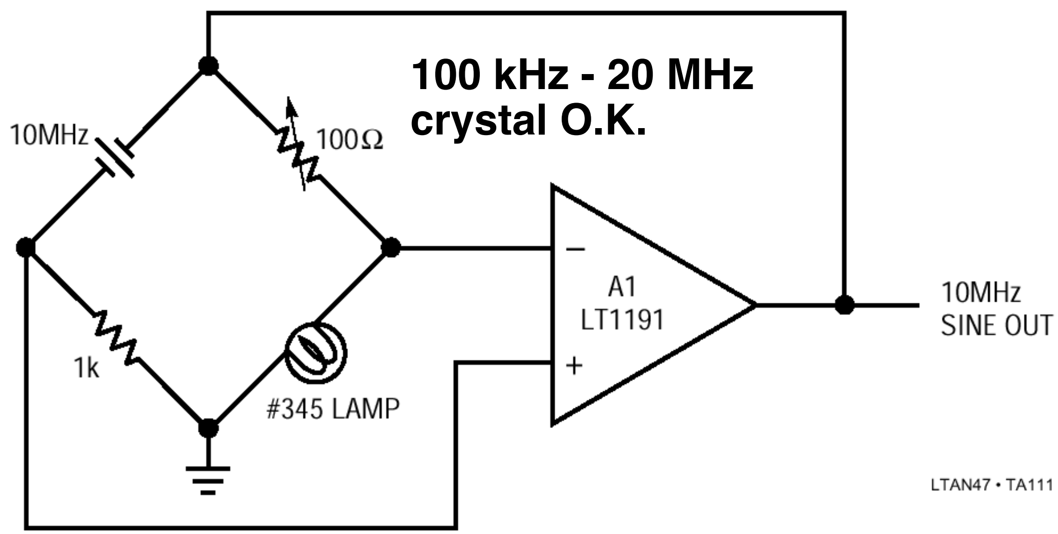
# Quartz Crystals and You



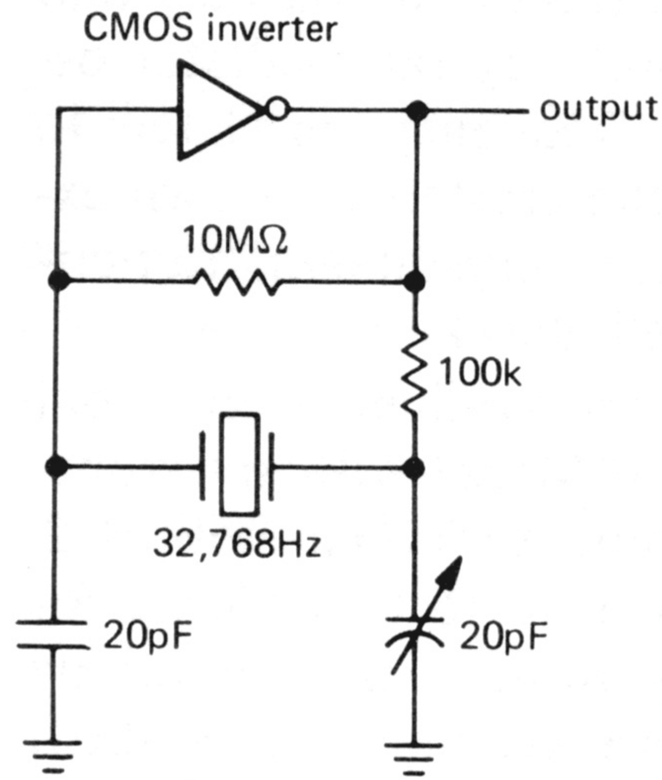
# Quartz Oscillators

## Sinewave Output



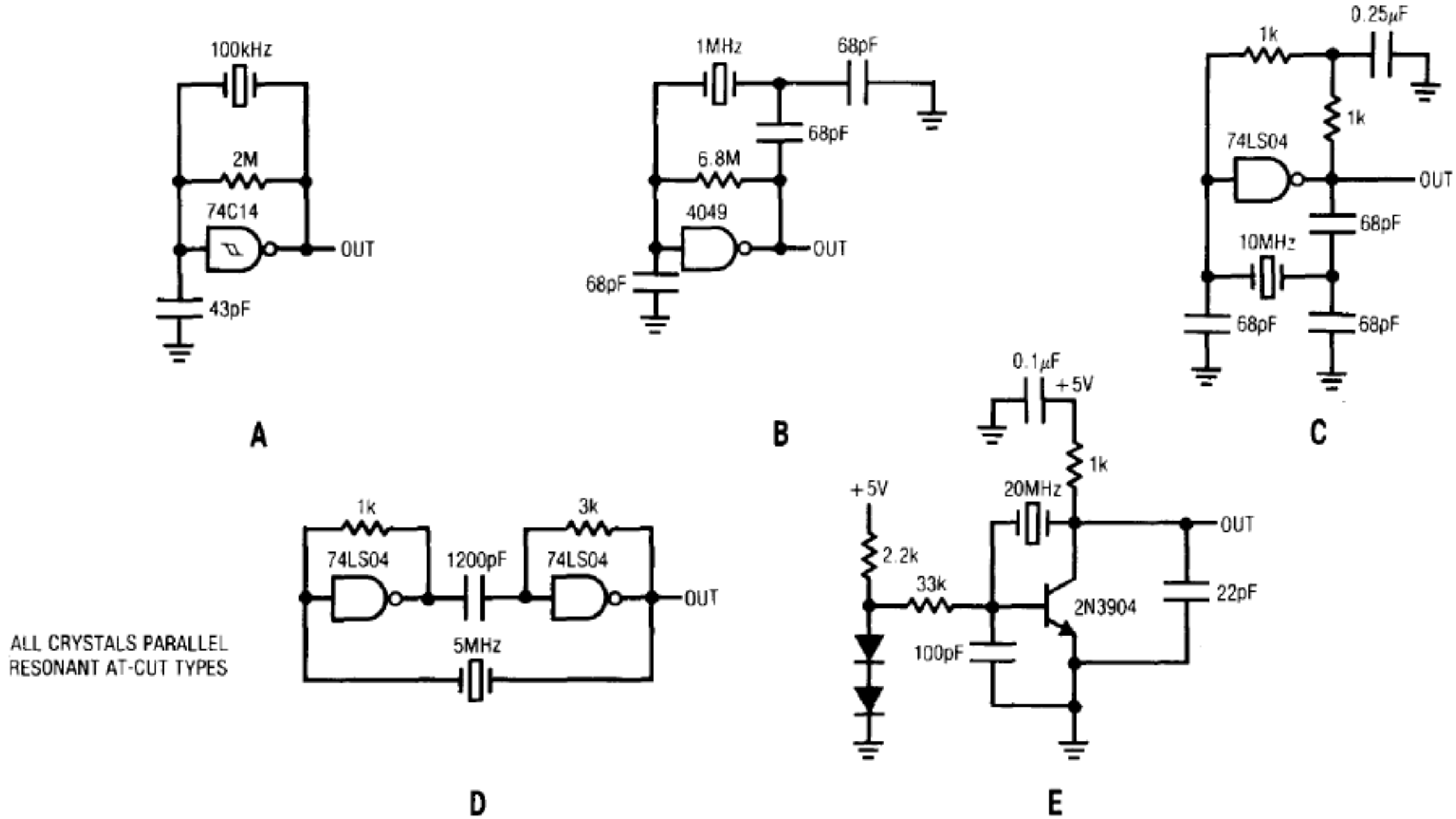

Source: Linear Technology AN-47.

## Squarewave Output



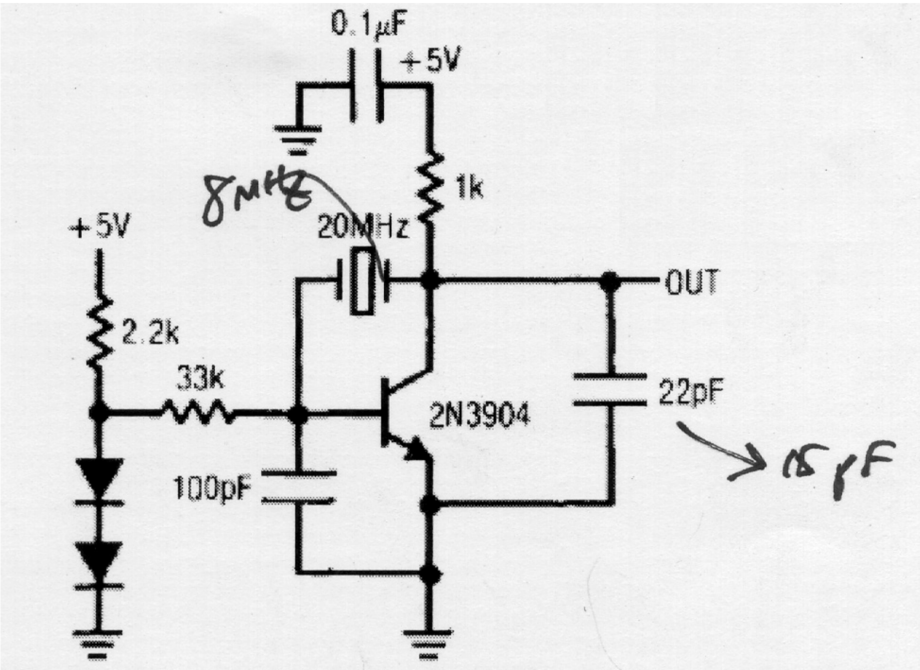

Source: Horowitz & Hill, "The Art of Electronics," Cambridge University Press, 1989.

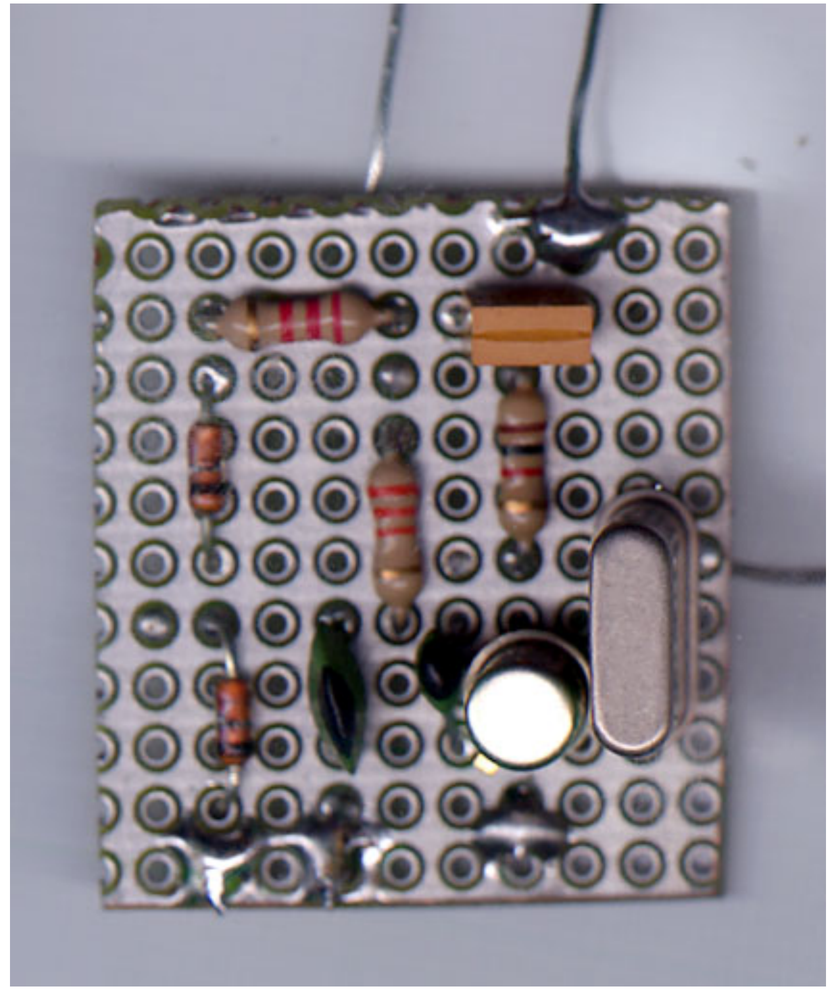
# Other Handy Quartz Digital Oscillators



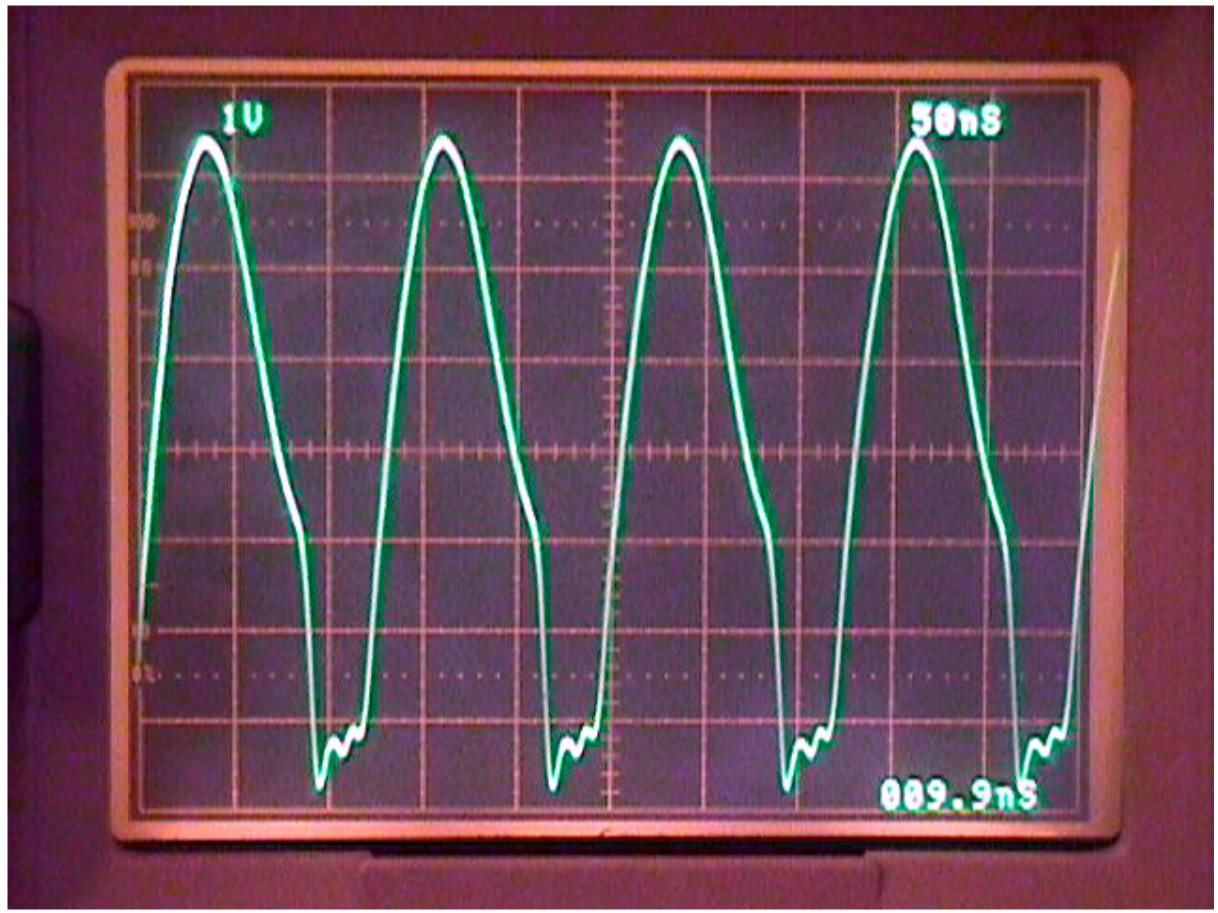

Source: Linear Technology AN-12.

# Example Quartz Oscillator...

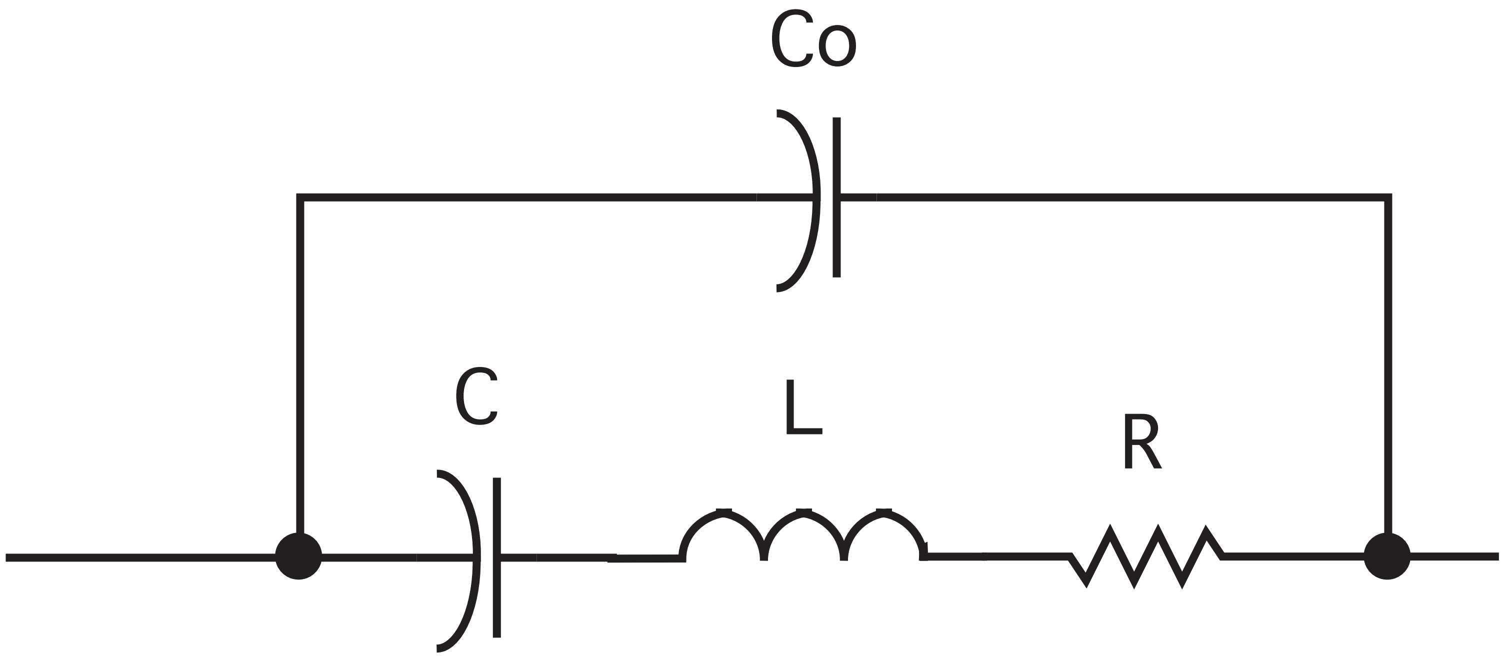


# Quartz Oscillator Results

# Modeling Quartz Crystals




Note: these values are comparable, but not identical to those given in the first set of lecture notes.

**Typical Values (LTC AN-12):**

**R = 100 Ω**

**L = 500 μH**

**C = 0.01 pF**

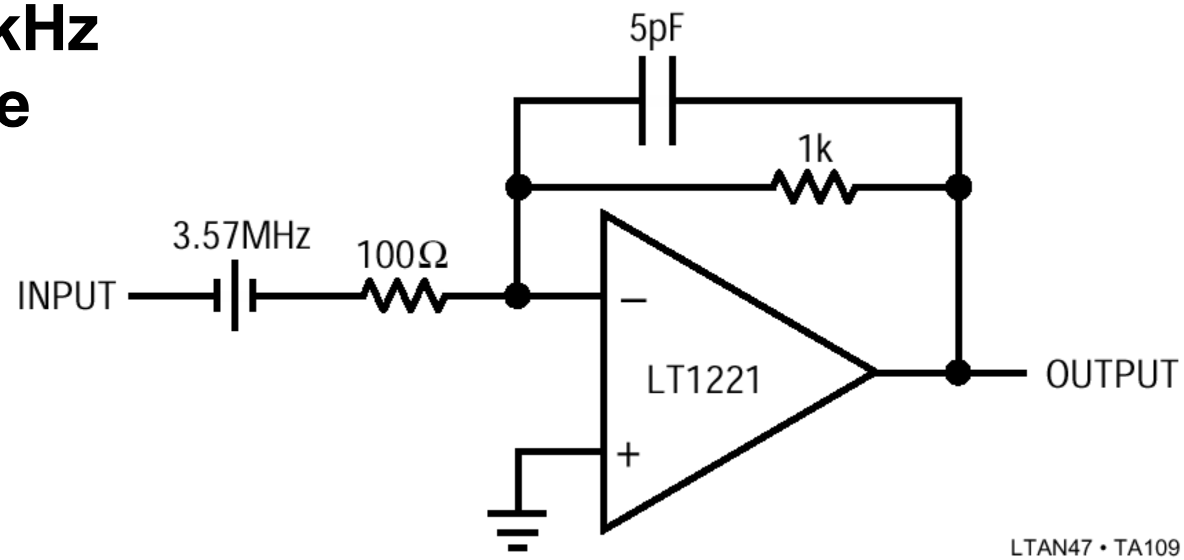
**Co = 5 pf**

**Q = 50,000**

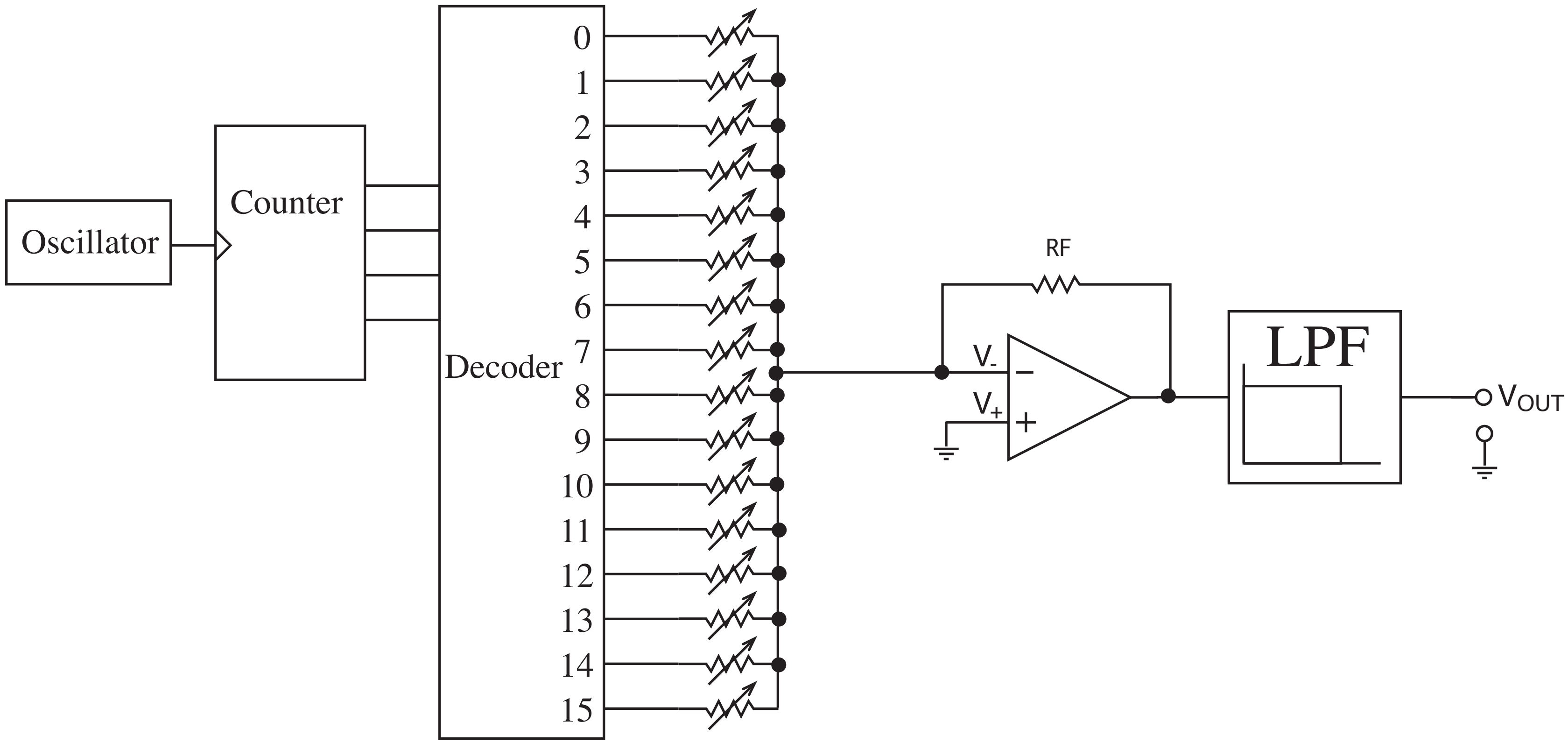
# Crystal Filters

- **Extremely narrow-bandpass filters can be designed using quartz crystals.**
- **Note that 32.768 kHz watch crystals are handy for low-frequency applications.**




**Source: Linear Technology AN-47.**

# Gilligan's Island Synthesizer



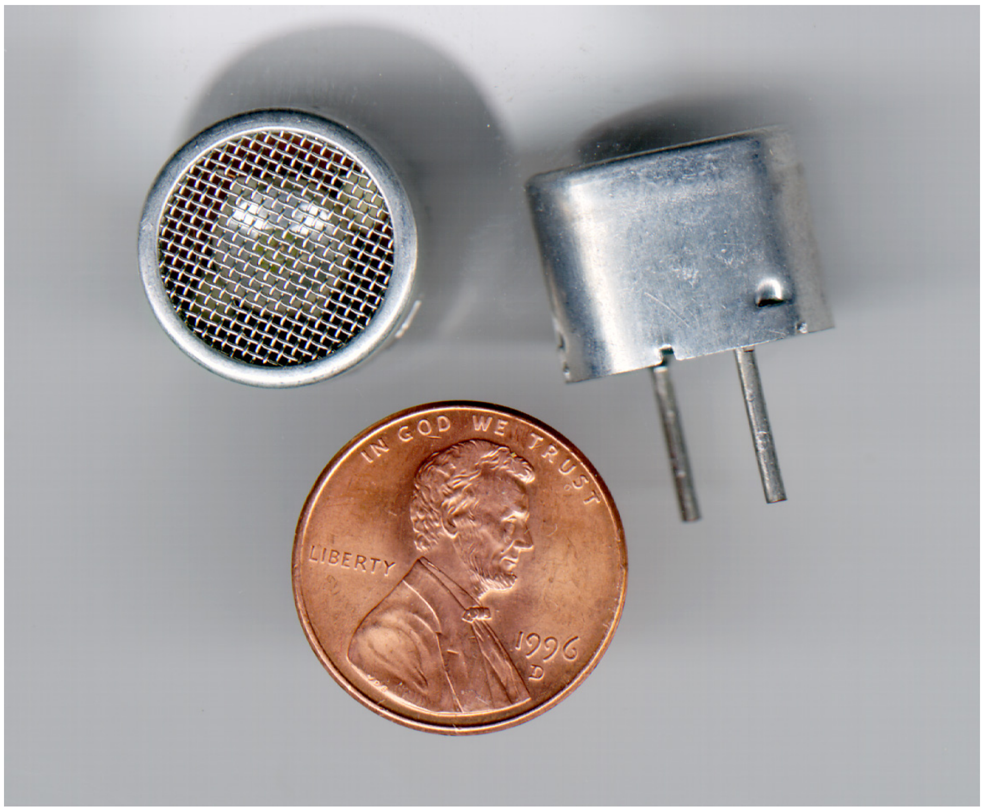

**CMOS outputs (0 - 5 V) of decoder sum currents into an op-amp. By setting the pots to desired values, any 16-segment waveform can be synthesized.**

**Can use CdS cells (light-dependent resistors) for COOL effects!**

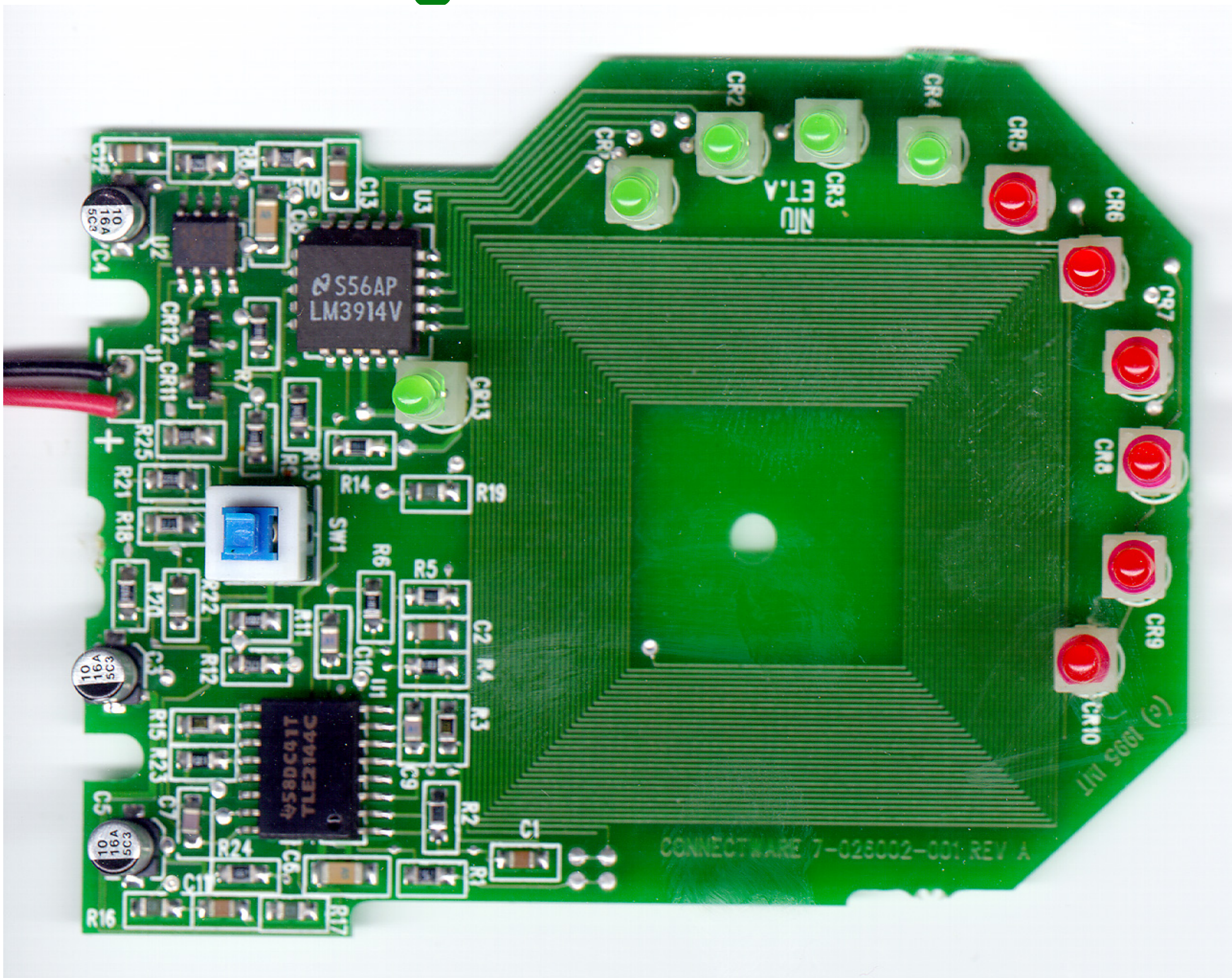
# Other Interesting Circuits

# Ultrasonic Transducers




# Electromagnetic Field Detector



# Electromagnetic Transmitters

- As used in the Louvre (at least in 1972!) for guided tours.
- Can run a fine-gauge wire around the perimeter of a room (e.g., under carpet) and drive directly with a power amplifier.
- Multi-turn magnetic coil "receivers" (such as the coils used in EE122) can pick up the signal ("baseband AM") and, if amplified, it can be heard on a speaker or earphones.