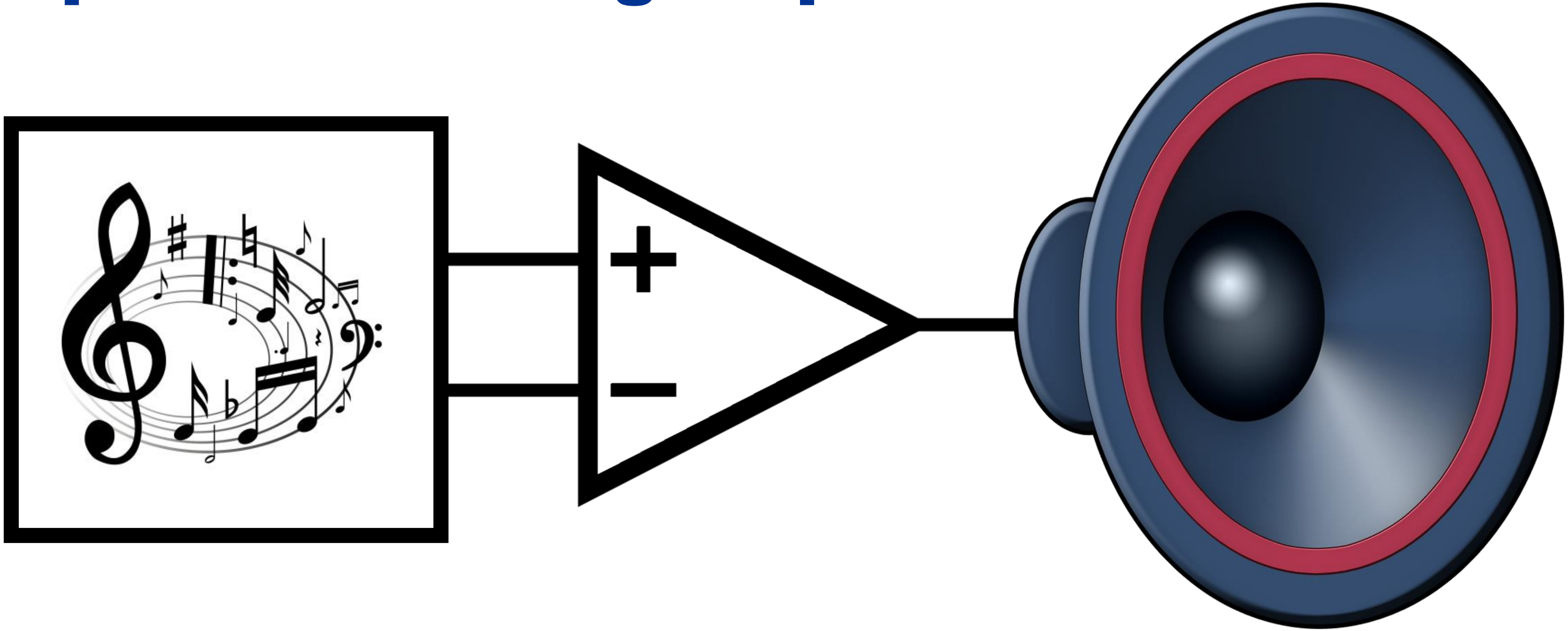
Junior Design

Circuit Design

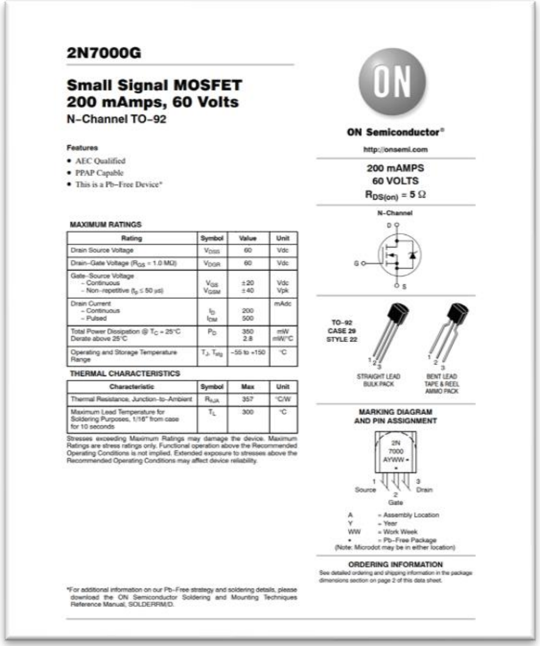
Samuel Dickerson, Ph.D.
ECE Department
University of Pittsburgh

University of Pittsburgh

Challenge: Design an audio amplifier capable of driving a speaker



Circuit Design Process



2N7000G

Small Signal MOSFET
200 mAmps, 60 Volts
N–Channel TO–92

Features
- AEC Qualified
- PPAP Capable
- This is a Pb–Free Device*

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Drain Source Voltage	V_{DSS}	60	Vdc
Drain–Gate Voltage (R_{GS} = 1.0 MΩ)	V_{DGR}	60	Vdc
Gate–Source Voltage – Continuous – Non–repetitive ($t_p \le 50$ μs)	V_{GS} V_{GSM}	±20 ±40	Vdc Vpk
Drain Current – Continuous – Pulsed	I_D I_{DM}	200 500	mAdc
Total Power Dissipation @ T_C = 25°C Derate above 25°C	P_D	350 2.8	mW mW/°C
Operating and Storage Temperature Range	T_J, T_{stg}	−55 to +150	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction–to–Ambient	$R_{\theta JA}$	357	°C/W
Maximum Lead Temperature for Soldering Purposes, 1/16″ from case for 10 seconds	T_L	300	°C

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

*For additional information on our Pb–Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

ON Semiconductor®
http://onsemi.com

200 mAMPS
60 VOLTS
$R_{DS(on)} = 5\ \Omega$

N–Channel

D
G
S

TO–92
CASE 29
STYLE 22

1 2 3
STRAIGHT LEAD
BULK PACK

1 2 3
BENT LEAD
TAPE & REEL
AMMO PACK

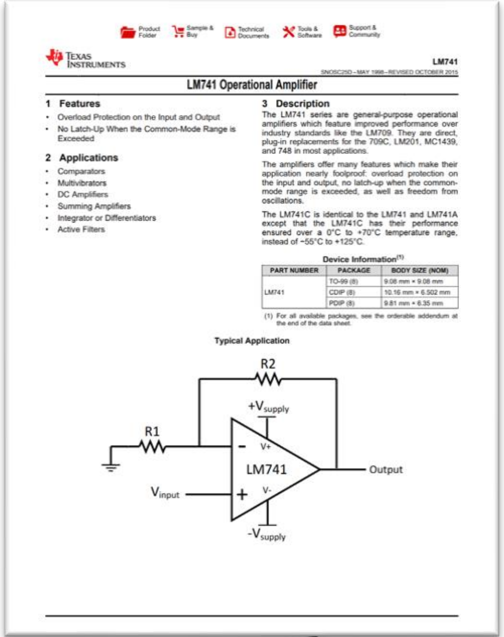
MARKING DIAGRAM AND PIN ASSIGNMENT

2N
7000
AYWW •
•

1 Source
2 Gate
3 Drain

A = Assembly Location
Y = Year
WW = Work Week
• = Pb–Free Package
(Note: Microdot may be in either location)

ORDERING INFORMATION
See detailed ordering and shipping information in the package dimensions section on page 2 of this data sheet.



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TEXAS INSTRUMENTS

LM741
SNOSC25D – MAY 1998 – REVISED OCTOBER 2015

LM741 Operational Amplifier

1 Features
- Overload Protection on the Input and Output
- No Latch-Up When the Common-Mode Range is Exceeded

2 Applications
- Comparators
- Multivibrators
- DC Amplifiers
- Summing Amplifiers
- Integrator or Differentiators
- Active Filters

3 Description

The LM741 series are general-purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439, and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common-mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741 and LM741A except that the LM741C has their performance ensured over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

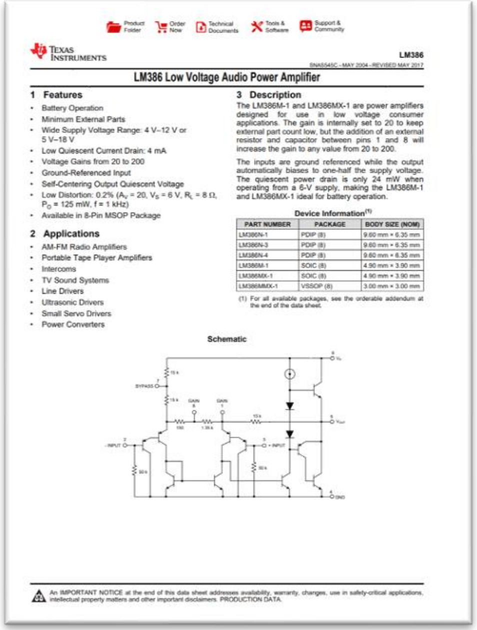
Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM741	TO-99 (8)	9.08 mm × 9.08 mm
	CDIP (8)	10.16 mm × 6.502 mm
	PDIP (8)	9.81 mm × 6.35 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Typical Application

R2
$+V_{supply}$
R1
LM741
V+
V-
V_{input}
Output
$-V_{supply}$



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TEXAS INSTRUMENTS

LM386
SNAS545C – MAY 2004 – REVISED MAY 2017

LM386 Low Voltage Audio Power Amplifier

1 Features
- Battery Operation
- Minimum External Parts
- Wide Supply Voltage Range: 4 V–12 V or 5 V–18 V
- Low Quiescent Current Drain: 4 mA
- Voltage Gains from 20 to 200
- Ground-Referenced Input
- Self-Centering Output Quiescent Voltage
- Low Distortion: 0.2% (A_V = 20, V_S = 6 V, R_L = 8 Ω, P_O = 125 mW, f = 1 kHz)
- Available in 8-Pin MSOP Package

2 Applications
- AM-FM Radio Amplifiers
- Portable Tape Player Amplifiers
- Intercoms
- TV Sound Systems
- Line Drivers
- Ultrasonic Drivers
- Small Servo Drivers
- Power Converters

3 Description

The LM386M-1 and LM386MX-1 are power amplifiers designed for use in low voltage consumer applications. The gain is internally set to 20 to keep external part count low, but the addition of an external resistor and capacitor between pins 1 and 8 will increase the gain to any value from 20 to 200.

The inputs are ground referenced while the output automatically biases to one-half the supply voltage. The quiescent power drain is only 24 mW when operating from a 6-V supply, making the LM386M-1 and LM386MX-1 ideal for battery operation.

Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM386N-1	PDIP (8)	9.60 mm × 6.35 mm
LM386N-3	PDIP (8)	9.60 mm × 6.35 mm
LM386N-4	PDIP (8)	9.60 mm × 6.35 mm
LM386M-1	SOIC (8)	4.90 mm × 3.90 mm
LM386MX-1	SOIC (8)	4.90 mm × 3.90 mm
LM386MMX-1	VSSOP (8)	3.00 mm × 3.00 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Schematic

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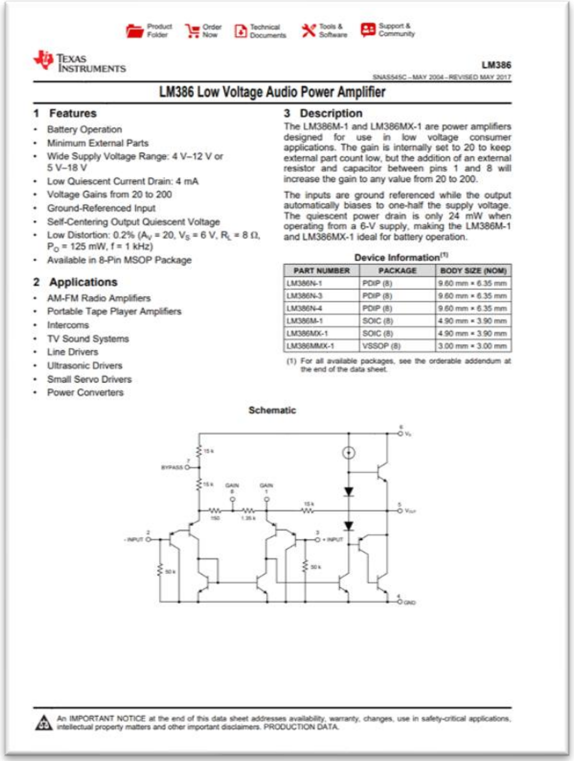
Evaluate Options

Circuit Design Process



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TEXAS INSTRUMENTS

LM386

SNAS545C – MAY 2004 – REVISED MAY 2017

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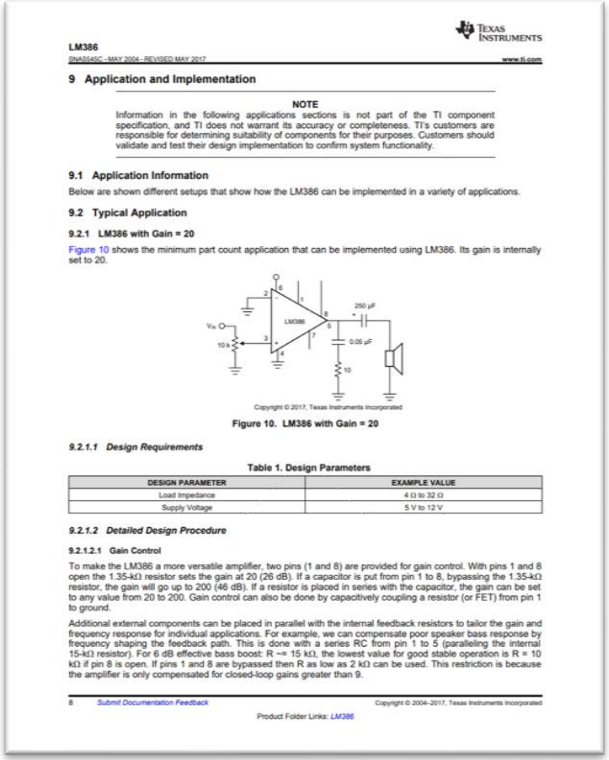

TEXAS INSTRUMENTS

LM386

SNAS545C – MAY 2004 – REVISED MAY 2017 www.ti.com

9 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

9.1 Application Information

Below are shown different setups that show how the LM386 can be implemented in a variety of applications.

9.2 Typical Application

9.2.1 LM386 with Gain = 20

Figure 10 shows the minimum part count application that can be implemented using LM386. Its gain is internally set to 20.

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Figure 10. LM386 with Gain = 20

9.2.1.1 Design Requirements

Table 1. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Load Impedance	4 Ω to 32 Ω
Supply Voltage	5 V to 12 V

9.2.1.2 Detailed Design Procedure

9.2.1.2.1 Gain Control

To make the LM386 a more versatile amplifier, two pins (1 and 8) are provided for gain control. With pins 1 and 8 open the 1.35-kΩ resistor sets the gain at 20 (26 dB). If a capacitor is put from pin 1 to 8, bypassing the 1.35-kΩ resistor, the gain will go up to 200 (46 dB). If a resistor is placed in series with the capacitor, the gain can be set to any value from 20 to 200. Gain control can also be done by capacitively coupling a resistor (or FET) from pin 1 to ground.

Additional external components can be placed in parallel with the internal feedback resistors to tailor the gain and frequency response for individual applications. For example, we can compensate poor speaker bass response by frequency shaping the feedback path. This is done with a series RC from pin 1 to 5 (paralleling the internal 15-kΩ resistor). For 6 dB effective bass boost: R ~= 15 kΩ, the lowest value for good stable operation is R = 10 kΩ if pin 8 is open. If pins 1 and 8 are bypassed then R as low as 2 kΩ can be used. This restriction is because the amplifier is only compensated for closed-loop gains greater than 9.

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Product Folder Links: LM386

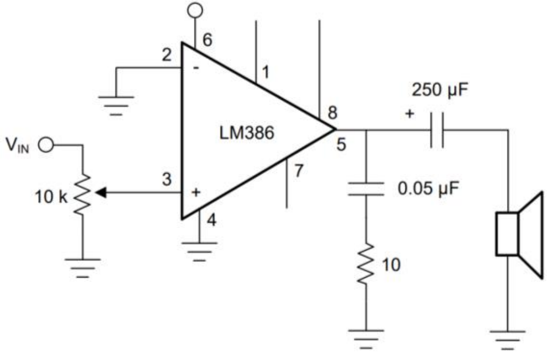

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Figure 10. LM386 with Gain = 20

Datasheet "Application Note"

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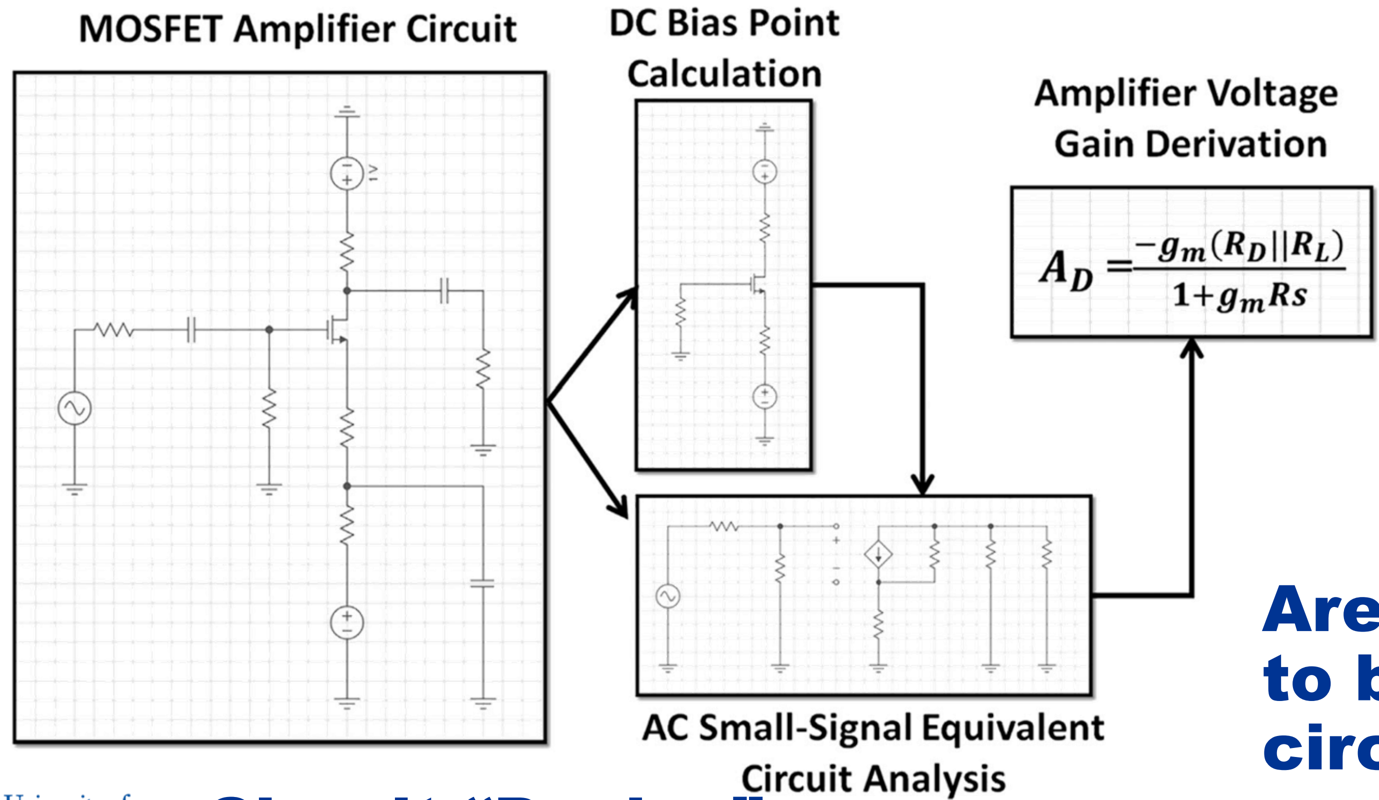
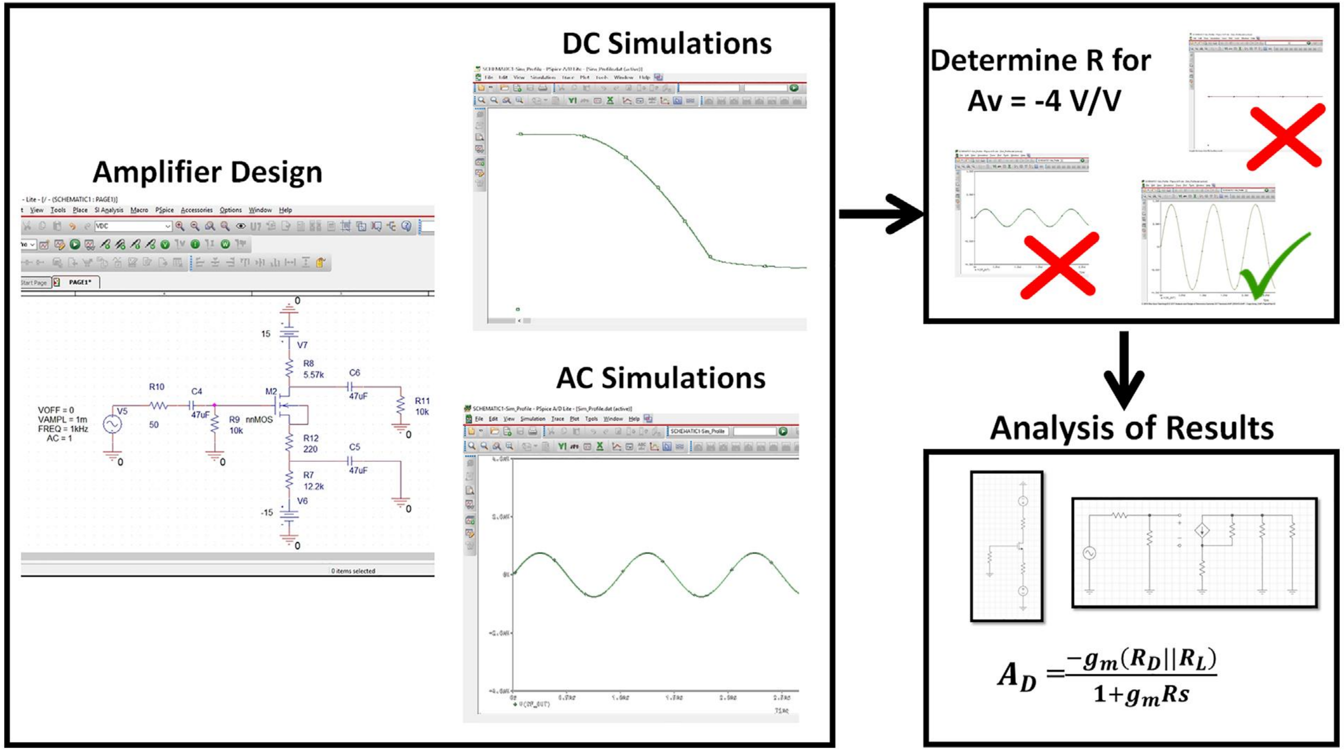
Circuit Design Process



Are we ready to build the circuit?

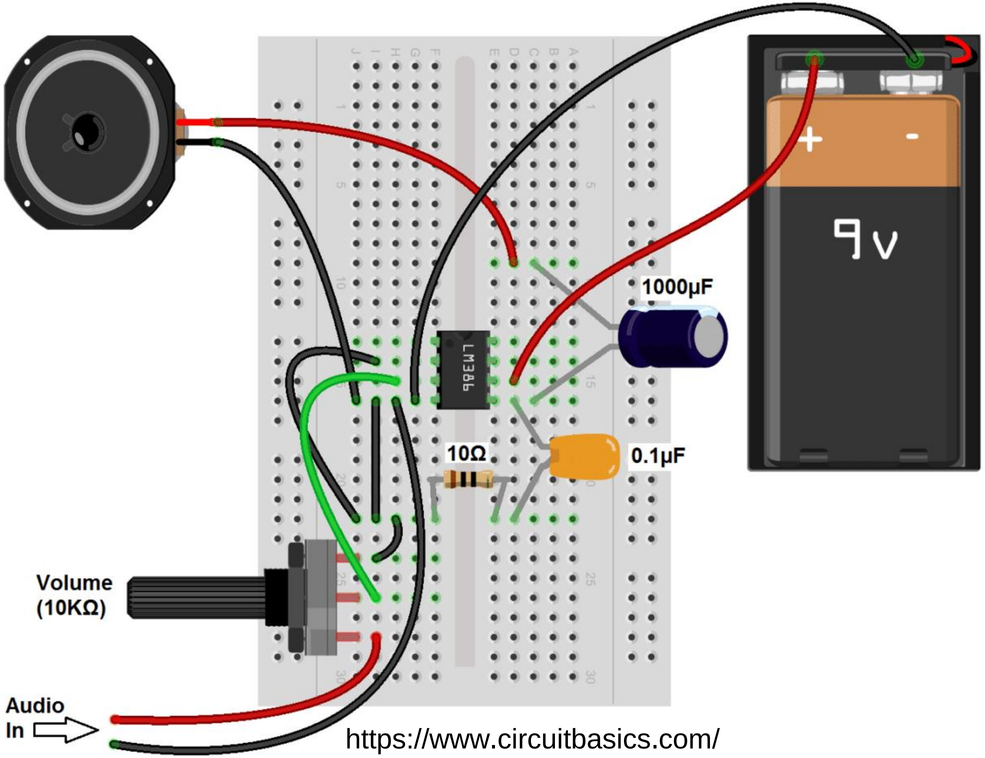
Circuit "Design"

Circuit Design Process



Circuit Simulation

Circuit Design Process



https://www.circuitbasics.com/

Circuit Prototype

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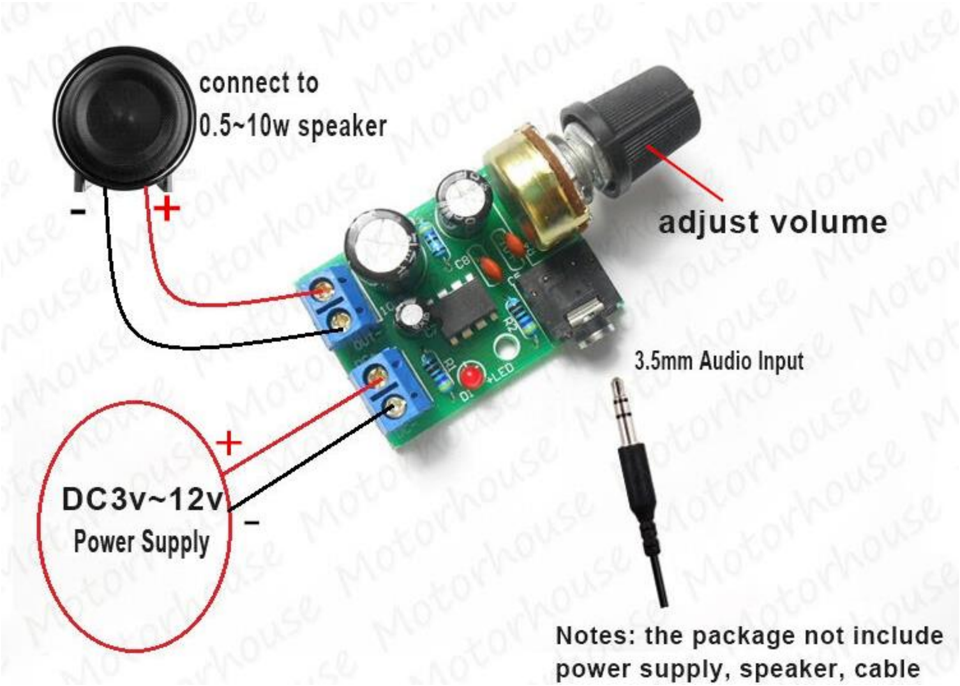
Circuit Design Process



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Final Product

https://www.ebay.com/itm/LM386-Audio-Power-Amplifier-Board-DC-3V-12V-5V-AMP-Module-Adjustable-volume-Knob-/191921396767

SPICE Simulation

- Simulation is an essential part of the circuit design process (for Analog and Digital circuits!)

- SPICE simulation is the de facto standard software tool for circuit simulation

- Used in education, industry and research

History of SPICE

The natural course of a diverse engineering tool

C. C. Mcandrew, "How Come SPICE Is a Verb?: The Natural Course of a Diverse Engineering Tool," in *IEEE Solid-State Circuits Magazine*, vol. 11, no. 1, pp. 14-18, winter 2019, doi: 10.1109/MSSC.2018.2882279.

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History of SPICE

- **Started as a class project at the University of California Berkeley in 1969**

- **Students team develop a program called CANCER (Computer Analysis of Nonlinear Circuits, Excluding Radiation)**
  - First circuit simulator to utilize sparse matrix techniques
  - Used Newton-Raphson iteration method heuristically modified for bipolar circuits (Ebers-Moll model)
  - Utilized implicit integration algorithms to accommodate widely spread time-constants of an IC
  - Integrated DC operating point analysis, small-signal AC analysis and transient analysis

Prof. Ronald Rohrer

- **One of the students continued the project as a MS thesis topic (Larry Nagel)**

http://ltwiki.org/index.php?title=LTspice_Genealogy_-_The_Heritage_of_Simulation_Ubiquity

History of SPICE

Larry Nagel

Prof. Donald Peterson

- **Larry's thesis was successful, and continued working on it for PhD research with Prof. Donald Peterson under the name SPICE**
  - Simulation Program with Integrated Circuit Emphasis
- **Prof. Peterson insists that the program be released into the public domain for free as an Open Source project.**
- **Quickly became adopted for use in education, research and industry**
- **Still open-source, but today it is primarily modified, packaged and sold as commercial products**
  - NGspice, HSPICE, Spectre, LTSpice, PSPICE, etc.

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SPICE History

- **Netlist file describes circuit and component connections**

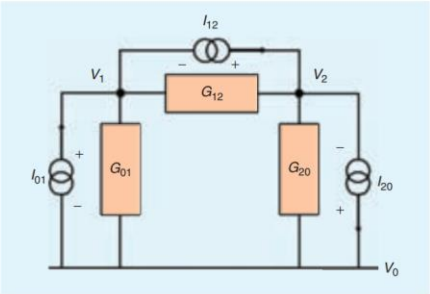

Fig. 1.

$$\begin{bmatrix} (G_{01}+G_{20}) & -G_{01} & -G_{20} \\ -G_{01} & (G_{12}+G_{01}) & -G_{12} \\ -G_{20} & -G_{12} & (G_{20}+G_{12}) \end{bmatrix} \begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} I_{20}-I_{01} \\ I_{01}-I_{12} \\ I_{12}-I_{20} \end{bmatrix}$$

Note the 'pattern of four' that each conductance (e.g. G_{01} highlighted below) impresses into the conductance matrix (Table 1).

In SPICE parlance, making this 'pattern of four' impression is called 'stamping the matrix.' Conveniently, this 'stamping' generalizes for any number of nodes and two terminal components. In a future article, we'll show how a small modification to this

TABLE 1.

	Column x	Column y
Row x	$+G_{xy}$	$-G_{xy}$
Row y	$-G_{xy}$	$+G_{xy}$

[1] For example "Computer Methods for Circuit Analysis and Design" by Kishore Singhal and Jiri Vlach

[2] The *ch* in Kir*ch*hoff is pronounced like the *ch* in the Scots' word lo *ch*.


```
*//////////////////////////////////////////////////////////////
*LM741 OPERATIONAL AMPLIFIER MACRO-MODEL
*//////////////////////////////////////////////////////////////
*
* connections:      non-inverting input
*                   |   inverting input
*                   |   |   positive power supply
*                   |   |   |   negative power supply
*                   |   |   |   |   output
*                   |   |   |   |   |
*                   |   |   |   |   |
.SUBCKT LM741/NS    1   2   99  50  28
*
*Features:
*Improved performance over industry standards
*Plug-in replacement for LM709,LM201,MC1439,748
*Input and output overload protection
*
****************INPUT STAGE**************
*
IOS 2 1 20N
*^Input offset current
R1 1 3 250K
R2 3 2 250K
I1 4 50 100U
R3 5 99 517
R4 6 99 517
Q1 5 2 4 QX
Q2 6 7 4 QX
*Fp2=2.55 MHz
C4 5 6 60.3614P
*
***********COMMON MODE EFFECT***********
*
I2 99 50 1.6MA
*^Quiescent supply current
EOS 7 1 POLY(1) 16 49 1E-3 1
*Input offset voltage.^
R8 99 49 40K
R9 49 50 40K
```

LM741 Op Amp Netlist

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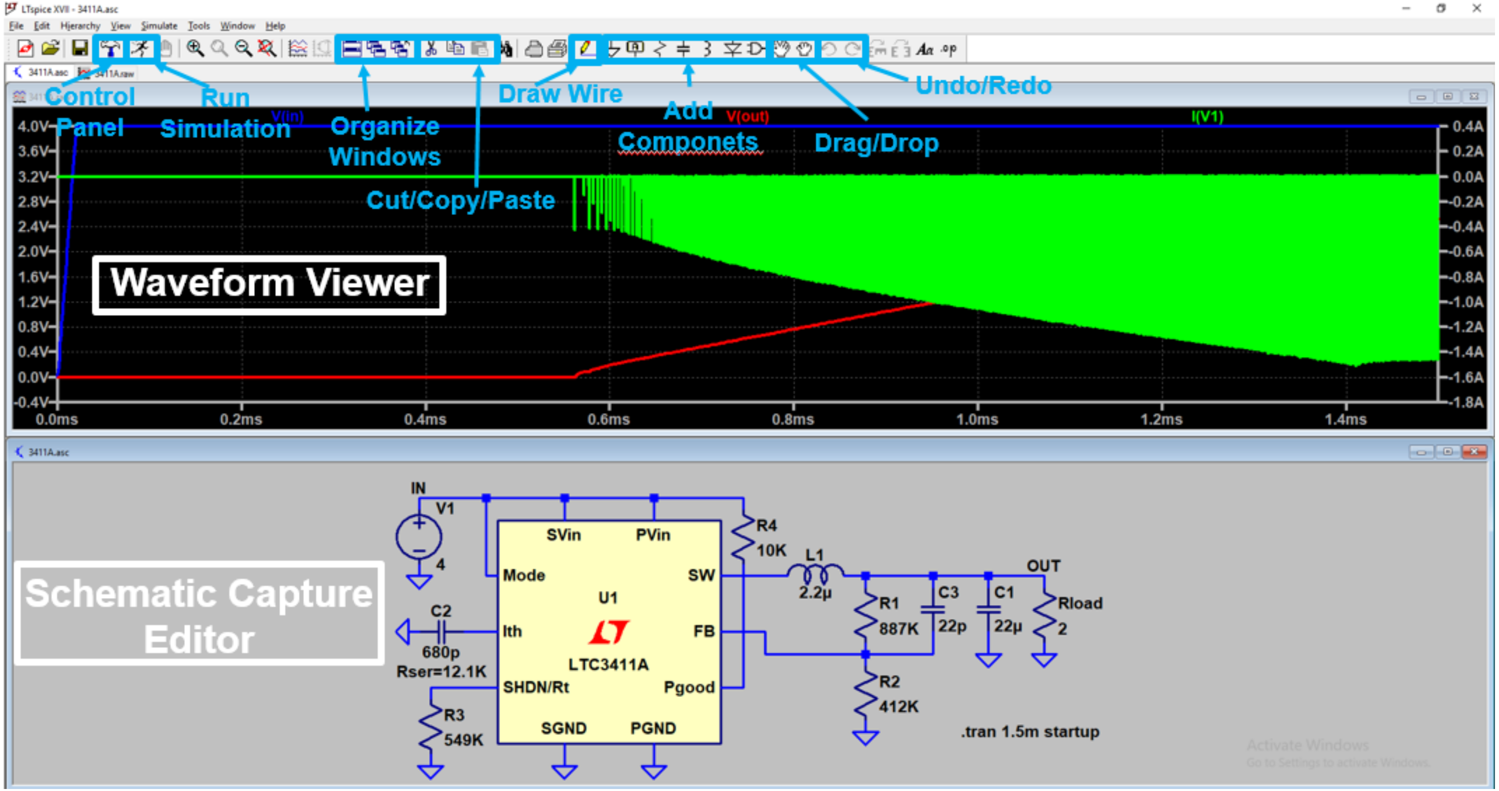
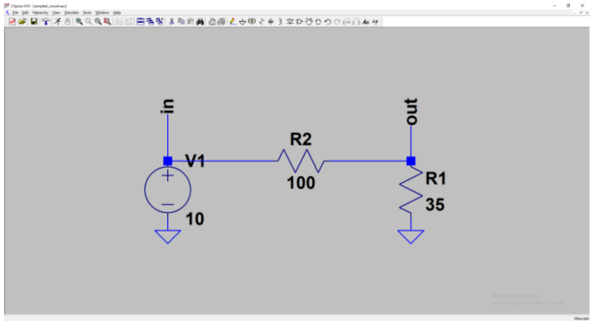
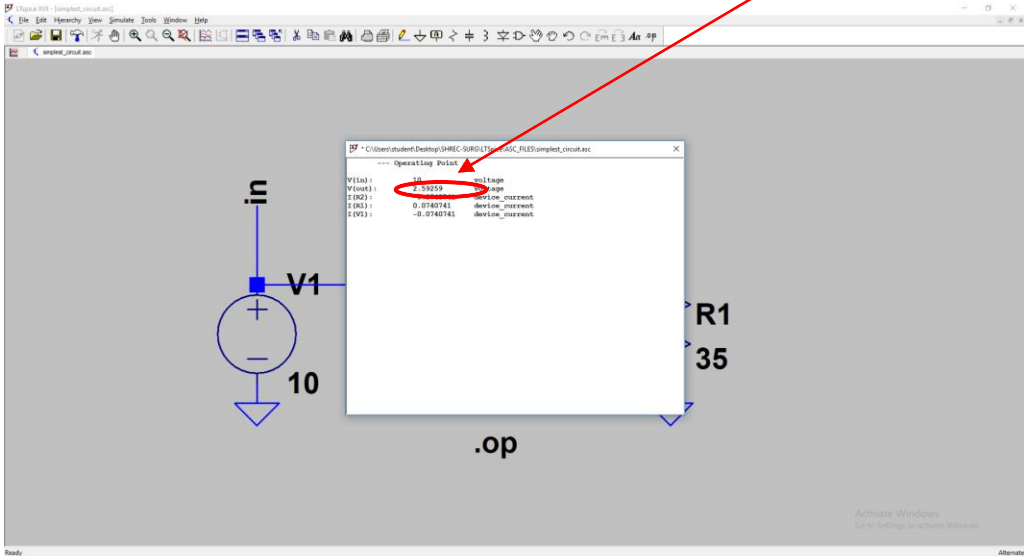
LTSPICE: Development Environment



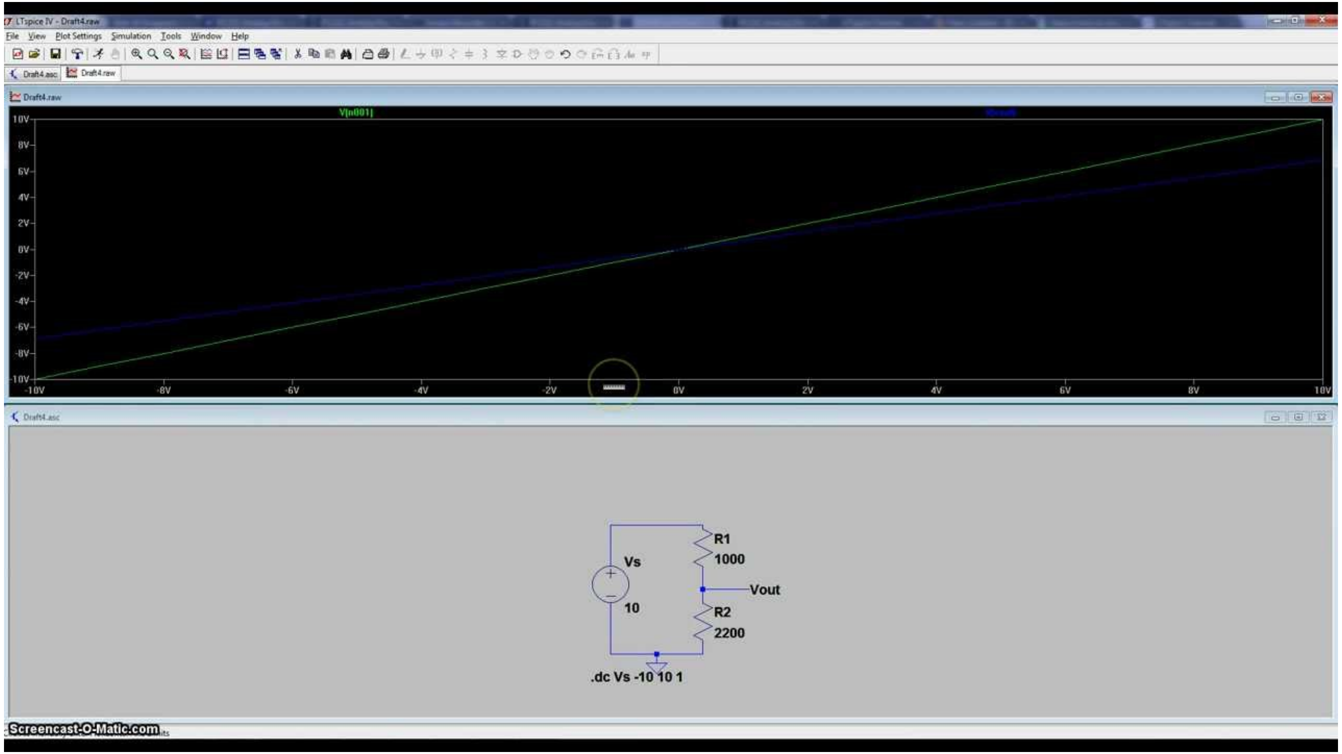
LTSPICE – DC Operating Point

$$out = in \cdot \frac{R1}{R1 + R2} = \mathbf{2.59259259\ V}$$





LT SPICE – DC Sweep



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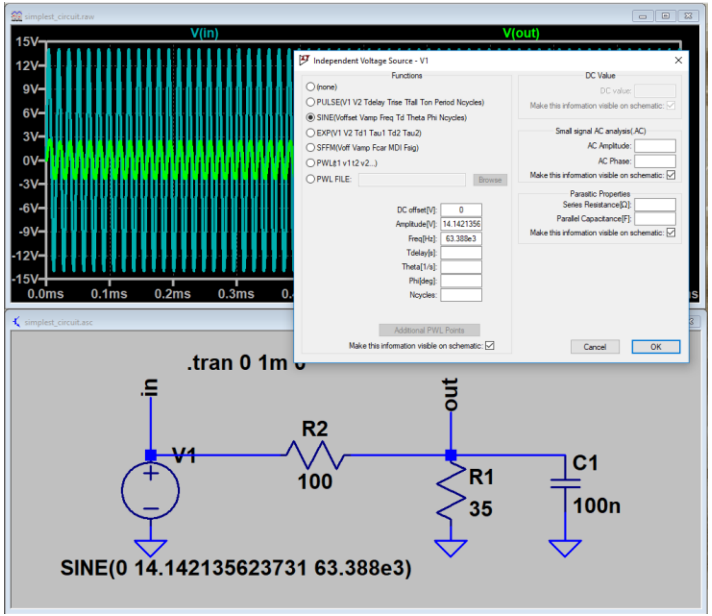
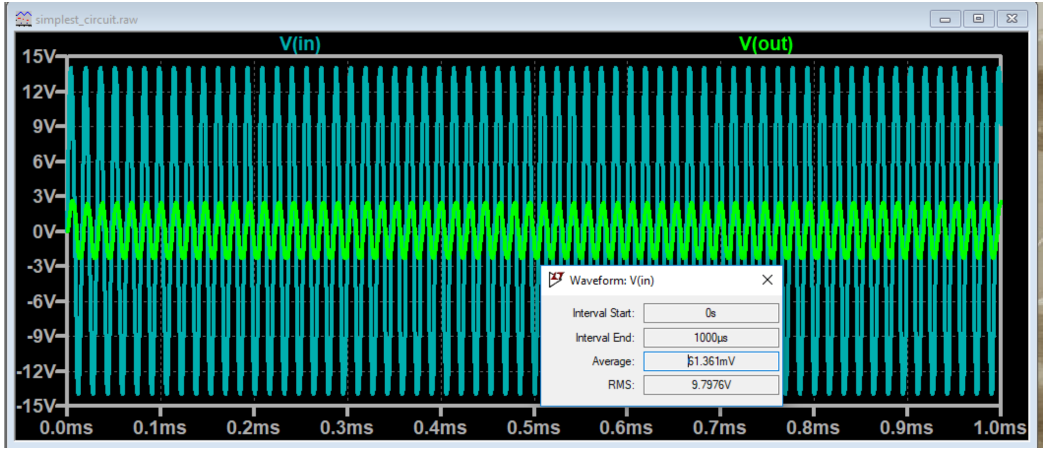
LTSPICE – Transient Analysis





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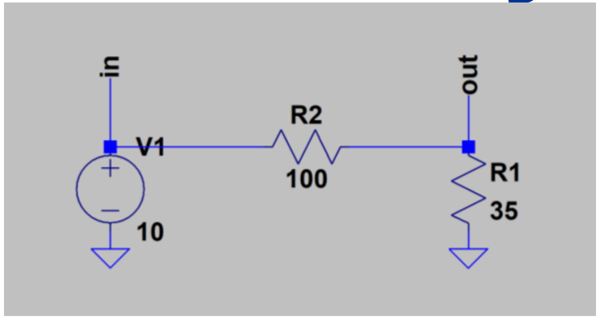
LTSPICE – AC Analysis

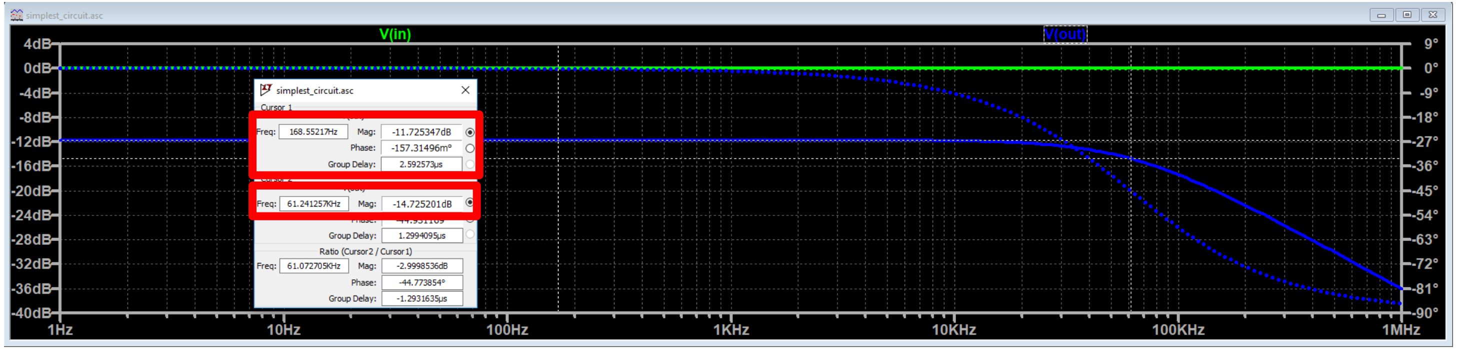


Amplitude at low frequencies

$$out\ (dB) = 20\log_{10}\frac{10\ V\cdot\frac{R1}{R1+R2}}{10\ V} = \ -11.725\ dB$$

3 dB Frequency

$$f_{3\ dB}(Hz) = \frac{1}{2\pi\cdot R1||R2\cdot C} = \ 61.388\ \text{kHz}$$



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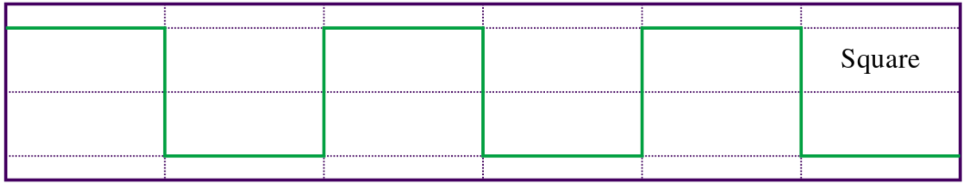
Square Wave Oscillators

- Square waves are used in many electronic applications



- There are several ways for us to construct a circuit that can produce the above waveform
- The 555 timer, is an Integrated Circuit (IC) that allows us to do so

Square Wave Oscillators

REVIEW 555 Timer Datasheet

Assignment #1

- Design a square wave oscillator using the 555 timer chip
- Design the circuit to have a clock period between 20 & 500 microseconds
- The circuit is unloaded
- Verify your design using LTSPICE
  - Edit→Component→MISC→NE555