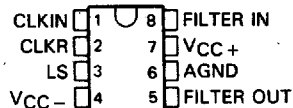


**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

D2970, NOVEMBER 1986—REVISED NOVEMBER 1988

- Low Clock-to-Cutoff-Frequency Ratio Error  
 TLC04/MF4A-50 ...  $\pm 0.8\%$   
 TLC14/MF4A-100 ...  $\pm 1\%$
- Filter Cutoff Frequency Dependent Only on External-Clock Frequency Stability
- Minimum Filter Response Deviation Due to External Component Variations Over Time and Temperature
- Cutoff Frequency Range from 0.1 Hz to 30 kHz,  $V_{CC} \pm = \pm 2.5 V$
- 5-V to 12-V Operation
- Self Clocking or TTL-Compatible and CMOS-Compatible Clock Inputs
- Low Supply Voltage Sensitivity
- Designed to be Interchangeable with National MF4-50 and MF4-100

D OR P PACKAGE  
 (TOP VIEW)



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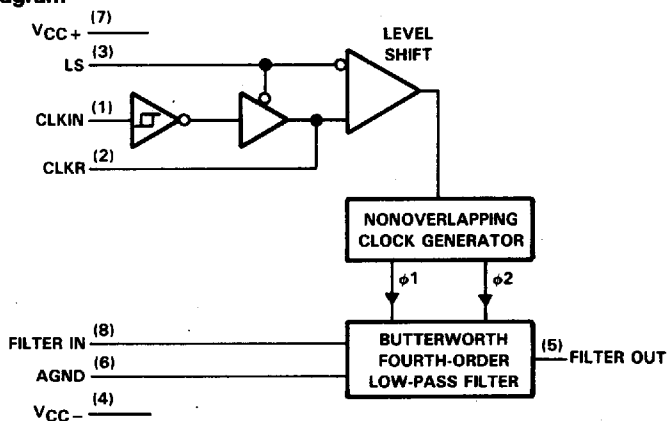
**description**

The TLC04/MF4A-50 and TLC14/MF4A-100 are monolithic Butterworth low-pass switched-capacitor filters. Each is designed as a low-cost, easy-to-use device providing accurate fourth-order low-pass filter functions in circuit design configurations.

Each filter features cutoff frequency stability that is dependent only on the external-clock frequency stability. The cutoff frequency is clock tunable and has a clock-to-cutoff frequency ratio of 50:1 with less than  $\pm 0.8\%$  error for the TLC04/MF4A-50 and a clock-to-cutoff frequency ratio of 100:1 with less than  $\pm 1\%$  error for the TLC14/MF4A-100. The input clock features self-clocking or TTL- or CMOS-compatible options in conjunction with the level shift (LS) pin.

The TLC04M/MF4A-50M and TLC14M/MF4A-100M are characterized over the full military temperature range of  $-55^{\circ}C$  to  $125^{\circ}C$ . The TLC04I/MF4A-50I and TLC14I/MF4A-100I are characterized for operation from  $-40^{\circ}C$  to  $85^{\circ}C$ . The TLC04C/MF4A-50C and TLC14C/MF4A-100C are characterized for operation from  $0^{\circ}C$  to  $70^{\circ}C$ .

**functional block diagram**



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**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

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## AVAILABLE OPTIONS

T <sub>A</sub>	CLOCK-TO-CUTOFF FREQUENCY RATIO	PACKAGE	
		SMALL OUTLINE (D)	PLASTIC DIP (P)
0°C to 70°C	50:1  100:1	TLC04CD/MF4A-50CD  TLC14CD/MF4A-100CD	TLC04CP/MF4A-50CP  TLC14CP/MF4A-100CP
-40°C to 85°C	50:1  100:1	TLC04ID/MF4A-50ID  TLC14ID/MF4A-100ID	TLC04IP/MF4A-50IP  TLC14IP/MF4A-100IP
-55°C to 125°C	50:1  100:1		TLC04MP/MF4A-50MP  TLC14MP/MF4A-100MP

The D package is available taped and reeled. Add the suffix R to the device type (e.g., TLC04CDR/MF4A-50CDR).

## pin description

PIN NAME	NO.	I/O	DESCRIPTION
AGND	6	I	Analog Ground — The noninverting input to the operational amplifiers of the Butterworth fourth-order low-pass filter.
CLKIN	1	I	Clock In — The clock input terminal for CMOS-compatible clock or self-clocking options. For either option, the Level Shift (LS) terminal is at V <sub>CC-</sub> . For self-clocking, a resistor is connected between the CLKIN and CLKR terminal pins and a capacitor is connected from the CLKIN terminal pin to ground.
CLKR	2	I	Clock R — The clock input for a TTL-compatible clock. For a TTL clock, the level shift pin is connected to mid-supply and the CLKIN pin may be left open, but it is recommended that it be connected to either V <sub>CC+</sub> or V <sub>CC-</sub> .
FILTER IN	8	I	Filter Input
FILTER OUT	5	O	Butterworth fourth-order low-pass Filter Output
LS	3	I	Level Shift — This terminal accommodates the various input clocking options. For CMOS-compatible clocks or self-clocking, the level-shift terminal is at V <sub>CC-</sub> and for TTL-compatible clocks, the level-shift terminal is at mid-supply.
V <sub>CC+</sub>	7	I	Positive supply voltage terminal
V <sub>CC-</sub>	4	I	Negative supply voltage terminal

  
**TEXAS**  
**INSTRUMENTS**

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**TLC04/MF4A-50, TLC14/MF4A-100  
BUTTERWORTH FOURTH-ORDER LOW-PASS  
SWITCHED-CAPACITOR FILTERS**

**absolute maximum ratings over operating free-air temperature range (unless otherwise noted)**

Supply voltage, $V_{CC\pm}$ (see Note 1) .....	$\pm 7$ V
Operating free-air temperature range: TLC04M/MF4A-50M, TLC14M/MF4A-100M	-55°C to 125°C
TLC04I/MF4A-50I, TLC14I/MF4A-100I .....	-40°C to 85°C
TLC04C/MF4A-50C, TLC14C/MF4A-100C .....	0°C to 70°C
Storage temperature .....	-65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds .....	260°C

NOTE 1: All voltage values are with respect to the AGND terminal.

**recommended operating conditions**

		TLC04/MF4A-50		TLC14/MF4A-100		UNIT	
		MIN	MAX	MIN	MAX		
$V_{CC+}$	Positive supply voltage	2.25	6	2.25	6	V	
$V_{CC-}$	Negative supply voltage	-2.25	-6	-2.25	-6	V	
$V_{IH}$	High-level input voltage	2		2		V	
$V_{IL}$	Low-level input voltage		0.8		0.8	V	
$f_{clock}$	Clock frequency (see Note 2)	$V_{CC\pm} = \pm 2.5$ V	5	$1.5 \times 10^6$	5	$1.5 \times 10^6$	Hz
		$V_{CC\pm} = \pm 5$ V	5	$2 \times 10^6$	5	$2 \times 10^6$	
$f_{co}$	Cutoff frequency (see Note 3)	0.1	$40 \times 10^3$	0.05	$20 \times 10^3$	Hz	
$T_A$	Operating free-air temperature	TLC04M/MF4A-50M, TLC14M/MF4A-100M	-55	125	-55	125	°C
		TLC04I/MF4A-50I, TLC14I/MF4A-100I	-40	85	-40	85	
		TLC04C/MF4A-50C, TLC14C/MF4A-100C	0	70	0	70	

- NOTES: 2. Above 250 kHz, the input clock duty cycle should be 50% to allow the operational amplifiers the maximum time to settle while processing analog samples.
3. The cutoff frequency is defined as the frequency where the response is 3.01 dB less than the dc gain of the filter.

**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

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electrical characteristics over recommended operating free-air temperature range,  $V_{CC+} = 2.5\text{ V}$ ,  
 $V_{CC-} = -2.5\text{ V}$ ,  $f_{\text{clock}} \leq 250\text{ kHz}$  (unless otherwise noted)

## filter section

PARAMETER		TEST CONDITIONS	TLC04/MF4A-50			TLC14/MF4A-100			UNIT	
			MIN	TYP†	MAX	MIN	TYP†	MAX		
$V_{OO}$	Output voltage offset		25			50			mV	
$V_{OM}$	Peak output voltages	$R_L = 10\text{ k}\Omega$	$V_{OM+}$	1.8	2	1.8	2	V		
			$V_{OM-}$	-1.25	-1.7	-1.25	-1.7			
$I_{OS}$	Short-circuit output current	$T_A = 25^\circ\text{C}$ , See Note 4	Source	-0.5			-0.5			mA
			Sink	4			4			
$I_{CC}$	Supply current	$f_{\text{clock}} = 250\text{ kHz}$	1.2	2.25	1.2	2.25	mA			

NOTE 4:  $I_{OS}$  (source current) is measured by forcing the output to its maximum positive voltage and then shorting the output to the negative supply ( $V_{CC-}$ ) terminal.  $I_{OS}$  (sink current) is measured by forcing the output to its maximum negative voltage and then shorting the output to the positive supply ( $V_{CC+}$ ) terminal.

operating characteristics over recommended operating free-air temperature range,  $V_{CC+} = 2.5\text{ V}$ ,  
 $V_{CC-} = -2.5\text{ V}$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	TLC04/MF4A-50			TLC14/MF4A-100			UNIT	
		MIN	TYP†	MAX	MIN	TYP†	MAX		
Maximum clock frequency, $f_{\text{max}}$	See Note 2	1.5	3	1.5	3	MHz			
Clock-to-cutoff-frequency ratio ( $f_{\text{clock}}/f_{\text{co}}$ )	$f_{\text{clock}} \leq 250\text{ kHz}$ , $T_A = 25^\circ\text{C}$	49.27	50.07	50.87	99	100	101		
Temperature coefficient of clock-to-cutoff frequency ratio	$f_{\text{clock}} \leq 250\text{ kHz}$	±25			±25			ppm/°C	
Frequency response above and below cutoff frequency (see Note 5)	$f_{\text{co}} = 5\text{ kHz}$ , $f_{\text{clk}} = 250\text{ kHz}$ , $T_A = 25^\circ\text{C}$	$f = 6\text{ kHz}$	-7.9	-7.57	-7.1			dB	
		$f = 4.5\text{ kHz}$	-1.7	-1.46	-1.3				
	$f_{\text{co}} = 2.5\text{ kHz}$ , $f_{\text{clk}} = 250\text{ kHz}$ , $T_A = 25^\circ\text{C}$	$f = 3\text{ kHz}$				-7.9	-7.42	-7.1	dB
		$f = 2.25\text{ kHz}$				-1.7	-1.51	-1.3	
Dynamic range (see Note 6)	$T_A = 25^\circ\text{C}$	80			78			dB	
Stop-band frequency attenuation at $2f_{\text{co}}$	$f_{\text{clock}} \leq 250\text{ kHz}$	24	25	24	25	dB			
DC voltage amplification	$f_{\text{clock}} \leq 250\text{ kHz}$ , $R_S \leq 2\text{ k}\Omega$	-0.15	0	0.15	-0.15	0	0.15	dB	
Peak-to-peak clock feedthrough voltage	$T_A = 25^\circ\text{C}$	5			5			mV	

† All typical values are at  $T_A = 25^\circ\text{C}$ .

NOTES: 2. Above 250 kHz, the input clock duty cycle should be 50% to allow the operational amplifiers the maximum time to settle while processing analog samples.

5. The frequency responses at  $f$  are referenced to a dc gain of 0 dB.

6. The dynamic range is referenced to 1.06 V rms (1.5 V peak) where the wideband noise over a 30-kHz bandwidth is typically 106  $\mu\text{V}$  rms for the TLC04/MF4A-50 and 135  $\mu\text{V}$  rms for the TLC14/MF4A-100.

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**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

electrical characteristics over recommended operating free-air temperature range,  $V_{CC+} = 5\text{ V}$ ,  
 $V_{CC-} = -5\text{ V}$ ,  $f_{\text{clock}} \leq 250\text{ kHz}$ , (unless otherwise noted)

filter section

PARAMETER	TEST CONDITIONS	TLC04/MF4A-50		TLC14/MF4A-100		UNIT	
		MIN	TYP†	MAX	MIN		TYP†
$V_{OO}$ Output voltage offset		150		200		mV	
$V_{OM}$ Peak output voltages	$V_{OM+}$	$R_L = 10\text{ k}\Omega$	3.75	4.3	3.75	4.5	V
	$V_{OM-}$		-3.75	-4.1	-3.75	-4.1	
$I_{OS}$ Short-circuit output current	Source	$T_A = 25^\circ\text{C}$ , See Note 4	-2		-2		mA
	Sink		5		5		
$I_{CC}$ Supply current	$f_{\text{clock}} = 250\text{ kHz}$	1.8	3	1.8	3	mA	
$k_{\text{sys}}$ Supply voltage sensitivity (see Figures 1 and 2)		-30		-30		dB	

NOTE 4:  $I_{OS}$  (source current) is measured by forcing the output to its maximum positive voltage and then shorting the output to the negative supply ( $V_{CC-}$ ) terminal.  $I_{OS}$  (sink current) is measured by forcing the output to its maximum negative voltage and then shorting the output to the positive supply ( $V_{CC+}$ ) terminal.

clocking section

PARAMETER	TEST CONDITIONS‡	MIN	TYP†	MAX	UNIT
$V_{T+}$ Positive-going input threshold voltage	$V_{CC+} = 10\text{ V}$ , $V_{CC-} = 0$	6.1	7	8.9	V
	$V_{CC+} = 5\text{ V}$ , $V_{CC-} = 0$	3.1	3.5	4.4	
$V_{T-}$ Negative-going input threshold voltage	$V_{CC+} = 10\text{ V}$ , $V_{CC-} = 0$	1.3	3	3.8	V
	$V_{CC+} = 5\text{ V}$ , $V_{CC-} = 0$	0.6	1.5	1.9	
$V_{\text{hys}}$ , Hysteresis ( $V_{T+} - V_{T-}$ )	$V_{CC+} = 10\text{ V}$ , $V_{CC-} = 0$	2.3	4	7.6	V
	$V_{CC+} = 5\text{ V}$ , $V_{CC-} = 0$	1.2	2	3.8	
$V_{OH}$ High-level output voltage	$V_{CC} = 10\text{ V}$	9			V
	$V_{CC} = 5\text{ V}$	4.5			
$V_{OL}$ Low-level output voltage	$V_{CC} = 10\text{ V}$			1	V
	$V_{CC} = 5\text{ V}$			0.5	
Input leakage current	$V_{CC} = 10\text{ V}$	Level Shift pin at mid-supply,		2	$\mu\text{A}$
	$V_{CC} = 5\text{ V}$	$T_A = 25^\circ\text{C}$		2	
Output current	$V_{CC} = 10\text{ V}$	CLKR and CLKIN		-3	mA
	$V_{CC} = 5\text{ V}$	shorted to $V_{CC-}$		-0.75	
Output current	$V_{CC} = 10\text{ V}$	CLKR and CLKIN		3	mA
	$V_{CC} = 5\text{ V}$	shorted to $V_{CC+}$		0.75	

†All typical values are at  $T_A = 25^\circ\text{C}$ .

‡ $V_{CC} = V_{CC+} - V_{CC-}$

**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

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operating characteristics over recommended operating free-air temperature range,  $V_{CC+} = 5\text{ V}$ ,  
 $V_{CC-} = -5\text{ V}$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	TLC04/MF4A-50			TLC14/MF4A-100			UNIT	
		MIN	TYP†	MAX	MIN	TYP†	MAX		
Maximum clock frequency, $f_{\text{max}}$ (see Note 2)		2	4		2	4		MHz	
Clock-to-cutoff-frequency ratio ( $f_{\text{clock}}/f_{\text{co}}$ )	$f_{\text{clock}} \leq 250\text{ kHz}$ , $T_A = 25^\circ\text{C}$	49.58	49.98	50.38	99	100	101		
Temperature coefficient of clock-to-cutoff frequency ratio	$f_{\text{clock}} \leq 250\text{ kHz}$	±15			±15			ppm/°C	
Frequency response above and below cutoff frequency (see Note 5)	$f_{\text{co}} = 5\text{ kHz}$ , $f_{\text{clk}} = 250\text{ kHz}$ , $T_A = 25^\circ\text{C}$	$f = 6\text{ kHz}$	-7.9	-7.57	-7.1			dB	
		$f = 4.5\text{ kHz}$	-1.7	-1.44	-1.3				
	$f_{\text{co}} = 2.5\text{ kHz}$ , $f_{\text{clk}} = 250\text{ kHz}$ , $T_A = 25^\circ\text{C}$	$f = 3\text{ kHz}$				-7.9	-7.42	-7.1	dB
		$f = 2.25\text{ kHz}$				-1.7	-1.51	-1.3	
Dynamic range (see Note 7)	$T_A = 25^\circ\text{C}$	86			84			dB	
Stop-band frequency attenuation at $2 f_{\text{co}}$	$f_{\text{clock}} \leq 250\text{ kHz}$	24	25		24	25		dB	
DC voltage amplification	$f_{\text{clock}} \leq 250\text{ kHz}$ , $R_S \leq 2\text{ k}\Omega$	-0.15	0	0.15	-0.15	0	0.15	dB	
Peak-to-peak clock feedthrough voltage	$T_A = 25^\circ\text{C}$	7			7			mV	

† All typical values are at  $T_A = 25^\circ\text{C}$ .

NOTES: 2. Above 250 kHz, the input clock duty cycle should be 50% to allow the operational amplifiers the maximum time to settle while processing analog samples.

5. The frequency responses at  $f$  are referenced to a dc gain of 0 dB.

7. The dynamic range is referenced to 2.82 V rms (4 V peak) where the wideband noise over a 30-kHz bandwidth is typically 142  $\mu\text{V}$  rms for the TLC04/MF4A-50 and 178  $\mu\text{V}$  rms for the TLC14/MF4A-100.

**TLC04/MF4A-50, TLC14/MF4A-100  
BUTTERWORTH FOURTH-ORDER LOW-PASS  
SWITCHED-CAPACITOR FILTERS**

**TYPICAL CHARACTERISTICS**

*7-64-05*

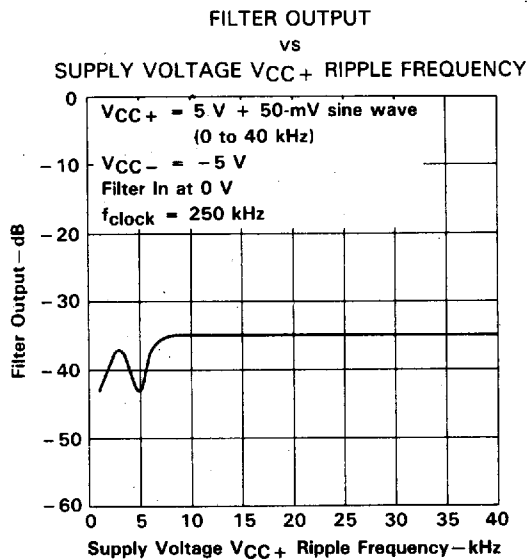


FIGURE 1

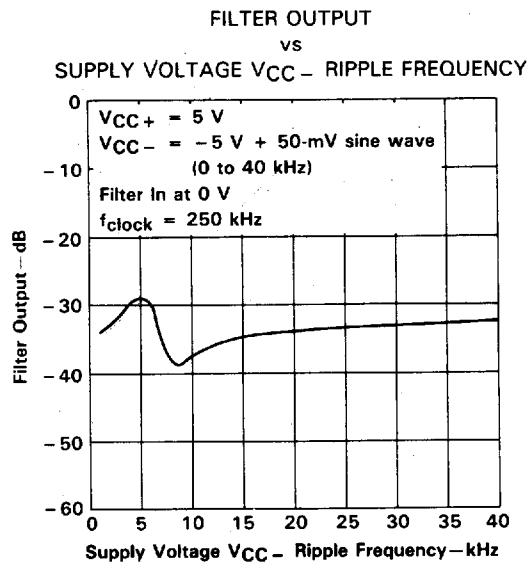


FIGURE 2

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**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

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## TYPICAL APPLICATION DATA

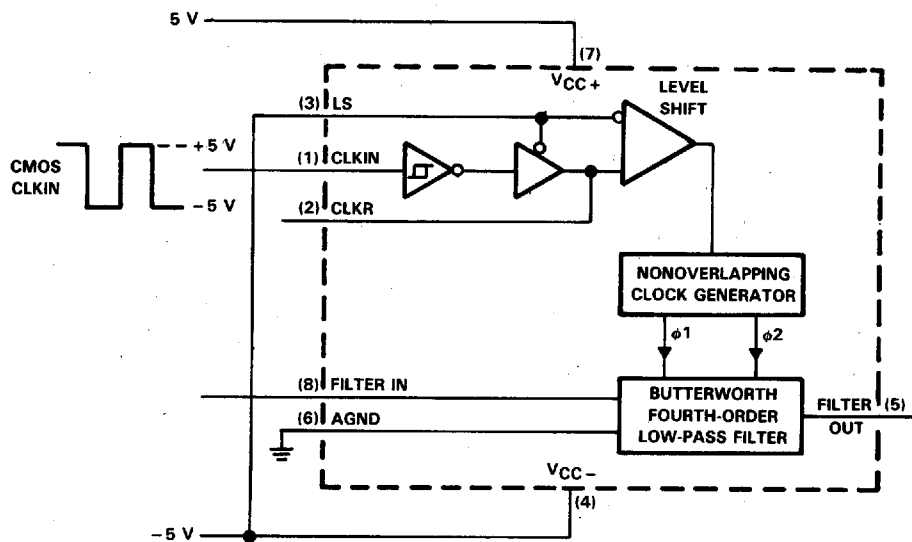


FIGURE 3. CMOS-CLOCK-DRIVEN, DUAL-SUPPLY OPERATION

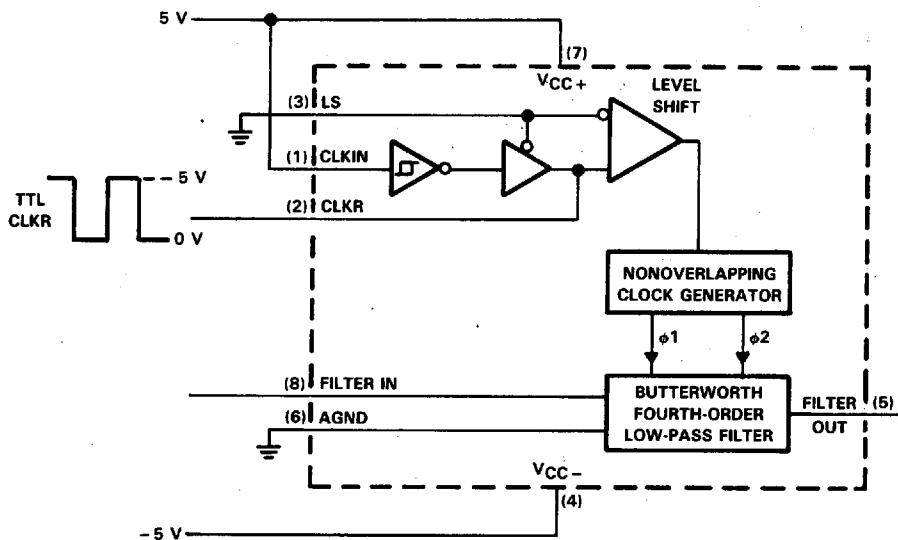


FIGURE 4. TTL-CLOCK-DRIVEN, DUAL-SUPPLY OPERATION

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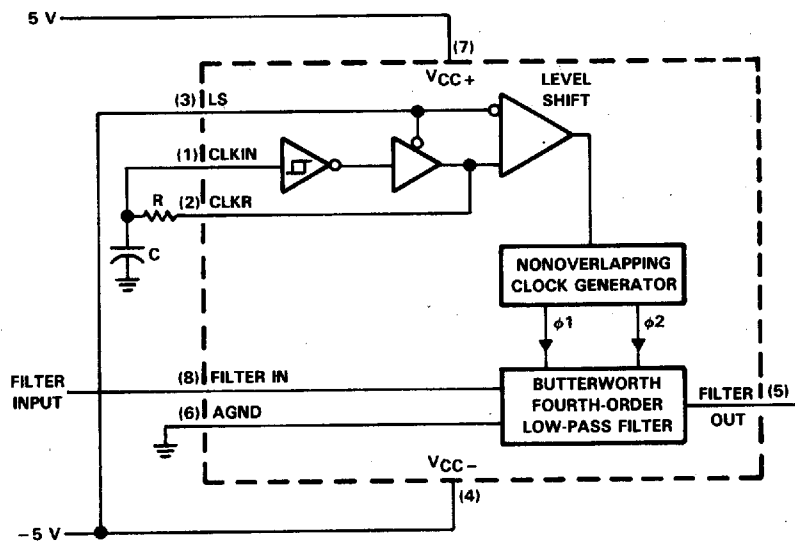
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**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

## TYPICAL APPLICATION DATA

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$$f_{\text{clock}} = \frac{1}{RC \times \ln \left[ \left( \frac{V_{CC} - V_{T-}}{V_{CC} - V_{T+}} \right) \left( \frac{V_{T+}}{V_{T-}} \right) \right]}$$

For  $V_{CC} = 10 \text{ V}$ ,

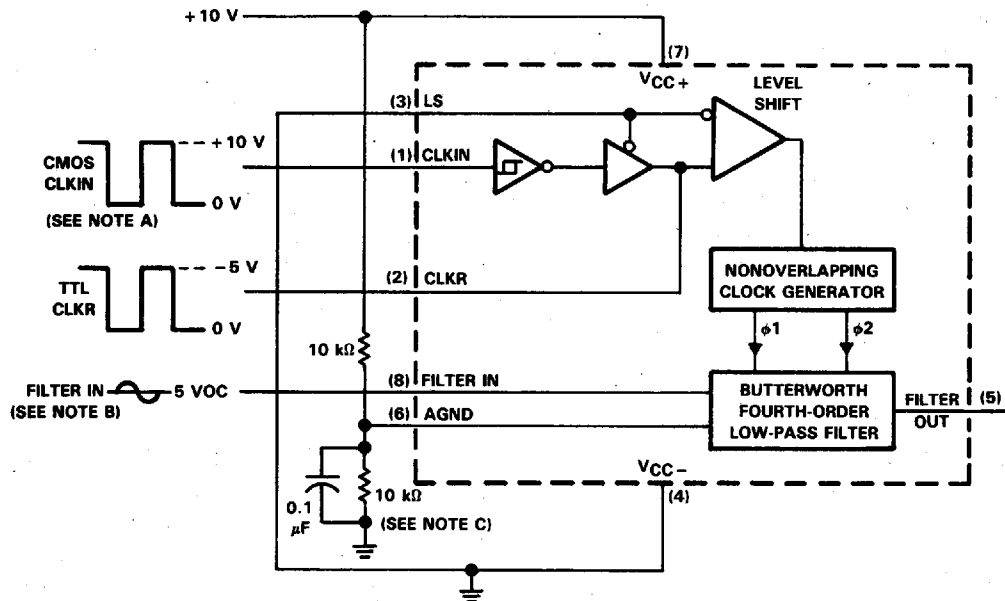
$$f_{\text{clock}} = \frac{1}{1.69 RC}$$

FIGURE 5. SELF-CLOCKING THROUGH SCHMITT-TRIGGER OSCILLATOR, DUAL-SUPPLY OPERATION

**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

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## TYPICAL APPLICATION DATA



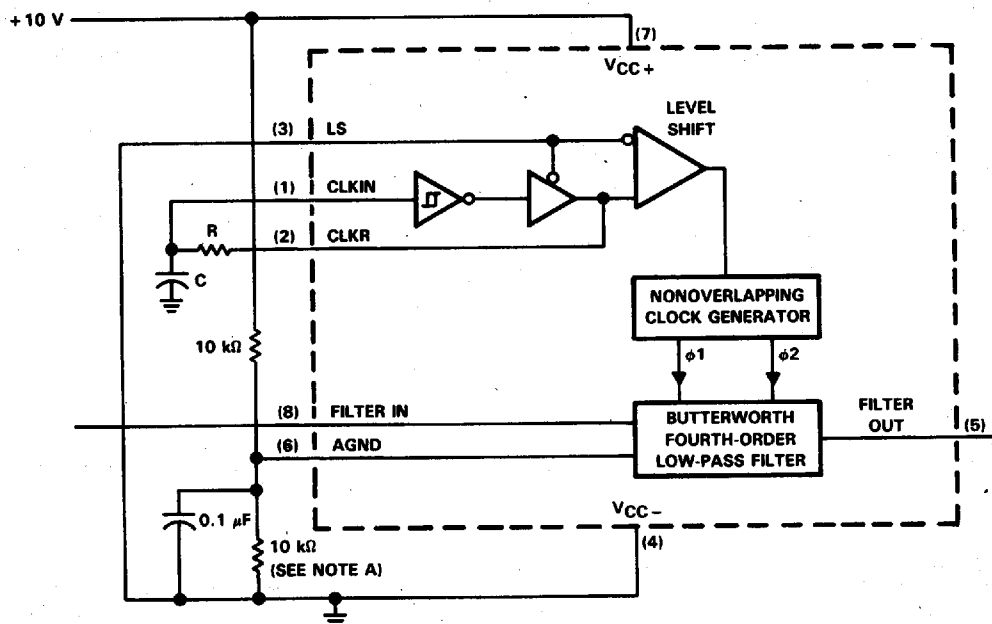
- NOTES: A. The external clock used must be of CMOS level because the clock is input to a CMOS Schmitt trigger.  
 B. The Filter input signal should be dc-biased to mid-supply or ac-coupled to the terminal.  
 C. The AGND terminal must be biased to mid-supply.

**FIGURE 6. EXTERNAL-CLOCK-DRIVEN SINGLE-SUPPLY OPERATION**

**TLC04/MF4A-50, TLC14/MF4A-100**  
**BUTTERWORTH FOURTH-ORDER LOW-PASS**  
**SWITCHED-CAPACITOR FILTERS**

## TYPICAL APPLICATION DATA

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$$f_{\text{clock}} = \frac{1}{RC \times \ln \left[ \left( \frac{V_{CC} - V_{T-}}{V_{CC} - V_{T+}} \right) \left( \frac{V_{T+}}{V_{T-}} \right) \right]}$$

For  $V_{CC} = 10 \text{ V}$ ,

$$f_{\text{clock}} = \frac{1}{1.69 RC}$$

NOTE A: The AGND terminal must be biased to mid-supply.

FIGURE 7. SELF-CLOCKING THROUGH SCHMITT-TRIGGER OSCILLATOR, SINGLE-SUPPLY OPERATION

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## TYPICAL APPLICATION DATA

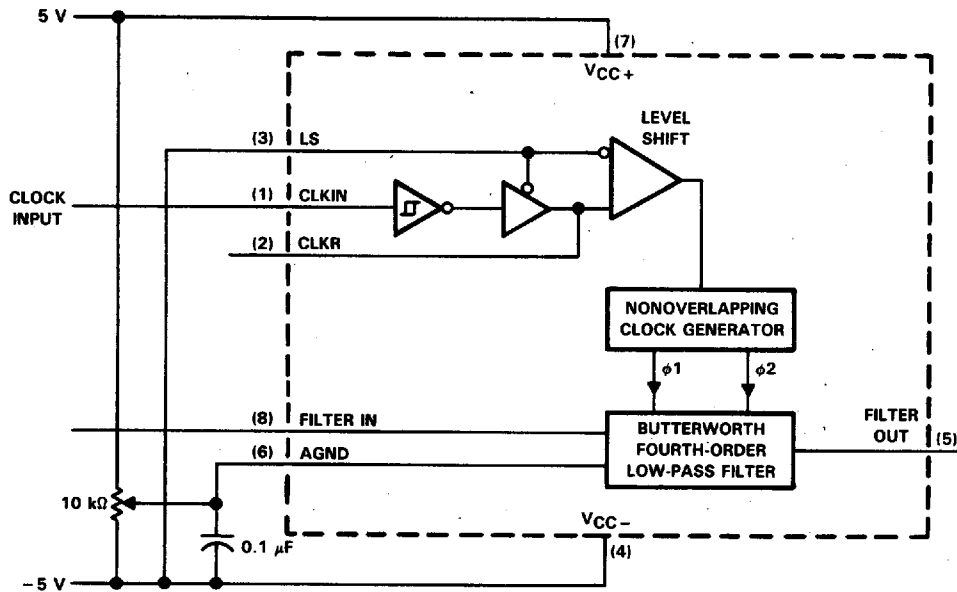


FIGURE 8. DC OFFSET ADJUSTMENT

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