A-3. Wzmacniacz Operacyjny - parametryzacja i zastosowanie

wersja 03’2022

1. Zakres ćwiczenia

Wyznaczenie stałoprądowych funkcji przenoszenia, amplitudowych charakterystyk częstotliwościowych oraz parametrów czasowych dla przykładowych konfiguracji:

1. wtórnika napięciowego,
2. wzmacniacza nieodwracającego o wzmocnieniu +11V/V,
3. wzmacniacza odwracającego o wzmocnieniu -10V/V,
4. wzmacniacza odwracającego o wzmocnieniu -100V/V,
5. wzmacniacza odejmującego o wzmocnieniu +10V/V,
6. wzmacniacza sumującego (wzm -10V/V jednego wejścia, wzm. -2V/V drugiego wejścia).

Przykładowe wykorzystanie wzmacniacza operacyjnego w układach nieliniowych zaprezentowane zostanie na przykładzie konfiguracji:

1. generatora funkcyjnego,
2. wzmacniacza logarytmicznego.

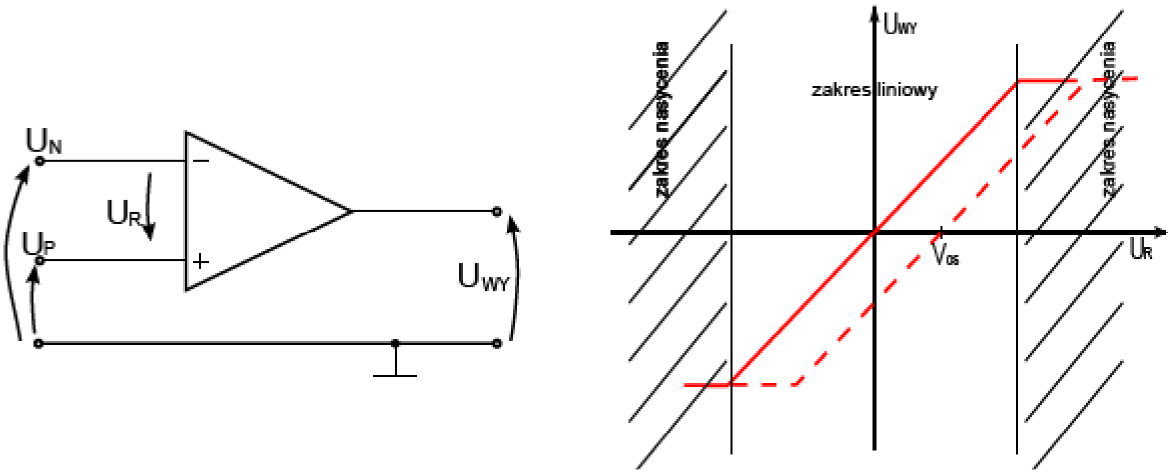
2. Wstęp teoretyczny

2.1 Podstawowe parametry wzmacniaczy operacyjnych

Wzmacniacz operacyjny jest elektronicznym elementem aktywnym z symetrycznym wejściem różnicowym oraz niesymetrycznym wyjściem. Symbol wzmacniacza operacyjnego przedstawiony jest na rysunku 1. Wejście oznaczone symbolem ”-” jest wejściem odwracającym, zaś wejście oznaczone symbolem ”+” jest wejściem nieodwracającym fazę napięcia wyjściowego względem wejściowego. Wzmacniacze operacyjne charakteryzują się dużym wzmocnieniem w otwartej pętli oraz przeznaczone są do pracy z ujemnym sprzężeniem zwrotnym, które stabilizuje ich pracę, zwiększa zakres dynamiczny, poprawia liniowość i poszerza pasmo przenoszenia. Podstawowe parametry idealnego wzmacniacza operacyjnego zebrane są w tabeli 2.1.

W celu oceny na ile dany wzmacniacz operacyjny jest bliski idealnemu, określa się kilka podstawowych parametrów:

1. **Wzmocnienie różnicowe k_{UR},** zwane też wzmocnieniem w otwartej pętli (*ang. open loop gain*), definiowane jako stosunek zmiany napięcia wyjściowego do wywołującej ją zmiany różnicowego napięcia wejściowego: $k_{UR} = \frac{\partial U_{WY}}{\partial U_R}$ dla zakresu nienasycenia wzmacniacza. Na rysunku 1 pokazana jest charakterystyka przenoszenia dla wzmacniacza idealnego (linia ciągła) i rzeczywistego (linia przerywana). Nachylenie charakterystyki w zakresie liniowym odpowiada wzmocnieniu różnicowemu. Typowy liniowy zakres zmian napięcia wyjściowego, zależy od konfiguracji układowej, napięć zasilających i wewnętrznej architektury samego wzmacniacza operacyjnego.



Rysunek 1. Symbol graficzny wzmacniacza operacyjnego i jego charakterystyka przenoszenia

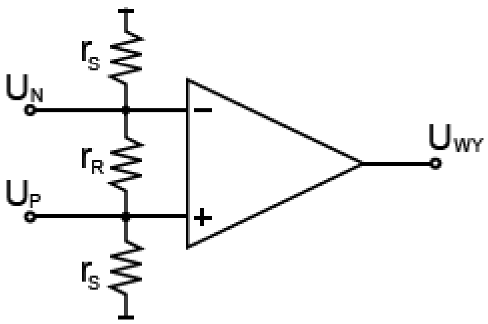
2. **Wejściowe napięcie niezrównoważenia *Vos*** - jest to napięcie różnicowe jakie należy przyłożyć na wejściu wzmacniacza rzeczywistego, aby na jego wyjściu uzyskać napięcie równe zeru (patrz rys.1). Typowo jest ono rzędu kilku μV do kilku mV i w zależności od zastosowań można je pominąć lub skompensować do zera.

3. **Temperaturowy dryf wejściowego napięcia niezrównoważenia** - definiowany jest jako stosunek zmiany wejściowego napięcia niezrównoważenia do wywołującej ja zmiany temperatury. Typowe wartości tego współczynnika są rzędu kilku do kilkudziesięciu $\mu V/^oC$.

4. **Wzmocnienie sygnału wspólnego k_{US}**- podając na oba wejścia wzmacniacza identyczny sygnał (tzw. sygnał wspólny U_S) w przypadku wzmacniacza idealnego spodziewamy się, że napięcie wyjściowe będzie równe zeru. Dla wzmacniaczy rzeczywistych obserwujemy różne od zera napięcie wyjściowe, co oznacza niezerowe wzmocnienie sygnału wspólnego: $k_{US} = \dfrac{\partial U_{WY}}{\partial U_S}$.

Właściwość tą opisuje współczynnik tłumienia sygnału wspólnego *CMRR* (*ang. common mode rejection ratio*), definiowany jako stosunek wzmocnienia różnicowego do wzmocnienia sygnału wspólnego: $CMRR = \frac{k_{UR}}{k_{US}}$, gdzie k_{UR} - wzmocnienie różnicowe, k_{US} – wzmocnienie sygnału wspólnego. Widzimy stąd, że dla wzmacniacza idealnego oczekujemy $CMRR \rightarrow \infty$. W rzeczywistych wzmacniaczach operacyjnych *CMRR* jest rzędu 80 - 120 dB.

5. **Współczynnik tłumienia zakłóceń zasilania *PSRR*** (*ang. power supply rejection ratio*) - współczynnik określający odporność wzmacniacza na zmiany napięć zasilających, definiowany jako stosunek zmiany napięcia niezrównoważenia do zmiany napięcia zasilania.



Rysunek 2: Schemat zastępczy wzmacniacza operacyjnego z uwzględnieniem rezystancji wejściowych.

6. **Rezystancja wejściowa**: na rys.2 przedstawiony jest schemat zastępczy wzmacniacza operacyjnego z uwzględnieniem wejściowej rezystancji różnicowej r_R (mierzonej między końcówkami wejściowymi wzmacniacza z otwartą pętlą) oraz wspólnej r_S (mierzonej między jednym z wejść a masa).

7. Do wejść wzmacniacza operacyjnego wpływają niezerowe **prądy polaryzujące** jego stopień wejściowy. W zależności od technologii wzmacniacza wartości tych prądów wahają się w granicach od kilku *fA* do kilku *nA*, a w przypadku szybkich wzmacniaczy *1-2 μA*. Wejściowe prądy polaryzujące są przyczyną błędów wzmacniacza, gdyż mimo braku napięcia wejściowego powodują zmiany napięcia na wyjściu. Różnica wejściowych prądów polaryzujących jest nazywana **wejściowym prądem niezrównoważenia *Ios*.**

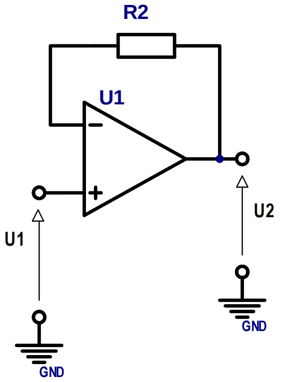
W poniższej tabelce, w ramach podsumowania, zestawione są wybrane parametry wzmacniacza operacyjnego idealnego i rzeczywistego:

Tabela 1: Wybrane parametry wzmacniacza idealnego i rzeczywistego.

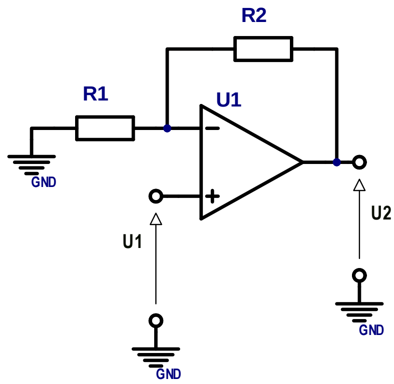
Wybrane parametry	Idealny wzm. op.	Rzeczywisty wzm. op.
wzmocnienie różnicowe	∞	10^5 - 10^7
pasmo przenoszenia	od 0 do ∞	kilka MHz
napięcie niezrównoważenia	0	kilka μV – Mv
CMRR	∞	80 – 120 dB
PSRR	∞	50- 100 dB
rezystancja wejściowa	∞	kilka MΩ
rezystancja wyjściowa	0	kilkadziesiąt do kilkaset Ω
prąd polaryzujący	0	kilka fA - nA

2.2 Podstawowe konfiguracje pracy wzmacniaczy operacyjnych w układach liniowych

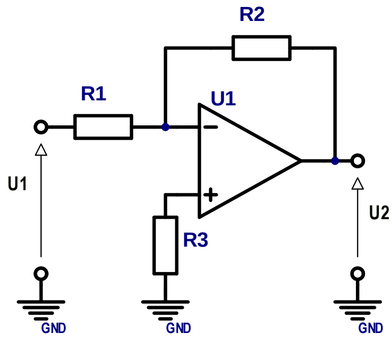
2.2.1 Wtórnik napięciowy



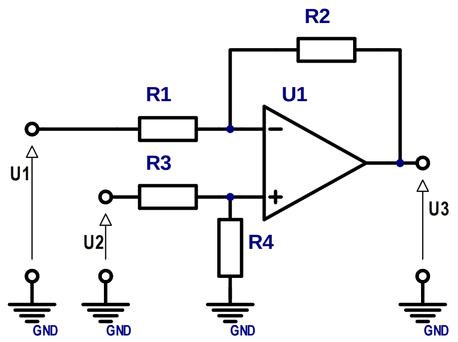
2.2.2 Wzmacniacz nieodwracający



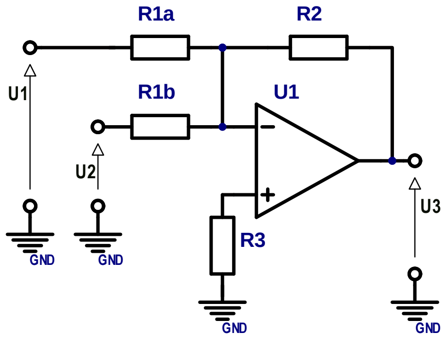
2.2.3 Wzmacniacz odwracający



2.2.4 Wzmacniacz odejmujący

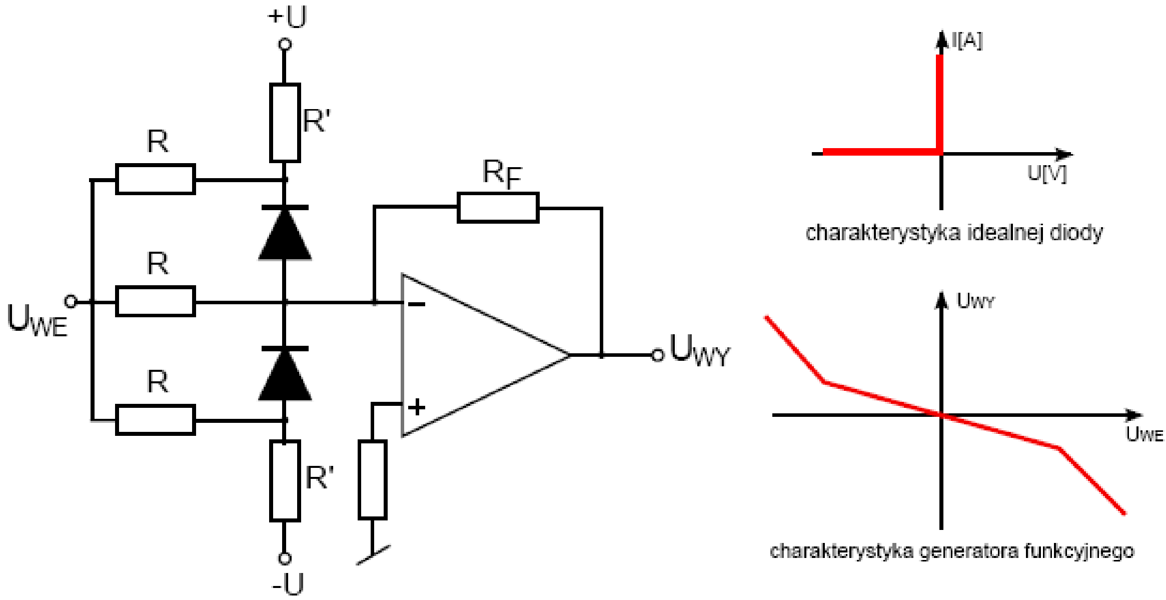


2.2.5 Wzmacniacz sumujący (z odwróceniem)



2.3 Przykładowe wykorzystanie wzmacniaczy operacyjnych w układach nieliniowych

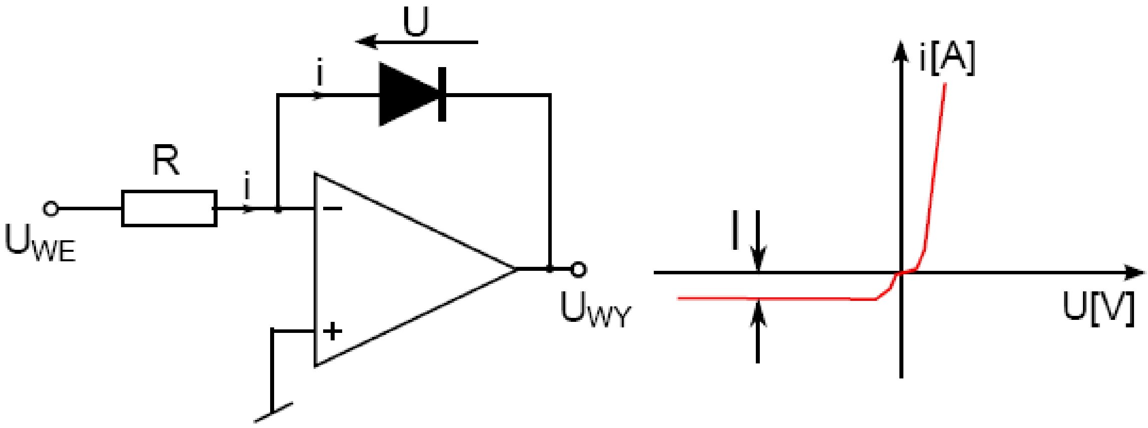
2.3.1 Generator funkcyjny



Rysunek 3. Generator funkcyjny i jego charakterystyka.

Dla U_{WE} = *0* diody są odcięte napięciem $\left|\frac{UR}{R+R'}\right|$ i nachylenie charakterystyki wyjściowo - wejściowej wynosi $-\frac{R_F}{R}$. Jeśli jedna z diod zacznie przewodzić, to nachylenie wzrośnie dwukrotnie co do wartości bezwzględnej, bowiem $\frac{dU_{WY}}{dU_{WE}} = \frac{R_F}{R \| R}$. Zajdzie to w przypadku, gdy potencjał katody górnej diody zbliży się do zera po wartościach dodatnich, albo też gdy potencjał anody dolnej diody zbliży się do zera po wartościach ujemnych, to jest gdy $\left|\frac{U_{WE}}{R}\right| = \frac{U}{R'}$. Zakłada się tutaj idealną charakterystykę diod jako zaworów.

2.3.2 Wzmacniacz logarytmiczny



Rysunek 4. Wzmacniacz logarytmiczny i charakterystyka diody.

Zasada działania wzmacniacza logarytmicznego opiera się na nieliniowej charakterystyce prądowo-napięciowej diody, tutaj spolaryzowanej w kierunku przewodzenia: $i = I_S\left(e^{\frac{U}{\eta U_T}} - 1\right) \approx I_S e^{\frac{-U_{WY}}{\eta U_T}}$ (dla $U > 4U_T$), gdzie:

$U_T = \frac{kT}{q}$ (przy 20°C $U_T = 25mV$),

k- stała Boltzmanna
T -temperatura w [K]
q – ładunek elektronu w [C]
η - czynnik skalujący z zakresu 1 - 2

3. Uwagi do ćwiczenia

1. Układy są badane przy zastosowaniu:
    a) regulowanego źródła napięcia stałego do wyznaczania charakterystyk przejściowych,
    b) generatora sinusoidalnego w celu wyznaczenia charakterystyk częstotliwościowych,
    c) generatora przebiegu prostokątnego i trójkątnego w celu zaobserwowania odpowiedzi na skok jednostkowy i napięcie narastające liniowo.
2. Wielkości zmierzone należy porównać z wyliczonymi teoretycznie na podstawie schematów lub z zamieszczonymi w nocie katalogowej producenta.
3. Charakterystyki częstotliwościowe rysować w typowym układzie współrzędnych, tj. wzmocnienie w liniowej skali wyrażone w jednostkach [dB], częstotliwość w skali logarytmicznej.

4. Program ćwiczenia

Program ćwiczenia i sposób opracowania sprawozdań zgodnie z wytycznymi prowadzącego.

Literatura

1. Kulka Z., Nadachowski M.: *Liniowe układy scalone i ich zastosowanie*.

2. Tietze U., Schenk Ch.: *Układy półprzewodnikowe.*
3. Zumbahlen H.: *Linear Circuit Design Handbook.*
4. Low Power, Precision Rail-to-Rail Output Operational Amplifier AD8622 – data sheet: link AD8622
5. Dual Low-Power JFET-Input General-Purpose Operational Amplifier TL062 – data sheet: link TL062
6. Wide Bandwidth Dual JFET Input Operational Amplifier TL082 – data sheet: link TL082
7. Precision Operational Amplifiers OP07 - data sheet: link OP07
8. General-Purpose Operational Amplifiers µA741 – data sheet: link µA741
9. Low-Noise FET-Input Operational Amplifier: link TL071

Dodatek A:

Parametry katalogowe wzmacniacza operacyjnego OP07:

Precision Operational Amplifiers OP07 - data sheet: [link OP07]

OP07x Precision Operational Amplifiers

1 Features

- Low Noise
- No External Components Required
- Replace Chopper Amplifiers at a Lower Cost
- Wide Input-Voltage Range: 0 to ±14 V (Typ)
- Wide Supply-Voltage Range: ±3 V to ±18 V

2 Applications

- Wireless Base Station Control Circuits
- Optical Network Control Circuits
- Instrumentation
- Sensors and Controls
- Precision Filters

3 Description

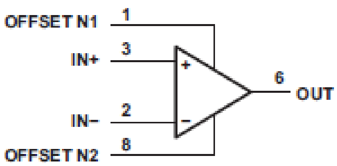
These devices offer low offset and long-term stability by means of a low-noise, chopperless, bipolar-input-transistor amplifier circuit. For most applications, external components are not required for offset nulling and frequency compensation. The true differential input, with a wide input-voltage range and outstanding common-mode rejection, provides maximum flexibility and performance in high-noise environments and in noninverting applications. Low bias currents and extremely high input impedances are maintained over the entire temperature range.

Device Information(1)

PART NUMBER	PACKAGE (PIN)	BODY SIZE
OP07x	SO (8)	6.20 mm × 5.30 mm
	SOIC (8)	4.90 mm × 3.91 mm
	PDIP (8)	9.81 mm × 6.35 mm

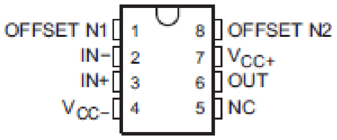
(1) For all available packages, see the orderable addendum at the end of the data sheet.

4 Simplified Schematic



6 Pin Functions

D OR P PACKAGE
(TOP VIEW)



NC – No internal connection

Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
IN+	3	I	Noninverting input
IN–	2	I	Inverting input
NC	5	—	Do not connect
OFFSET N1	1	I	External input offset voltage adjustment
OFFSET N2	8	I	External input offset voltage adjustment
OUT	6	O	Output
$V_{CC}+$	7	—	Positive supply
$V_{CC}-$	4	—	Negative supply

7 Specifications

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

		MIN	MAX	UNIT
V_{CC+} (2)	Supply voltage	0	22	V
V_{CC-} (2)	Supply voltage	–22	0	V
	Differential input voltage (3)		±30	V
V_I	Input voltage range (either input) (4)		±22	V
	Duration of output short circuit (5)	Unlimited		
T_J	Operating virtual-junction temperature		150	°C
	Lead temperature 1.6 mm (1/16 in) from case for 10 s		260	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values, unless otherwise noted, are with respect to the midpoint between V_{CC+} and V_{CC-}.
(3) Differential voltages are at IN+ with respect to IN−.
(4) The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 V, whichever is less.
(5) The output may be shorted to ground or to either power supply.

7.2 Handling Ratings

PARAMETER	DEFINITION		MIN	MAX	UNIT
T_{STG}	Storage temperature range		–65	150	°C
$V_{(ESD)}$	Electrostatic Discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins (1)	0	1000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins (2)	0	1000	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

			MIN	MAX	UNIT
V_{CC+}	Supply voltage		3	18	V
V_{CC-}	Supply voltage		–3	–18	V
V_{IC}	Common-mode input voltage	$V_{CC\pm} = \pm 15$ V	–13	13	V
T_A	Operating free-air temperature		0	70	°C

7.4 Thermal Information

THERMAL METRIC (1)		D	P	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	97	85	°C/W

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report (SPRA953).

7.5 Electrical Characteristics

at specified free-air temperature, $V_{CC\pm} = \pm 15$ V (unless otherwise noted)(1)

PARAMETER		TEST CONDITIONS		T_A(2)	OP07C			OP07D			UNIT
					MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	$V_O = 0$ V	$R_S = 50\ \Omega$	25°C		60				150	µV
				0°C to 70°C		85				250	
α_{VIO}	Temperature coefficient of input offset voltage	$V_O = 0$ V	$R_S = 50\ \Omega$	0°C to 70°C		0.5				2.5	µV/°C
	Long-term drift of input offset voltage	See				0.4					µV/mo
	Offset adjustment range	$R_S = 20$ kΩ,	See Figure 2	25°C		±4					mV
I_{IO}	Input offset current			25°C		0.8				6	nA
				0°C to 70°C		1.6				8	
α_{IIO}	Temperature coefficient of input offset current			0°C to 70°C		12				50	pA/°C
I_{IB}	Input bias current			25°C		±1.8				±12	nA
				0°C to 70°C		±2.2				±14	
α_{IIB}	Temperature coefficient of input bias current			0°C to 70°C		18				50	pA/°C
V_{ICR}	Common-mode input voltage range			25°C	±13	±14		±13	±14		V
				0°C to 70°C	±13	±13.5		±13	±13.5		
V_{OM}	Peak output voltage	$R_L \geq 10$ kΩ		25°C	±12	±13		±12	±13		V
		$R_L \geq 2$ kΩ			±11.5	±12.8		±11.5	±12.8		
		$R_L \geq 1$ kΩ				±12			±12		
		$R_L \geq 2$ kΩ		0°C to 70°C	±11	±12.6		±11	±12.6		
A_{VD}	Large-signal differential voltage amplification	$V_{CC} = 15$ V, $V_O = 1.4$ V to 11.4 V, $R_L \geq 500$ kΩ		25°C	100	400			400		V/mV
		$V_O = \pm 10$, $R_L = 2$ kΩ		25°C	120	400		120	400		
				0°C to 70°C	100	400		100	400		
B_1	Unity-gain bandwidth			25°C	0.4	0.6		0.4	0.6		MHz
r_i	Input resistance			25°C	8	33		7	31		MΩ
CMRR	Common-mode rejection ratio	$V_{IC} = \pm 13$ V, $R_S = 50\ \Omega$		25°C	100	120		94	110		dB
				0°C to 70°C	97	120		94	106		
k_{SVS}	Supply-voltage sensitivity ($\Delta V_{IO}/\Delta V_{CC}$)	$V_{CC\pm} = \pm 3$ V to ±18 V, $R_S = 50\ \Omega$		25°C		7	32		7	32	µV/V
				0°C to 70°C		10	51		10	51	
P_D	Power dissipation	$V_O = 0$, No load		25°C		80	150		80	150	mW
		$V_{CC\pm} = \pm 3$ V, $V_O = 0$, No load				4	8		4	8	

(1) Because long-term drift cannot be measured on the individual devices prior to shipment, this specification is not intended to be a warranty. It is an engineering estimate of the averaged trend line of drift versus time over extended periods after the first 30 days of operation.

(2) All characteristics are measured with zero common-mode input voltage, unless otherwise specified.

7.6 Operating Characteristics

at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS[1]	OP07C TYP	OP07D TYP	UNIT
V_n	Input offset voltage	f = 10 Hz	10.5	10.5	nV/√Hz
		f = 100 Hz	10.2	10.3	
		f = 1 kHz	9.8	9.8	
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	f = 0.1 Hz to 10 Hz	0.38	0.38	μV
I_n	Equivalent input noise current	f = 10 Hz	0.35	0.35	nV/√Hz
		f = 100 Hz	0.15	0.15	
		f = 1 kHz	0.13	0.13	
$I_{N(PP)}$	Peak-to-peak equivalent input noise current	f = 0.1 Hz to 10 Hz	15	15	pA
SR	Slew rate	$R_L \geq 2$ kΩ	0.3	0.3	V/μs

(1) All characteristics are measured under open-loop conditions, with zero common-mode input voltage, unless otherwise noted.

8 Typical Characteristics

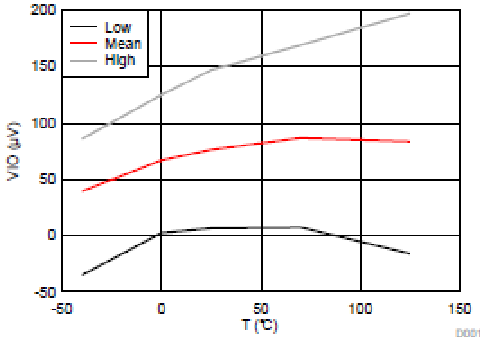


Figure 1. Input-Offset Voltage vs. Temperature

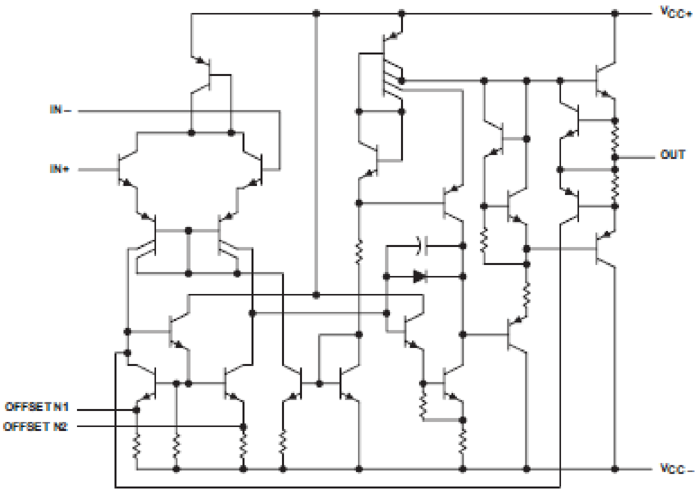
9 Detailed Description

9.1 Overview

These devices offer low offset and long-term stability by means of a low-noise, chopperless, bipolar-input-transistor amplifier circuit. For most applications, external components are not required for offset nulling and frequency compensation. The true differential input, with a wide input-voltage range and outstanding common-mode rejection, provides maximum flexibility and performance in high-noise environments and in noninverting applications. Low bias currents and extremely high input impedances are maintained over the entire temperature range.

These devices are characterized for operation from 0°C to 70°C.

9.2 Functional Block Diagram



Component Count	
Transistors	22
Resistors	11
Diode	1
Capacitor	1

9.3 Feature Description

9.3.1 Offset-Voltage Null Capability

The input offset voltage of operational amplifiers (op amps) arises from unavoidable mismatches in the differential input stage of the op-amp circuit caused by mismatched transistor pairs, collector currents, current-gain betas (β), collector or emitter resistors, et cetera. The input offset pins allow the designer to adjust for these mismatches by external circuitry. See the *Application and Implementation* section for more details on design techniques.

9.3.2 Slew Rate

The slew rate is the rate at which an operational amplifier can change its output when there is a change on the input. The OP07 has a 0.3-V/µs slew rate.

9.4 Device Functional Modes

The OP07 is powered on when the supply is connected. It can be operated as a single supply operational amplifier or dual supply amplifier depending on the application.

10 Application and Implementation

10.1 General Application

The input offset voltage of operational amplifiers (op amps) arises from unavoidable mismatches in the differential input stage of the op-amp circuit caused by mismatched transistor pairs, collector currents, current-gain betas (β), collector or emitter resistors, etc. The input offset pins allow the designer to adjust for these mismatches by external circuitry. These input mismatches can be adjusted by putting resistors or a potentiometer between the inputs as shown in Figure 2. A potentiometer can be used to fine tune the circuit during testing or for applications which require precision offset control. More information about designing using the input-offset pins, see Nulling Input *Offset Voltage of Operational Amplifiers* (SLOA045).

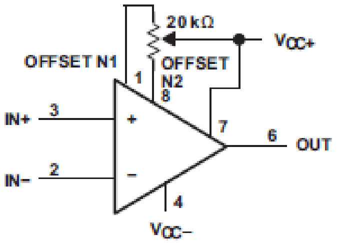


Figure 2. Input Offset-Voltage Null Circuit

10.2 Typical Application

The voltage follower configuration of the operational amplifier is used for applications where a weak signal is used to drive a relatively high current load. This circuit is also called a buffer amplifier or unity gain amplifier. The inputs of an operational amplifier have a very high resistance which puts a negligible current load on the voltage source. The output resistance of the operational amplifier is almost negligible, so it can provide as much current as necessary to the output load.

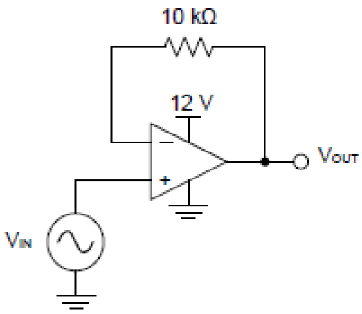


Figure 3. Voltage Follower Schematic

Typical Application (continued)

10.2.1 Design Requirements

- Output range of 2 V to 11 V
- Input range of 2 V to 11 V

10.2.2 Detailed Design Procedure

10.2.2.1 Output Voltage Swing

The output voltage of an operational amplifier is limited by its internal circuitry to some level below the supply rails. For this amplifier, the output voltage swing is within ±12 V, which accommodates the input and output voltage requirements.

10.2.2.2 Supply and Input Voltage

For correct operation of the amplifier, neither input must be higher than the recommended positive supply rail voltage or lower than the recommended negative supply rail voltage. The chosen amplifier must be able to operate at the supply voltage that accommodates the inputs. Because the input for this application goes up to 11 V, the supply voltage must be 12 V. Using a negative voltage on the lower rail, rather than ground, allows the amplifier to maintain linearity for inputs below 2 V.

10.2.3 Application Curves for Output Characteristics

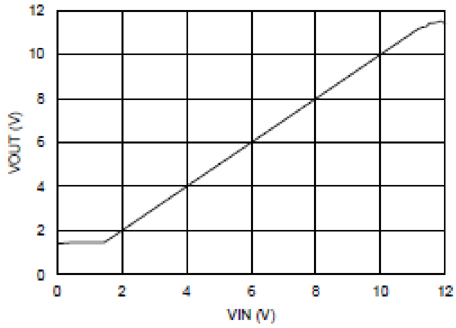


Figure 4. Output Voltage vs Input Voltage

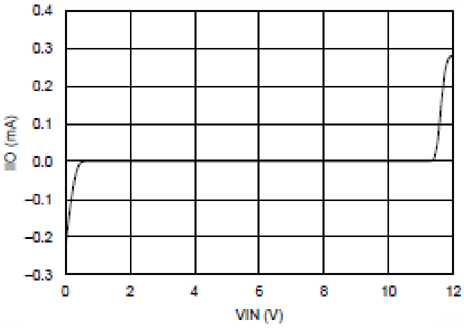


Figure 5. Current Drawn by the Input of the Voltage Follower (I_{IO}) vs the Input Voltage

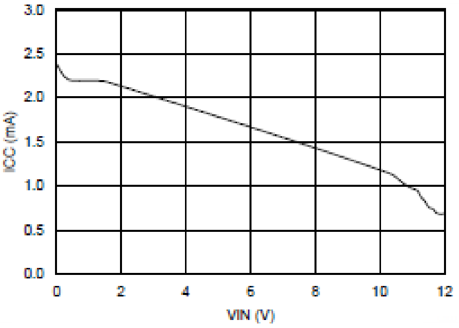


Figure 6. Current Drawn from Supply (I_{CC}) vs the Input Voltage

Parametry katalogowe wzmacniacza operacyjnego LM741 (μA741):

(http://www.ti.com/lit/ds/symlink/lm741.pdf)

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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.

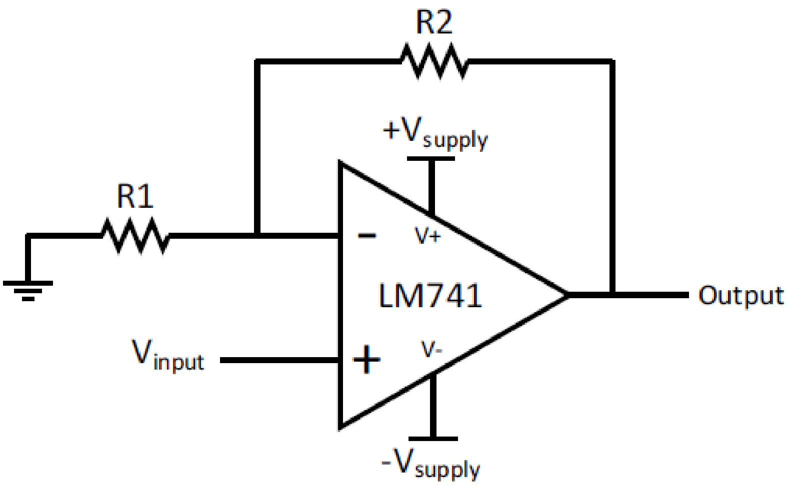
The LM741C is identical to the LM741 and LM741A except that the LM741C has their performance ensured over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

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

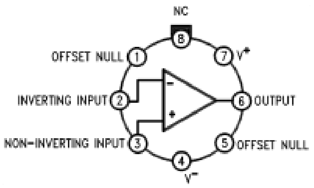
(1) For all available packages, see the orderable addendum at the end of the data sheet.

Typical Application



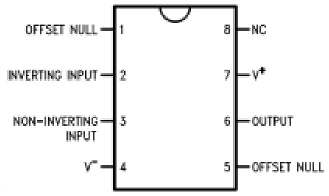
5 Pin Configuration and Functions

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 OFFSET NULL	1, 5	I	Offset null pin used to eliminate the offset voltage and balance the input voltages.
OUTPUT	6	O	Amplified signal output
V+	7	I	Positive supply voltage
V–	4	I	Negative supply voltage

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1][2][3]

		MIN	MAX	UNIT
Supply voltage	LM741, LM741A		±22	V
	LM741C		±18	V
Power dissipation [4]			500	mW
Differential input voltage			±30	V
Input voltage [5]			±15	V
Output short circuit duration		Continuous		
Operating temperature	LM741, LM741A	–50	125	°C
	LM741C	0	70	°C
Junction temperature	LM741, LM741A		150	°C
	LM741C		100	°C
Soldering information	PDIP package (10 seconds)		260	°C
	CDIP or TO-99 package (10 seconds)		300	°C
Storage temperature, T_{stg}		–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) For military specifications see RETS741X for LM741 and RETS741AX for LM741A.
(3) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(4) For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_J max. (listed under "Absolute Maximum Ratings"). $T_J = T_A + (\theta_{JA} P_D)$.
(5) For supply voltages less than ±15 V, the absolute maximum input voltage is equal to the supply voltage.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	±400	V

(1) Level listed above is the passing level per ANSI, ESDA, and JEDEC JS-001. JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
Supply voltage (VDD-GND)	LM741, LM741A	±10	±15	±22	V
	LM741C	±10	±15	±18	V
Temperature	LM741, LM741A	–55		125	°C
	LM741C	0		70	°C

6.4 Thermal Information

THERMAL METRIC[1]		LM741			UNIT
		LMC (TO-99)	NAB (CDIP)	P (PDIP)	
		8 PINS	8 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	170	100	100	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	25	—	—	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics, LM741[1]

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage		$R_S \leq 10$ kΩ	T_A = 25°C		1	5	mV
			$T_{AMIN} \leq T_A \leq T_{AMAX}$			6	mV
Input offset voltage adjustment range		T_A = 25°C, V_S = ±20 V			±15		mV
Input offset current		T_A = 25°C			20	200	nA
		$T_{AMIN} \leq T_A \leq T_{AMAX}$			85	500	
Input bias current		T_A = 25°C			80	500	nA
		$T_{AMIN} \leq T_A \leq T_{AMAX}$				1.5	µA
Input resistance		T_A = 25°C, V_S = ±20 V		0.3	2		MΩ
Input voltage range		$T_{AMIN} \leq T_A \leq T_{AMAX}$		±12	±13		V
Large signal voltage gain		V_S = ±15 V, V_O = ±10 V, $R_L \geq 2$ kΩ	T_A = 25°C	50	200		V/mV
			$T_{AMIN} \leq T_A \leq T_{AMAX}$	25			
Output voltage swing		V_S = ±15 V	$R_L \geq 10$ kΩ	±12	±14		V
			$R_L \geq 2$ kΩ	±10	±13		
Output short circuit current		T_A = 25°C			25		mA
Common-mode rejection ratio		$R_S \leq 10$ Ω, V_{CM} = ±12 V, $T_{AMIN} \leq T_A \leq T_{AMAX}$		80	95		dB
Supply voltage rejection ratio		V_S = ±20 V to V_S = ±5 V, $R_S \leq 10$ Ω, $T_{AMIN} \leq T_A \leq T_{AMAX}$		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 = ±15 V	T_A = 25°C		50	85	mW
			$T_A = T_{AMIN}$		60	100	
			$T_A = T_{AMAX}$		45	75	

(1) Unless otherwise specified, these specifications apply for V_S = ±15 V, −55°C ≤ T_A ≤ +125°C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0°C ≤ T_A ≤ +70°C.

6.6 Electrical Characteristics, LM741A[1]

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage	$R_S \leq 50$ Ω	T_A = 25°C		0.8	3	mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$			4	mV
Average input offset voltage drift					15	µV/°C
Input offset voltage adjustment range	T_A = 25°C, V_S = ±20 V		±10			mV
Input offset current	T_A = 25°C			3	30	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				70	
Average input offset current drift					0.5	nA/°C
Input bias current	T_A = 25°C			30	80	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				0.21	µA
Input resistance	T_A = 25°C, V_S = ±20 V		1	6		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, V_S = ±20 V		0.5			
Large signal voltage gain	V_S = ±20 V, V_O = ±15 V, $R_L \geq 2$ kΩ	T_A = 25°C	50			V/mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$	32			
	V_S = ±5 V, V_O = ±2 V, $R_L \geq 2$ kΩ, $T_{AMIN} \leq T_A \leq T_{AMAX}$		10			

(1) Unless otherwise specified, these specifications apply for V_S = ±15 V, −55°C ≤ T_A ≤ +125°C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0°C ≤ T_A ≤ +70°C.

Electrical Characteristics, LM741A(1) (continued)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Output voltage swing		V_S = ±20 V	R_L ≥ 10 kΩ	±16			V
			R_L ≥ 2 kΩ	±15			
Output short circuit current		T_A = 25°C		10	25	35	mA
		$T_{AMIN} \le T_A \le T_{AMAX}$		10		40	
Common-mode rejection ratio		R_S ≤ 50 Ω, V_{CM} = ±12 V, $T_{AMIN} \le T_A \le T_{AMAX}$		80	95		dB
Supply voltage rejection ratio		V_S = ±20 V to V_S = ±5 V, R_S ≤ 50 Ω, $T_{AMIN} \le T_A \le T_{AMAX}$		86	96		dB
Transient response	Rise time	T_A = 25°C, unity gain			0.25	0.8	μs
	Overshoot				6%	20%	
Bandwidth (2)		T_A = 25°C		0.437	1.5		MHz
Slew rate		T_A = 25°C, unity gain		0.3	0.7		V/μs
Power consumption		V_S = ±20 V	T_A = 25°C		80	150	mW
			$T_A = T_{AMIN}$			165	
			$T_A = T_{AMAX}$			135	

(2) Calculated value from: BW (MHz) = 0.35/Rise Time (μs).

6.7 Electrical Characteristics, LM741C(1)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage		R_S ≤ 10 kΩ	T_A = 25°C		2	6	mV
			$T_{AMIN} \le T_A \le T_{AMAX}$			7.5	mV
Input offset voltage adjustment range		T_A = 25°C, V_S = ±20 V			±15		mV
Input offset current		T_A = 25°C			20	200	nA
		$T_{AMIN} \le T_A \le T_{AMAX}$				300	
Input bias current		T_A = 25°C			80	500	nA
		$T_{AMIN} \le T_A \le T_{AMAX}$				0.8	μA
Input resistance		T_A = 25°C, V_S = ±20 V		0.3	2		MΩ
Input voltage range		T_A = 25°C		±12	±13		V
Large signal voltage gain		V_S = ±15 V, V_O = ±10 V, R_L ≥ 2 kΩ	T_A = 25°C	20	200		V/mV
			$T_{AMIN} \le T_A \le T_{AMAX}$	15			
Output voltage swing		V_S = ±15 V	R_L ≥ 10 kΩ	±12	±14		V
			R_L ≥ 2 kΩ	±10	±13		
Output short circuit current		T_A = 25°C			25		mA
Common-mode rejection ratio		R_S ≤ 10 kΩ, V_{CM} = ±12 V, $T_{AMIN} \le T_A \le T_{AMAX}$		70	90		dB
Supply voltage rejection ratio		V_S = ±20 V to V_S = ±5 V, R_S ≤ 10 Ω, $T_{AMIN} \le T_A \le T_{AMAX}$		77	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 = ±15 V, T_A = 25°C			50	85	mW

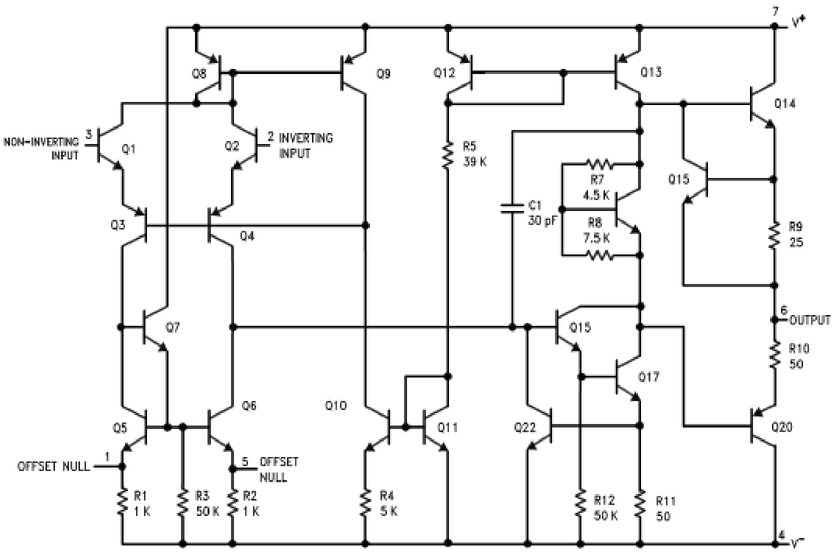
(1) Unless otherwise specified, these specifications apply for V_S = ±15 V, −55°C ≤ T_A ≤ +125°C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0°C ≤ T_A ≤ +70°C.

7 Detailed Description

7.1 Overview

The LM74 devices are general-purpose operational amplifiers which feature improved performance over industry standards like the LM709. It is intended for a wide range of analog applications. The high gain and wide range of operating voltage provide superior performance in integrator, summing amplifier, and general feedback applications. The LM741 can operate with a single or dual power supply voltage. The LM741 devices are direct, plug-in replacements for the 709C, LM201, MC1439, and 748 in most applications.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Overload Protection

The LM741 features overload protection circuitry on the input and output. This prevents possible circuit damage to the device.

7.3.2 Latch-up Prevention

The LM741 is designed so that there is no latch-up occurrence when the common-mode range is exceeded. This allows the device to function properly without having to power cycle the device.

7.3.3 Pin-to-Pin Capability

The LM741 is pin-to-pin direct replacements for the LM709C, LM201, MC1439, and LM748 in most applications. Direct replacement capabilities allows flexibility in design for replacing obsolete parts.

7.4 Device Functional Modes

7.4.1 Open-Loop Amplifier

The LM741 can be operated in an open-loop configuration. The magnitude of the open-loop gain is typically large thus for a small difference between the noninverting and inverting input terminals, the amplifier output will be driven near the supply voltage. Without negative feedback, the LM741 can act as a comparator. If the inverting input is held at 0 V, and the input voltage applied to the noninverting input is positive, the output will be positive. If the input voltage applied to the noninverting input is negative, the output will be negative.

7.4.2 Closed-Loop Amplifier

In a closed-loop configuration, negative feedback is used by applying a portion of the output voltage to the inverting input. Unlike the open-loop configuration, closed loop feedback reduces the gain of the circuit. The overall gain and response of the circuit is determined by the feedback network rather than the operational amplifier characteristics. The response of the operational amplifier circuit is characterized by the transfer function.

8 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.

8.1 Application Information

The LM741 is a general-purpose amplifier than can be used in a variety of applications and configurations. One common configuration is in a noninverting amplifier configuration. In this configuration, the output signal is in phase with the input (not inverted as in the inverting amplifier configuration), the input impedance of the amplifier is high, and the output impedance is low. The characteristics of the input and output impedance is beneficial for applications that require isolation between the input and output. No significant loading will occur from the previous stage before the amplifier. The gain of the system is set accordingly so the output signal is a factor larger than the input signal.

8.2 Typical Application

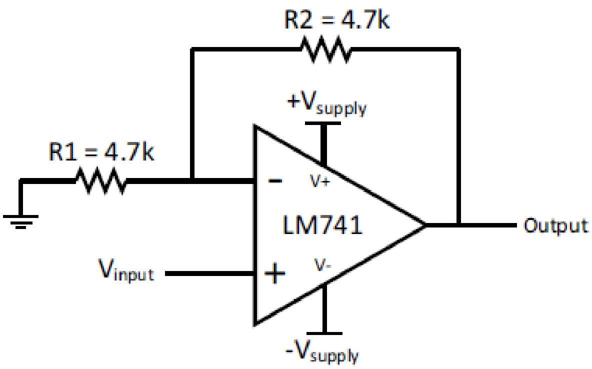


Figure 1. LM741 Noninverting Amplifier Circuit

8.2.1 Design Requirements

As shown in Figure 1, the signal is applied to the noninverting input of the LM741. The gain of the system is determined by the feedback resistor and input resistor connected to the inverting input. The gain can be calculated by Equation 1:

$$\text{Gain} = 1 + (R2/R1) \quad (1)$$

The gain is set to 2 for this application. R1 and R2 are 4.7-k resistors with 5% tolerance.

8.2.2 Detailed Design Procedure

The LM741 can be operated in either single supply or dual supply. This application is configured for dual supply with the supply rails at ±15 V. The input signal is connected to a function generator. A 1-Vpp, 10-kHz sine wave was used as the signal input. 5% tolerance resistors were used, but if the application requires an accurate gain response, use 1% tolerance resistors.

Typical Application (continued)

8.2.3 Application Curve

The waveforms in Figure 2 show the input and output signals of the LM741 non-inverting amplifier circuit. The blue waveform (top) shows the input signal, while the red waveform (bottom) shows the output signal. The input signal is 1.06 Vpp and the output signal is 1.94 Vpp. With the 4.7-kΩ resistors, the theoretical gain of the system is 2. Due to the 5% tolerance, the gain of the system including the tolerance is 1.992. The gain of the system when measured from the mean amplitude values on the oscilloscope was 1.83.

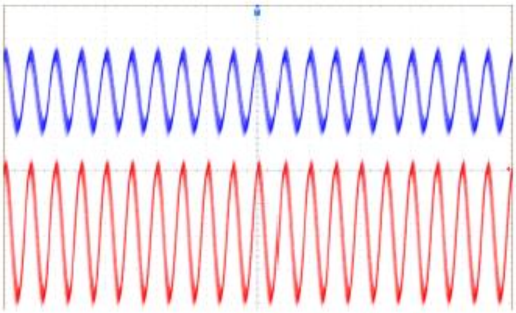
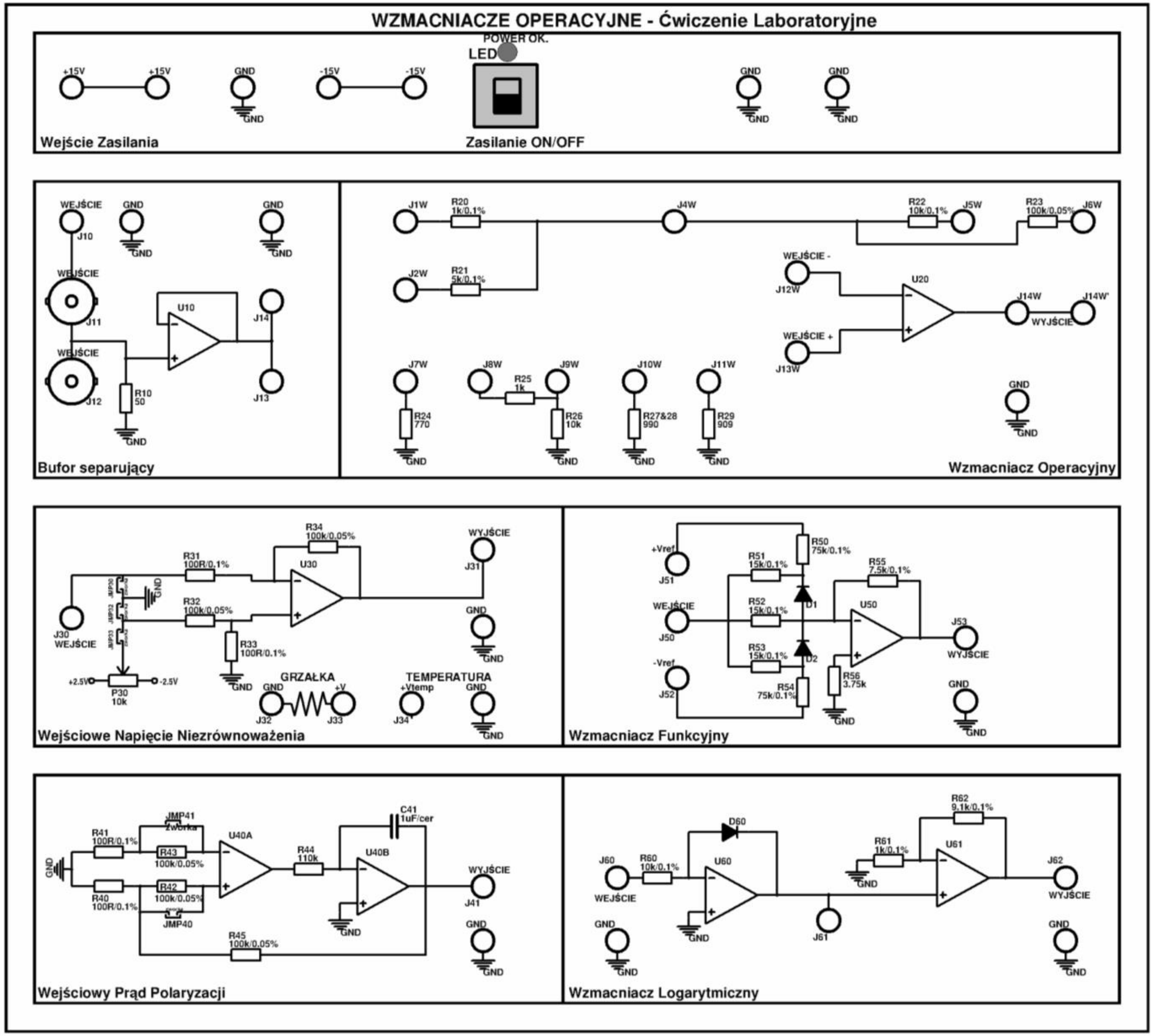


Figure 2. Waveforms for LM741 Noninverting Amplifier Circuit

9 Power Supply Recommendations

For proper operation, the power supplies must be properly decoupled. For decoupling the supply lines, a 0.1-µF capacitor is recommended and should be placed as close as possible to the LM741 power supply pins.

Dodatek C: Schemat funkcjonalny płytki pomiarowej (wersja 1)



Schemat funkcjonalny płytki pomiarowej (wersja 2):