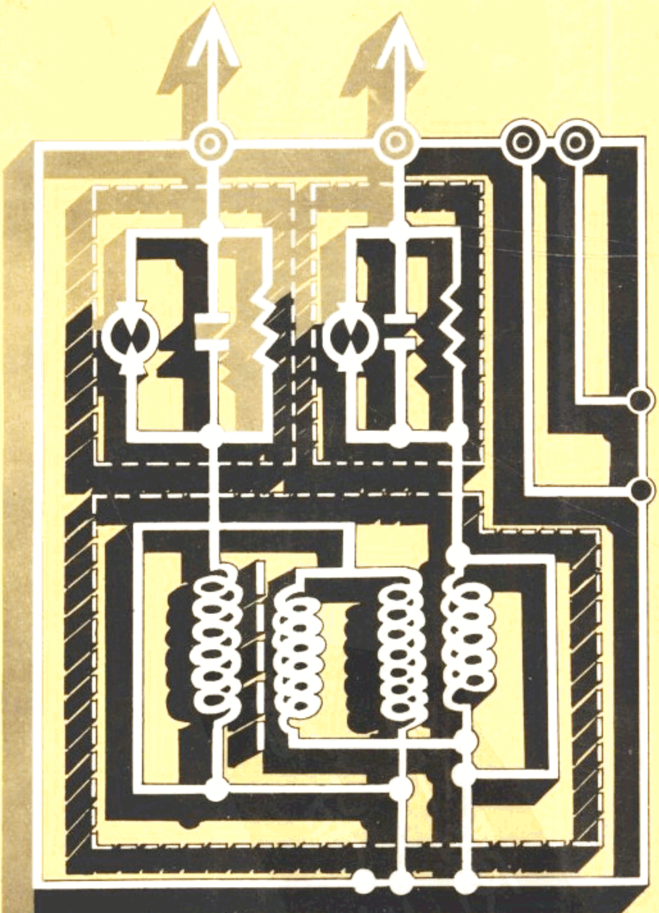
線性IC的應用、製作、實驗

林益海編譯・魏榮堂校閱



自　序

1. 本書係參考北川一雄所著オペアンプ IC 實驗と工作マニュアル一書及各大廠商 IC 資料編譯而成。

2. 在此感謝電機科主任魏榮堂先生之校閱及呂學成先生之提供資料。

3. 尤其感謝內人江雪惠女士給予各方面之協助。

4. 本書編譯如有錯誤之處，尚祈先進前輩不吝指正！

林益海　66年4月25日于台北工專

線性IC的應用、製作、實驗 目次

1-1 線性 IC 使用說明表

目前市面上出品 IC 的廠商很多:

1. 快捷公司 (Fairchild Semiconductor) 縮寫爲 FC
2. 國際半導體 (National Semiconductor) 公司縮寫爲 NS
3. 德州儀器公司 (Taxas Instrument) 縮寫爲 TI
4. 摩托羅拉 (Motorola Semiconductor)
5. RCA
6. 西門子公司 (Simens)

每家公司之產品及代號各不相同例如:

FC 公司以 μ 代表

RCA 以C代表

TI 公司以 SN 代表

Motorola 以MC代表

Signetics 公司以E代表

Rytheon 公司以R代表

日本東芝以T代表

日本日電以 μP 代表

日立公司以H代表

三菱公司以 M 代表

NS 公司以 LM 代表

μA741 是 FC 公司產品, 但其他公司亦仿造生產 μA741 之命名, 而 μA741 因爲價錢便宜, 而且有下列之優點故應用極廣, 普遍

應用於市面上之成品。

1. 電路內附有短路保護。

2. 附有抵補 (off set) 電壓調整端子。

3. 輸入訊號範圍大。

4. 不必外加相位補償用元件。

典型 μA741 電氣特性如下圖所示。

Parameter 參數	Conditions ($T_A=+25°C$, $V_S=\pm15V$)	Value	Unit
Input offset voltage V_{OS}	Source resistance, $R_S \leq 10k\Omega$	1.0	mV
Input offset current I_{OS}		30	nA
Input bias current		100	nA
Input resistance Z_{in}		1000	kΩ
Large signal voltage gain A_{VOL}	$R_L \geq 2k\Omega$, $V_{out}=\pm10V$	200,000	
Output voltage swing	$R_L \geq 10k\Omega$, $R_L \geq 2k\Omega$	±14	V
		±13	V
Input voltage range		±13	V
Usable frequency range		1	MHz
Common-mode rejection ratio (CMRR)	$R_S \leq 10k\Omega$	90	dB
Supply voltage rejection ratio	$R_S \leq 10k\Omega$	30	μV/V
Power consumption		50	mW
Maximum internal power dissipation		≥300	mW
Transient response (unity gain)	$V_{in}=20mV$, $R_L=2k\Omega$ $C_L \leq 100pF$		
Rise time		0.3	μs
Overshoot		5.0	μs
Slew rate (unity gain)	$R_L \geq 2k\Omega$	0.5	V/μs

圖 1-1

μA741 內部電路圖及各腳:

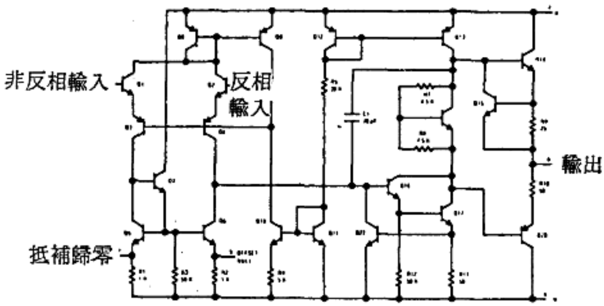


圖 1-2　μA741 內部電路

1. Q_1, Q_2 爲訊差放大器, 輸入由基極 (②脚及③脚輸入)。

2. Q_1, Q_2 的集極由偏壓二極體Q_8直接接到V_+。射極接Q_3和Q_4。

3. Q_3 和 Q_4 爲基極接地的訊差放大器, 當爲移位之用, 其輸出加到 Q_{16} 當爲驅動信號。Q_{16} 和 Q_{17} 接成達靈頓電路。

4. Q_{16}, Q_{17} 集極的輸出驅動 Q_{14}; Q_{14}、Q_{20} 爲一互補式射極隨耦器; 而 Q_{13} 爲一定電流源。

5. Q_{14} 和 Q_{20} 間的移位工作由 Q_{18}, R_7 (4.5KΩ)、R_8 (7.5KΩ) 來完成。

6. μA741的相位補償用 1 個30 PF 的電容在內部完成。

7. μA741 的抵補調整由 Q_5 和 Q_6 的射極間接一可變電阻而完成, 其接法如右圖 1-3 所示。

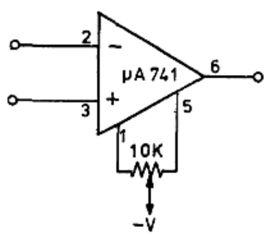


圖 1-3　μA741 的抵補調整

②—③脚接輸入　　　　　　　⑥脚接輸出
④脚接正電源　　　　　　　⑦脚接負電源
①脚⑤脚可接—10kΩ 可的變電阻供偏銷電壓調整之用。

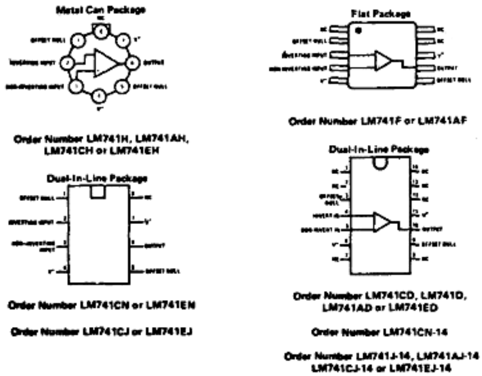


圖 1-4

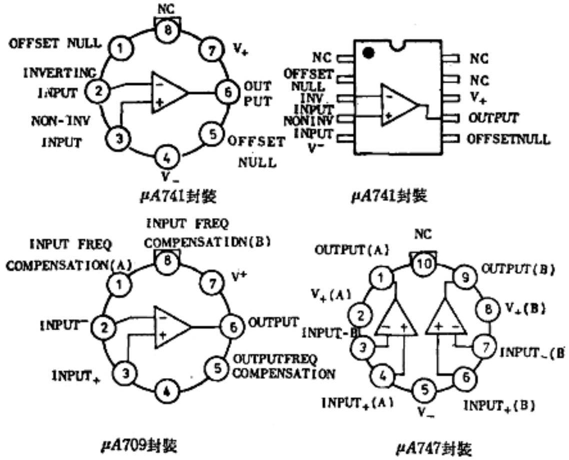


圖 1-5

NS 公司出產之 LM148 及 LM149 含有 4 個單獨 μA741 如圖 1-6 下面各圖表即其圖示接法及電氣特性，可比照採用。

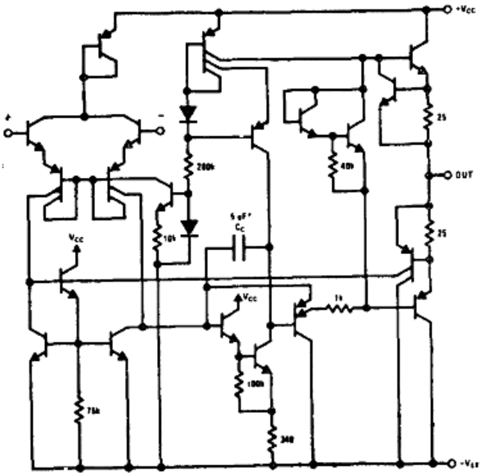
Operational Amplifiers/Buffers (運算放大器/緩衝級)

LM148, LM149 quad 741 op amps

LM148/LM248/LM348 quad 741 op amps

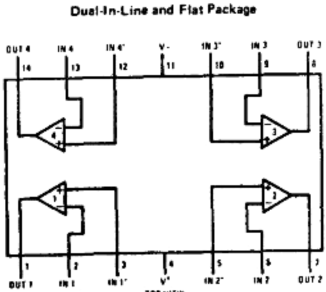
LM149/LM249/LM349 wide band decompensated (Av(MIN))=5

schematic and connection diagrams (結線圖)



*1 pF on the LM148

Dual-In-Line and Flat Package



Order Number LM148D, LM248D, LM348D, LM149D, LM249D or LM349D
See Package 1

Order Number LM248J, LM348J, LM249J or LM349J
See Package 16

Order Number LM148F or LM149F
See Package 4

Order Number LM348N or LM349N
See Package 22

absolute maximum ratings （最大額定）

		LM148/LM149	LM248/LM249	LM348/LM349
Supply Voltage		±22V	±18V	±18V
Differential Input Voltage		±44V	±36V	±36V
Input Voltage		±22V	±18V	±18V
Output Short Circuit Duration (Note 1)		Continuous	Continuous	Continuous
Power Dissipation (P_d at 25°C) and Thermal Resistance (θ_{jA}), (Note 2)				
Molded DIP (N)	P_d	–	–	500 mW
	θ_{jA}	–	–	150°C/W
Cavity DIP (D) (J)	P_d	900 mW	900 mW	900 mW
	θ_{jA}	100°C/W	100°C/W	100°C/W
Flat Pack (F)	P_d	675 mW	–	–
	θ_{jA}	185°C/W	–	–
Maximum Junction Temperature (T_{jMAX})		150°C	110°C	100°C
Operating Temperature Range		$-55°C \le T_A \le +125°C$	$-25°C \le T_A \le +85°C$	$0°C \le T_A \le +70°C$
Storage Temperature Range		−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Lead Temperature (Soldering, 60 seconds)		300°C	300°C	300°C

electrical characteristics (Note 3) 電氣特性

PARAMETER	CONDITIONS	LM148/LM149 MIN	LM148/LM149 TYP	LM148/LM149 MAX	LM248/LM249 MIN	LM248/LM249 TYP	LM248/LM249 MAX	LM348/LM349 MIN	LM348/LM349 TYP	LM348/LM349 MAX	UNITS
Input Offset Voltage	$T_A = 25°C$, $R_S \le 10\,k\Omega$		1.0	5.0		1.0	6.0		1.0	6.0	mV
Input Offset Current	$T_A = 25°C$		4	25		4	50		4	50	nA
Input Bias Current	$T_A = 25°C$		30	100		30	200		30	200	nA
Input Resistance	$T_A = 25°C$	0.8	2.5		0.8	2.5		0.8	2.5		MΩ
Supply Current All Amplifiers	$T_A = 25°C$, $V_S = \pm 15V$		2.4	3.6		2.4	4.5		2.4	4.5	mA
Large Signal Voltage Gain	$T_A = 25°C$, $V_S = \pm 15V$, $V_{OUT} = \pm 10V$, $R_L \ge 2\,k\Omega$	50	160		25	160		25	160		V/mV
Amplifier to Amplifier Coupling	$T_A = 25°C$, f = 1 Hz to 20 kHz (Input Referred) See Crosstalk Test Circuit		−120			−120			−120		dB
Small Signal Bandwidth	$T_A = 25°C$ LM148 series		1.0			1.0			1.0		MHz
	$T_A = 25°C$ LM149 series		4.0			4.0			4.0		MHz
Phase Margin	$T_A = 25°C$ LM148 series ($A_V = 1$)		60			60			60		degrees
	$T_A = 25°C$ LM149 series ($A_V = 5$)		60			60			60		degrees
Slew Rate	$T_A = 25°C$ LM148 series ($A_V = 1$)		0.5			0.5			0.5		V/μs
	$T_A = 25°C$ LM149 series ($A_V = 5$)		2.0			2.0			2.0		V/μs
Output Short Circuit Current	$T_A = 25°C$		25			25			25		mA
Input Offset Voltage	$R_S \le 10\,k\Omega$			6.0			7.5			7.5	mV
Input Offset Current				75			125			100	nA
Input Bias Current				325			500			400	nA
Large Signal Voltage Gain	$V_S = \pm 15V$, $V_{OUT} = \pm 10V$, $R_L > 2\,k\Omega$	25			15			15			V/mV
Output Voltage Swing	$V_S = \pm 15V$, $R_L = 10\,k\Omega$	±12	±13		±12	±13		±12	±13		V
	$R_L = 2\,k\Omega$	±10	±12		±10	±12		±10	±12		V
Input Voltage Range	$V_S = \pm 15V$	±12			±12			±12			V
Common-Mode Rejection Ratio	$R_S \le 10\,k\Omega$	70	90		70	90		70	90		dB
Supply Voltage Rejection	$R_S \le 10\,k\Omega$	77	96		77	96		77	96		dB

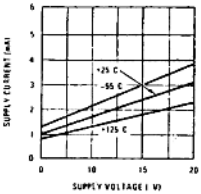
Note 1: Any of the amplifier outputs can be shorted to ground indefinitely; however, more than one should not be simultaneously shorted as the maximum junction temperature will be exceeded.

Note 2: The maximum power dissipation for these devices must be derated at elevated temperatures and is dictated by T_{jMAX}, θ_{jA}, and the ambient temperature, T_A. The maximum available power dissipation at any temperature is $P_d = (T_{jMAX} - T_A)/\theta_{jA}$ or the 25°C P_{dMAX}, whichever is less.

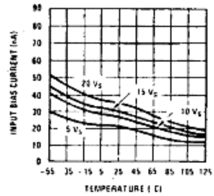
Note 3: These specifications apply for $V_S = \pm 15V$ and over the absolute maximum operating temperature range ($T_L \le T_A \le T_H$) unless otherwise noted.

typical performance characteristics (典型運用特性)

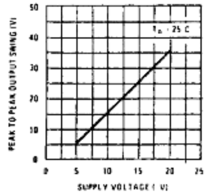
Supply Current



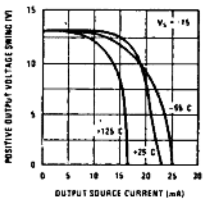
Input Bias Current



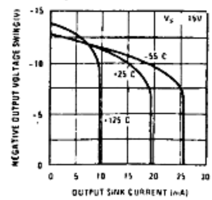
Voltage Swing



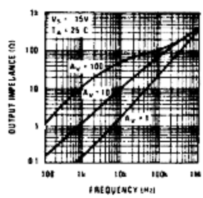
Positive Current Limit



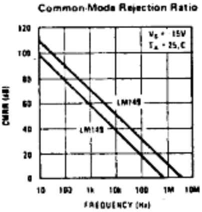
Negative Current Limit



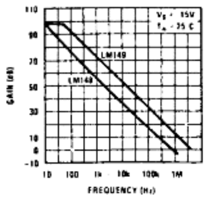
Output Impedance



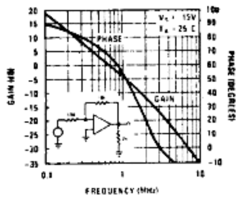
Common-Mode Rejection Ratio



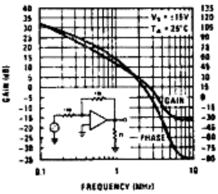
Open Loop Frequency Response



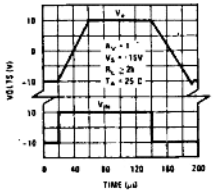
Bode Plot LM148



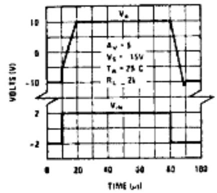
Bode Plot LM149



Large Signal Pulse Response (LM148)

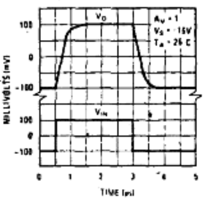


Large Signal Pulse Response (LM149)

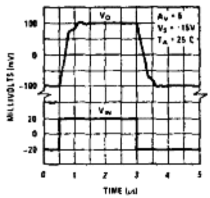


typical performance characteristics (con't) (典型運用特性)

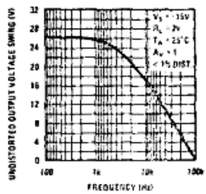
Small Signal Pulse Response (LM148)



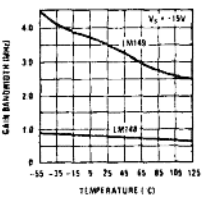
Small Signal Pulse Response (LM149)



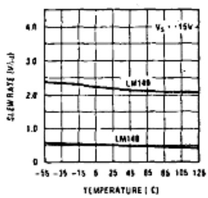
Undistorted Output Voltage Swing



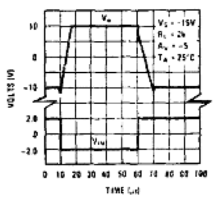
Gain Bandwidth



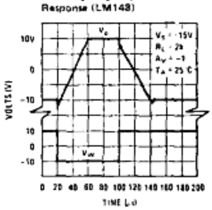
Slew Rate



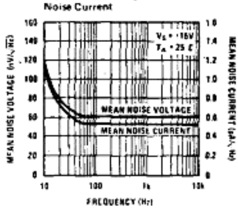
Inverting Large Signal Pulse Response (LM149)



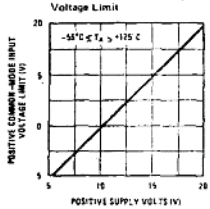
Inverting Large Signal Pulse Response (LM148)



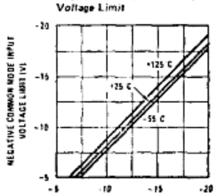
Input Noise Voltage and Noise Current



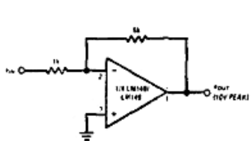
Positive Common-Mode Input Voltage Limit

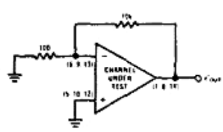


Negative Common-Mode Input Voltage Limit



cross talk test circuits



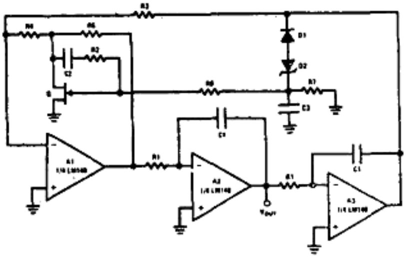


$$\text{Crosstalk} = -20 \log \frac{e'_{OUT}}{101 \times e_{OUT}} \text{ (dB)}$$

$V_S = \pm 15V$

typical applications-LM148（典型應用例）

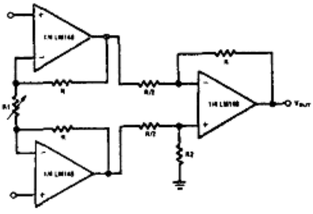
One Decade Low Distortion Sinewave Generator



$$f = \frac{1}{2\pi R1C1} \times \sqrt{K},\ K = \frac{R4R5}{R3}\left(\frac{1}{r_{DS}} + \frac{1}{R4} + \frac{1}{R5}\right),\ r_{DS} \approx \frac{R_{ON}}{\left(1 - \frac{V_{GS}}{V_P}\right)^{1/2}}$$

f_{MAX} = 5 kHz, THD ≤ 0.03%
R1 = 100k pot., C1 = 0.0047μF, C2 = 0.01μF, C3 = 0.1μF, R2 = R6 = R7 = 1M,
R3 = 5.1k, R4 = 12Ω, R5 = 240Ω, Q = NS5102, D1 = 1N914, D2 = 3.6V avalanche diode (ex. LM103), V_S = ±15V
A simpler version with some distortion degradation at high frequencies can be made by using A1 as a simple inverting amplifier, and by putting back to back zeners in the feedback loop of A3.

Low Cost Instrumentation Amplifier

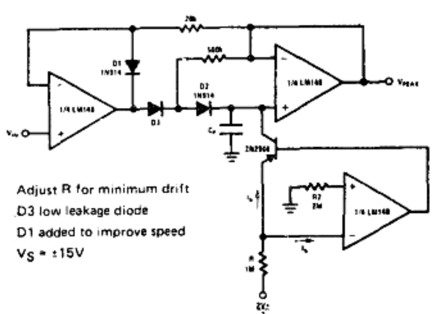


$$V_{OUT} = 2\left(\frac{2R}{R1} + 1\right),\ V_S^- - 3V \le V_{IN\ CM} \le V_S^+ - 3V,$$

V_S = ±15V
R = R2, trim R2 to boost CMRR

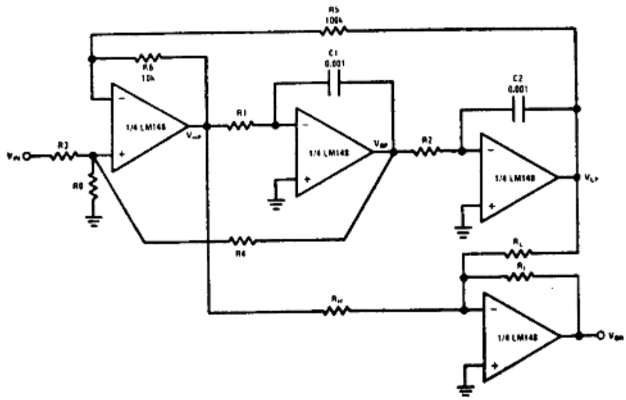
typical applications-LM148 (con't)（典型應用例）

Low Drift Peak Detector with Bias Current Compensation



Adjust R for minimum drift
D3 low leakage diode
D1 added to improve speed
V_S = ±15V

Universal State-Space Filter



Tune Q through R0.

For predictable results: $f_O\,Q \leq 4 \times 10^4$

Use Band Pass output to tune for Q

$$\frac{V(s)}{V_{IN}(s)} = \frac{N(s)}{D(s)} \quad D(s) = S^2 + \frac{S\omega_o}{Q} + \omega_o^2$$

$$N_{HP}(s) = S^2 H_{OHP},\ N_{BP}(s) = \frac{-S\omega_O H_{OBP}}{Q} \qquad N_{LP} = \omega_o^2 H_{OLP}$$

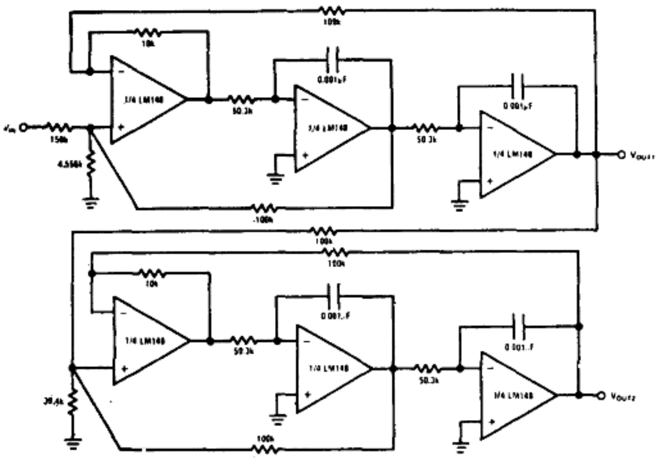
$$f_o = \frac{1}{2\pi}\sqrt{\frac{R6}{R5}}\ \sqrt{\frac{1}{t1t2}},\ t_i = R_iC_i,\ Q = \left(\frac{1 + R4/R3 + R4/R0}{1 + R6/R5}\right)\left(\frac{R6}{R5}\ \frac{t_1}{t_2}\right)^{1/2}$$

$$f_{NOTCH} = \frac{1}{2\pi}\left(\frac{R_H}{R_L t_1 t_2}\right)^{1/2},\ H_{OHP} = \frac{1 + R6/R5}{1 + R3/R0 + R3/R4},\ H_{OBP} = \frac{1 + R4/R3 + R4/R0}{1 + R3/R0 + R3/R4}$$

$$H_{OLP} = \frac{1 + R5/R6}{1 + R3/R0 + R3/R4}$$

typical applications-LM148 (con't) (典型應用例)

A 1 kHz 4 Pole Butterworth

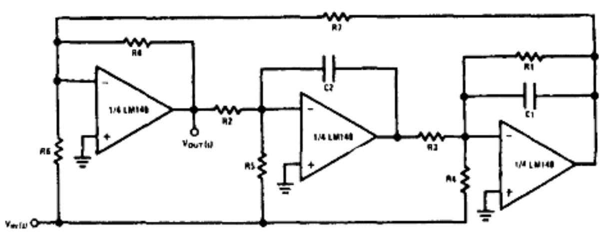


Use general equations, and tune each section separately

$Q_{1stSECTION} = 0.541$, $Q_{2ndSECTION} = 1.306$

The response should have 0 dB peaking

A 3 Amplifier Bi-Quad Notch Filter



$$Q = \sqrt{\frac{R8}{R7}} \times \frac{R1C1}{\sqrt{R3C2R2C1}}, \quad f_o = \frac{1}{2\pi}\sqrt{\frac{R8}{R7}} \times \frac{1}{\sqrt{R2R3C1C2}}, \quad f_{NOTCH} = \frac{1}{2\pi}\sqrt{\frac{R6}{R3R5R7C1C2}}$$

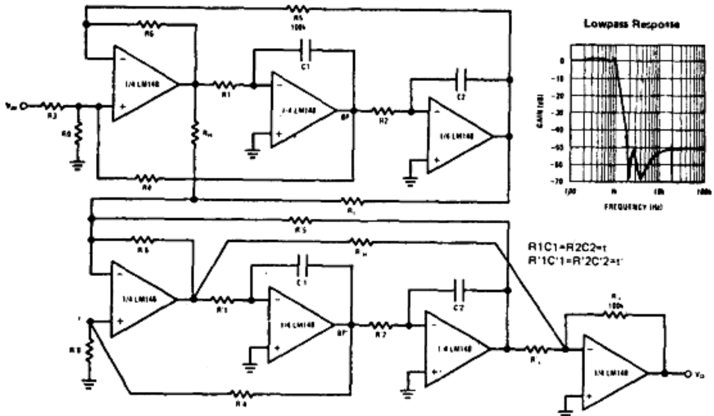
Necessary condition for notch: $\frac{1}{R6} = \frac{R1}{R4R7}$

Ex: f_{NOTCH} = 3 kHz, Q = 5, R1 = 270k, R2 = R3 = 20k, R4 = 27k, R5 = 20k, R6 = R8 = 10k, R7 = 100k, C1 = C2 = 0.001µF

Better noise performance than the state-space approach

typical applications-LM148 (con't) (典型應用例)

A 4th Order 1 kHz Elliptic Filter (4 Poles, 4 Zeros)



$f_C = 1$ kHz, $f_S = 2$ kHz, $f_P = 0.543$, $f_Z = 2.14$, $Q = 0.841$, $f'_P = 0.987$, $f'_Z = 4.92$, $Q' = 4.403$, normalized to ripple BW

$$f_P = \frac{1}{2\pi}\sqrt{\frac{R6}{R5}} \times \frac{1}{t},\quad f_Z = \frac{1}{2\pi}\sqrt{\frac{R_H}{R_L}} \times \frac{1}{t},\quad Q = \left(\frac{1 + R4/R3 + R4/R0}{1 + R6/R5}\right) \times \sqrt{\frac{R6}{R5}},\quad Q' = \sqrt{\frac{R'6}{R'5}}\ \frac{1 + R'4/R'0}{1 + R'6/R'5 + R'6/R_P}$$

$$R_P = \frac{R_H R_L}{R_H + R_L}$$

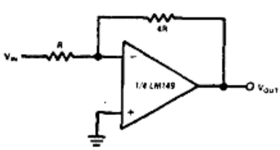
Use the BP outputs to tune Q, Q', tune the 2 sections separately

R1 = R2 = 92.6k, R3 = R4 = R5 = 100k, R6 = 10k, R0 = 107.8k, R_L = 100k, R_H = 155.1k,

R'1 = R'2 = 50.9k, R'4 = R'5 = 100k, R'6 = 10k, R'0 = 5.78k, R'_L = 100k, R'_H = 248.12k, R'f = 100k. All capacitors are 0.001μF.

typical applications-LM149

Minimum Gain to Insure LM149 Stability



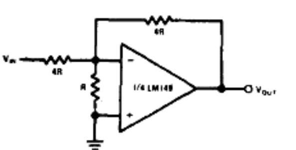
$$A_{CL(S)} = \frac{V_{OUT}}{V_{IN}} = \frac{4}{\left(1 + \dfrac{5}{A_{OL(s)}}\right)}$$

$$V_O \Big|_{V_{IN}=0} \cong \pm 5\ V_{OS}$$

Power BW = 40 kHz

Small Signal BW = G BW/5

The LM149 as a Unity Gain Inverter



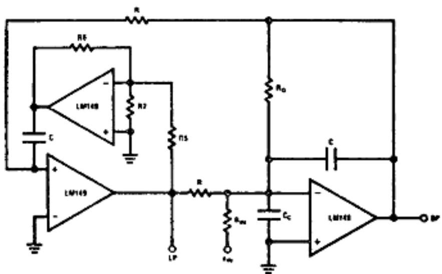
$$A_{CL(s)} = \frac{V_{OUT}}{V_{IN}} = \left(\frac{1}{1 + \dfrac{6}{A_{OL(s)}}}\right)$$

$$V_O \Big|_{V_{IN}=0} \cong \pm 5\ V_{OS}$$

Small signal BW = G BW/5

typical applications-LM149 (con't) (典型應用例)

Non-inverting-Integrater Bandpass Filter (非反相積分帶通濾波器)



For stability purposes: R7 = R6/4, 10R6 = R5, C_C = 10C

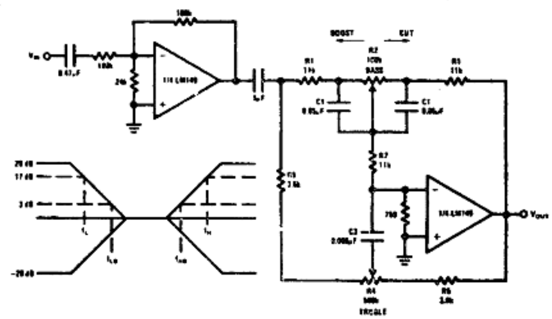
$$f_O = \frac{1}{2\pi}\sqrt{\frac{R5}{R6}} \times \frac{1}{RC},\quad Q = \frac{R_Q}{R}\sqrt{\frac{R5}{R6}},\quad Ho_{BP} = \frac{R_Q}{R_{IN}}$$

$(f_{O(MAX)}, Q_{MAX})$ = 20 kHz, 10

Better Q sensitivity with respect to open loop gain variations than the state variable filter.

R7, C_C added for compensation

Active Tone Control with Full Output Swing (No Slew Limiting at 20 kHz)(音調控制)



$V_S = \pm 15V$, $V_{OUT(MAX)} = 9.1\ V_{RMS}$.

f_{MAX} = 20 kHz, THD $\leq$ 1%

Duplicate the above circuit for stereo

$$f_L = \frac{1}{2\pi R2C1},\quad f_{LB} = \frac{1}{2\pi R1C1}$$

$$f_H = \frac{1}{2\pi R5C3},\quad f_{HB} = \frac{1}{2\pi(R1 + 2R7)\,C3}$$

Max Bass Gain $\cong$ (R1 + R2)/R1

Max Treble Gain $\cong$ (R1 + 2R7)/R5

as shown: $f_L \cong$ 32 Hz, $f_{LB} \cong$ 320 Hz

$f_H \cong$ 11 kHz, $f_{HB} \cong$ 1.1 Hz