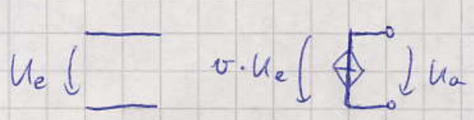
19.4.05

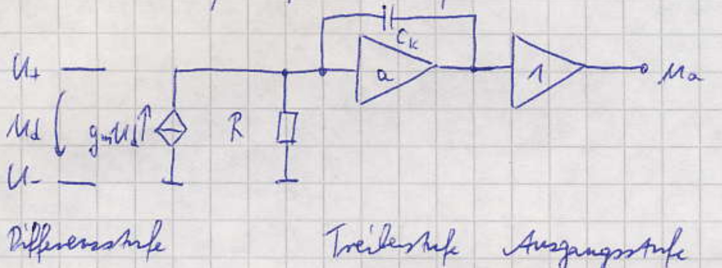
## 2.2. Spannungsgesteuerte Spannungsquellen



Anwendung:
- OPV
- Instrumentationsverstärker
- Isolationsverstärker
- Breitbandverstärker

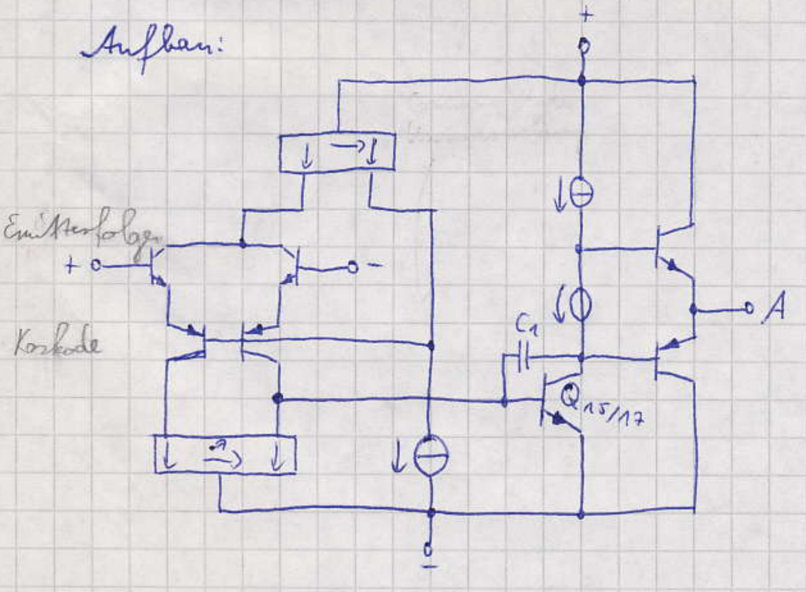
### 2.2.1. Operationsverstärker

#### 2.2.1.1. prinzipieller Aufbau



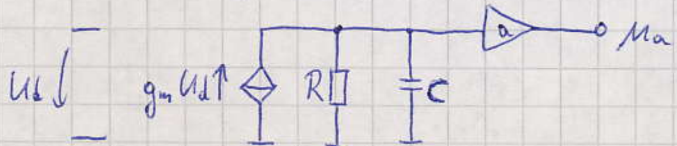
R: $r_e$ der Treiberstufe
$C_k$: Frequenzgangkompensation
-> Folie LM 741

Aufbau:



#### 2.2.1.2. Kleinsignalverhalten

Modell: (nur dominanter Pol)



$C \approx -a \cdot C_k$ (Millereffekt)

$$U_a = a \cdot g_m \left(R \parallel \frac{1}{sC}\right) \cdot U_d = \underbrace{a\, g_m R}_{v_0} \frac{1}{1+s\underbrace{CR}_{\tau}}$$

$v_0 \approx 10^4 \dots 10^6$
$\omega_g = \frac{1}{\tau} \approx 10 \dots 100\,\mathrm{Hz}$

## Electrical Characteristics (Note 5) (Continued)

**Note 3:** For operation at elevated temperatures, these devices must be derated based on thermal resistance, and $T_j$ max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

| Thermal Resistance | Cerdip (J) | DIP (N) | HO8 (H) | SO-8 (M) |
|---|---|---|---|---|
| $\theta_{jA}$ (Junction to Ambient) | 100°C/W | 100°C/W | 170°C/W | 195°C/W |
| $\theta_{jC}$ (Junction to Case) | N/A | N/A | 25°C/W | N/A |

**Note 4:** For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

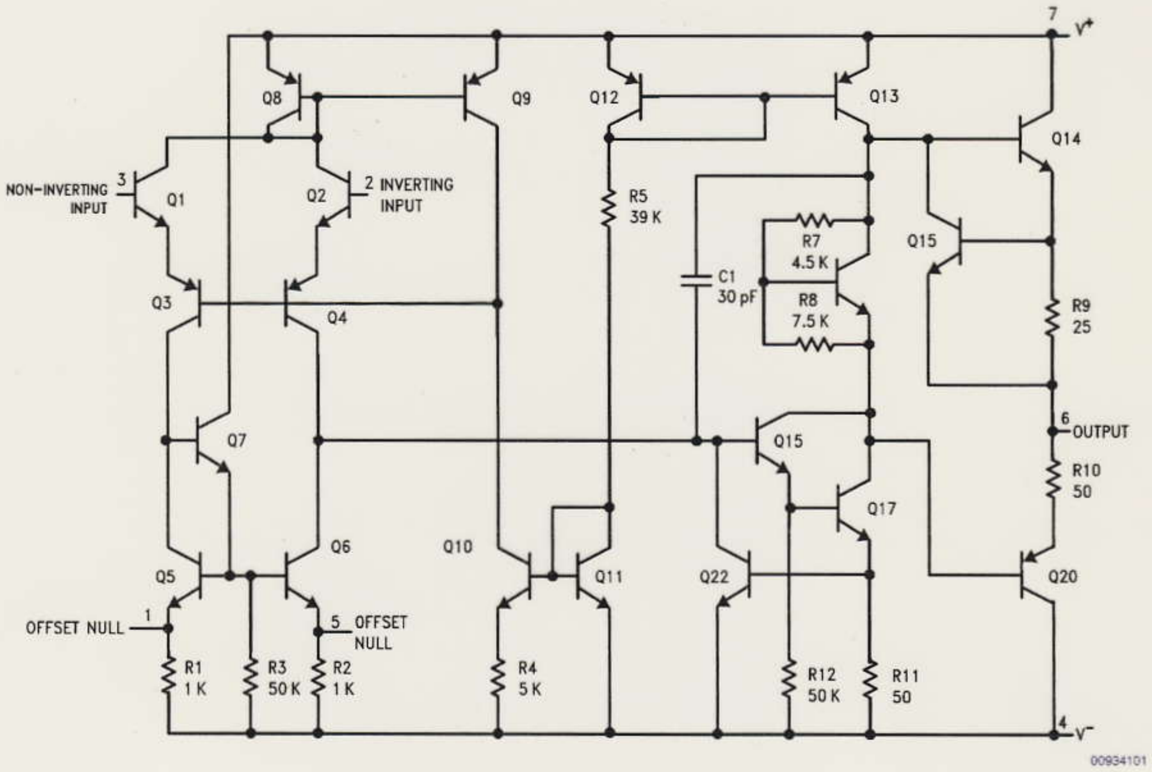
**Note 5:** Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55°C \le T_A \le +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \le T_A \le +70°C$.

**Note 6:** Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

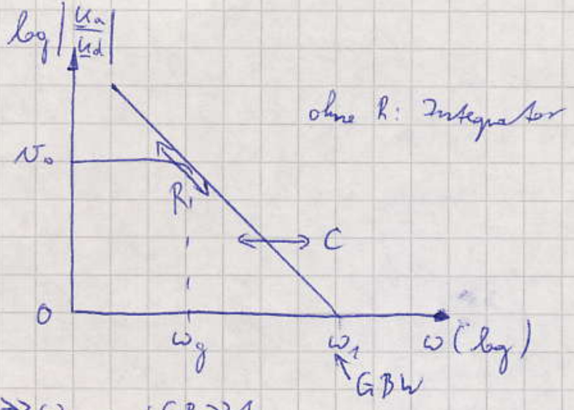
**Note 7:** For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

**Note 8:** Human body model, 1.5 kΩ in series with 100 pF.

## Schematic Diagram



$\underline{v}(s) = \frac{v_0}{1+s\sigma}$



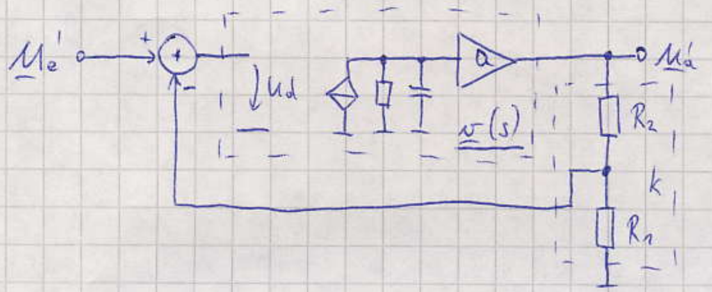
für $\omega \approx \omega_1, \; \omega \gg \omega_g \; : \; sCR \gg 1$

$$\left|\frac{U_a}{U_d}\right| = \frac{a\, g_m R}{\omega C R} = \frac{a\, g_m}{\omega C} = \frac{g_m a}{\omega\, a\, C_k} = \frac{g_m}{\omega C_k}$$

$\omega_1 = \frac{g_m}{C_k}$ $\qquad \frac{1}{\omega_g} = CR = a\, C_k R \quad \left(= \frac{v_0}{g_m} C_k\right)$

$\boxed{\text{Folien} \quad R, C}$

### Wirkung der Gegenkopplung



$\underline{v}(s) = \frac{v_0}{1+s\tau}$

$k = \frac{R_1}{R_1+R_2}$

$$\underline{U}_a' = \underline{v}(s)\left(\underline{U}_e' - k\,\underline{U}_a'\right) \rightarrow \frac{\underline{U}_a'}{\underline{U}_e'} = \frac{\underline{v}(s)}{1+k\,\underline{v}(s)} = \frac{v_0}{1+k v_0 + s\tau} = \frac{v_0}{g+s\tau}$$

$v'(0) = \frac{v_0}{g}$ $\qquad \omega_g' = \omega_g \cdot g$ $\qquad \rightarrow \omega_1 = v'(0)\cdot\omega_g' = v_0 \cdot \omega_g$

↳ GBW unabhängig von g, aussagekräftiger als $\omega_g$

Folie g, Folie g 741, Hinweis 2. Pol

Beispiel LMX321 GBW = 1,3 MHz → Folie LMX321

gefordert: Verstärker mit $v_0' = 100$, $f_{gr} = 100$ kHz

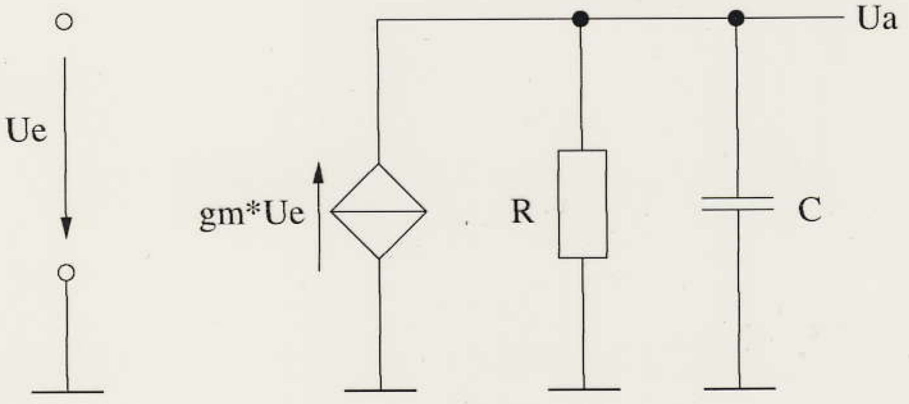
LMX321: einstufig: $f_{gr}' = \text{GBW}/v' = 13$ kHz → zu niedrig

Abhilfe: 2-stufiger Aufbau mit $v_{Stufe} = 10$, $f_{gr} = 130$ kHz

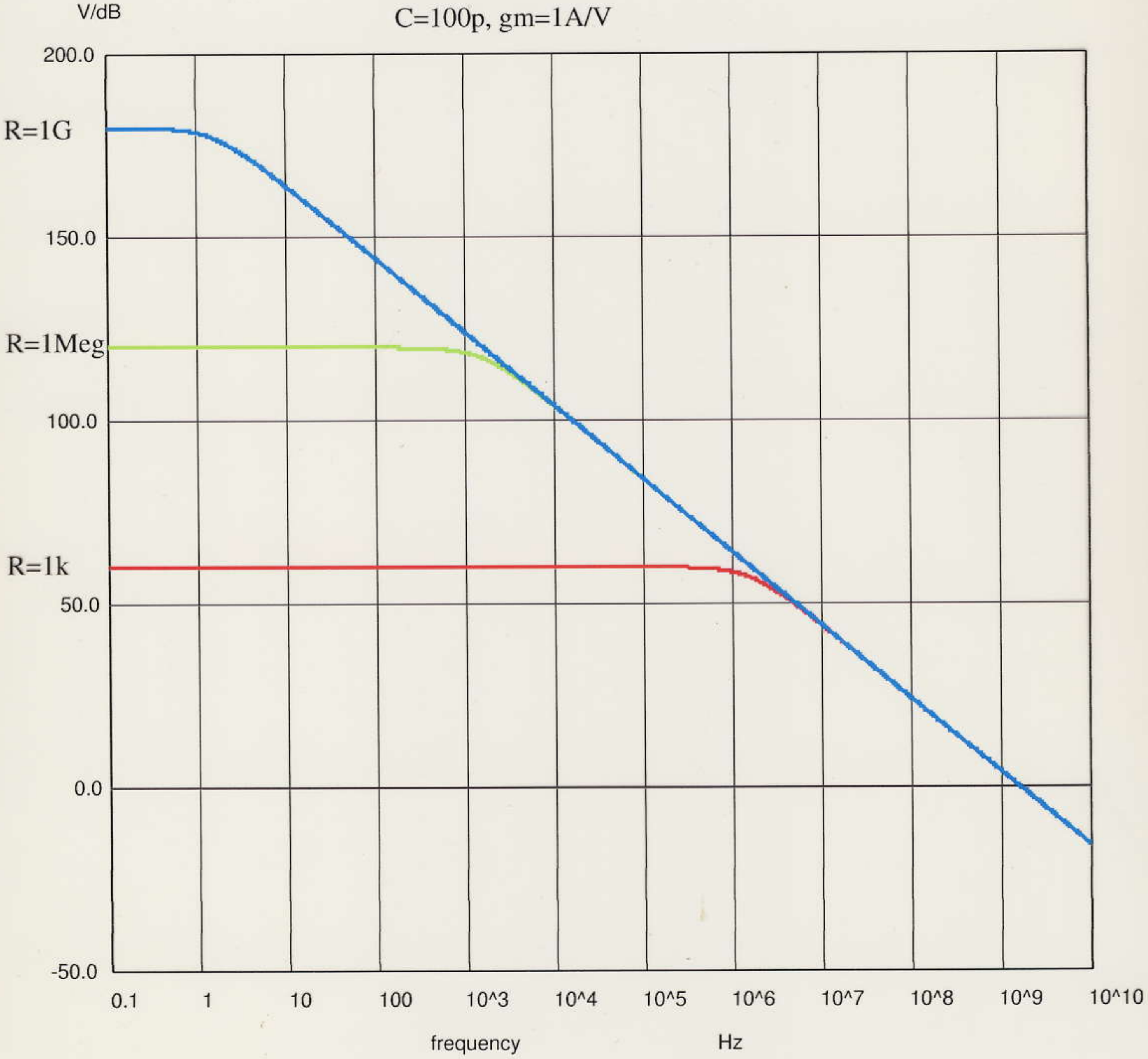
oder schnellerer OPV mit $\text{GBW} = f_{gr} \cdot v_0' = 100$ MHz

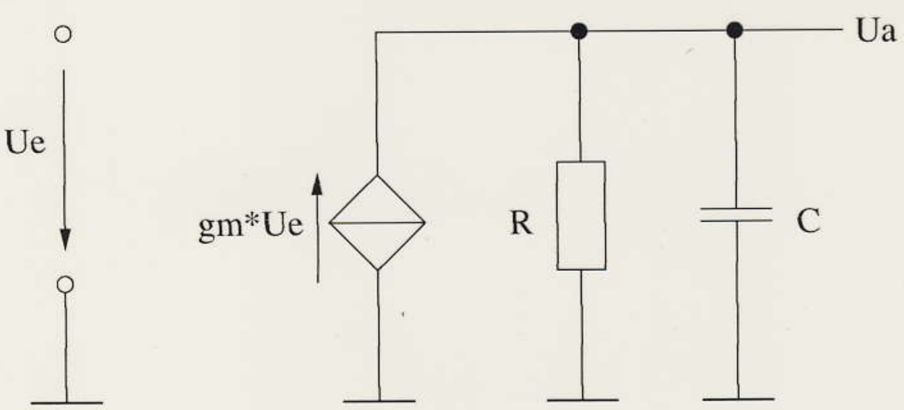
z.B. CLC 430 von National ~~Instruments~~ Semiconductor

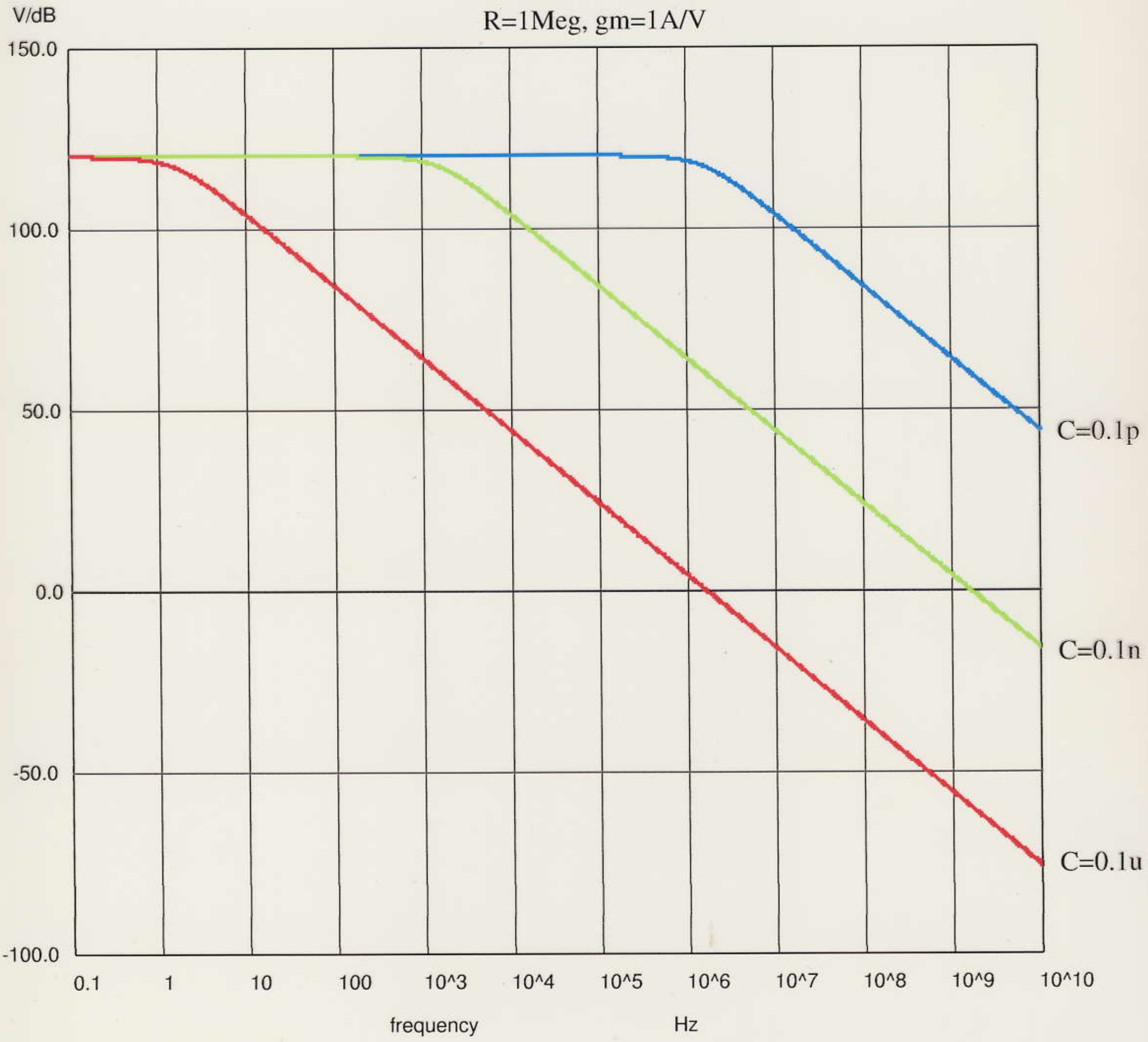
100 MHz General Purpose OPA

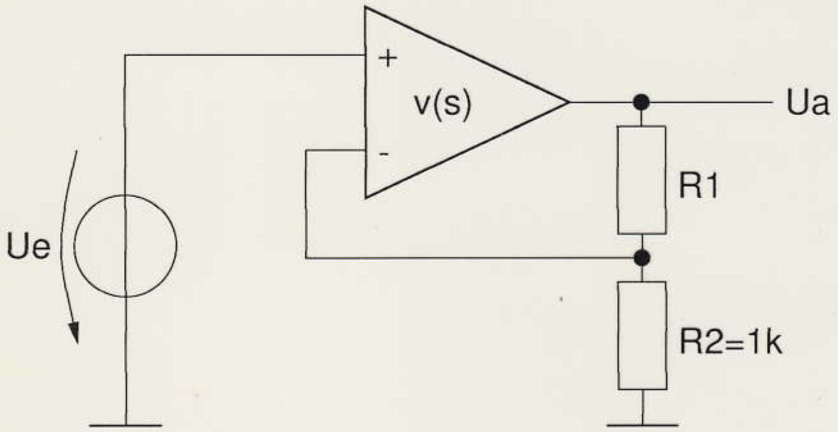

Ue
gm*Ue
R
C
Ua

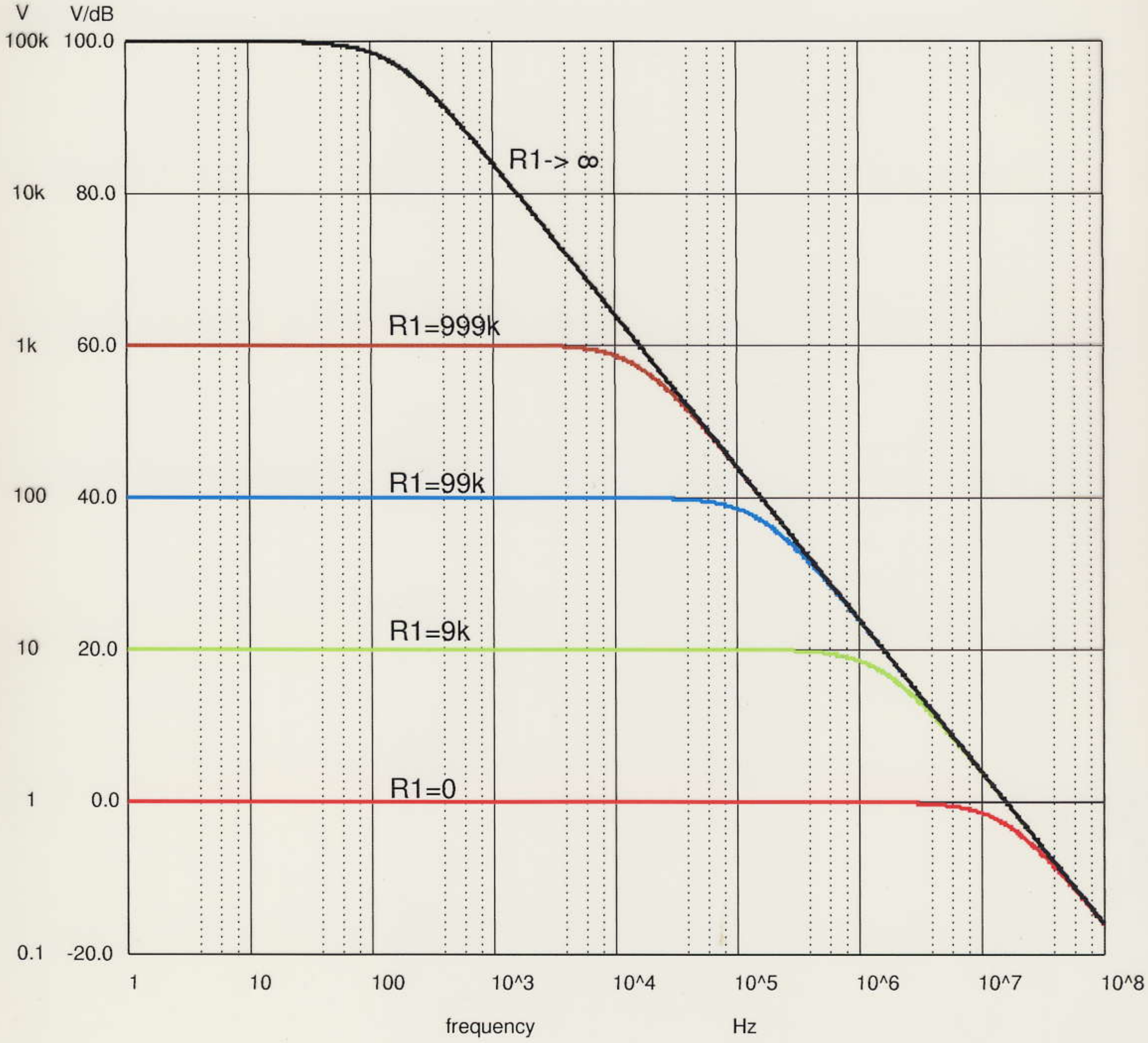
C=100p, gm=1A/V

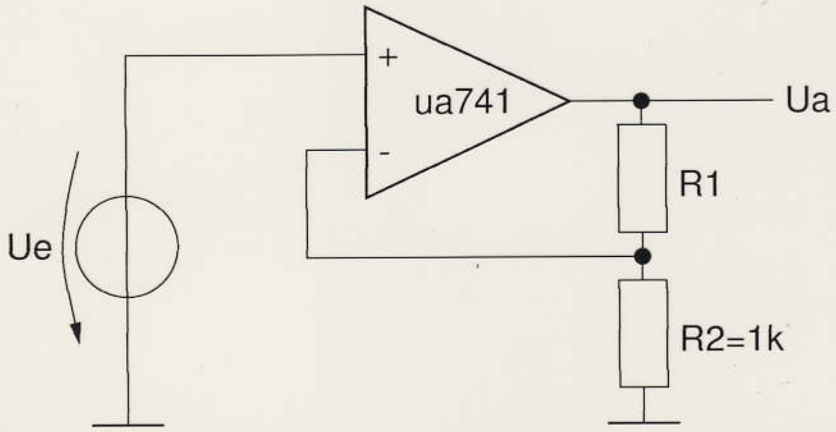

V/dB
200.0
150.0
100.0
50.0
0.0
-50.0
R=1G
R=1Meg
R=1k
0.1
1
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
frequency
Hz

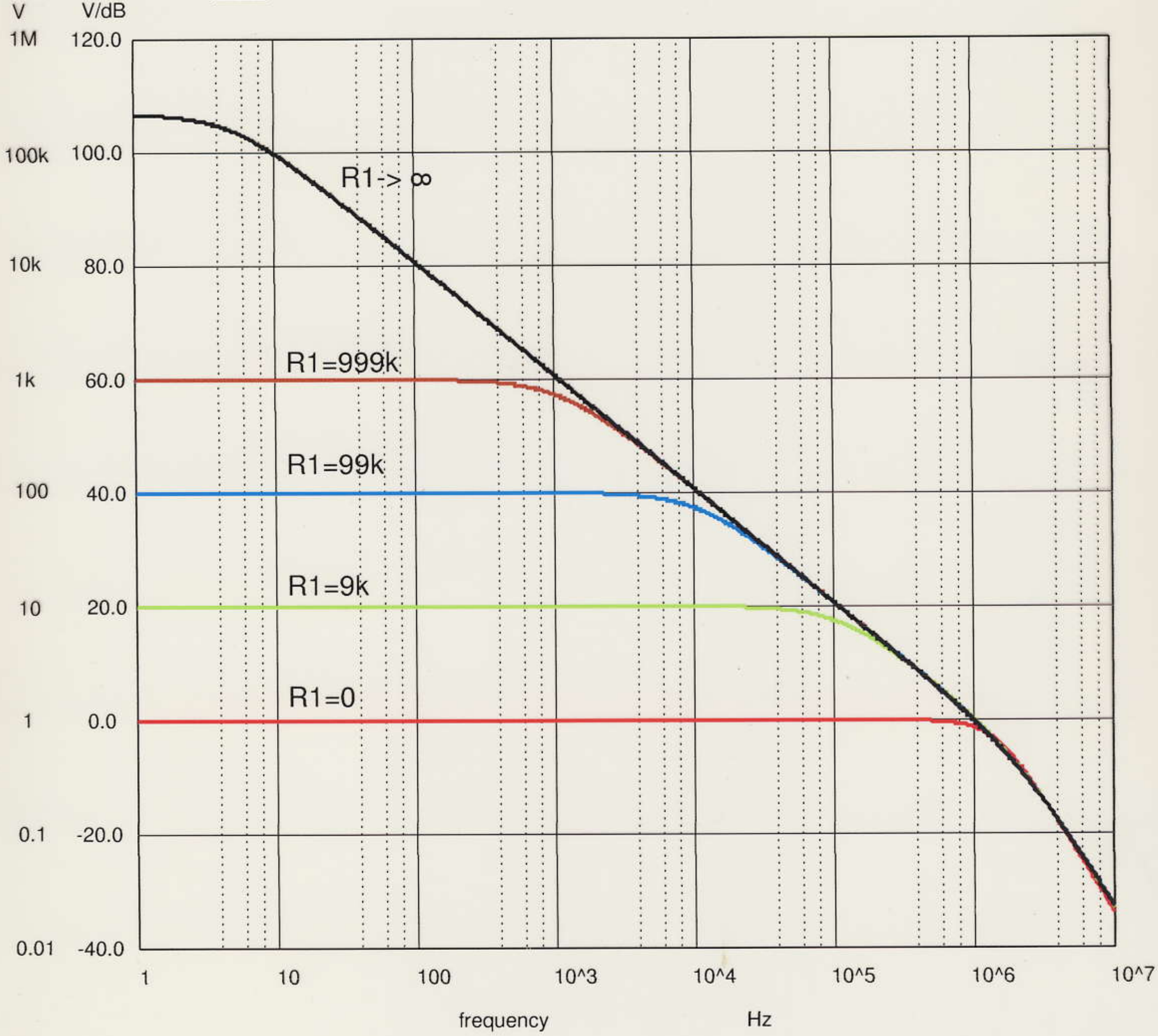

Ua
Ue
gm*Ue
R
C


V/dB
R=1Meg, gm=1A/V
150.0
100.0
50.0
0.0
-50.0
-100.0
0.1
1
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
frequency
Hz
C=0.1p
C=0.1n
C=0.1u


+
v(s)
-
Ua
R1
Ue
R2=1k


V
V/dB
100k
100.0
10k
80.0
1k
60.0
100
40.0
10
20.0
1
0.0
0.1
-20.0
R1-> ∞
R1=999k
R1=99k
R1=9k
R1=0
1
10
100
10^3
10^4
10^5
10^6
10^7
10^8
frequency
Hz


+
-
ua741
Ua
R1
Ue
R2=1k


V
V/dB
1M
120.0
100k
100.0
10k
80.0
1k
60.0
100
40.0
10
20.0
1
0.0
0.1
-20.0
0.01
-40.0
R1-> ∞
R1=999k
R1=99k
R1=9k
R1=0
1
10
100
10^3
10^4
10^5
10^6
10^7
frequency
Hz

19-2103; Rev 0; 8/01

# Single/Dual/Quad, General-Purpose, Low-Voltage, Rail-to-Rail Output Op Amps

## General Description

The LMX321/LMX358/LMX324 are single/dual/quad, low-cost, low-voltage, pin-to-pin compatible upgrades to the LMV321/LMV358/LMV324 family of general purpose op amps. These devices offer Rail-to-Rail® outputs and an input common-mode range that extends below ground. These op amps draw only 105µA of quiescent current per amplifier, operate from a single +2.3V to +7V supply, and drive 2kΩ resistive loads to within 40mV of either rail. The LMX321/LMX358/LMX324 are unity-gain stable with a 1.3MHz gain-bandwidth product capable of driving capacitive loads up to 400pF. The combination of low voltage, low cost, and small package size makes these amplifiers ideal for portable/battery-powered equipment.

The LMX321 single op amp is available in ultra-small 5-pin SC70 and space-saving 5-pin SOT23 packages. The LMX358 dual op amp is available in the tiny 8-pin SOT23 package. The LMX324 quad op amp is available in 14-pin TSSOP and SO packages.

## Applications

Cellular Phones

Laptops

Low-Power, Low-Voltage Applications

Portable/Battery-Powered Equipment

Cordless Phones

Active Filters

## Features

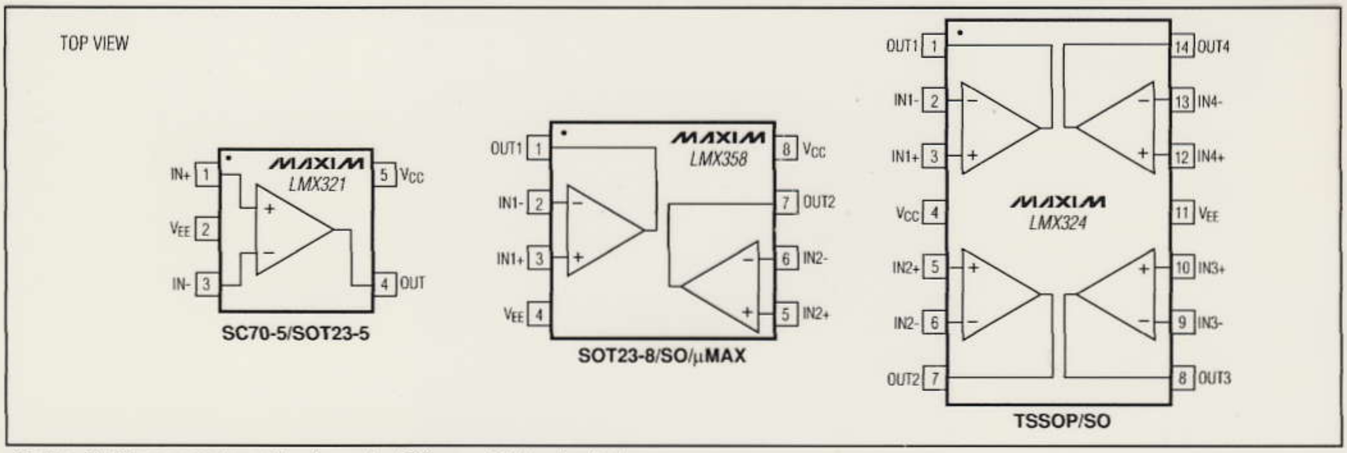
- **Upgrade to LMV321/LMV358/LMV324 Family**
- **Single +2.3V to +7V Supply Voltage Range**
- **Available in Space-Saving Packages**
  - **5-Pin SC70 (LMX321)**
  - **8-Pin SOT23 (LMX358)**
  - **14-Pin TSSOP (LMX324)**
- **1.3MHz Gain-Bandwidth Product**
- **105µA Quiescent Current per Amplifier ($V_{CC}$ = +2.7V)**
- **No Phase Reversal for Overdriven Inputs**
- **No Crossover Distortion**
- **Rail-to-Rail Output Swing**
- **Input Common-Mode Voltage Range: $V_{EE}$ - 0.2V to $V_{CC}$ - 0.8V**
- **Drives 2kΩ Resistive Loads**

## Ordering Information

| PART | TEMP. RANGE | PIN-PACKAGE |
|---|---|---|
| **LMX321**AXK-T | -40°C to +125°C | 5 SC70-5 |
| LMX321AUK-T | -40°C to +125°C | 5 SOT23-5 |
| **LMX358**AKA-T | -40°C to +125°C | 8 SOT23-8 |
| LMX358ASA | -40°C to +125°C | 8 SO |
| LMX358AUA | -40°C to +125°C | 8 µMAX |
| **LMX324**ASD | -40°C to +125°C | 14 SO |
| LMX324AUD | -40°C to +125°C | 14 TSSOP |

***Selector Guide appears at end of data sheet.***

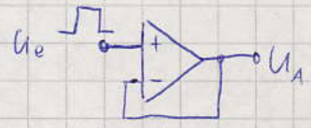
## Pin Configurations

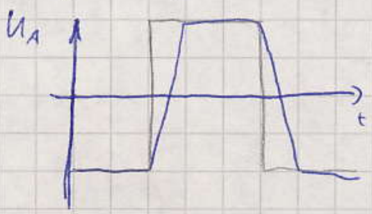


*Rail-to-Rail is a registered trademark of Nippon Motorola, Ltd.*

***For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.***

## 2.2.1.3. Dynam. Großsignalverhalten





→ <u>Folie LM107</u>

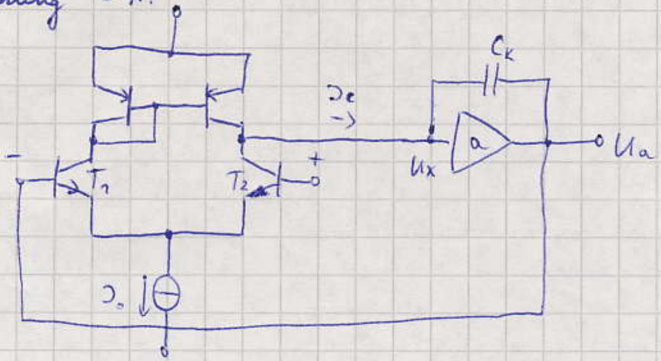
Definition Slew-Rate ($SR^+$, $SR^-$) aus maximalen Spannungsanstiegen

$$SR = \left|\frac{dU_A}{dt}\right|_{max}$$

daraus: Full Power Response Bandwidth (Leistungsbandbreite)

$$FPBW = \frac{SR}{2\pi \hat{U}_A}$$

Berechnung SR:



_|‾ Sprung am + Eingang → $T_1$ sperrt, $I_c = -I_0 = C_K \frac{d(U_x - U_a)}{dt}$

zeitlich linearer Anstieg von $U_c$, $a \gg 1 \rightarrow +I_0 = C_K \frac{dU_a}{dt}$

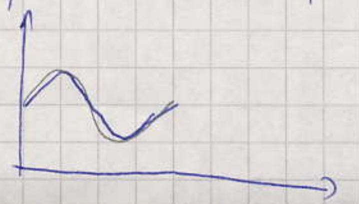
$$SR = \left|\frac{dU_a}{dt}\right|_{max} = \frac{I_0}{C_K}$$

Bsp. LMX 321 $SR = 1 V/\mu s$
$\mu$A 741 $SR = 0{,}3 V/\mu s$

Bsp.: Verstärker mit LMX 321 und 100 kHz Kleinsignalbandbreite:

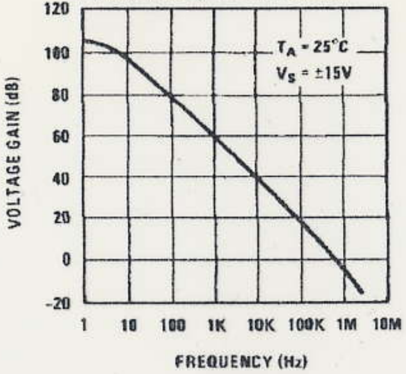
$$\hat{U}_{A max} = \frac{SR}{2\pi f} = 1{,}6 V$$

bei höheren Frequenzen / ~~Am~~ Amplituden:

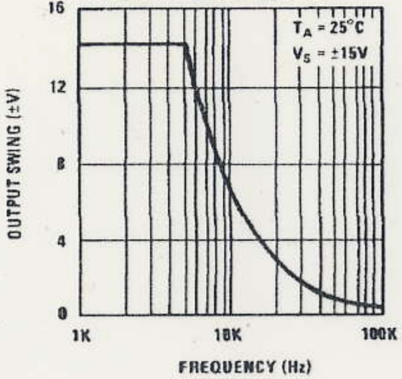


## Typical Performance Characteristics (Continued)

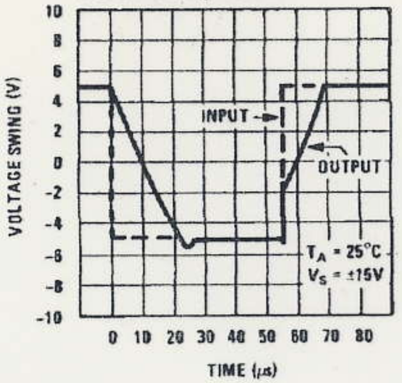
### Open Loop Frequency Response



### Large Signal Frequency Response



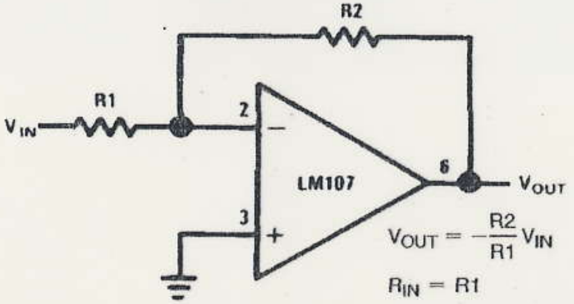
### Voltage Follower Pulse Response



TL/H/7757-7

## Typical Applications**

### Inverting Amplifier

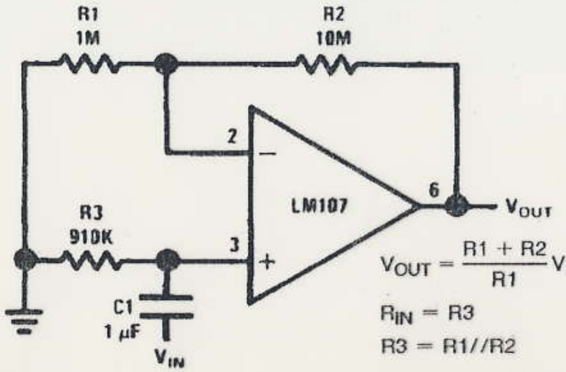


$$V_{OUT} = -\frac{R2}{R1} V_{IN}$$

$$R_{IN} = R1$$

TL/H/7757-8

### Non-Inverting AC Amplifier



$$V_{OUT} = \frac{R1 + R2}{R1} V_{IN}$$

$$R_{IN} = R3$$

$$R3 = R1//R2$$

TL/H/7757-9

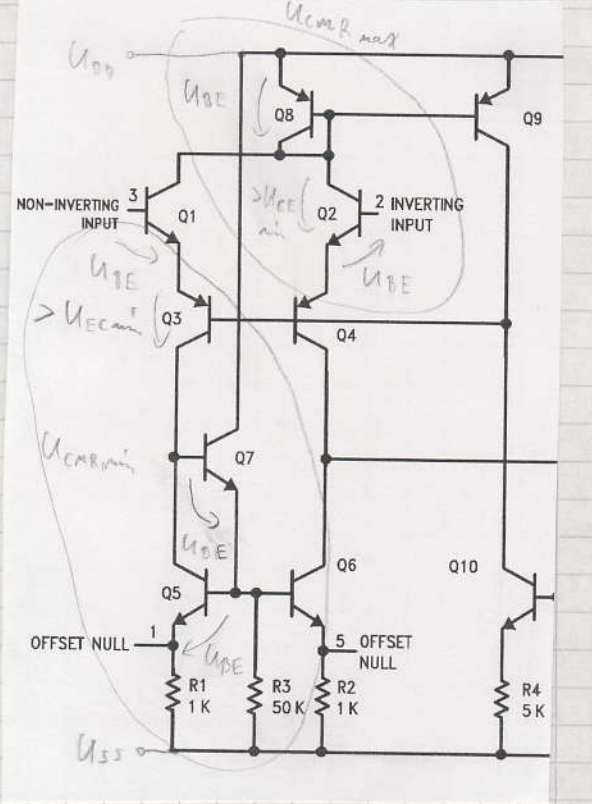
### Non-Inverting Amplifier

$\mu A\,741$: $FPBW = \dfrac{0{,}33 \cdot 10^{6}\,V}{2\pi \cdot 10\,V\ s} = 5{,}3\,kHz$

weitere Kenngrößen:

Input Voltage Range / Common mode input range, CMRI — statische Großsignalgröße

Begrenzung des Eingangsspannungsbereiches durch Arbeitsbereichsgrenzen, Bsp. µA 741: (Folie 741)



min. Eingangsspannung:

$$U_{CMR\,min} = U_{SS} + \underset{0{,}1V}{U_{R_1}} + 3U_{BE} + \underset{0{,}3V}{U_{CE\,min}}$$
$$\approx U_{SS} + 2{,}5\,V$$

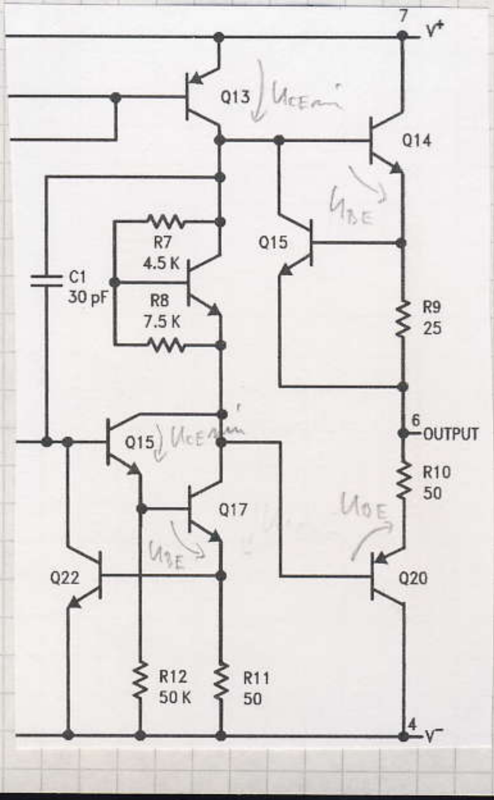
$$U_{CMR\,max} = U_{DD} - U_{BE} - U_{CE\,min} + U_{BE}$$
$$= U_{DD} - U_{CE\,min}$$

Nutzbarer Bereich

$$U_{CMR\,min} < U_e < U_{CMR\,max}$$

Output Voltage Swing — statische Großsignalgröße

741



$$U_{SS} + U_{CE\,min} + 2U_{BE} < U_a < U_{DD} - U_{CE\,min} - U_{DE}$$

## Common Mode Rejection CMR

Kleinsignalgröße

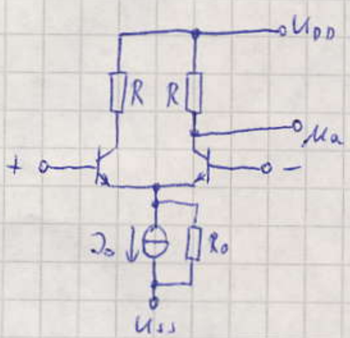
$$CMR = \left|\frac{v_o}{v_{gl}}\right| \quad \text{mit} \quad v_{gl} = \frac{u_a}{u_{egl}}$$

Common Mode Rejection Ratio CMRR

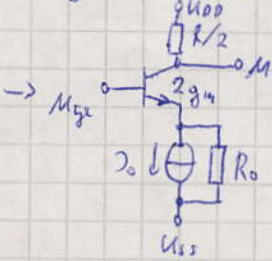
$$\frac{CMRR}{dB} = 20 \log CMR$$

Ursache: endlicher Ausgangswiderstand von Spannungs- / Stromquellen im OPV

Beispiel Differenzstufe



Gleichtaktverstärkung: $u_+ = u_-$



für $g_m \cdot R \gg 1$:

$$v_{gl} = -\frac{R}{2R_0}$$

$$v_d = \frac{g_m R}{2} \gg v_{gl}$$

gängige Werte: CMRR ≈ 80.. 100 dB

## Power supply rejection ratio PSRR

Kleinsignalgröße

Ursache: Arbeitspunktmodulation mit der Versorgungsspannung

Beispiel Differenzstufe

$$v_{PWRSS} = \frac{u_a}{u_{SS}}, \quad \text{Ursache } R_0$$

$$\frac{u_a}{u_{SS}} = \frac{R}{R+R_0}$$

$$v_{PWRDD} = \frac{u_a}{u_{DD}} \quad \text{für } r_{CE} \to \infty\text{!} \quad u_a = u_{DD}, \; v_{PWRDD} = 1$$

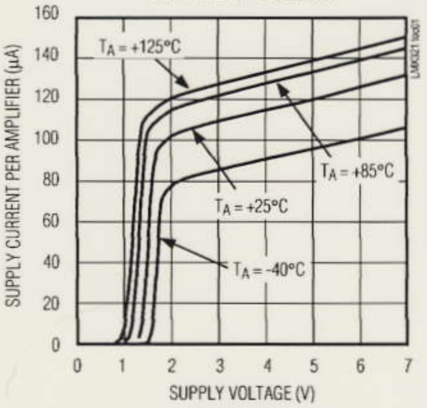
$$\frac{PSRR}{dB} = 20 \log \frac{v}{v_{PWR}}$$

übliche Werte: 80.. 100 dB

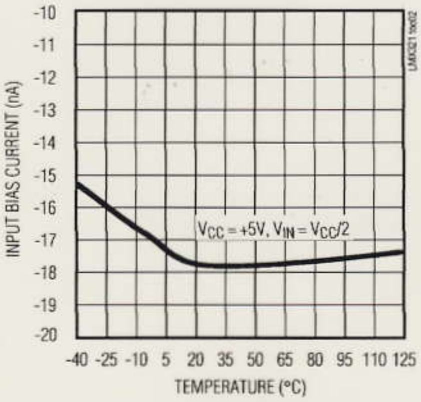
## Typical Operating Characteristics

($T_A$ = +25°C, $V_{EE}$ = 0, unless otherwise noted.)

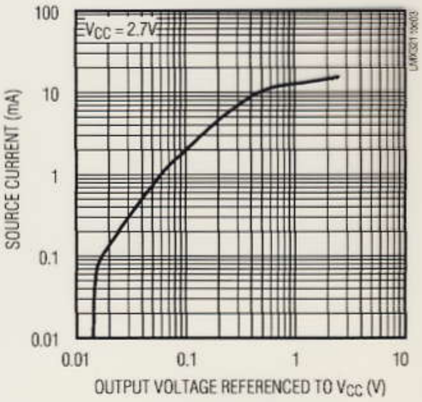
**SUPPLY CURRENT PER AMPLIFIER vs. SUPPLY VOLTAGE**



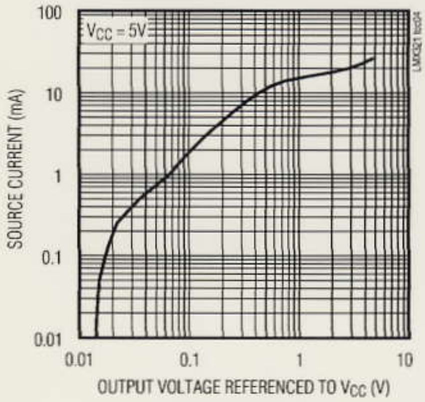
**INPUT BIAS CURRENT vs. TEMPERATURE**



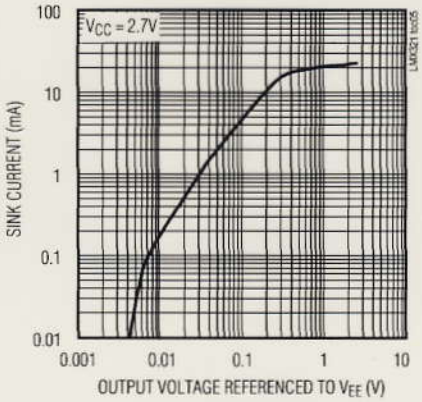
**SOURCE CURRENT vs. OUTPUT VOLTAGE**



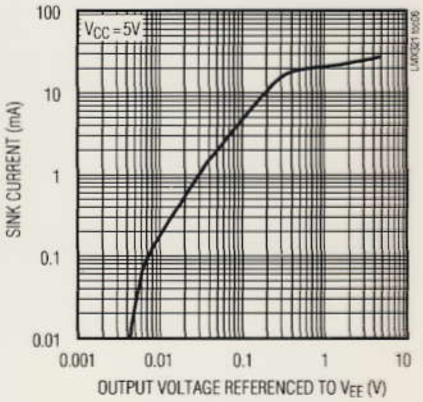
**SOURCE CURRENT vs. OUTPUT VOLTAGE**



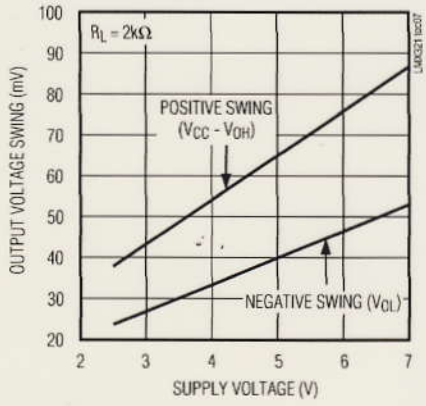
**SINK CURRENT vs. OUTPUT VOLTAGE**



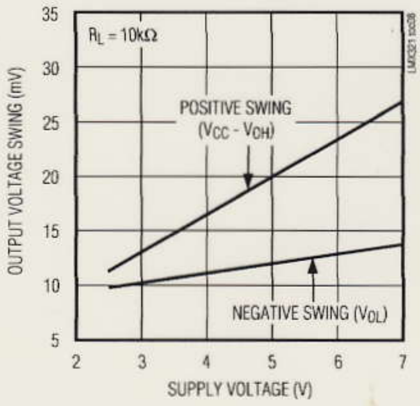
**SINK CURRENT vs. OUTPUT VOLTAGE**



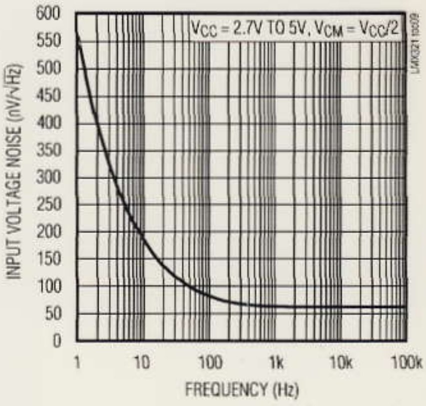
**OUTPUT VOLTAGE SWING vs. SUPPLY VOLTAGE**



**OUTPUT VOLTAGE SWING vs. SUPPLY VOLTAGE**



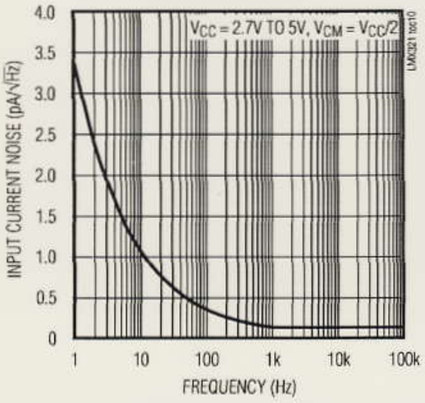
**INPUT VOLTAGE NOISE vs. FREQUENCY**

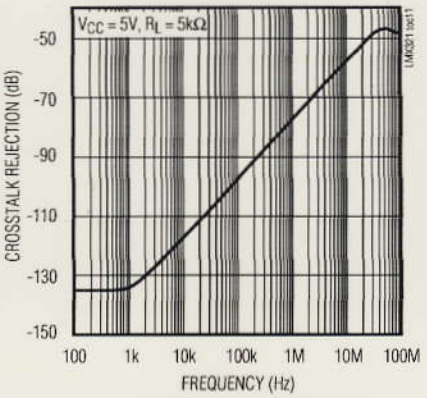


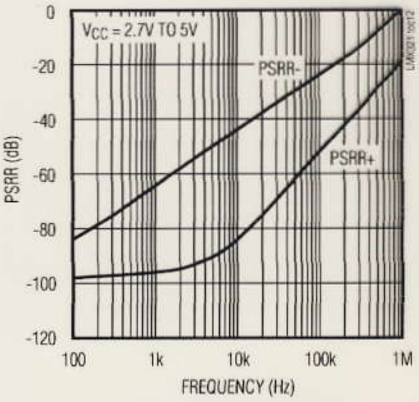
# Single/Dual/Quad, General-Purpose, Low-Voltage, Rail-to-Rail Output Op Amps

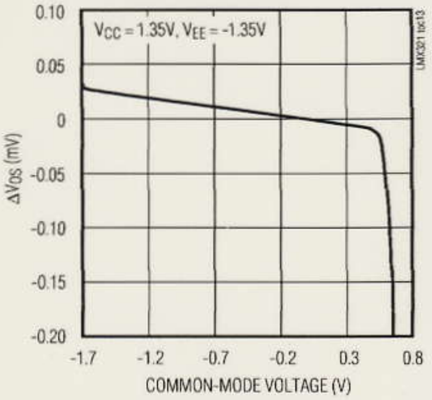
## Typical Operating Characteristics (continued)

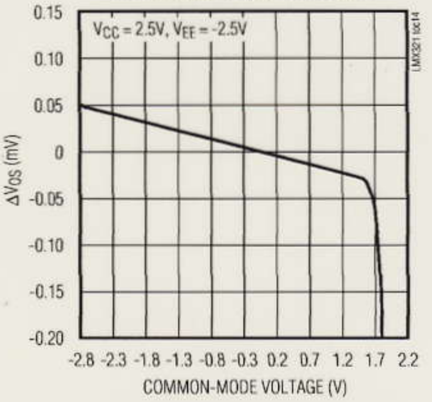
($T_A$ = +25°C, $V_{EE}$ = 0, unless otherwise noted.)

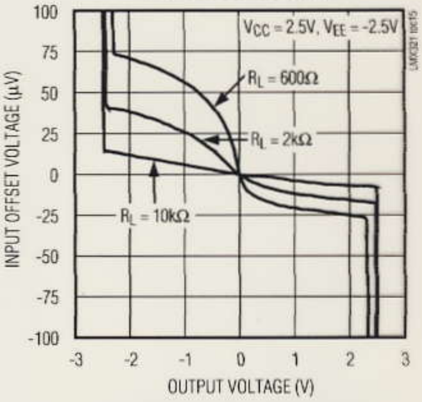

INPUT CURRENT NOISE vs. FREQUENCY

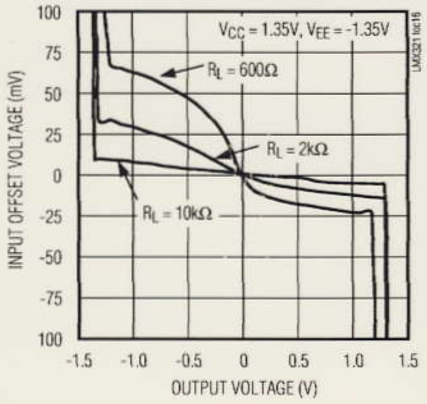

CROSSTALK REJECTION vs. FREQUENCY

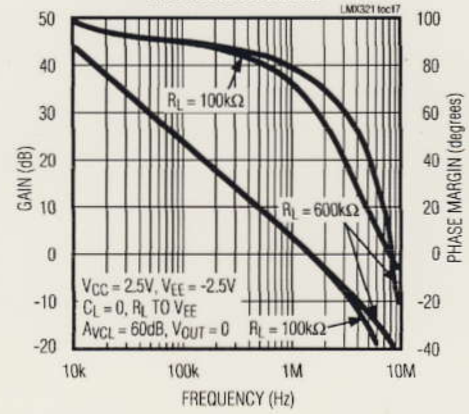

POWER-SUPPLY REJECTION RATIO vs. FREQUENCY

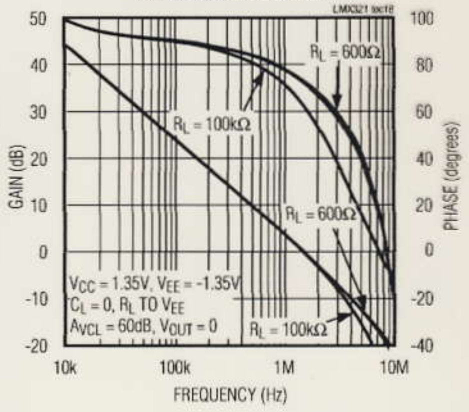

INPUT OFFSET VOLTAGE vs. COMMON-MODE VOLTAGE


INPUT OFFSET VOLTAGE vs. COMMON-MODE VOLTAGE


INPUT OFFSET VOLTAGE vs. OUTPUT VOLTAGE


INPUT OFFSET VOLTAGE vs. OUTPUT VOLTAGE

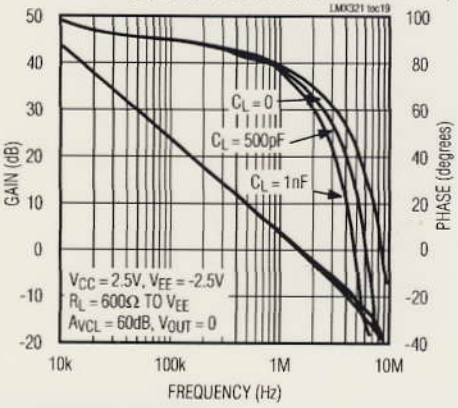

GAIN AND PHASE vs. FREQUENCY and RESISTIVE LOAD


GAIN AND PHASE vs. FREQUENCY AND RESISTIVE LOAD

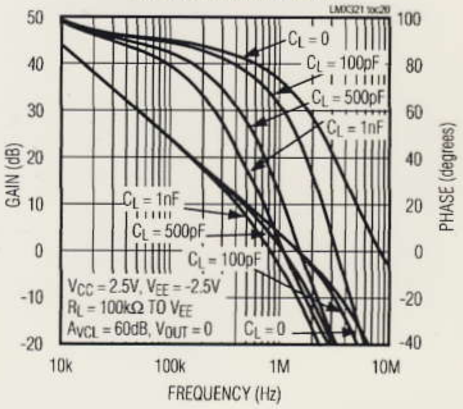
## Typical Operating Characteristics (continued)

($T_A$ = +25°C, $V_{EE}$ = 0, unless otherwise noted.)

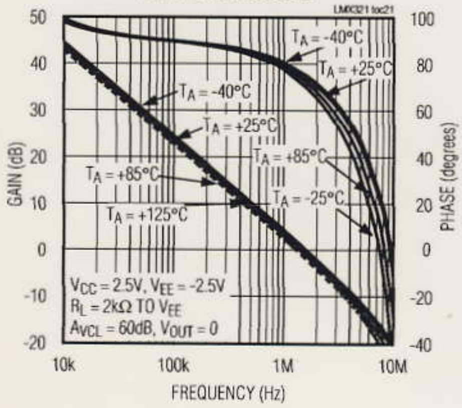
**GAIN AND PHASE vs. FREQUENCY AND CAPACTIVE LOAD**



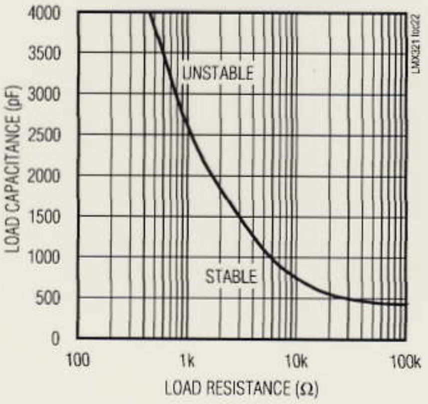
**GAIN AND PHASE vs. FREQUENCY AND CAPACITIVE LOAD**



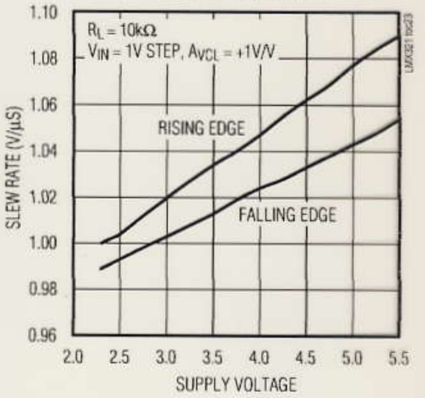
**GAIN AND PHASE vs. FREQUENCY AND TEMPERATURE**



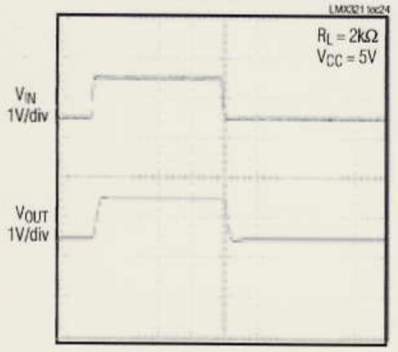
**CAPACITIVE-LOAD STABILITY**



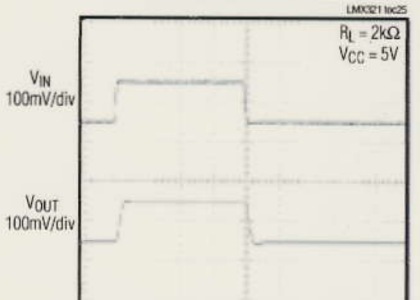
**SLEW RATE vs. SUPPLY VOLTAGE**



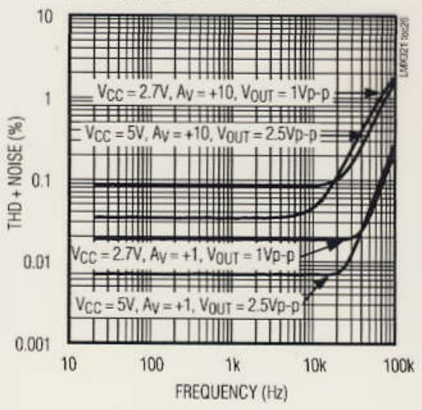
**NONINVERTING LARGE-SIGNAL RESPONSE**



**NONINVERTING SMALL-SIGNAL RESPONSE**



**TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY**



### Input Offset Voltage $V_{OS}$   statische Großsignalgröße

Wirkung: $U_a \neq 0$ für $U_d = 0$

$U_a = 0$ für $U_d = V_{OS}$

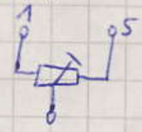
Ursache: mismatch (~~Art~~ Abweichung von Bauelementeparametern zwischen gleich dimensionierten BE)

Folie $\mu A$ 741 z.B. Abweichung des Spiegelverhältnisses von $Q_5$ $Q_6$

AP-Abweichungen z.B. Stromquelle $Q_{13}$

→ einige OPV bieten externe Offset-Kompensation

z.B. $\mu A$ 741



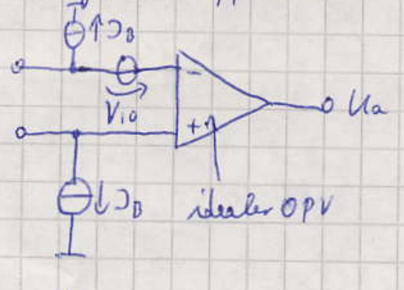
übliche Werte : $V_{OS} = 0{,}1 .. 10\,mV$

### Input Bias Current $I_B$

Ursache: endliche Verstärkung von Bipolartransistoren in der Eingangsstufe - siehe $\mu A$ 741

Größenordnung 10.. 100 nA

Modellierung von Offset und Biasstrom



### Input Offset Current

Ursache Biasstrom in Verbindung mit Mismatch in der Eingangsstufe

Größenordnung $< \frac{1}{10} I_B$

### Folien

Offset Voltage, Input Bias und Input Offset Current sind temperaturabhängig (Drift)

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage ($V_{CC}$ to $V_{EE}$) ....................................-0.3V to +8V
Differential Input Voltage ($V_{IN+}$ - $V_{IN-}$) ........................$V_{EE}$ to $V_{CC}$
OUT_ to $V_{EE}$ ..............................................-0.3V to ($V_{CC}$ + 0.3V)
Output Short-Circuit Duration
OUT_ Shorted to $V_{CC}$ or $V_{EE}$.................................Continuous
Continuous Power Dissipation ($T_A$ = +70°C)
5-Pin SC70-5 (derate 3.1mW/°C above +70°C)...........247mW
5-Pin SOT23-5 (derate 7.1mW/°C above +70°C) ........571mW
8-Pin SOT23-8 (derate 7.52mW/°C above +70°C) ......602mW
8-Pin SO (derate 5.9mW/°C above +70°C)..................471mW
8-Pin µMAX (derate 4.5mW/°C above +70°C) .............362mW
14-Pin TSSOP (derate 9.1mW/°C above +70°C) .........727mW
14-Pin SO (derate 8.3mW/°C above +70°C)................667mW
Operating Temperature Range .........................-40°C to +125°C
Junction Temperature.....................................................+150°C
Storage Temperature Range ............................-65°C to +150°C
Lead Temperature (soldering, 10s) ................................+300°C

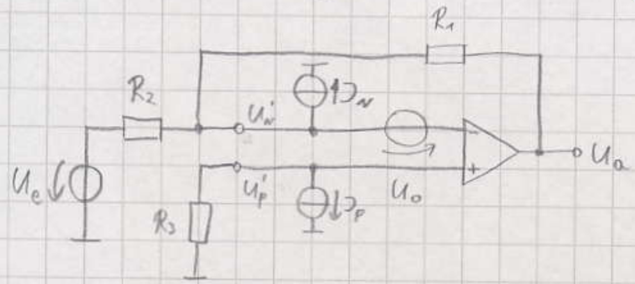
*Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

## ELECTRICAL CHARACTERISTICS

($V_{CC}$ = +2.7V, $V_{EE}$ = 0, $V_{OUT}$ = $V_{CC}$/2, $V_{CM}$ = 1V, $R_L$ > 1MΩ, **$T_A$ = +25°C**, unless otherwise noted.)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| **DC Characteristics** | | | | | | | |
| Input Offset Voltage | $V_{OS}$ | | | | 1 | 6 | mV |
| Input Offset Voltage Average Drift | $TCV_{OS}$ | | | | 6 | | µV/°C |
| Input Bias Current | $I_B$ | | | | 18 | 50 | nA |
| Input Offset Current | $I_{OS}$ | | | | 1 | 8 | nA |
| Common-Mode Rejection Ratio | CMRR | -0.2V < $V_{CM}$ < 1.8V | | 72 | 92 | | dB |
| Power-Supply Rejection Ratio | PSRR | 2.3V ≤ $V_{CC}$ ≤ 7V, $V_{OUT}$ = 1V | | 82 | 96 | | dB |
| Input Common-Mode Voltage Range | $V_{CM}$ | For CMRR ≥ 72dB | Limit | -0.2 | | 1.8 | V |
| | | | Typ | -0.2 | | 1.9 | |
| Large-Signal Voltage Gain | $A_{VOL}$ | $R_L$ = 2kΩ to $V_{EE}$, 0.3V < $V_{OUT}$ < 2.4V | | 20 | 120 | | V/mV |
| Output Voltage Swing | $V_{OUT}$ | $R_L$ = 10kΩ to 1.35V | $V_{CC}$ - $V_{OH}$ | | 12 | 50 | mV |
| | | | $V_{OL}$ | | 10 | 40 | |
| | | $R_L$ = 2kΩ to 1.35V | $V_{CC}$ - $V_{OH}$ | | 40 | 110 | |
| | | | $V_{OL}$ | | 25 | 60 | |
| Supply Current | $I_{CC}$ | LMX321 (Single) | | | 105 | 150 | µA |
| | | LMX358 (Dual) | | | 210 | 300 | |
| | | LMX324 (Quad) | | | 420 | 600 | |
| **AC Characteristics** | | | | | | | |
| Slew Rate | SR | 1V step Input | | | 1 | | V/µs |
| Gain-Bandwidth Product | GBW | $C_L$ = 200pF | | | 1.3 | | MHz |
| Phase Margin | $\phi_M$ | | | | 64 | | degrees |
| Gain Margin | GM | | | | 24 | | dB |
| Input Noise Voltage Density | $e_n$ | f = 1kHz | | | 66 | | nV/√Hz |
| Input Current Noise Density | $i_n$ | f = 1kHz | | | 0.13 | | pA/√Hz |

## Auswirkungen auf die Schaltung und Kompensation



$U_+ = U_-$

$$-I_P R_3 = U_E \frac{R_1}{R_1+R_2} + U_a \frac{R_2}{R_1+R_2} - I_N R_1 || R_2 - U_0$$ (Überlagerungssatz)

ideales Verhalten

Fehler durch Biasstrom

Offsetfehler

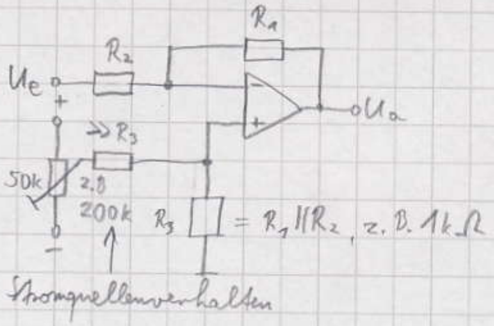
- Biasstromkompensation (für $I_N = I_P$) bei $R_3 = R_1 || R_2$

Betrachtung des Restfehlers mit $I_N = I_P + I_0$

$$0 = \frac{U_e R_1 + U_a R_2}{R_1 + R_2} - I_0 R_1 || R_2 - U_0$$

Beschaltung für hochohmige Quellen: $R_2$ groß, $I_0 R_1 || R_2 > U_0$ → Kompensation von $I_0$
niederohmige Quellen: $R_2$ klein, $I_0 R_1 || R_2 < U_0$ → von $U_0$

### Biasstrom- und ~~Offsetkompensation~~ Offsetspannungskompensation



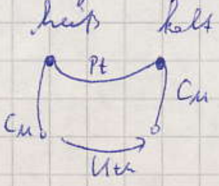
- Kompensation funktioniert für konstante $I_B$ und $U_0$
- Restfehler durch Drift bleibt
- Problem bei Gleichspannungsverstärkung / Verstärkung niedriger Frequenzen

Auswahl des OPV

| Verstärkung von | Kriterium |
|---|---|
| kleinen Strömen | geringer Offsetstrom-Drift |
| kleinen Spannungen | geringer Offsetspannungs-Drift |

Beispiel Temperaturmessung mit Thermoelement

$U_{th} = 7{,}5\,\mu V/°C \cdot \Delta\vartheta$
↓
zu verarbeitende Spannung
im µV-Bereich



Offset-Drift des LM321 typ. 6µV/°C — gleiche Größenordnung wie zu messendes Signal

Abhilfe: - Chopper-Verstärker (Zerhackerverstärker)
- Verstärker mit Driftkorrektur

Chopper-Verstärker

Prinzip: Folie       alte Methode (früher Relaistechnik)

Modulator: DC-Spannung → AC-Spannung   AM

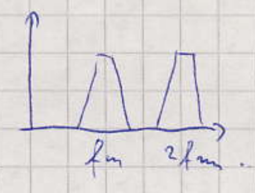
HP: Entfernen von DC-Anteilen ~~(Offset)~~

v: Verstärkung des Wechselsignals

Demodulator: AC → DC - Conversion

TP: Entfernen der anderen Mischprodukte (Reconstruction-Filter)

- Funktion
- Blockschaltbild
- Verweis auf Spektralverhalten, Aliasing, Abtasttheorem



Rauschen abhängig von Chopperfrequenz

höhere Chopper-Frequenz führt zu niedrigerem Rauschen

typische Werte 10 Hz ... 100 kHz

Folie TC 7652

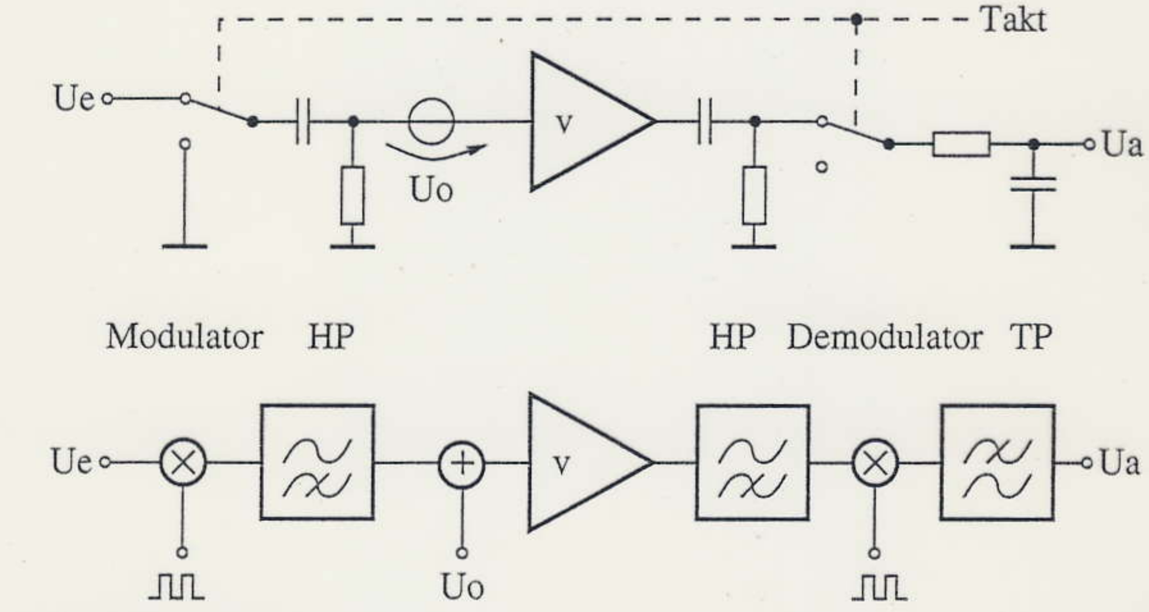
Verstärker mit Driftkorrektur (Auto-Zero)

Folie Driftunterdrückung

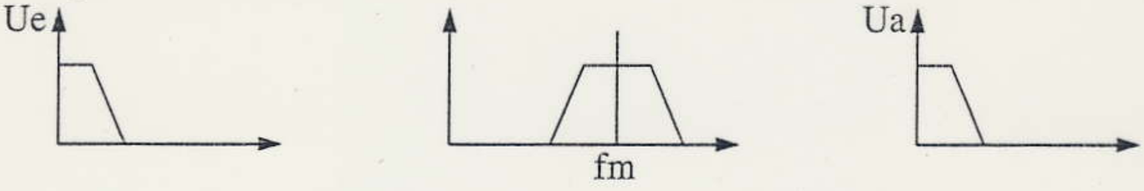
dargestellte Schalterstellung: normaler Betrieb mit $U_a = v \cdot U_e$
zweite Schalterstellung: Kalibrierung - $U_- = U_0$, $U_a$ = konst. wegen zweiter Kapazität

## Driftunterdrückung

### a) Prinzip Chopperverstärker

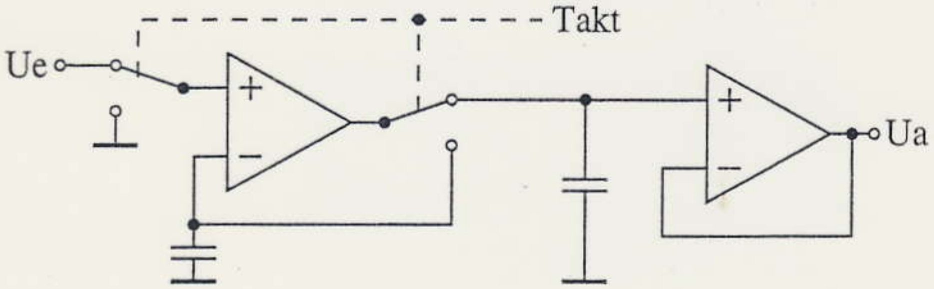


Spektralverhalten:



Störung:

### b) Prinzip Verstärker mit Driftkorrektur (Auto–Zero)



**MICROCHIP**

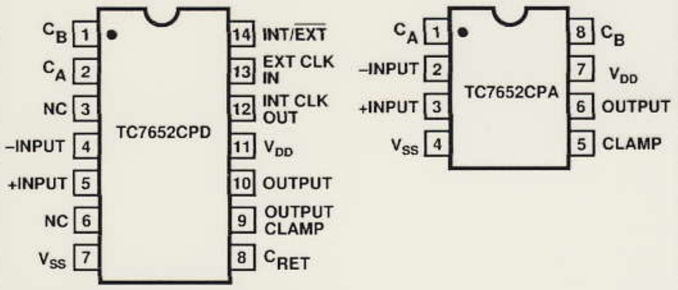
**TC7652**

# Low Noise, Chopper-Stabilized Operational Amplifier

## FEATURES

- Low Offset Over Temperature Range ............ 10μV
- Ultra-Low Long-Term Drift .................150nV/Month
- Low Temperature Drift ............................ 100nV/°C
- Low DC Input Bias Current ............................ 15pA
- High Gain, CMRR and PSRR ................. 110dB Min
- Low Input Noise Voltage ......... 0.2μV$_{P-P}$; DC to 1Hz
- Internally-Compensated for Unity-Gain Operation
- Clamp Circuit for Fast Overload Recovery

## PIN CONFIGURATIONS



NC = NO INTERNAL CONNECTION
(MAY BE USED AS INPUT GUARD)

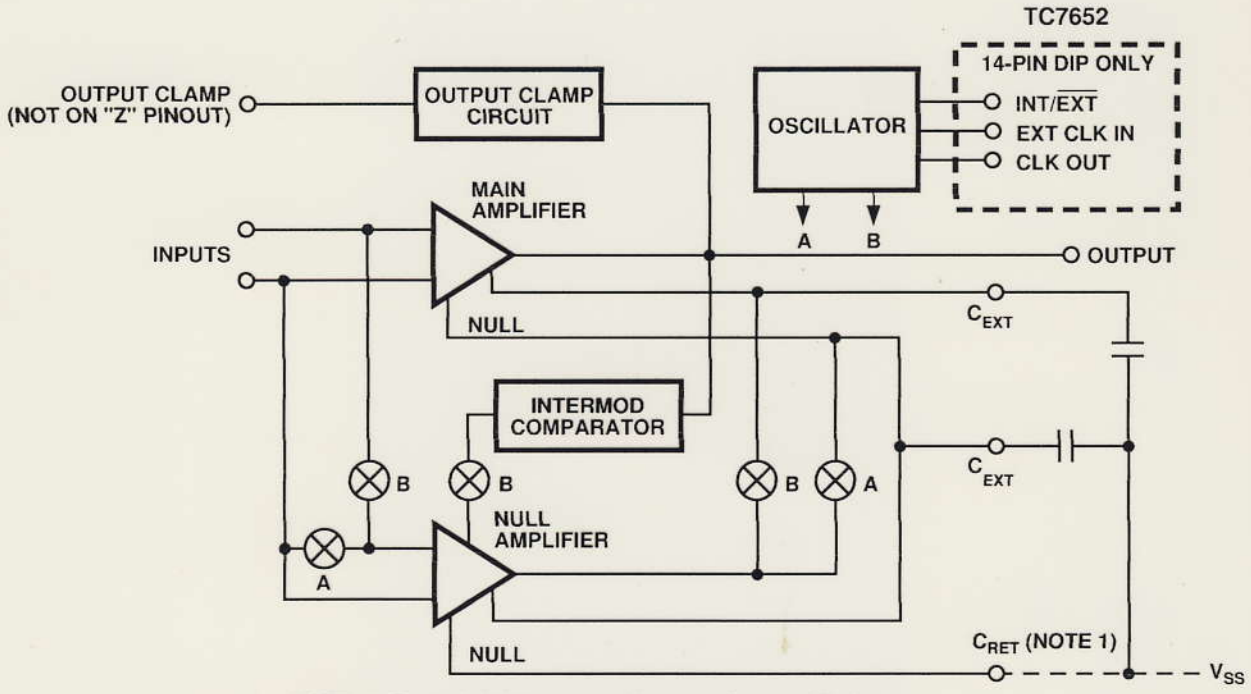
## GENERAL DESCRIPTION

The TC7652 is a lower noise version of the TC7650, sacrificing some input specifications (bias current and bandwidth) to achieve a 10x reduction in noise. All the other benefits of the chopper technique are present, i.e. freedom from offset adjust, drift, and reliability problems from external trim components. Like the TC7650, the TC7652 requires only two noncritical external caps for storing the chopped null potentials. There are no significant chopping spikes, internal effects or overrange lockup problems.

## ORDERING INFORMATION

| Part No. | Package | Temp. Range |
|---|---|---|
| TC7652CPA | 8-Pin Plastic DIP | 0°C to +70°C |
| TC7652CPD | 14-Pin Plastic DIP | 0°C to +70°C |

## FUNCTIONAL BLOCK DIAGRAM



**NOTE:** 1. For 8-pin DIP connect to V$_{SS}$, or to C$_{RET}$ on "Z" pinout.

~~Verzerrungen~~

## Breitbandverstärker

Es gibt:
- schnelle OPV mit schlechten Offset-Eigenschaften ②
- langsame OPV mit guten Offset-Eigenschaften ①

Kombination führt auf Breitbandverstärker

Folie Breitbandverstärker

Prinzip: niedrige Frequenzen: $v_1$ wirksam, $v \approx -v_1 v_2$

$v_1$ hat niedrigen Eingangsoffset und kompensiert in der Gesamtschaltung $U_0$ von $V_2$.

hohe Frequenzen: $v \approx -v_2$

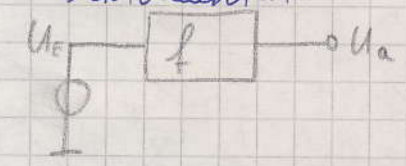
$U_0 \approx U_{01}$

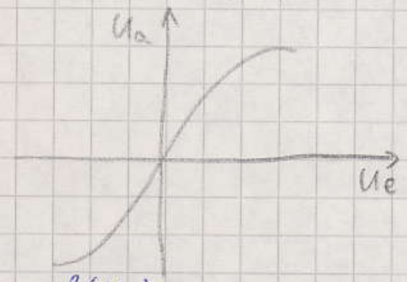
Folie Frequenzgänge

~~Folie Oszi~~

## Verzerrungen

### Nichtlinearität





$U_E = \hat{U}_E \sin(\omega t)$

→ Folie

$U_a = f(U_e)$

Approximation durch Taylor-Reihe

$f(x) = v \cdot x + a_2 x^2 + a_3 x^3 + \ldots$

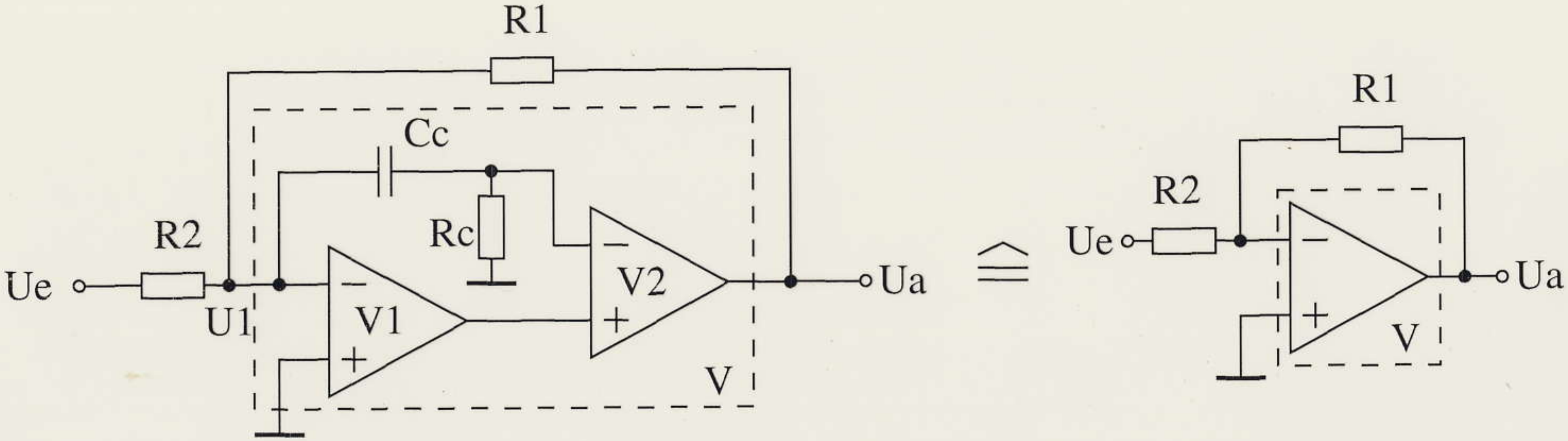
Annahme: $a_2 \approx 0$
$a_{4\ldots} \approx 0$

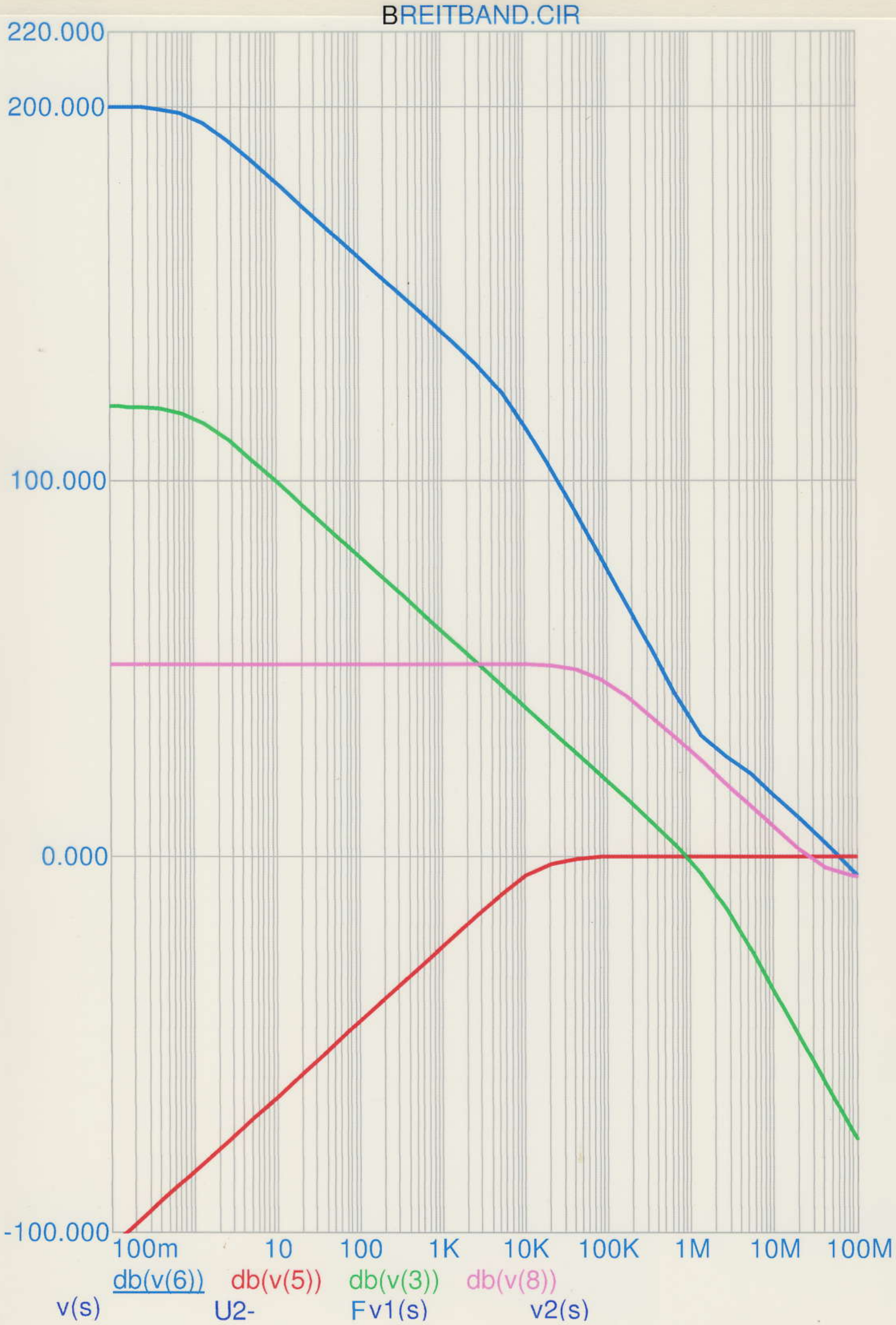
$f(x) = v \cdot x + a_3 x^3$

$$u_a = v\,\hat{U}_e \sin(\omega t) + \frac{3}{4} a_3 \hat{U}_e^3 \sin(\omega t) - \frac{1}{4} a_3 \hat{U}_e^3 \sin(3\omega t)$$
$$= \left(v + \frac{3}{4} a_3 \hat{U}_e^2\right) \hat{U}_e \sin(\omega t) - \frac{1}{4} a_3 \hat{U}_e^3 \sin(3\omega t)$$

Klirrfaktor: ~~(Total Harmonic Distortion, THD)~~

$$k = \sqrt{\frac{\sum_{n=2}^{\infty} \hat{U}_n^2}{\sum_{n=1}^{\infty} \hat{U}_n^2}} = \sqrt{\frac{\neq \frac{1}{4} a_3 \hat{U}_e^2}{\left(v + \frac{3}{4} a_3 \hat{U}_e^2\right)^2 + \left(\frac{1}{4} a_3 \hat{U}_e^2\right)^2}}$$


R1
Cc
R2
Rc
Ue
V2
U1
V1
V
Ua
≙
R1
R2
Ue
V
Ua


BREITBAND.CIR
220.000
200.000
100.000
0.000
-100.000
100m
10
100
1K
10K
100K
1M
10M
100M
db(v(6))
db(v(5))
db(v(3))
db(v(8))
v(s)
U2-
Fv1(s)
v2(s)

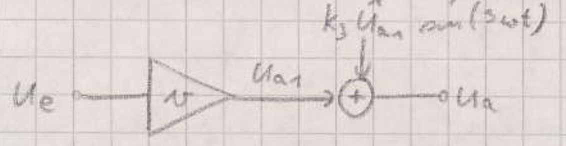
## Modellierung:

Total Harmonic Distortion (THD)

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} \hat{U}_n^2}}{\hat{U}_1}$$

Modellierung:

$$U_a = \hat{U}_{a1} \sin(\omega t) + k_3 \hat{U}_{a1} \sin(3\omega t)$$ mit $U_{a1} = v \cdot U_e$

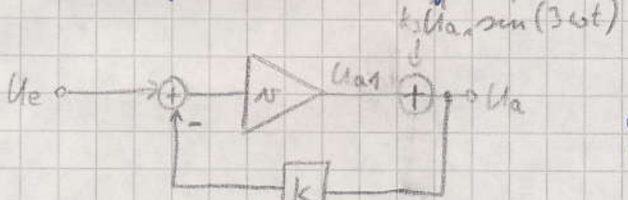


$k_3 = f(U_{a1})$

$$k = \frac{k_3 U_{a1}}{\sqrt{U_{a1}^2 + (k_3 U_{a1})^2}} = \frac{k_3}{\sqrt{1+k_3^2}} \approx k_3 \quad !$$

$$THD = \frac{k_3 U_{a1}}{U_{a1}} = k_3$$

## Wirkung der Rückkopplung



gültig für konstantes $U_{a1}$!

$$U_a = \hat{U}_{a1} \sin(\omega t) + k_3' \hat{U}_{a1} \sin(3\omega t)$$

Grundwelle: $U_{a1} = v(U_e - k U_a) \approx \underline{v(U_e - k U_{a1})}$ für kleine $k_3$

$$U_{a1} = U_e \frac{v}{1+kv}$$

3. Harmonische: $U_{a3} = k_3 U_{a1} - kv U_{a3}$

$$U_{a3} = \frac{k_3 U_{a1}}{1+kv}$$

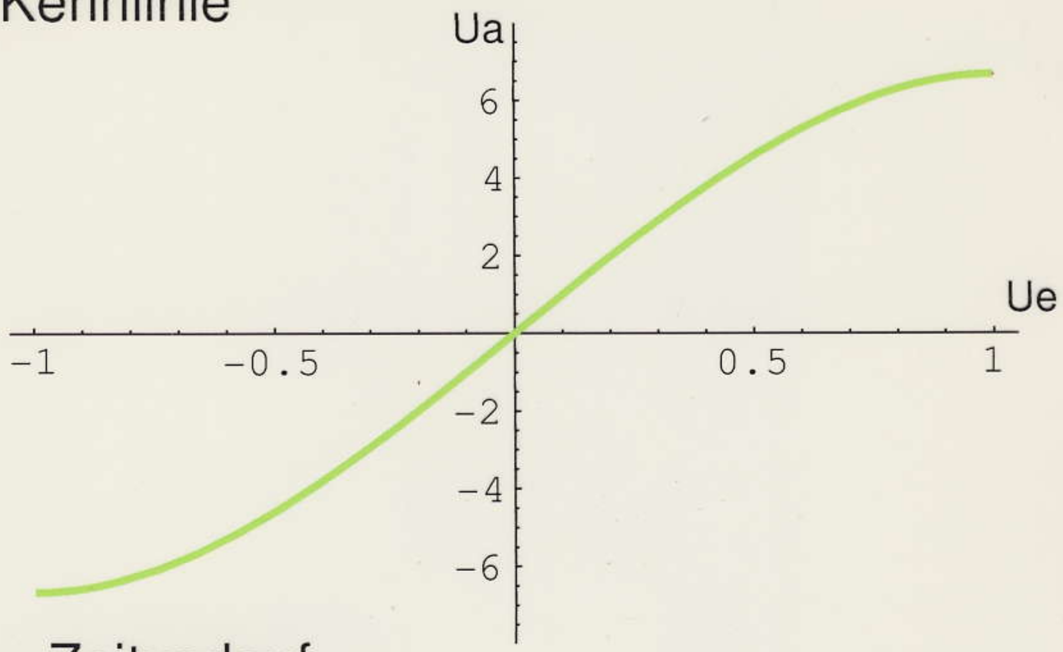
$$k_3' = \frac{\frac{k_3 U_{a1}}{1+kv}}{\sqrt{U_{a1}^2 + \left(\frac{k_3 U_{a1}}{1+kv}\right)^2}} = \frac{k_3}{\sqrt{(1+kv)^2 + k_3}} \approx \frac{k_3}{1+kv}$$ für $k_3 \ll 1$

$$THD' = \frac{k_3 U_{a1}}{U_{a1}(1+kv)} = \frac{k_3}{1+kv}$$

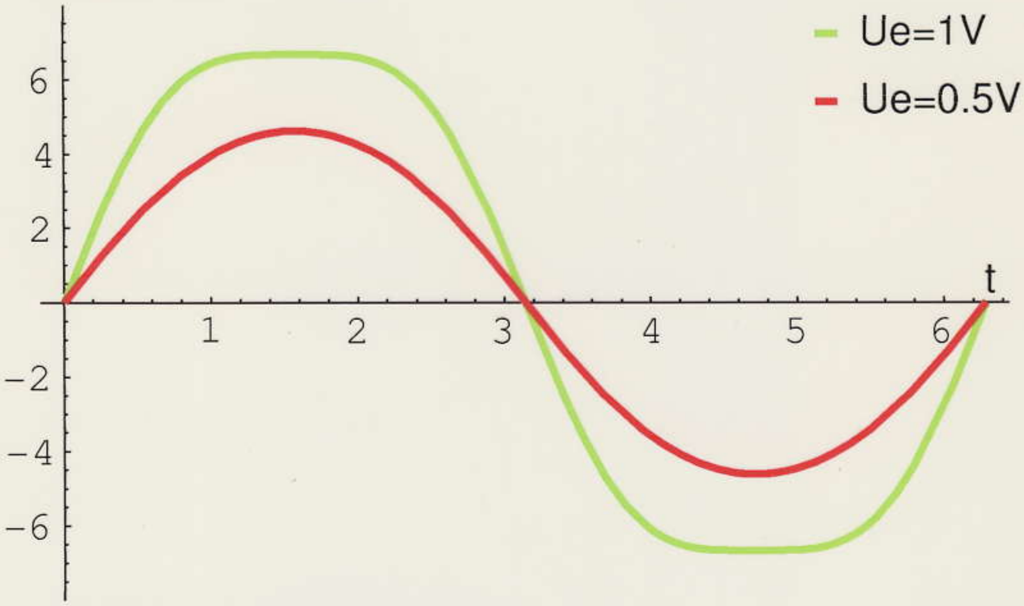
~~Bei gleichbleibender Verstärkung verringert sich mit~~

Bei gleichbleibender Aussteuerung des Verstärkers verringert sich mit zunehmender Gegenkopplung der Klirrfaktor, $k \sim \frac{1}{g}$.

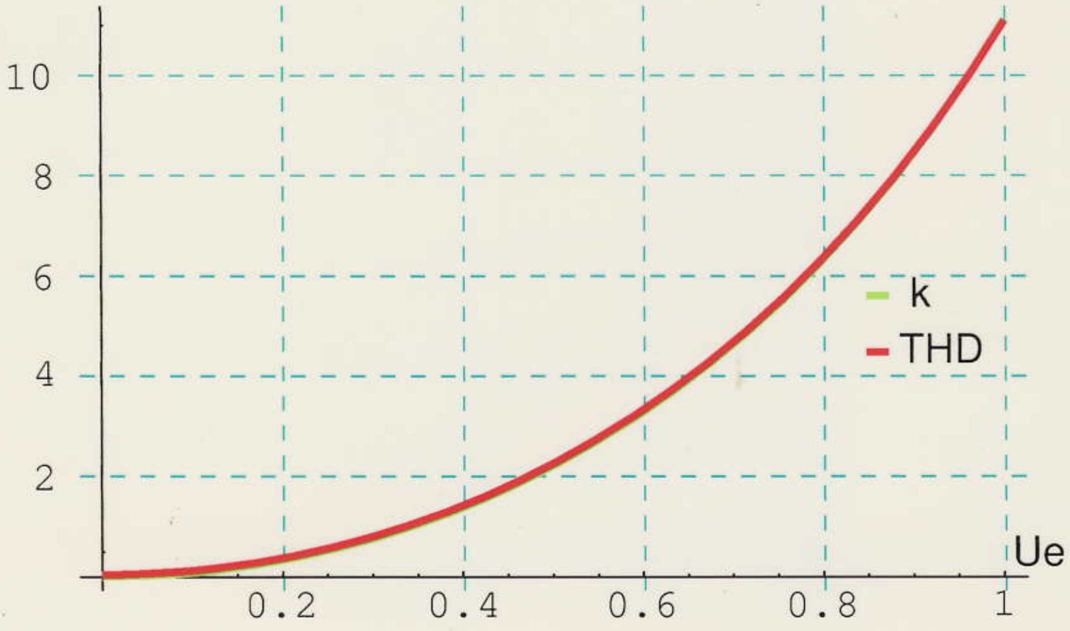
→ Nutzbarer Eingangsspannungsbereich wird vergrößert



Kennlinie

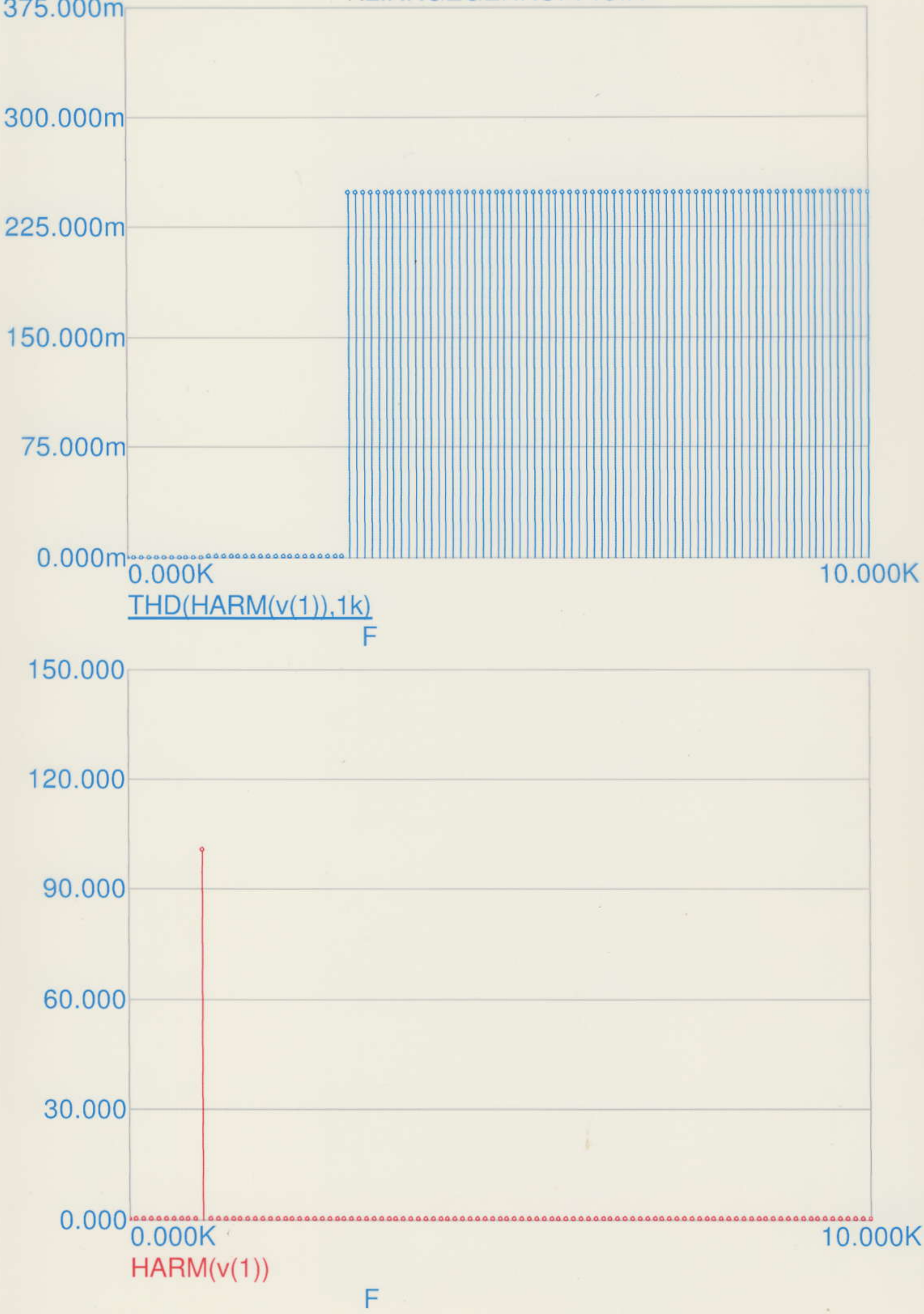


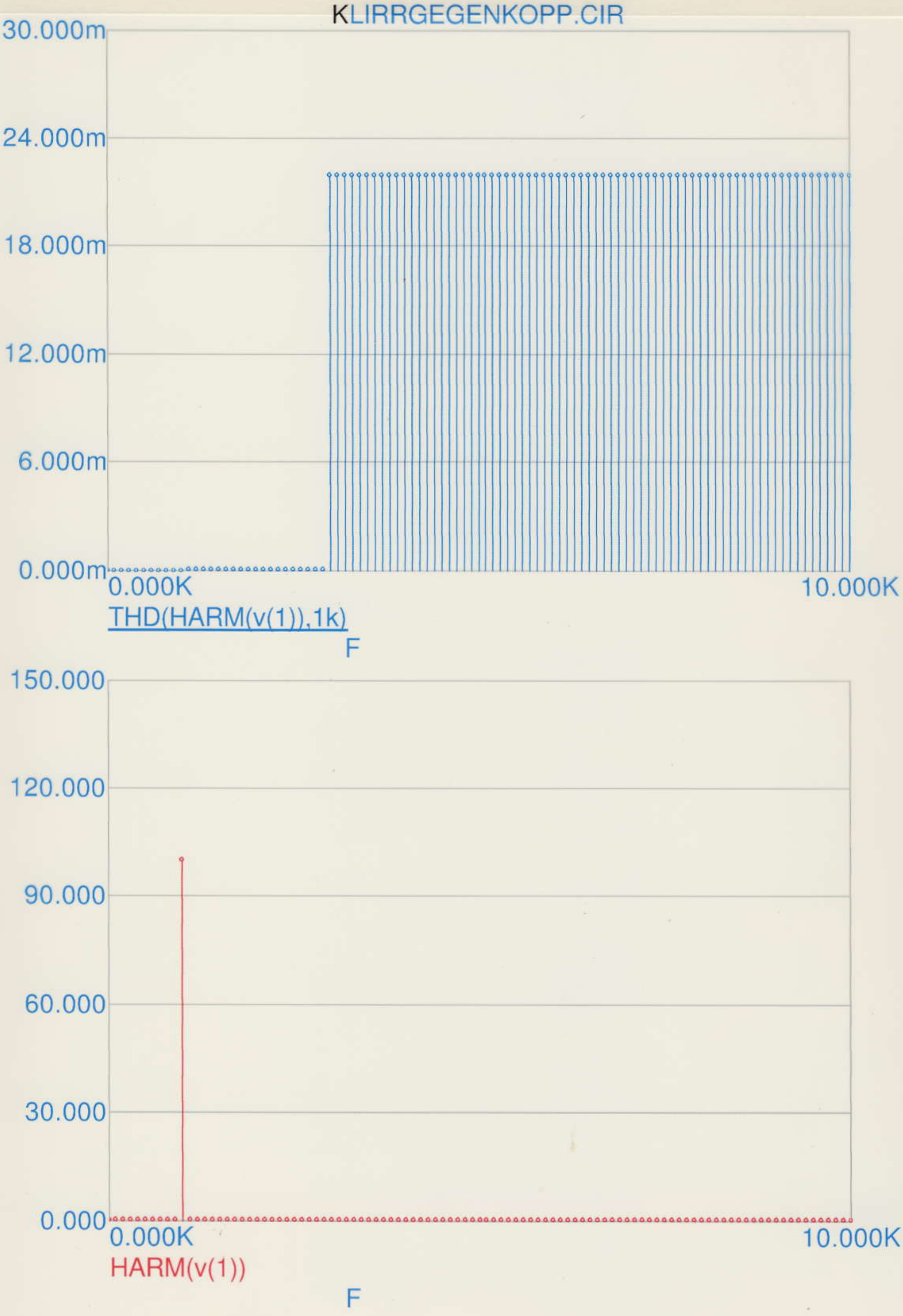
Zeitverlauf



Klirrgrad, THD in %

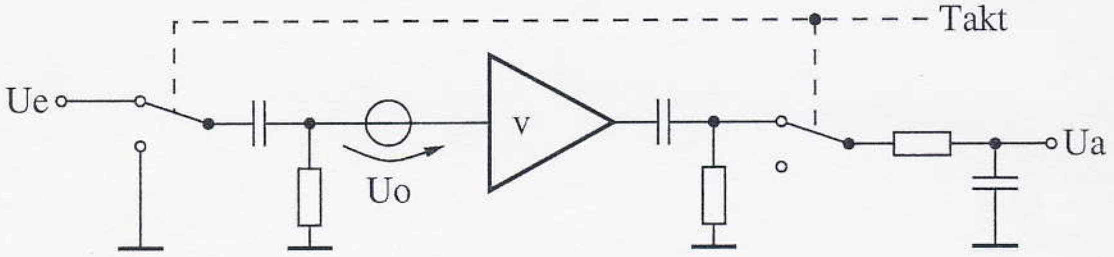
KLIRRGEGENKOPP.CIR

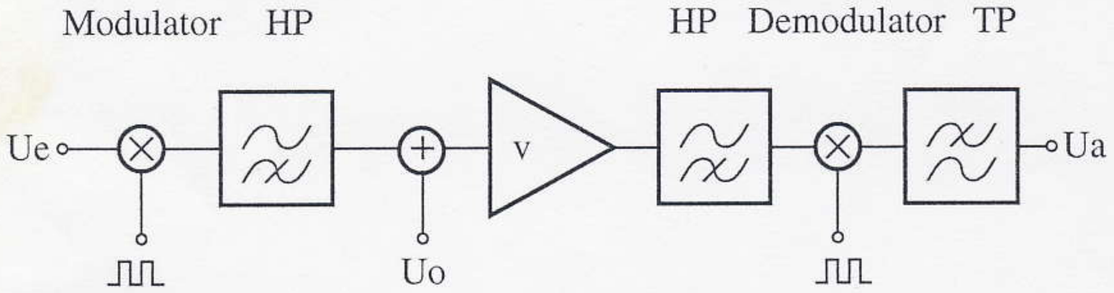



KLIRRGEGENKOPP.CIR
30.000m
24.000m
18.000m
12.000m
6.000m
0.000m
0.000K
10.000K
THD(HARM(v(1)),1k)
F
150.000
120.000
90.000
60.000
30.000
0.000
0.000K
10.000K
HARM(v(1))
F

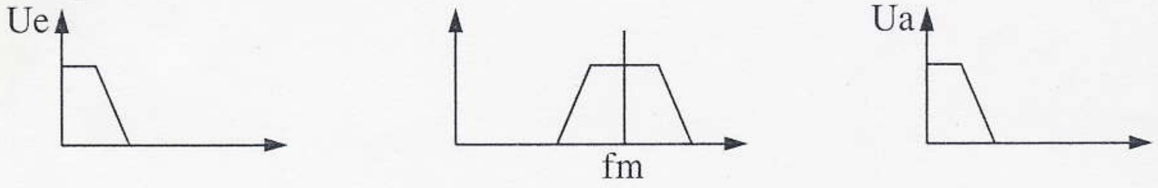
## Driftunterdrückung

### a) Prinzip Chopperverstärker





Spektralverhalten:



Störung:

### b) Prinzip Verstärker mit Driftkorrektur (Auto–Zero)