CDL Presents
Basic Electronics

Week3

1

Analog Integrated Circuits

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Questions from Last Week

Some Common Analog Integrated Circuits

- Operational Amplifier (OP-AMP)
- Voltage Regulators
- NE555 timer
- Audio Amplifier: LM386
- RF Amplifiers
- Motor Controllers
- Direct Digital Synthesis

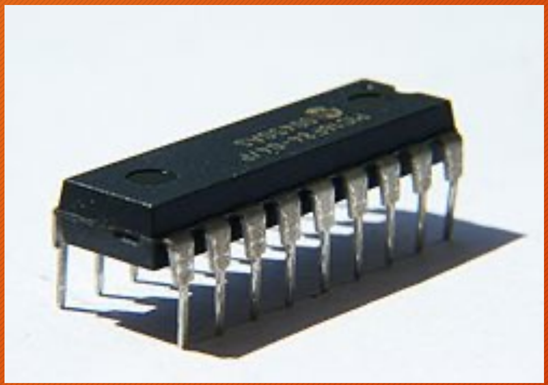
Analog Integrated Circuits (ICs)

- When a circuit design become very popular, they are often designed into a integrated circuit (IC)
- By providing an IC with:
  - a data sheet, and
  - a reference design
- The design time for circuits in shortened significantly

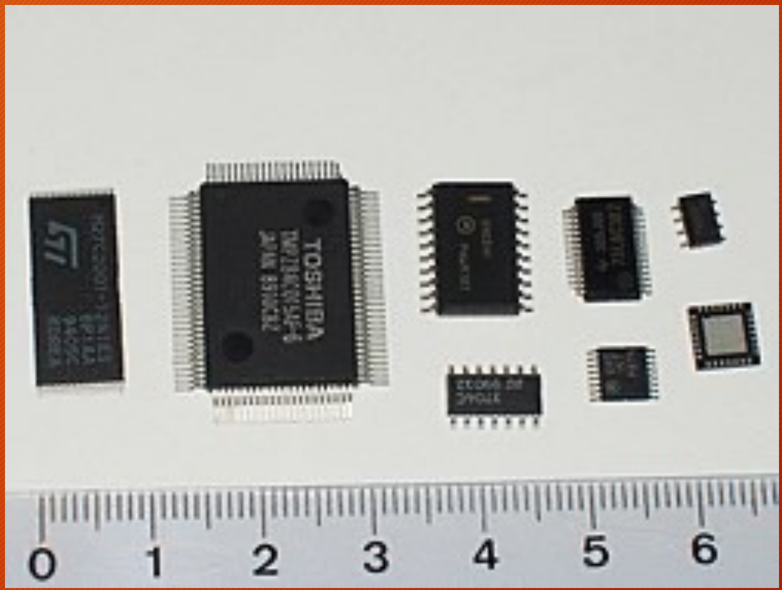
Today, these chips can be found in a variety of packages
  - Old school: Dual Inline Chip, with pins to go into holes
  - Surface mount to go on boards with no holes
- Most of the ICs in this talk can be purchased in multiple packages
- Some can now only be found in surface mount
- To get some with pins requires old stock or flea markets

Types of packages

Dual in line
4
8
10
16
18
24
28 pins



Surface Mount, multiple sizes



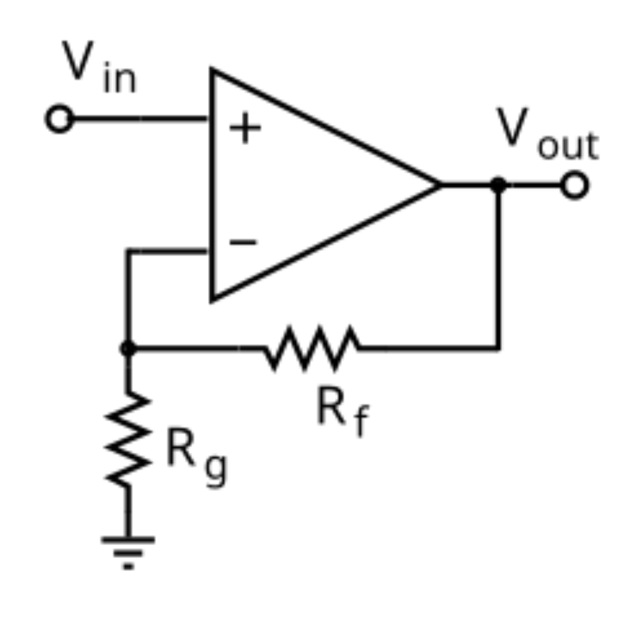
Some IC with only 3 leads, (typically voltage regulators) can be found in transistor size packages

Operational Amplifier (Op Amps)

- While vacuum tube op amps have been around a long time, they were are large sub-assemblies and often each designer had their own custom design
- Solid-state op-amps, including the μA702 from Fairchild in 1963 and the μA741 in 1968, provided an op amp in one package
- An operational amplifier (often op amp or opamp) is a
  - DC-coupled electronic voltage amplifier with a differential input,
  - A (usually) single-ended output, and
  - Extremely high gain.
- By using negative feedback, an op amp circuit's characteristics
  - (e.g. its gain, input and output impedance, bandwidth, and functionality)
- Can be determined by external components and have little dependence on temperature coefficients or engineering tolerance in the op amp itself.
- This flexibility has made the op amp a popular building block in analog circuits.

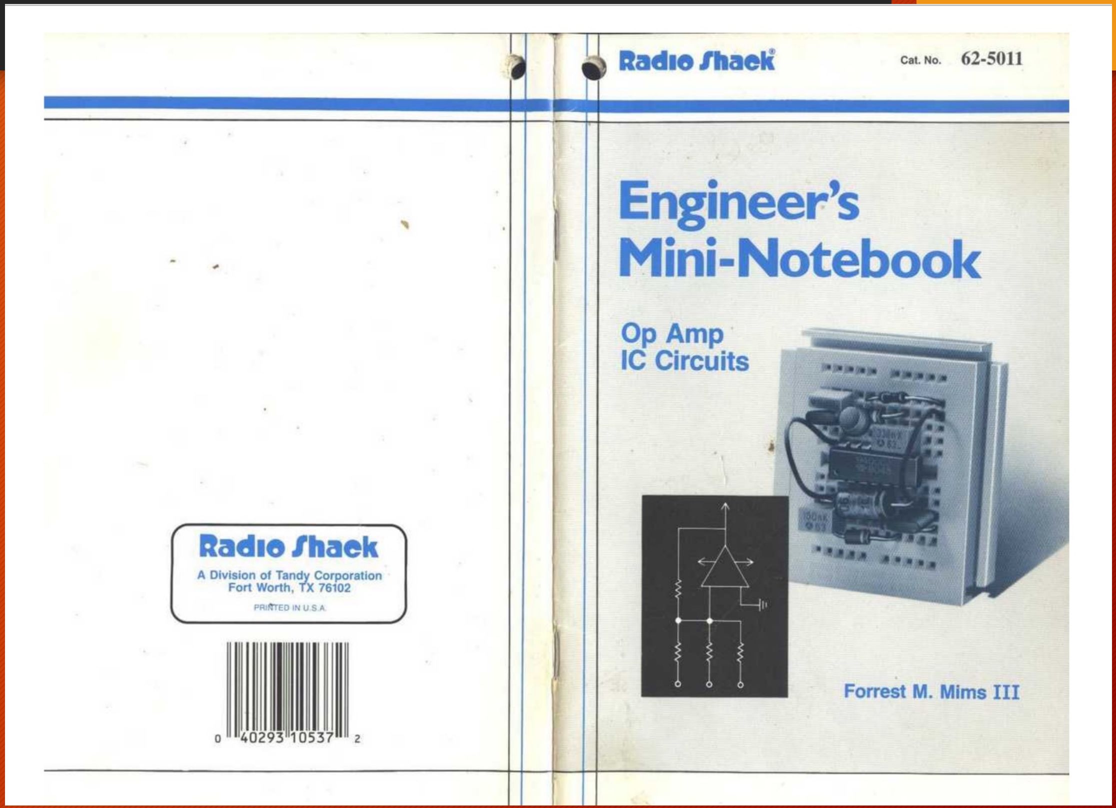
Simple OP AMP circuit

- Early OP Amps needed a set of equal positive and negative supply voltages
- Some OP Amps can operate on a single power supply
- The gain of the circuit is R_f/R_g
- Op Amps are used for audio and have a maximum frequency in the low MHz Range



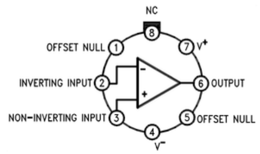
OP Amp Cookbook by Forrest Mims

- Out of print but can be found on web in pdf format
- Nuts and Volts Magazine also has a series on the op amp
- https://www.nutsvolts.com/magazine/article/op-amp-cookbook



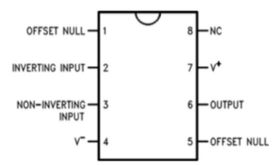
LM741 Op AMP

LMC Package
8-Pin TO-99
Top View



LM741H is available per JM38510/10101

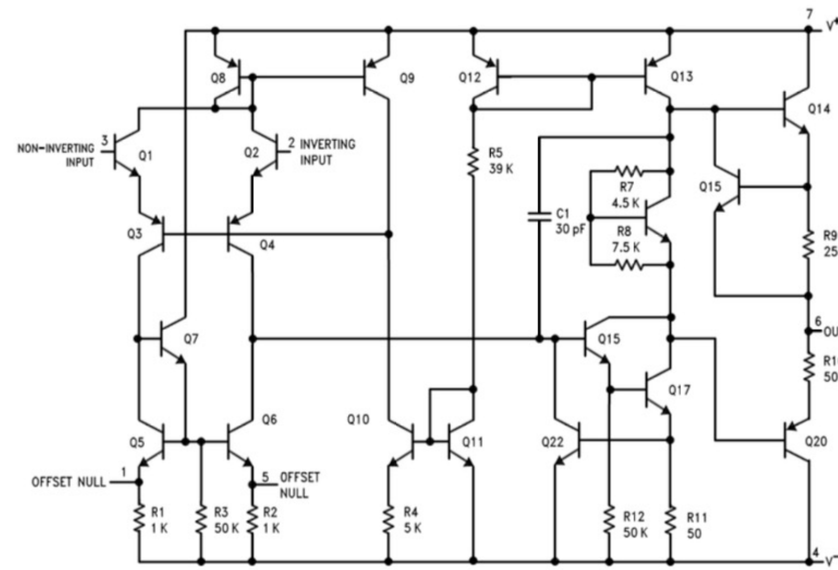
NAB Package
8-Pin CDIP or PDIP
Top View



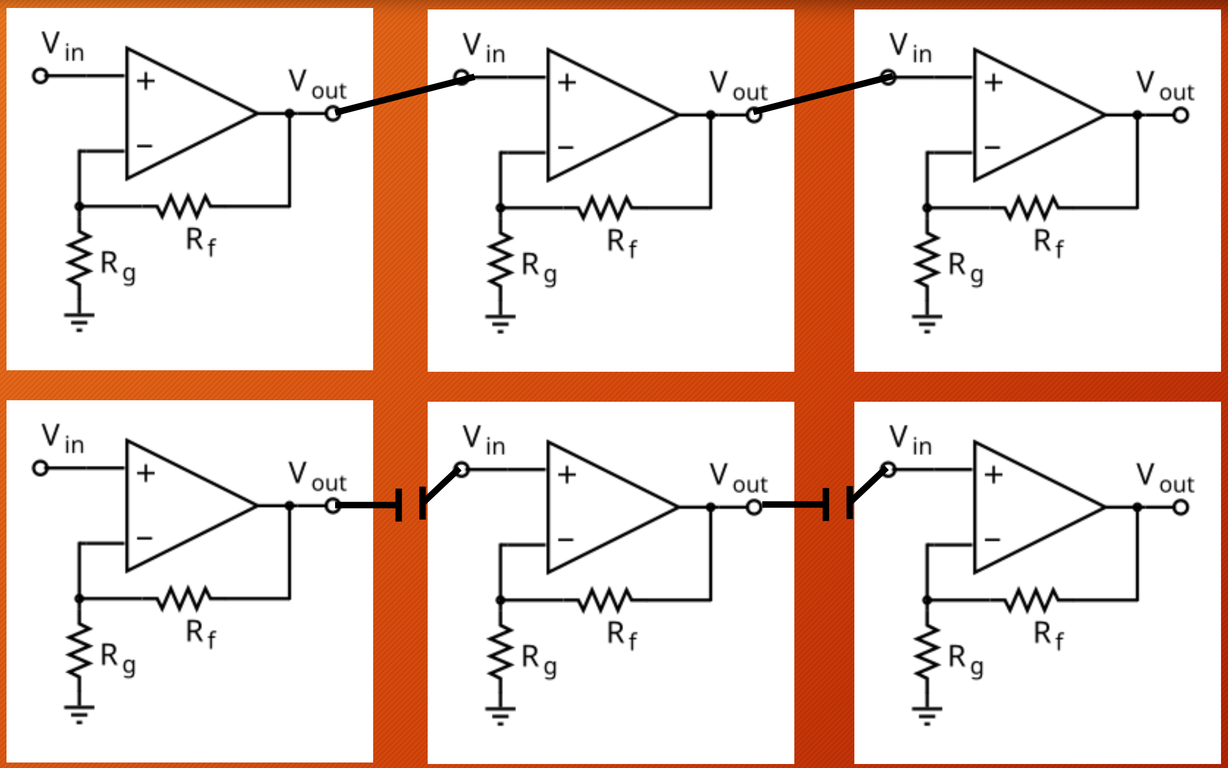
Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
INVERTING INPUT	2	I	Inverting signal input
NC	8	N/A	No Connect, should be left floating
NONINVERTING INPUT	3	I	Noninverting signal input
OFFSET NULL	1, 5	I	Offset null pin used to eliminate the offset voltage and balance the input voltages.
OFFSET NULL			
OUTPUT	6	O	Amplified signal output
V+	7	I	Positive supply voltage
V–	4	I	Negative supply voltage

7.2 Functional Block Diagram



Multi-stage Design



DC coupled

For Illustration Not for Design

AC coupled

Input Offset Adjustment

- We use two identical power supply voltages (e.g., +12 v, -12 v)
- When the two inputs have identical voltages on them
  - The output voltage should be 0 volts
- If it is not 0 volts, the voltage offset is amplified by the next stage, and grows through a multi-stage amplifier design
- We use the offset inputs to adjust the output to be 0 volts when the two inputs are identical
- If we capacitive couple stages, the offset may not affect the design

Typical Data Sheet

6.5 Electrical Characteristics, LM741 (1)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage		$R_S \le 10$ kΩ	$T_A = 25°C$		1	5	mV
			$T_{AMIN} \le T_A \le T_{AMAX}$			6	mV
Input offset voltage adjustment range		$T_A = 25°C$, $V_S = \pm 20$ V			±15		mV
Input offset current		$T_A = 25°C$			20	200	nA
		$T_{AMIN} \le T_A \le T_{AMAX}$			85	500	
Input bias current		$T_A = 25°C$			80	500	nA
		$T_{AMIN} \le T_A \le T_{AMAX}$				1.5	μA
Input resistance		$T_A = 25°C$, $V_S = \pm 20$ V		0.3	2		MΩ
Input voltage range		$T_{AMIN} \le T_A \le T_{AMAX}$		±12	±13		V
Large signal voltage gain		$V_S = \pm 15$ V, $V_O = \pm 10$ V, $R_L \ge 2$ kΩ	$T_A = 25°C$	50	200		V/mV
			$T_{AMIN} \le T_A \le T_{AMAX}$	25			
Output voltage swing		$V_S = \pm 15$ V	$R_L \ge 10$ kΩ	±12	±14		V
			$R_L \ge 2$ kΩ	±10	±13		
Output short circuit current		$T_A = 25°C$			25		mA
Common-mode rejection ratio		$R_S \le 10$ Ω, $V_{CM} = \pm 12$ V, $T_{AMIN} \le T_A \le T_{AMAX}$		80	95		dB
Supply voltage rejection ratio		$V_S = \pm 20$ V to $V_S = \pm 5$ V, $R_S \le 10$ Ω, $T_{AMIN} \le T_A \le T_{AMAX}$		86	96		dB
Transient response	Rise time	$T_A = 25°C$, unity gain			0.3		μs
	Overshoot				5%		
Slew rate		$T_A = 25°C$, unity gain			0.5		V/μs
Supply current		$T_A = 25°C$			1.7	2.8	mA
Power consumption		$V_S = \pm 15$ V	$T_A = 25°C$		50	85	mW
			$T_A = T_{AMIN}$		60	100	
			$T_A = T_{AMAX}$		45	75	

Note:
The 741 requires two power supplies

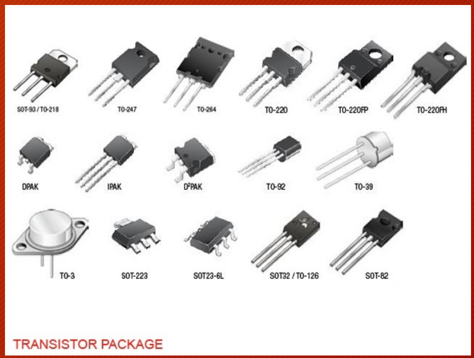
https://en.wikipedia.org/wiki/Operational_amplifier

Some Typical Op Amps

- LM741: A popular and widely used general-purpose op-amp, known for its low cost and availability. It's a good choice for beginner projects, but its performance specs are lower than newer models.
- LM324: A quad (four) op-amp with a low-power design and a wide gain-bandwidth product, making it suitable for various applications.
- TL072: A dual op-amp with JFET inputs, offering low noise and good performance in general-purpose applications.
- OP07: An ultra-low offset voltage op-amp, making it suitable for applications requiring high precision, such as instrumentation.
- LMH6629: A high-speed, ultra-low-noise voltage feedback operational amplifier, often used in audio applications.
- RC4558: A dual general-purpose op-amp with a relatively wide gain-bandwidth product.
- NE5532: A low-noise, high-speed audio op-amp suitable for applications requiring high audio fidelity.

Voltage Regulators

- These are three terminal devices that when inputting a DC voltage will lower it to a known fixed value
- The input voltage must be several volts higher than the desired output
- They are available in different voltages and for positive and negative voltages
- They can handle up to several amps of power
- Typical parts are:
  - Positive voltages: 7805, 7809, 7810, 7815, 7824
  - Negative voltages: 7905, 7809, 7912, 7915, 7924
- There are some models that can adjusted in voltage
- These regulators come in typical transistor packages



Partial Data Sheet

Line Regulation is often called dropout voltage

Electrical Characteristics LM78XXC (Note 2)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

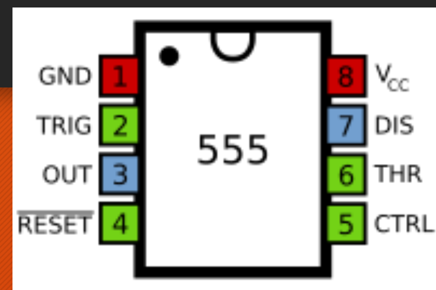
Output Voltage				**5V**			**12V**			**15V**			**Units**
Input Voltage (unless otherwise noted)				**10V**			**19V**			**23V**			
Symbol	**Parameter**	**Conditions**		**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)		V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}		(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 1A	Tj = 25°C			50			120			150	mV
			ΔV_{IN}		(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)		V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV

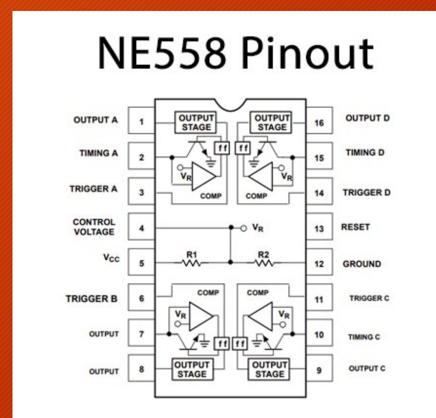
The input voltage needs to be about 2-3 volts higher than the output voltage

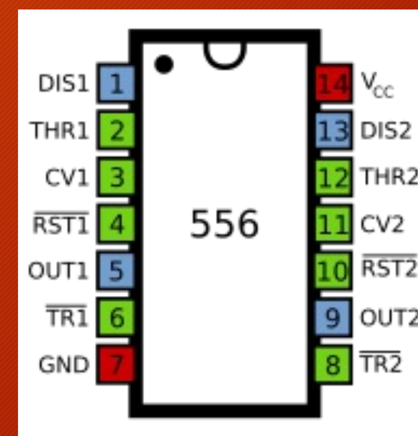
There are some "low dropout voltage" devices

NE555 Timer

- The NE555 Timer is probably the most used analog IC in the world
- Articles have been written for years about it and people are always inventing new ways to use it.
- It is cheap and versatile
- It is available in 1, 2 and 4 chips in the same package

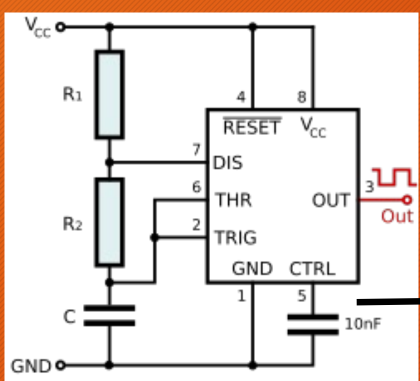


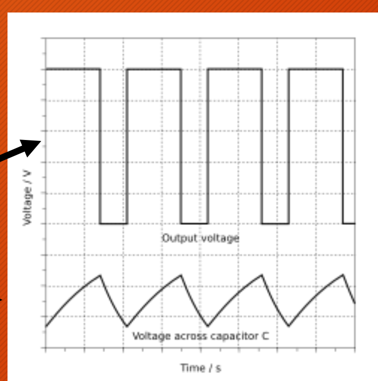




NE555 in Astable Mode

- By selecting which pin to provide the output, the astable mode provides
- A continuous pulse train, or
- A saw tooth waveform



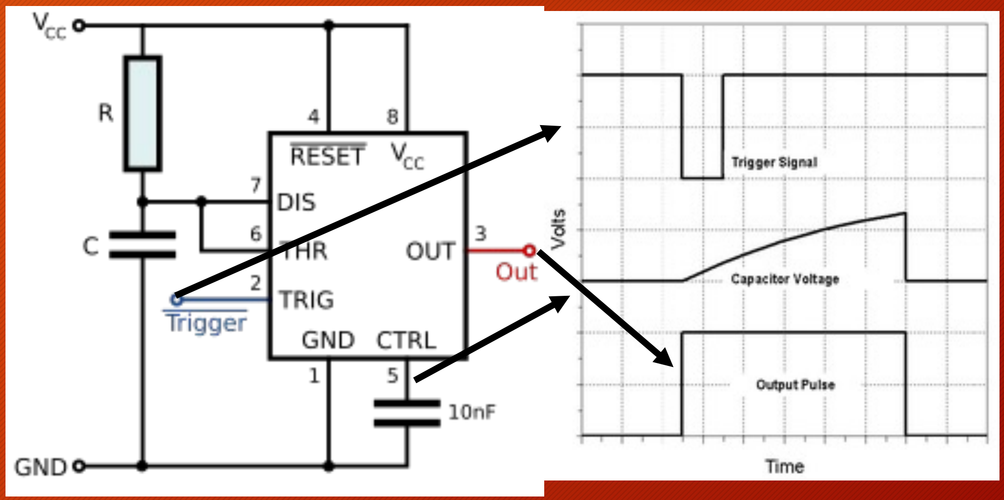


Astable mode examples with common values

Frequency	C	R_1	R_2	Duty cycle
0.1 Hz (+0.048%)	100 µF	8.2 kΩ	68 kΩ	52.8%
1 Hz (+0.048%)	10 µF	8.2 kΩ	68 kΩ	52.8%
10 Hz (+0.048%)	1 µF	8.2 kΩ	68 kΩ	52.8%
100 Hz (+0.048%)	100 nF	8.2 kΩ	68 kΩ	52.8%
1 kHz (+0.048%)	10 nF	8.2 kΩ	68 kΩ	52.8%
10 kHz (+0.048%)	1 nF	8.2 kΩ	68 kΩ	52.8%
100 kHz (+0.048%)	100 pF	8.2 kΩ	68 kΩ	52.8%

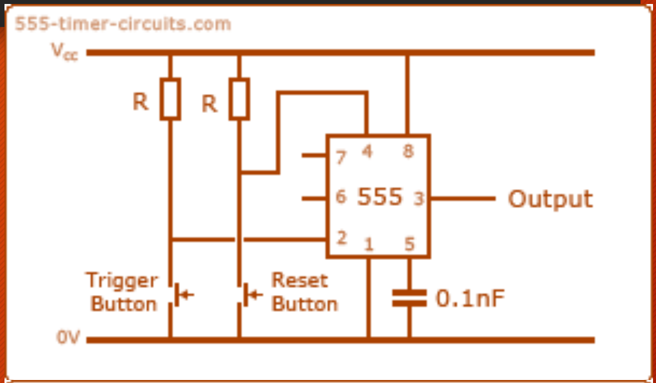
NE555 in Mono Stable Mode

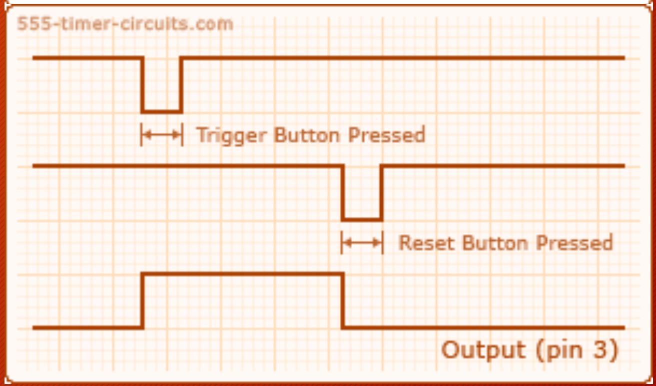
- Monostable mode produces an output pulse when the trigger signals drops below 1/3 VCC.
- An RC circuit sets the output pulse's duration as the time t in seconds it takes to charge C to 2/3 VCC
- $t = \ln(3) \cdot R \cdot C$, Where
  - R is the resistance in ohms,
  - C is the capacitance in farads,
  - ln(3) is the natural log of 3, i.e., log to base e, not base 10
- The output pulse duration can be lengthened or shortened as desired by adjusting the values of R and C.
- Subsequent triggering before the end of this timing interval won't affect the output pulse



Bistable Mode (or Schmitt Trigger)

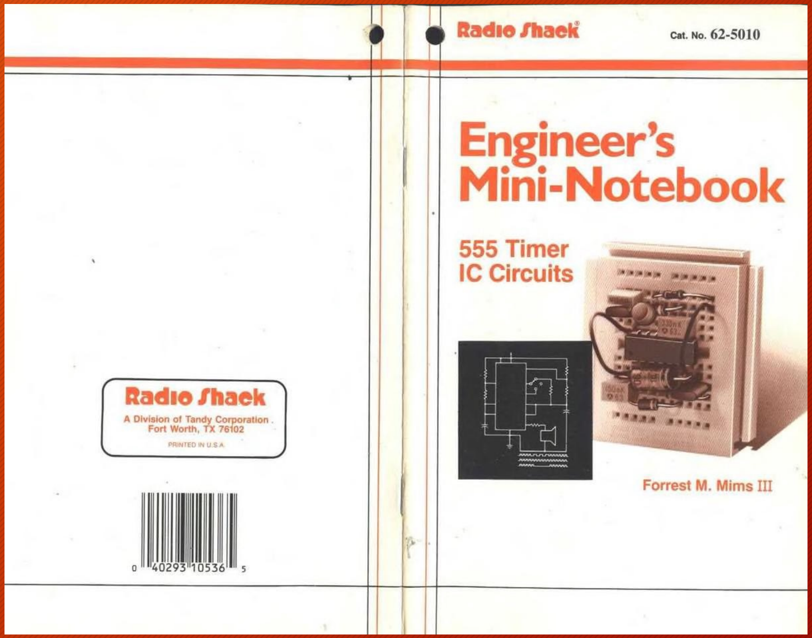
- A Bistable Mode or what is sometimes called a Schmitt Trigger, has two stable states, high and low.
- Taking the Trigger input low makes the output of the circuit go into the high state.
- Taking the Reset input low makes the output of the circuit go into the low state.





Other Uses for NE555

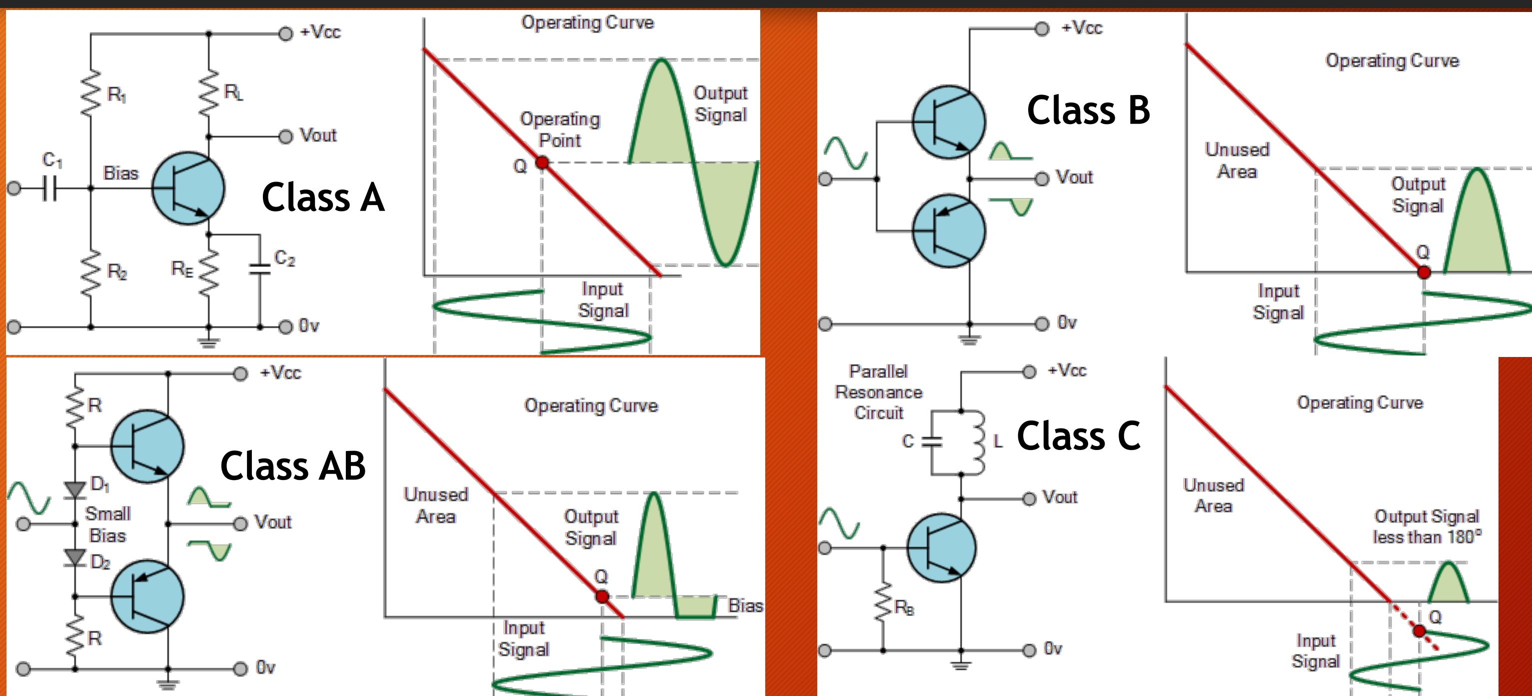
- There are many other circuits that have been adapted using the NE555
- The most popular is in a book by Forrest Mimms
- It is out of print but can be found on the Internet in pdf form
- Another source is https://www.555-timer-circuits.com/



Audio Amplifiers

- Audio Amplifiers are characterized by the class of the amplifier.
- Amplifier Classes relate back to vacuum tubes but are appropriate for transistor amplifiers also
- Class A is the most common and has the best fidelity but the lowest efficiency
- Class B has higher efficiency but needs to have two transistors in a push-pull configuration to achieve good fidelity
- Class AB tries to give better fidelity and better efficiency at the same time
- Class C is used for RF Amplifiers and has the best efficiency but high distortion
  - Not acceptable for audio applications
  - In RF applications, filters are necessary to remove distortion products that can interfere with other radio systems

Basic Diagram of Amplifier Classes

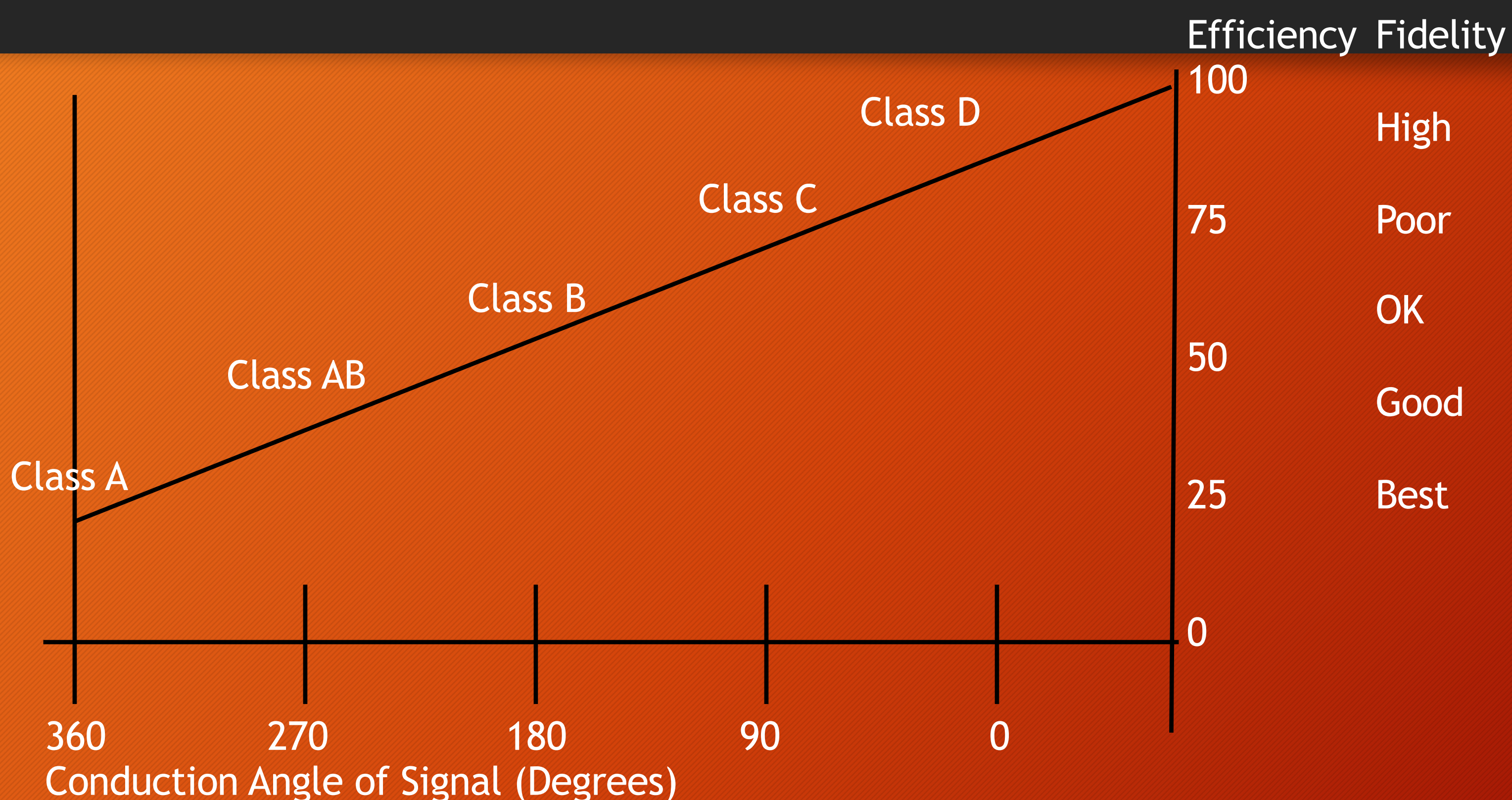


As the configuration evolves from Class A to Class C, the output signal gets more distorted

Bu the efficiency gets better

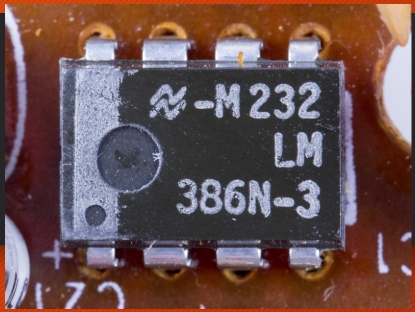
https://en.wikipedia.org/wiki/Power_amplifier_classes

Efficiency of Amplifier Classes

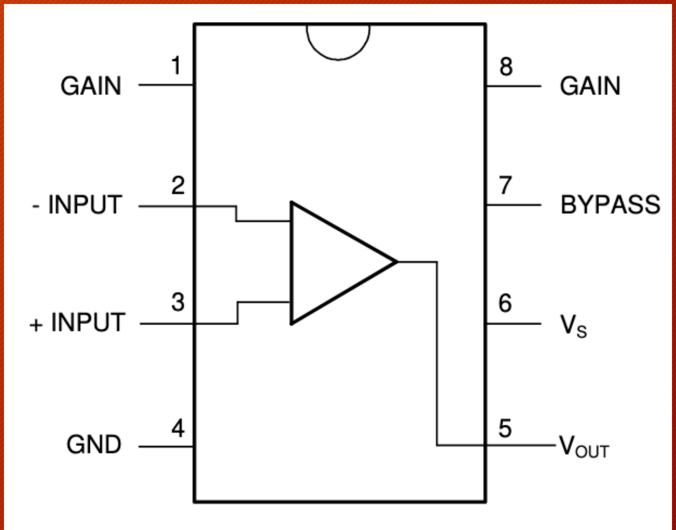


- We will look at class D digital amplifiers in the next class

Audio Amplifier: LM386

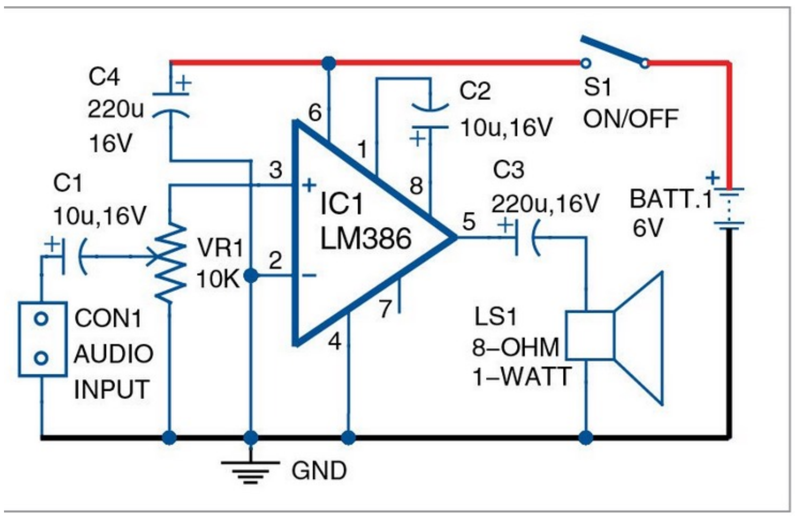


- A common class A audio amplifier is the LM386
- Its output power is about 0.25-0.7 watts of audio
- The LM386 is popular, cheap and readily available
- It is used in many projects
- In the next class, we will learn about class D amplifiers that deliver more power and are also cheap and readily available



Typical LM386 Circuit Diagram

Part number	Supply voltage, V		Min Speaker impedance, Ω	Output power, mW	
	Min.	Max.		Min.	Typical
LM386N-1	4	12	4	250	325 @ Vs=6V, Rl=8Ω
LM386N-3	4	12	4	500	700 @ Vs=9V, Rl=8Ω
LM386N-4	5	18	4	700	1000 @ Vs=16V, Rl=32Ω



RF Amplifiers

- Any circuits that are designed for radio frequencies (RF) are difficult to design, build and debug.
- RF circuit design is often called a "Black Art" since it needs special skills
- Several companies make special amplifiers that are designed for RF but they need inductor and capacitors to make them work
- They also may need special Printed Circuit Board designs
- https://www.kitsandparts.com/index.php provides circuit boards, kits and parts for various hobbyist RF projects
- There are alternatives

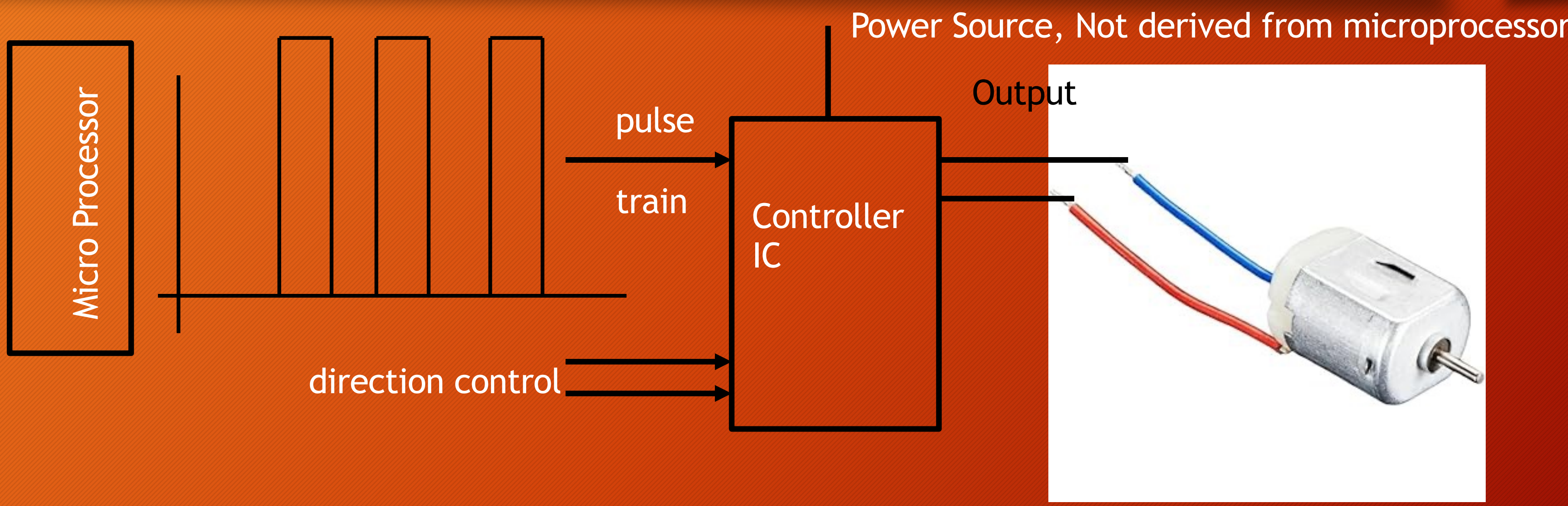
Mini-Circuit Labs RF amplifiers

- A Brooklyn, NY company makes a wide range of RF amplifiers that are used in circuit design, prototyping, and test set ups
- They make transistors, amplifiers, lab equipment, etc.
- For a full list of their equipment see: https://www.minicircuits.com/
- Note that some of the parts are expensive but very functional

Motor Controllers

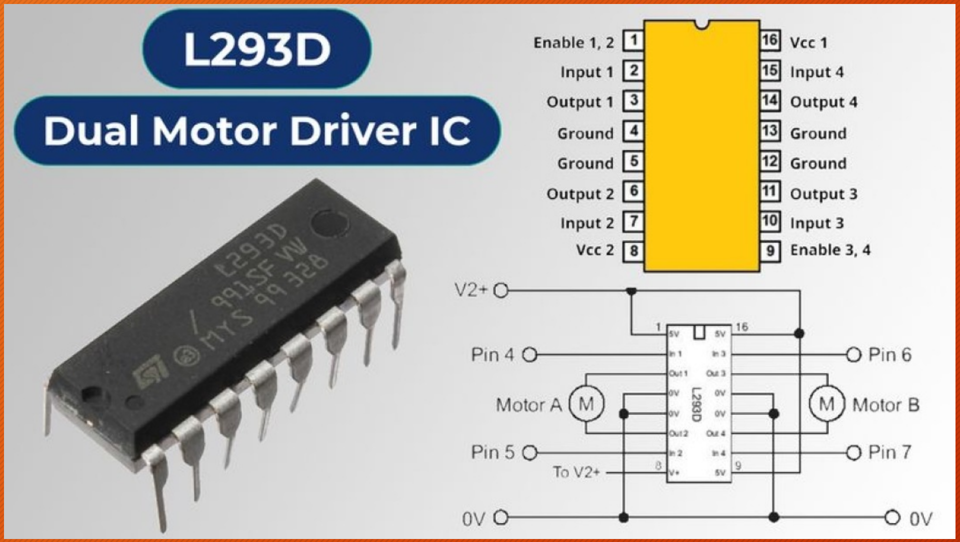
- Typical microcontrollers, Pi, Arduino, Feather, Pico, etc. can only deliver milliamps from their output ports
- Most motors require power in the range of amps to operate
- A motor controller IC will take the milliamp power from the microcontroller and control amps of power
- It requires a different power source than the one the runs the microcontroller.
- The motor controller IC does the following:
  - Change the speed of DC motors by pulsing the DC power on and off
  - Change direction of the motor by reversing the positive and negative leads to the motor
- Adafruit and others make shields/hats/etc. with motor controller ICs to use with popular microcontrollers

Interfacing motor controller and motor

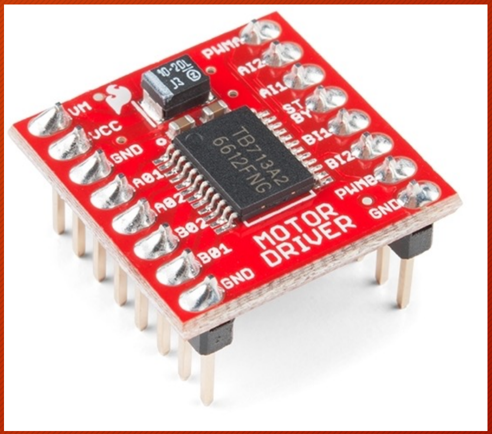


Two common motor controllers

- The L293D and the TB6612FNG are two popular motor controller ICs
- The both support two DC motors

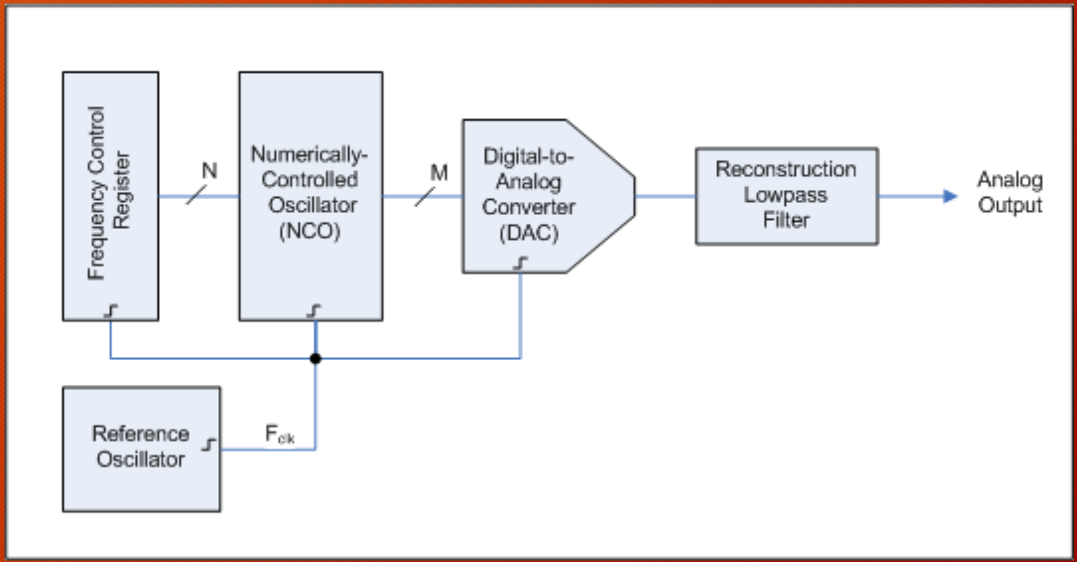


Sparkfun TB6612 motor driver board



Direct Digital Synthesis

- A quasi analog circuit is a Direct Digital Synthesizer (DDS)
- It is controlled by a microprocessor and delivers a analog sine wave signal at a given frequency
- There are two popular DDS ICs
- Each requires a driver library for the microcontroller



https://en.wikipedia.org/wiki/Direct_digital_synthesis

Ad9850 DDS vs Si5351 DDS

- Single Frequency Output
- Range 0-1/2 crystal frequency
- Practical limit is 0- 30% of crystal frequency
- Max Frequency is around 40 MHz
- Cost about $22 for module

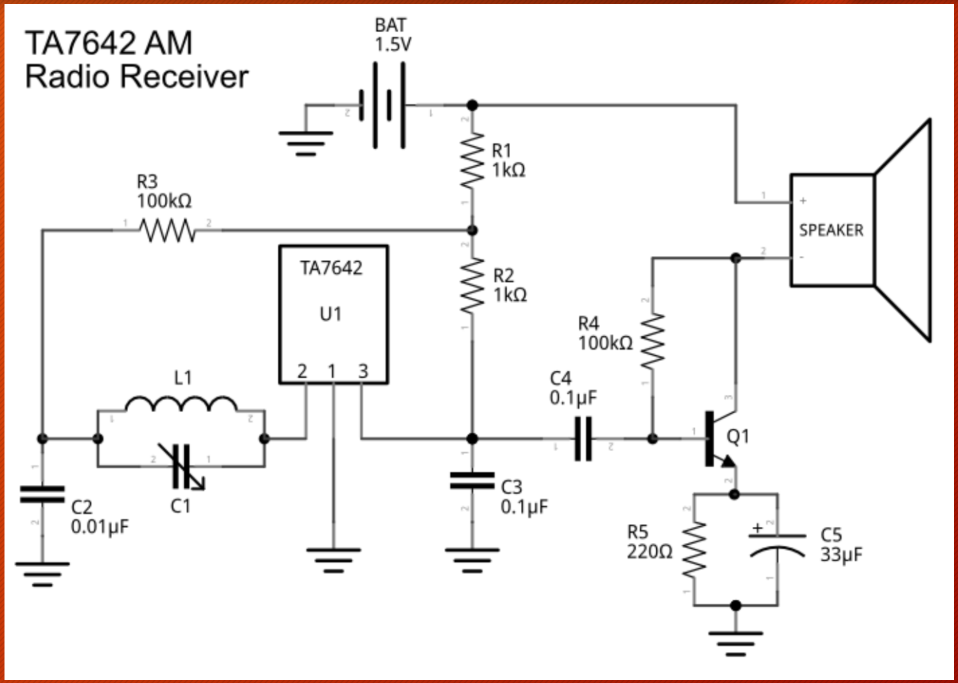
- 3 independent Output Frequencies
- Range up to several hundred Megahertz
- Two of the outputs can be programed to be 90 degrees out of phase
- Useful for SDR RX and TX
- Cost about $8 for module

Other Analog Integrated Circuits

- Several Analog integrated circuits were designed for use in radio and TV receivers
- Some of the best ones are no longer in production
- Two notable exceptions are:
  - TA7642 analog AM receiver
  - The Si4734/35 from Skyworks and Si4732, are single-chip solutions that integrate the entire radio receiver function, from antenna input to audio output, on a single chip.
- Most new designs for radio transmitter and receivers moves all of the signal processing to demodulate and modulate radio signals to Digital Signal Processors (DSPs)
- Our very small cell phones would not be possible without DSPs

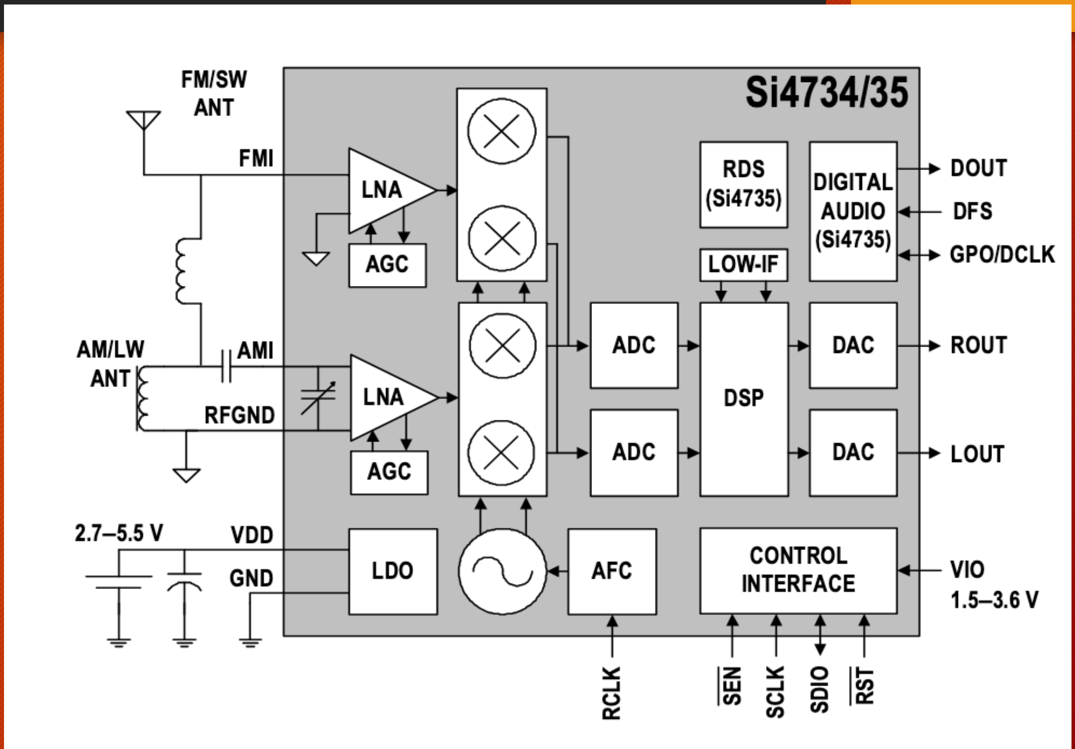
TA7642

- https://makerf.com/posts/make-your-own-rocket-radio-with-the-ta7642
- parts can be purchased from Amazon
  - https://www.amazon.com/DBParts-TA7642-Chip-Radio-Pack/dp/B07Z396FHD



The Si4734/35

- Needs to be controller by a microprocessor like an Arduino nano



Questions