Selected Filter Circuits

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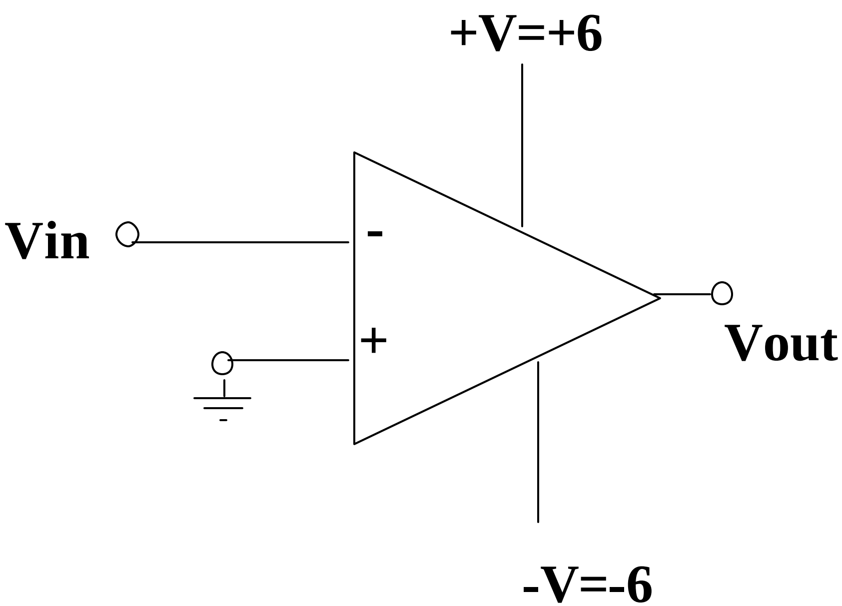
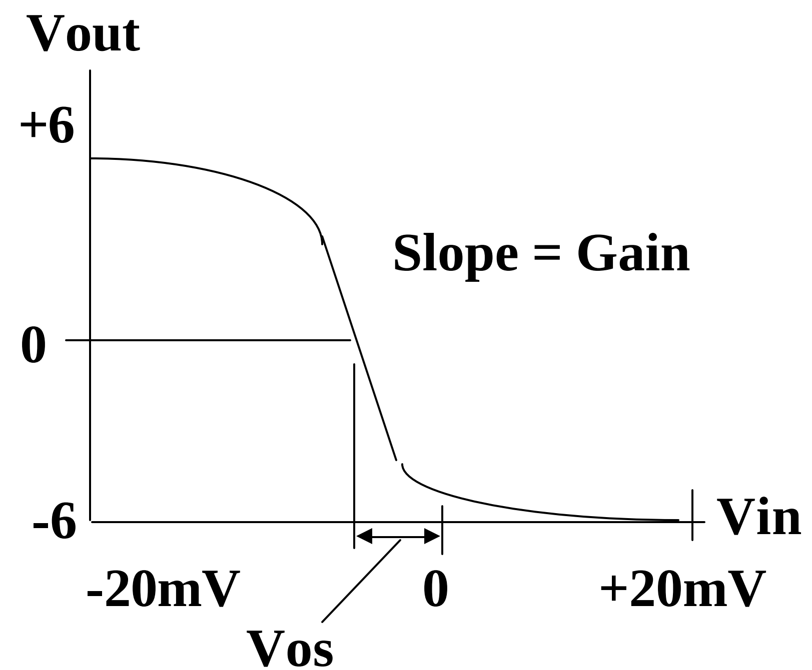
OUTLINE

Op Amp Frequency Response
Active Filters
Operational Transconductance Amplifier
Biquad Filter
Switched Capacitor Filters
References
Homework

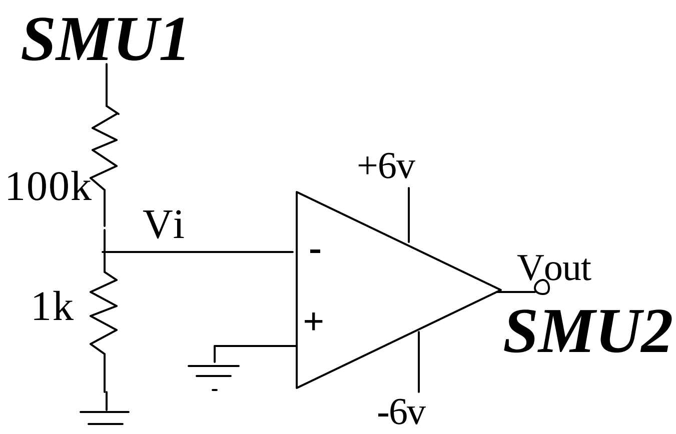
OPERATIONAL AMPLIFIER DC CHARACTERIZATION

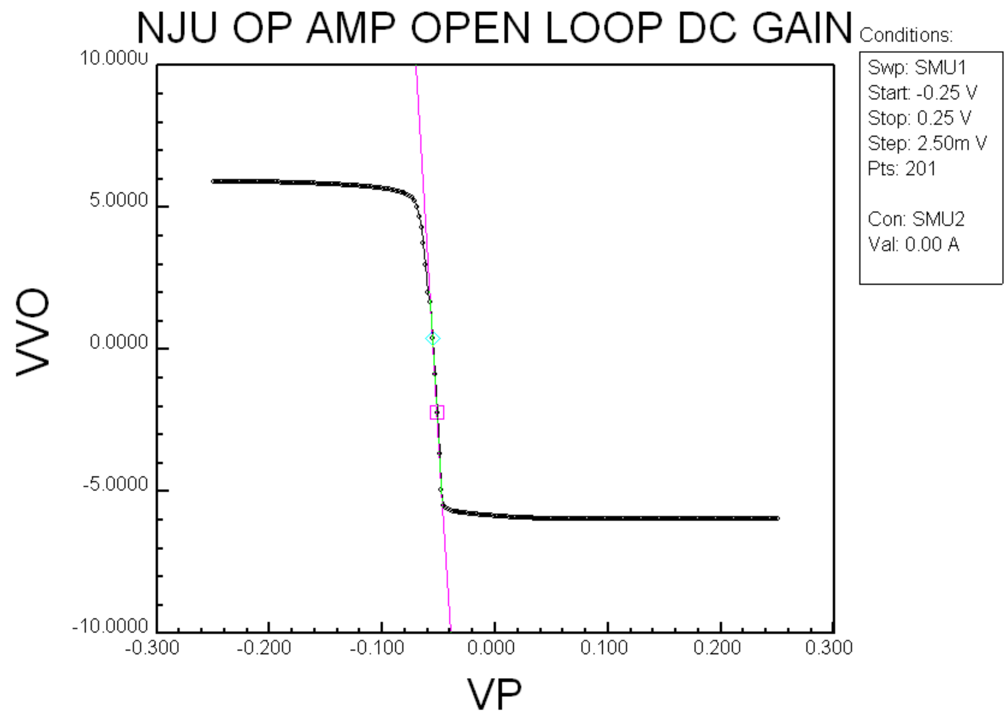




Set up the HP 4145 to sweep the Vin from -20 mV to +20 mV in 0.001V steps. Measure Gain and Input offset voltage.

MEASURED OPEN LOOP DC GAIN





Fit #1:	Fit #2:
Type: Cursor	None
Slp:-664.97	****
Yint:-36.84	****
Xint:-0.06	***

Cursors:	X	Y
□	-0.05	-2.26
◇	-0.06	0.40
○		
⧖		
⋈		
△		

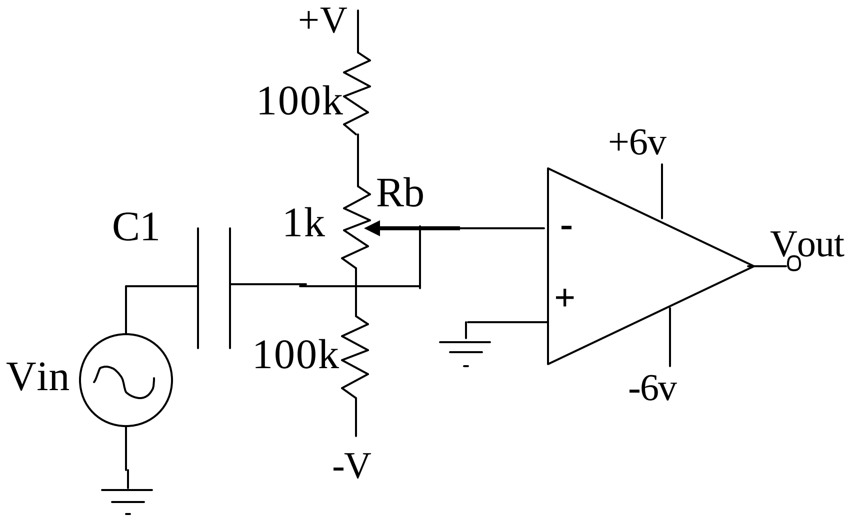
ICS 16:24:56 04/29/2009

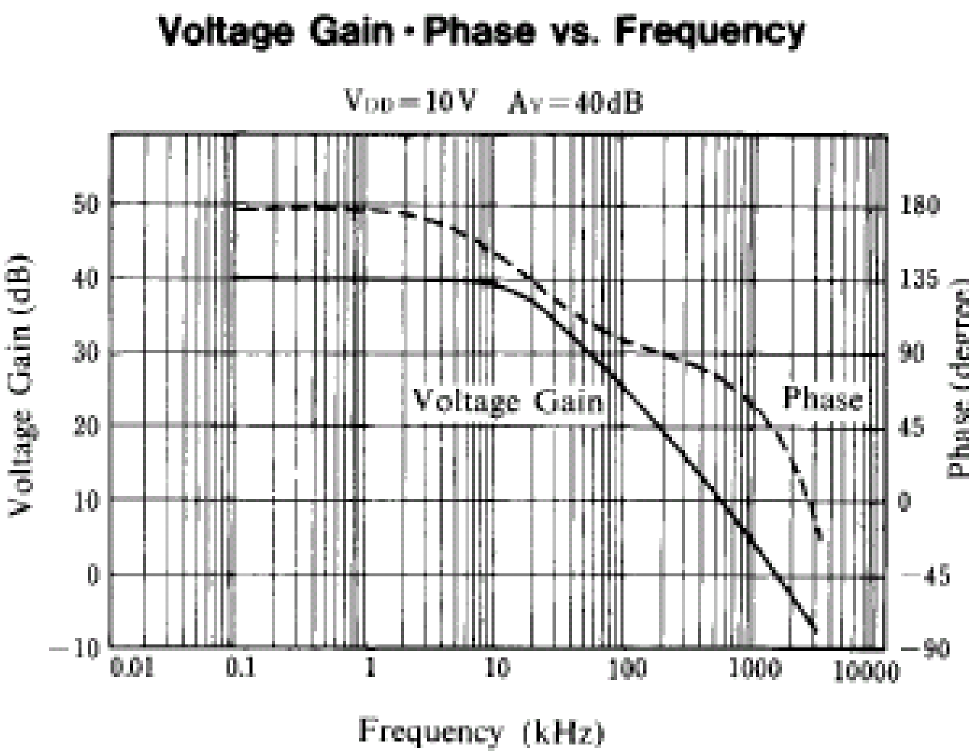
Gain = slope x 100

= 66,000

= 96 dB

FREQUENCY RESPONSE OF AN OP AMP





Adjust Rb to give Vout = zero with Vin = zero, Then use a network analyzer to collect data for Gain vs Frequency

NETWORK ANALYZER

<u>Quick Measurement Setup for 3577A Network Analyzer</u> (by Jirachai Getpreecharsawas)


Network Analyzer

Magnitude Plot:

1. Press INPUT button and select input A
2. Press DISPLY FCTN button and select LOG MAG
3. Press FREQ button and select STOP FREQ

Note: Other options are also available.

4. Press AMPTD button and adjust the amplitude if necessary, say –20 dBm
5. Press RES BW and select an appropriate frequency resolution, say 100 Hz

   Note: Sweep time might need to be adjusted so that it is higher than the settling time required for each Res BW, see table* below.

Res BW	Settling time
1 kHz	22 ms
100 Hz	55 ms
10 Hz	370 ms
1 Hz	3.707 s

* Instruction Manual for 3577A Network Analyzer, pp 4-62.

6. If applicable, press SWEEP TYPE button and select LOG FREQ SWEEP to display x-axis (freq) in log scale

   Note: You might need to readjust the frequency range again by pressing FREQ button

   ! Tip: Turning the knob will move the Marker along the trace (data readout).

Phase Plot:

1. Press TRACE 2 button
2. Press INPUT button and select input A
3. Press DISPLY FCTN button and select PHASE
4. If needed, adjust the frequency range using FREQ button

Obtain a plot using software Agilent Data Capture 2:

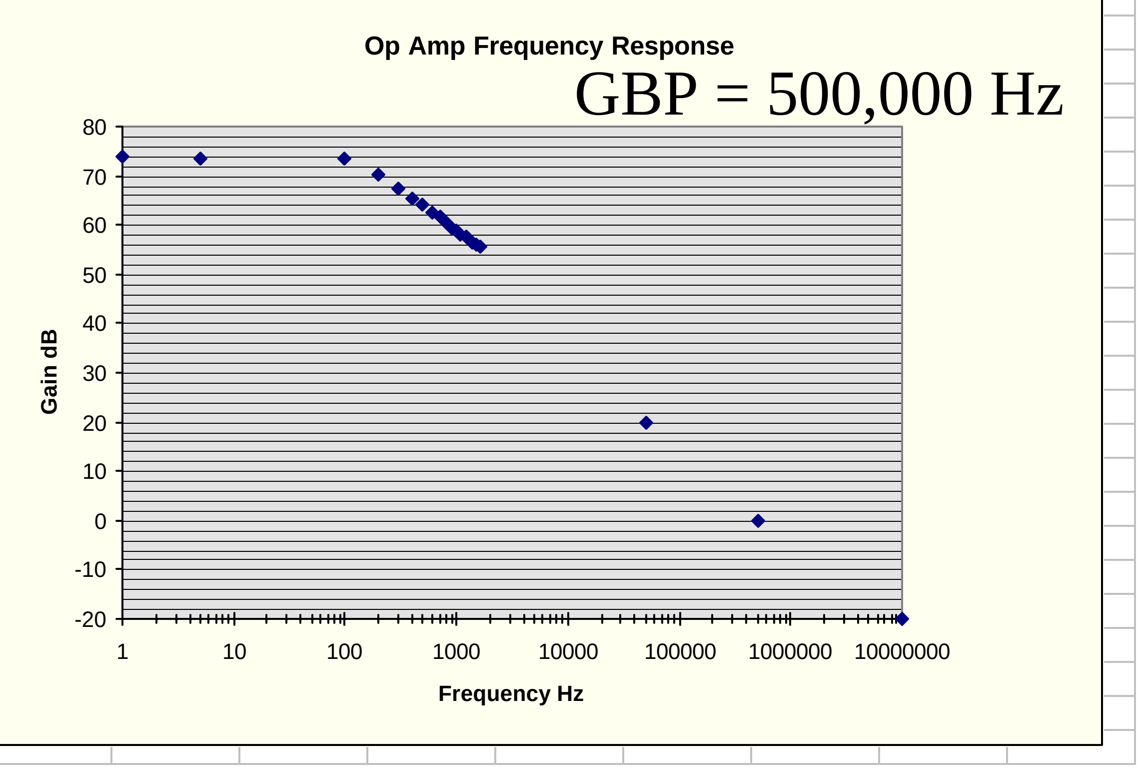
1. Go to Programs > Agilent IntuiLink> IntuiLink Data Capture Application
2. Click Instrument tab, choose 3577A if not selected, accept default setting, and click OK.
3. Click Get Data icon, the 2nd icon from the right, to open a plot window if no plot shown

AC TEST RESULTS

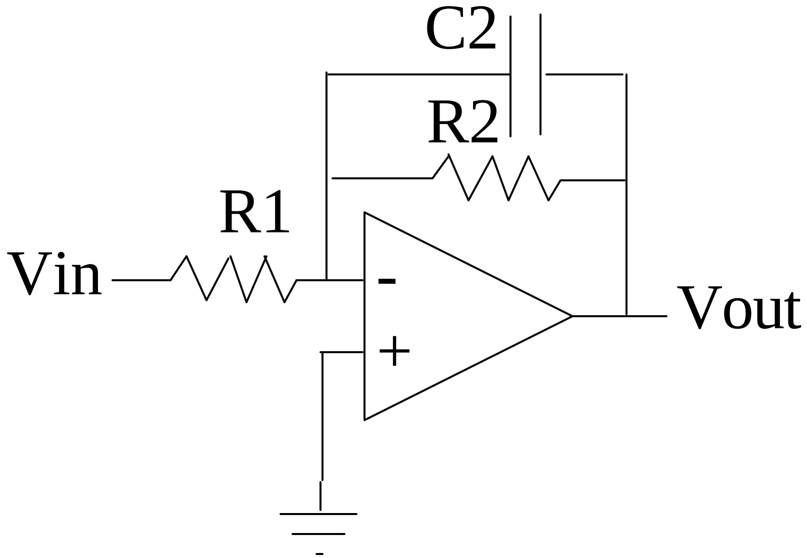
ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING — LFF OPAMP.XLS FILE3B

LOT F960319 OPAMP TEST RESULTS - 1-29-97

Frequency	Gain	Vout	Vin
hZ	dB	V	mV
1	73.9794	10	2
5	73.53387	9.5	2
100	73.33036	9.28	2
200	70.31748	6.56	2
300	67.53154	4.76	2
400	65.48316	3.76	2
500	63.97314	3.16	2
600	62.41148	2.64	2
700	61.51094	2.38	2
800	60.34067	2.08	2
900	59.46256	1.88	2
1000	58.68997	1.72	2
1100	58.0618	1.6	2
1200	57.50123	1.5	2
1300	57.14665	1.44	2
1400	56.5215	1.34	2
1500	56.1236	1.28	2
1600	55.56303	1.2	2
50000	20	0.02	2
500000	0	0.002	2
10000000	-20	0.0002	2



LOW PASS FILTER

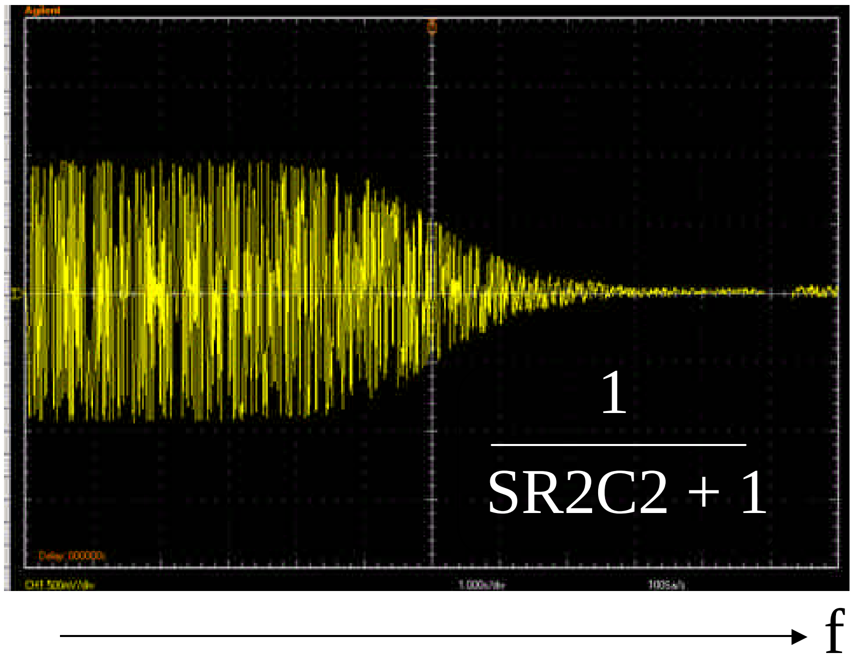


Derive an expression for Vo/Vin

Plot $20Log_{10}$ (Vo/Vin) vs frequency

Verify using SPICE

Verify by building the circuit

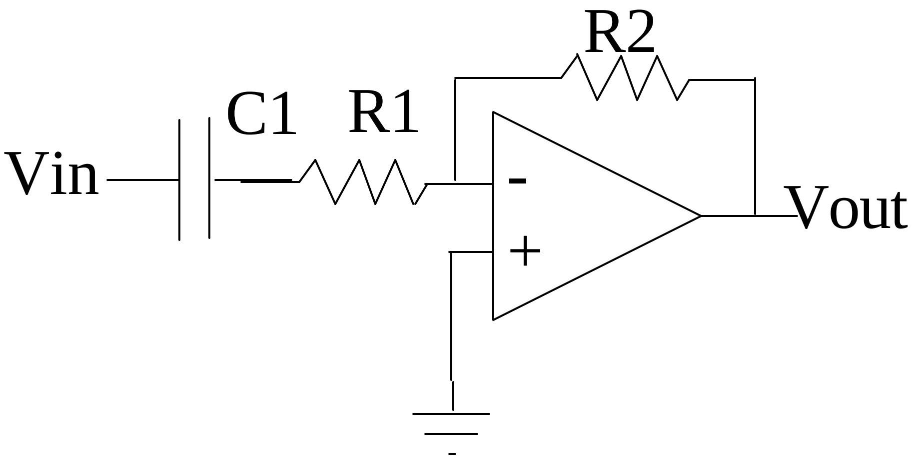


$$Vo/Vin = -R2/R1\left(\frac{1}{1 + j\,\omega/\omega 1}\right)$$

$$\omega = 2\,\pi\,f$$

$$\omega 1 = 1/R2C2$$

HIGH PASS FILTER

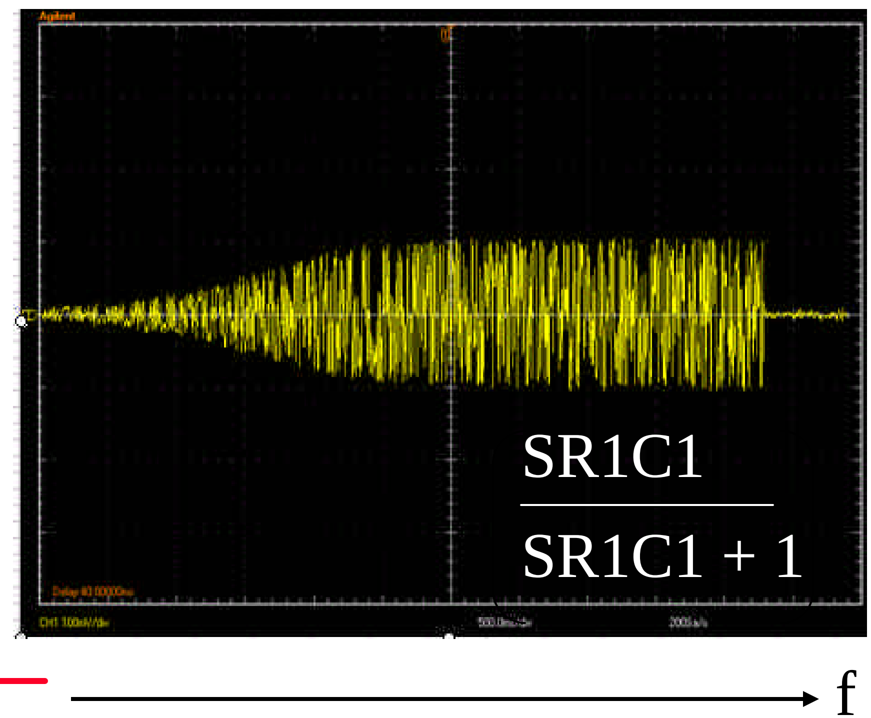


Derive an expression for Vo/Vin

Plot 20Log_{10} (Vo/Vin) vs frequency

Verify using SPICE

Verify by building the circuit



$$Vo/Vin = -R2/R1 \left(\frac{j\,\omega/\omega 1}{1 + j\,\omega/\omega 1} \right)$$

$$\omega = 2\,\pi\,f$$

$$\omega 1 = 1/R1C1$$

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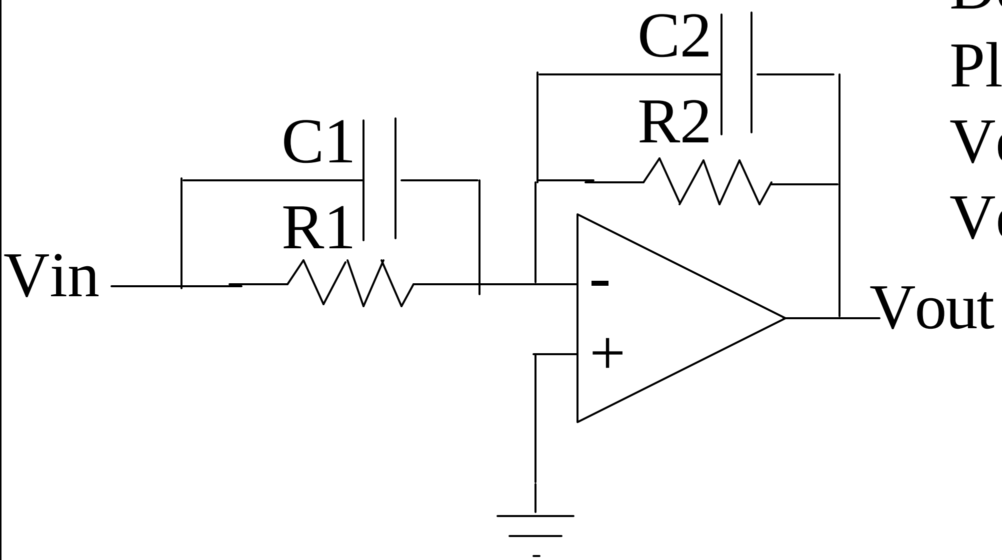
Microelectronic Engineering

GENERAL FILTER



Derive an expression for Vo/Vin

Plot $20Log_{10}$ (Vo/Vin) vs frequency

Verify using SPICE

Verify by building the circuit

$$Vo/Vin = -R2/R1\left(\frac{SR1C1 + 1}{SR2C2 + 1}\right) = -R2/R1\left(\frac{1 + j\,\omega/\omega 1}{1 + j\,\omega/\omega 2}\right)$$

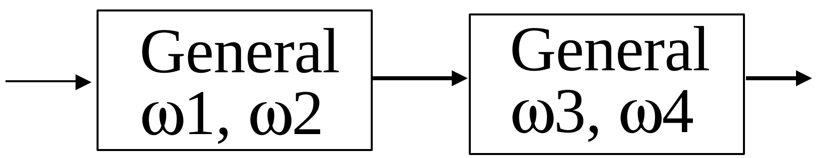
$\omega = 2\,\pi\,f$

$\omega 1 = 1/R1C1,\ \omega 2 = 1/R2C2$

COMBINATIONS OF FILTERS

$$Vo/Vin = -R2/R1 \left(\frac{1 + j\ \omega/\omega 1}{1 + j\ \omega/\omega 2} \right)$$

Two General Filters in series



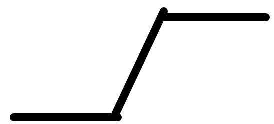
$$Vo/Vin = -R2R4/R1R3 \left(\frac{1 + j\ \omega/\omega 1}{1 + j\ \omega/\omega 2} \right) \left(\frac{1 + j\ \omega/\omega 3}{1 + j\ \omega/\omega 4} \right)$$

2^{nd} Order low-pass, high-pass, bandpass, bandrejection and all pass filter

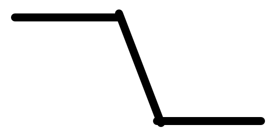
SKETCH OF VARIOUS FILTER FREQUENCY RESPONSE

$$Vo/Vin = -R2R4/R1R3 \left(\frac{1 + j\,\omega/\omega1}{1 + j\,\omega/\omega2}\right)\left(\frac{1 + j\,\omega/\omega3}{1 + j\,\omega/\omega4}\right)$$

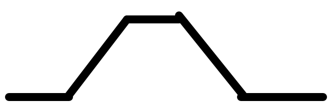
$\omega1 = \omega3 < \omega2 = \omega4$



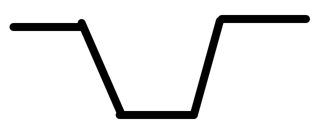
$\omega2 = \omega4 < \omega1 = \omega3$



$\omega1 < \omega2 < \omega4 < \omega3$



$\omega2 < \omega1 < \omega3 < \omega4$



OPERATIONAL TRANSCONDUCTANCE AMPLIFIER

National Semiconductor

June 2004

LM13700
Dual Operational Transconductance Amplifiers with Linearizing Diodes and Buffers

General Description

The LM13700 series consists of two current controlled transconductance amplifiers, each with differential inputs and a push-pull output. The two amplifiers share common supplies but otherwise operate independently. Linearizing diodes are provided at the inputs to reduce distortion and allow higher input levels. The result is a 10 dB signal-to-noise improvement referenced to 0.5 percent THD. High impedance buffers are provided which are especially designed to complement the dynamic range of the amplifiers. The output buffers of the LM13700 differ from those of the LM13600 in that their input bias currents (and hence their output DC levels) are independent of I_{ABC}. This may result in performance superior to that of the LM13600 in audio applications.

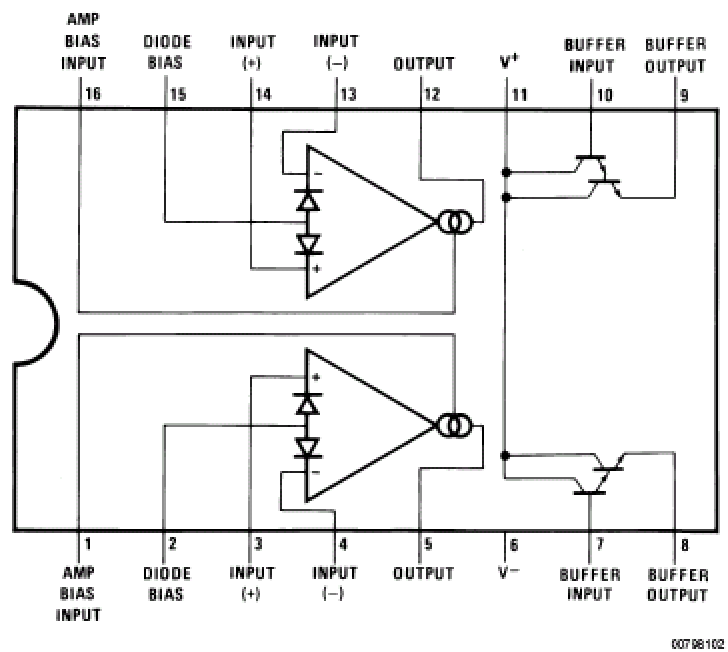
Features

- g_m adjustable over 6 decades
- Excellent g_m linearity
- Excellent matching between am
- Linearizing diodes
- High impedance buffers
- High output signal-to-noise ratio

Applications

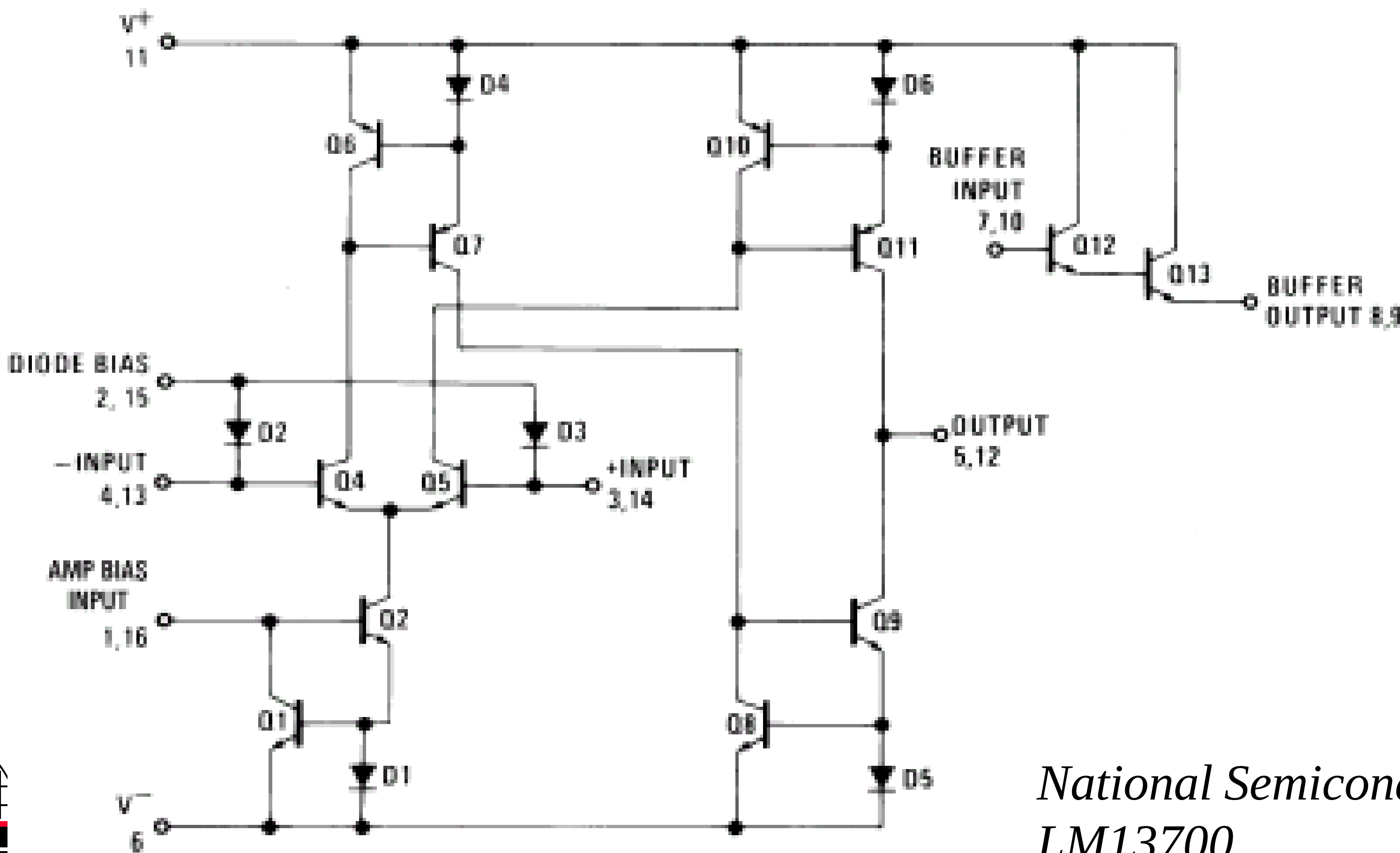
- Current-controlled amplifiers
- Current-controlled impedances
- Current-controlled filters
- Current-controlled oscillators
- Multiplexers
- Timers
- Sample-and-hold circuits

Dual-In-Line and Small Outline Packages



OPERATIONAL TRANSCONDUCTANCE AMPLIFIER

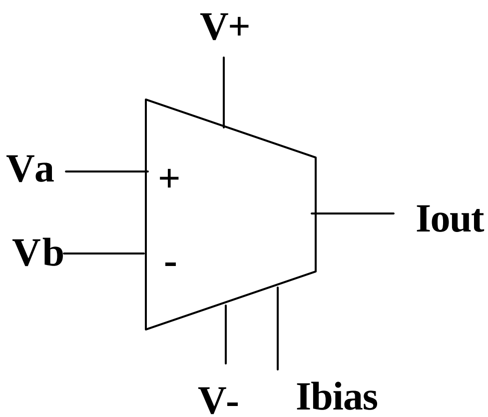
One Operational Transconductance Amplifier

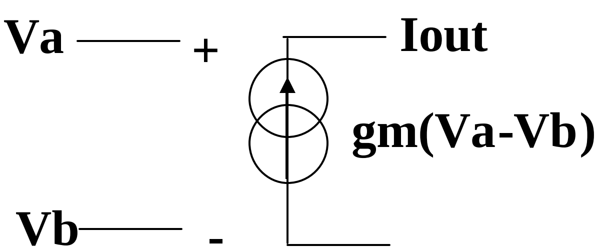


National Semiconductor
LM13700

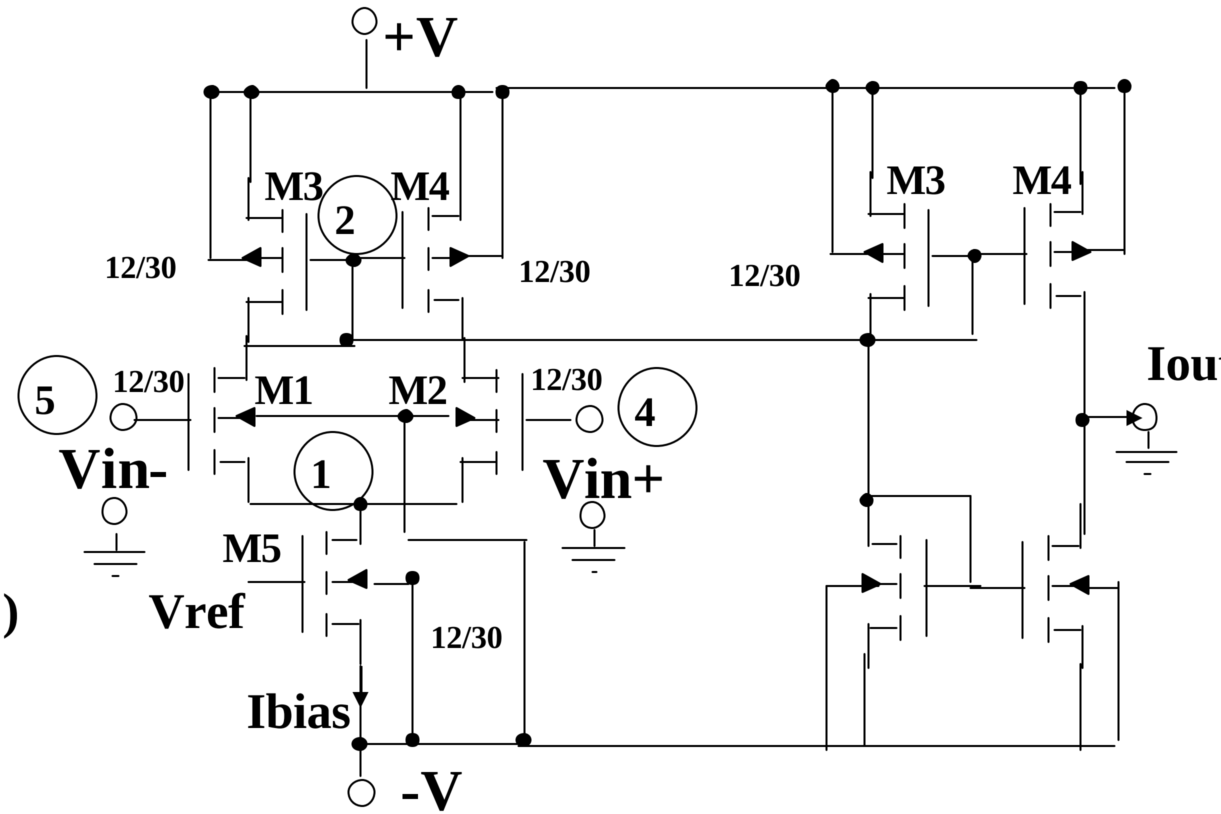
00798101

OPERATIONAL TRANSCONDUCTANCE AMPLIFIER



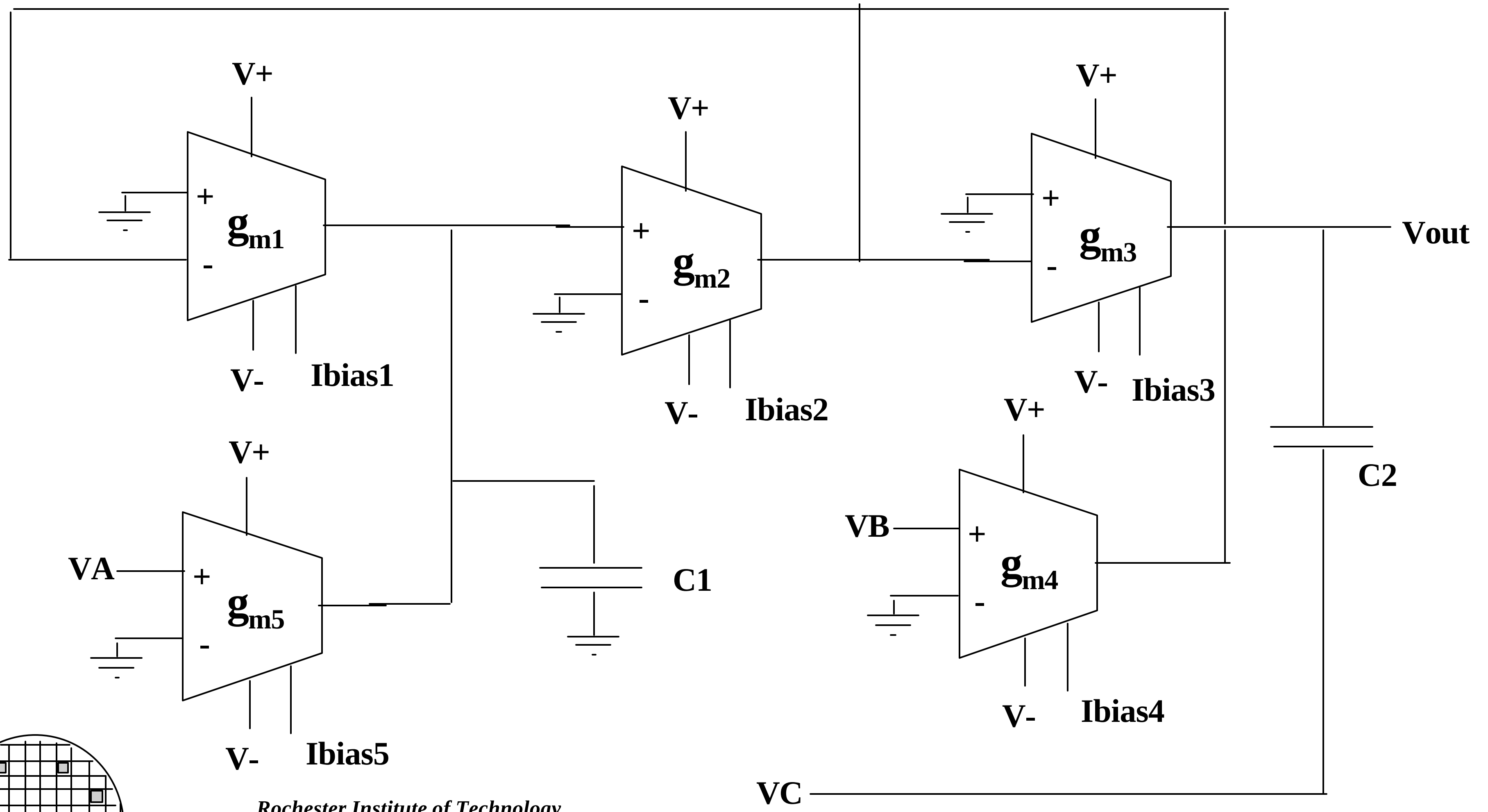


CMOS Realization



Note: gm is set by Ibias

BIQUAD FILTER



BIQUAD FILTER

$$V_{out} = (s^2C_1C_2V_c + s\, C_1\, g_{m4}\, V_b + g_{m2}\, g_{m5}\, V_a)/(s^2C_1C_2 + sC_1g_{m3} + g_{m2}g_{m1})$$

This filter can be used as a low-pass, high-pass, bandpass, bandrejection and all pass filter. Depending on the C and gm values a Butterworth, Chebyshev, Elliptic or any other configuration can be achieved

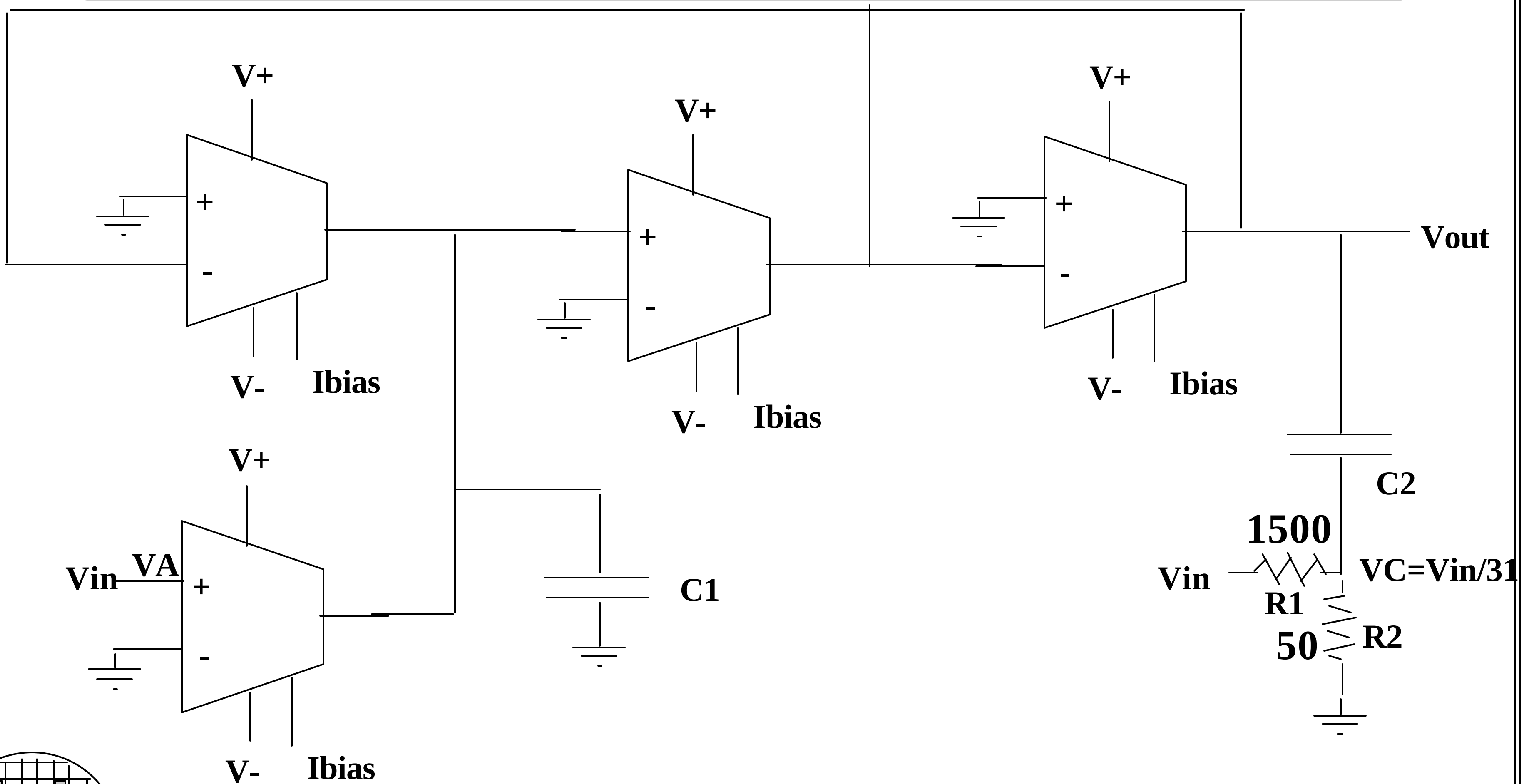
For example: let Vc=Vb=0 and Va=Vin, also let all g_m be equal, then

$$Vout = Vin / (s^2C_1C_2/ g_m g_m + sC_1/g_m + 1)$$

which is a second order low pass filter with corner frequency at

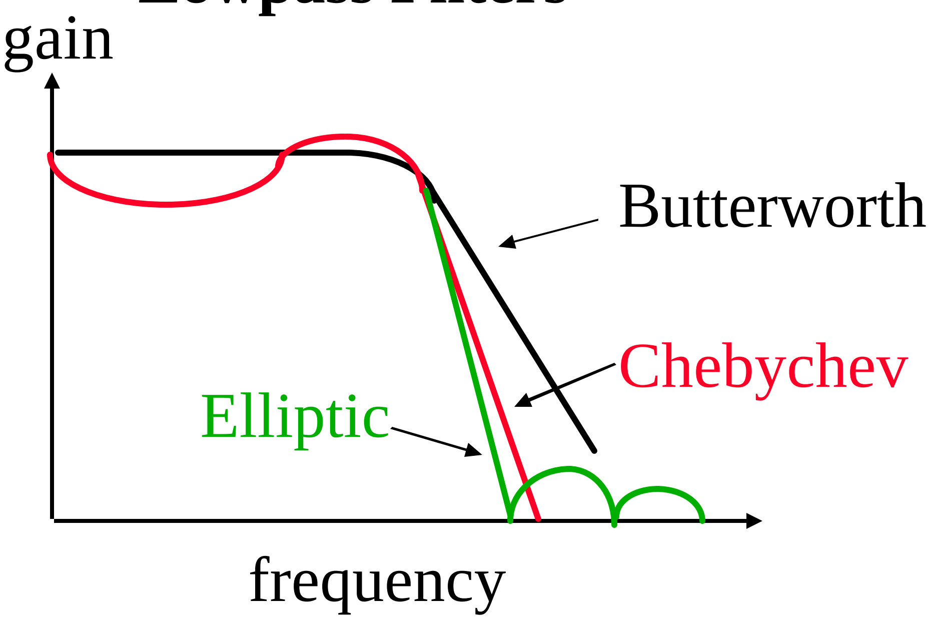
$$\omega_c = g_m / \sqrt{C_1C_2} \quad \text{and } Q = \sqrt{C_2/C_1}$$

ELLIPTIC FILTER



COMPARISON OF DIFFERENT FILTER DESIGNS

Lowpass Filters



Butterworth is flat in the band pass region, has the least steep transition to band stop region

Chebychev is not flat in the band pass region, has a steeper transition to band stop region than Butterworth

Elliptic is flat in the band pass region, has the steepest transition to band stop region but has some gain in the band stop region

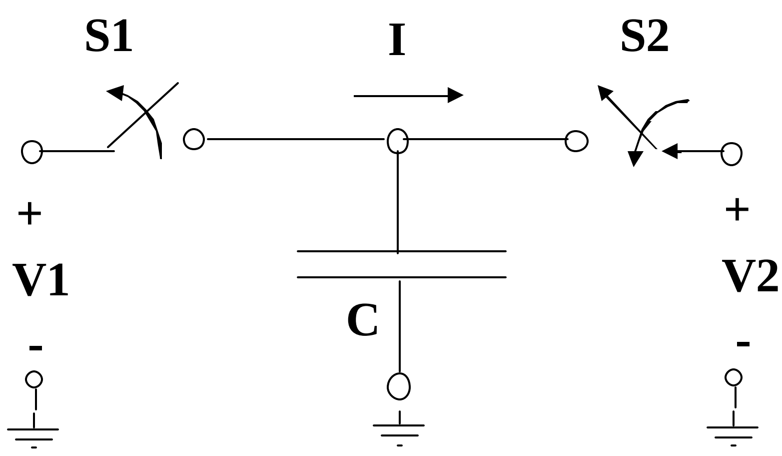
SWITCHED CAPACITOR CIRCUITS

Switched capacitor circuits makes use of analog switches and capacitors to replace resistors.

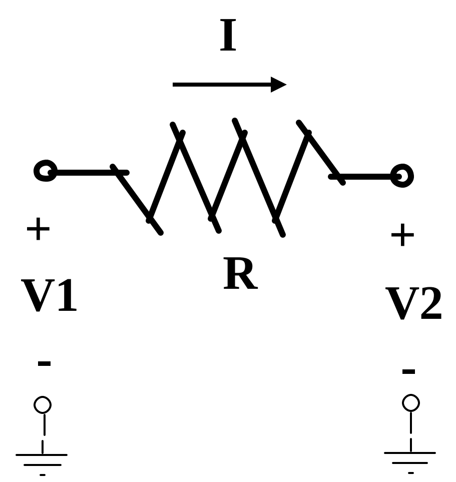
Saves space compared to using resistors

Low pass filter, filters out high frequency switching artifacts

SWITCHED CAPACITOR EQUIVALENT RESISTOR



I = Cfs (V1-V2)

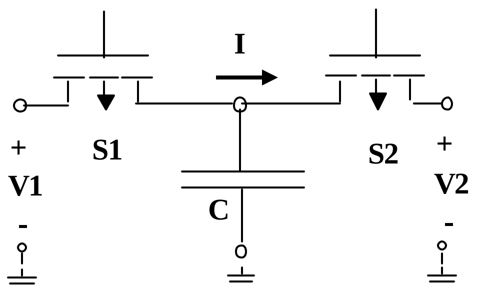


I = (1/R) (V1-V2)

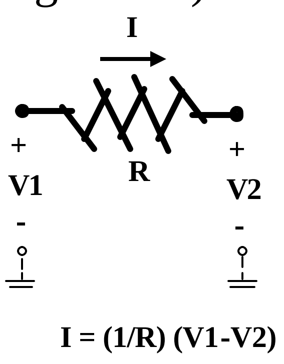
S1 closed C charges to V1, charge transferred is Q = CV1
S1 is opened
S2 is closed C charges to V2, charge transferred is Q = CV2
if the switches operate at a switching frequency fs, then I = Qfs = Cfs(V1-V2)
and Req = 1/(Cfs)

SWITCHED CAPACITOR CIRCUITS

1. The sampling frequency fs must be much higher than the signal frequencies
2. The voltages at node 1 and 2 must be unaffected by switch closures.
3. The switches are ideal.
4. S1 and S2 are not both on at same time. (use non overlapping clocks)



Req = 1/(Cfs)



Example: for audio applications with frequencies up to 10KHz, we select switch frequency of 500KHz, for a 1 MEG ohm resistor we find that

C = 1/ (500K 1MEG) = 2 p/F

If Xox = 4000 Å, then the capacitor will be about 150 µm by 150 µm

LMF100 SWITCHED CAPACITOR FILTER CHIP

National Semiconductor

July 1999

LMF100
High Performance Dual Switched Capacitor Filter

LMF100 High Performance Dual Switched Capacitor Filter

General Description

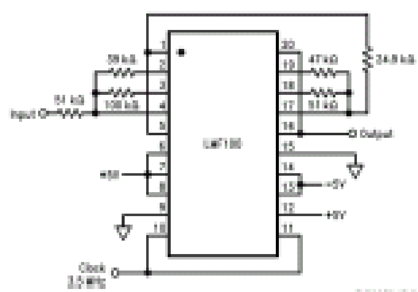
The LMF100 consists of two independent general purpose high performance switched capacitor filters. With an external clock and 2 to 4 resistors, various second-order and first-order filtering functions can be realized by each filter block. Each block has 3 outputs. One output can be configured to perform either an allpass, highpass, or notch function. The other two outputs perform bandpass and lowpass functions. The center frequency of each filter stage is tuned by using an external clock or a combination of a clock and resistor ratio. Up to a 4th-order biquadratic function can be realized with a single LMF100. Higher order filters are implemented by simply cascading additional packages, and all the classical filters (such as Butterworth, Bessel, Elliptic, and Chebyshev) can be realized.

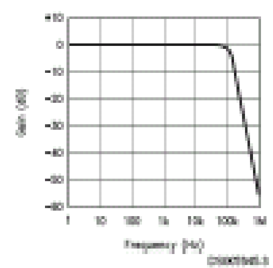
The LMF100 is fabricated on National Semiconductor's high performance analog silicon gate CMOS process, LMCMOS™. This allows for the production of a very low offset, high frequency filter building block. The LMF100 is pin-compatible with the industry standard MF10, but provides greatly improved performance.

Features

- Wide 4V to 15V power supply range
- Operation up to 100 kHz
- Low offset voltage: typically (50:1 or 100:1 mode): Vos1 = ±5 mV, Vos2 = ±15 mV, Vos3 = ±15 mV
- Low crosstalk −60 dB
- Clock to center frequency ratio accuracy ±0.2% typical
- f_0 x Q range up to 1.8 MHz
- Pin-compatible with MF10

4th Order 100 kHz Butterworth Lowpass Filter





Connection Diagram

CHEBYCHEV FILTER EXAMPLE USING LMF100

From LMF100 Data Sheet

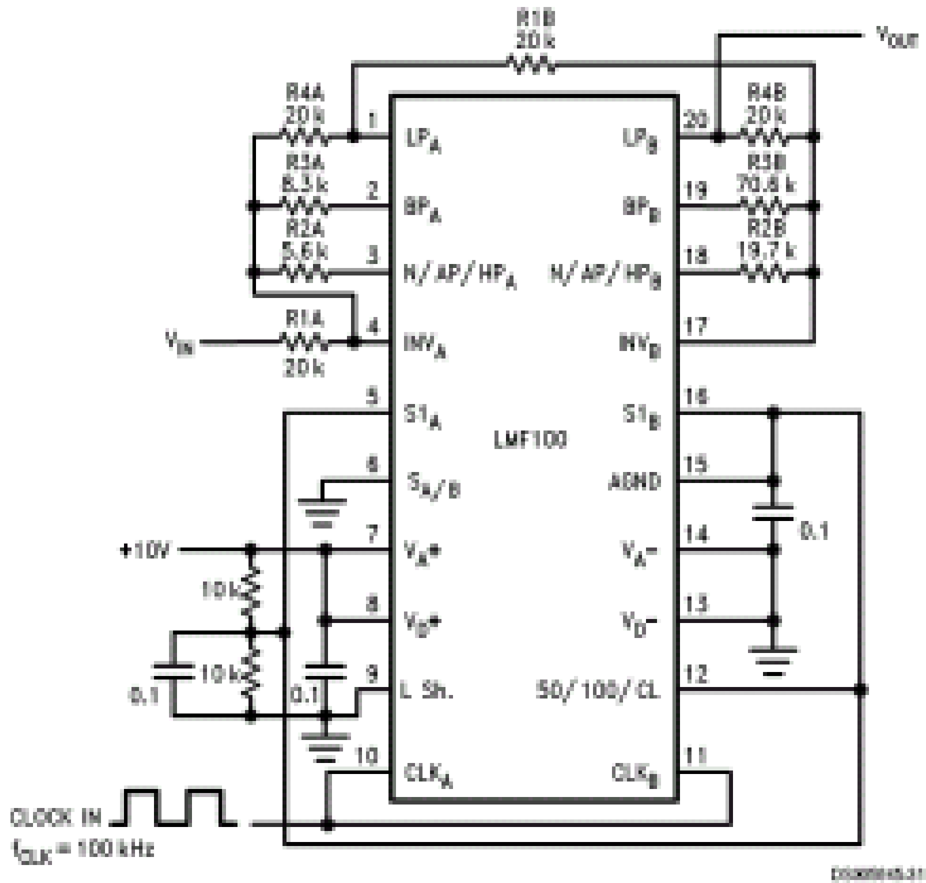


FIGURE 20. Fourth-order Chebyshev low-pass filter from example in 3.1. Single +10V power supply. 0V–5V TTL logic levels. Input signals should be referred to half-supply or applied through a coupling capacitor.

REFERENCES

1. Switched Capacitor Circuits, Phillip E. Allen and Edgar Sanchez-Sinencio, Van Nostrand Reinhold Publishers, 1984.

2. "Active Filter Design Using Operational Transconductance Amplifiers: A Tutorial," Randall L. Geiger and Edgar Sanchez-Sinencio, IEEE Circuits and Devices Magazine, March 1985, pg. 20-32.

3. Microelectronic Circuits, 5th Edition, Sedra and Smith

4. CMOS Analog Circuit Design, Phillip Allen, Douglas Holbert, Holt, Rinehard and Winston, 1987, pg 637-639.

HOMEWORK – SELECTED ANALOG CIRCUITS

1. Create one good homework problem and the solution related to the material covered in this document. (for next years students)
2. Design a high pass filter to have a gain of 100 and corner frequency of 10Mhz.
3. You have a 10pf switched capacitor equivalent resistor. What frequency is required to give an equivalent resistance of 10Mohm.
4. Design a bandpass filter to pass frequencies of 2K to 10Khz.