

Transimpedance amplifier (280MHz)

NE5210

DESCRIPTION

The NE5210 is a $7k\Omega$ transimpedance wide band, low noise amplifier with differential outputs, particularly suitable for signal recovery in fiber-optic receivers. The part is ideally suited for many other RF applications as a general purpose gain block.

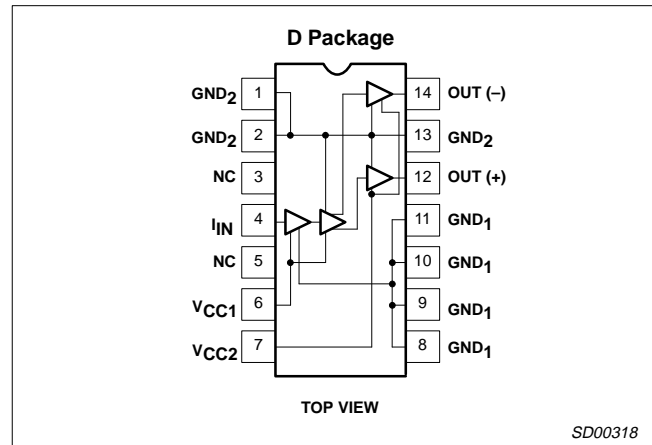
FEATURES

- Low noise: $3.5pA/\sqrt{Hz}$
- Single 5V supply
- Large bandwidth: 280MHz
- Differential outputs
- Low input/output impedances
- High power supply rejection ratio
- High overload threshold current
- High overload threshold current
- Wide dynamic range
- $7k\Omega$ differential transresistance

APPLICATIONS

- Fiber-optic receivers, analog and digital
- Current-to-voltage converters

PIN CONFIGURATION



- Wideband gain block
- Medical and scientific instrumentation
- Sensor preamplifiers
- Single-ended to differential conversion
- Low noise RF amplifiers
- RF signal processing

ORDERING INFORMATION

| DESCRIPTION | TEMPERATURE RANGE | ORDER CODE | DWG # |
|---|-------------------|------------|----------|
| 14-Pin Plastic Small Outline (SO) Package | 0 to +70°C | NE5210D | SOT108-1 |

ABSOLUTE MAXIMUM RATINGS

| SYMBOL | PARAMETER | RATING | UNIT |
|-------------|--|-------------|------|
| V_{CC} | Power supply | 6 | V |
| T_A | Operating ambient temperature range | 0 to +70 | °C |
| T_J | Operating junction temperature range | -55 to +150 | °C |
| T_{STG} | Storage temperature range | -65 to +150 | °C |
| P_{DMAX} | Power dissipation, $T_A=25^\circ C$ (still air) ¹ | 1.0 | W |
| I_{INMAX} | Maximum input current ² | 5 | mA |

NOTES:

1. Maximum dissipation is determined by the operating ambient temperature and the thermal resistance: $\theta_{JA}=125^\circ C/W$.
2. The use of a pull-up resistor to V_{CC} for the PIN diode, is recommended.

RECOMMENDED OPERATING CONDITIONS

| SYMBOL | PARAMETER | RATING | UNIT |
|----------|----------------------------|------------|------|
| V_{CC} | Supply voltage | 4.5 to 5.5 | V |
| T_A | Ambient temperature range | 0 to +70 | °C |
| T_J | Junction temperature range | 0 to +90 | °C |

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NE5210

DC ELECTRICAL CHARACTERISTICS

Min and Max limits apply over operating temperature range at $V_{CC}=5V$, unless otherwise specified. Typical data applies at $V_{CC}=5V$ and $T_A=25^\circ C$.

| SYMBOL | PARAMETER | TEST CONDITIONS | LIMITS | | | UNIT |
|-------------|--|-----------------------------|-----------|-----------|------|---------|
| | | | Min | Typ | Max | |
| V_{IN} | Input bias voltage | | 0.6 | 0.8 | 0.95 | V |
| $V_{O\pm}$ | Output bias voltage | | 2.8 | 3.3 | 3.7 | V |
| V_{OS} | Output offset voltage | | | 0 | 80 | mV |
| I_{CC} | Supply current | | 21 | 26 | 32 | mA |
| I_{OMAX} | Output sink/source current ¹ | | 3 | 4 | | mA |
| I_{IN} | Input current (2% linearity) | Test Circuit 8, Procedure 2 | ± 120 | ± 160 | | μA |
| I_{INMAX} | Maximum input current overload threshold | Test Circuit 8, Procedure 4 | ± 160 | ± 240 | | μA |

NOTES:

1. Test condition: output quiescent voltage variation is less than 100mV for 3mA load current.

AC ELECTRICAL CHARACTERISTICS

Typical data and Min/Max limits apply at $V_{CC}=5V$ and $T_A=25^\circ C$.

| SYMBOL | PARAMETER | TEST CONDITIONS | LIMITS | | | UNIT |
|---------------------|--|---|-----------|------|----------------|-----------------|
| | | | Min | Typ | Max | |
| R_T | Transresistance (differential output) | DC tested, $R_L=\infty$ Test Circuit 8, Procedure 1 | 4.9 | 7 | 10 | k Ω |
| R_O | Output resistance (differential output) | DC tested | 16 | 30 | 42 | Ω |
| R_T | Transresistance (single-ended output) | DC tested, $R_L=\infty$ | 2.45 | 3.5 | 5 | k Ω |
| R_O | Output resistance (single-ended output) | DC tested | 8 | 15 | 21 | Ω |
| f_{3dB} | Bandwidth (-3dB) | Test Circuit 1, $T_A=25^\circ C$ | 200 | 280 | | MHz |
| R_{IN} | Input resistance | | | 60 | | Ω |
| C_{IN} | Input capacitance | | | 7.5 | | pF |
| $\Delta R/\Delta V$ | Transresistance power supply sensitivity | $V_{CC}=5\pm 0.5V$ | | 9.6 | 20 | %/V |
| $\Delta R/\Delta T$ | Transresistance ambient temperature sensitivity | $\Delta T_A=T_{A\ MAX}-T_{A\ MIN}$ | | 0.05 | 0.1 | %/°C |
| I_N | RMS noise current spectral density (referred to input) | $f=10MHz$, $T_A=25^\circ C$ Test Circuit 2 | | 3.5 | 6 | pA/ \sqrt{Hz} |
| I_T | Integrated RMS noise current over the bandwidth (referred to input) $C_S=0^1$ | $T_A=25^\circ C$ Test Circuit 2 $\Delta f=100MHz$ $\Delta f=200MHz$ $\Delta f=300MHz$ | | 37 | | nA |
| | | | $C_S=1pF$ | | 40 66 89 | |
| PSRR | Power supply rejection ratio ² ($V_{CC1}=V_{CC2}$) | DC tested, $\Delta V_{CC}=0.1V$ Equivalent AC test circuit 3 | 20 | 36 | | dB |
| PSRR | Power supply rejection ratio ² (V_{CC1}) | DC tested, $\Delta V_{CC}=0.1V$ Equivalent AC test circuit 4 | 20 | 36 | | dB |
| PSRR | Power supply rejection ratio ² (V_{CC2}) | DC tested, $\Delta V_{CC}=0.1V$ Equivalent AC test circuit 5 | | 65 | | dB |
| PSRR | Power supply rejection ratio ² (ECL configuration) | $f=0.1MHz$, Test Circuit 6 | | 23 | | dB |

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NE5210

AC ELECTRICAL CHARACTERISTICS (Continued)

| SYMBOL | PARAMETER | TEST CONDITIONS | LIMITS | | | UNIT |
|--------------------|---|--|--------|-----|-----|-------------------|
| | | | Min | Typ | Max | |
| V _{OMAX} | Maximum output voltage swing differential | R _L =∞ Test Circuit 8, Procedure 3 | 2.4 | 3.2 | | V _{P-P} |
| V _{INMAX} | Maximum input amplitude for output duty cycle of 50±5% ³ | Test Circuit 7 | 650 | | | mV _{P-P} |
| t _R | Rise time for 50 mV _{P-P} output signal ⁴ | Test Circuit 7 | | 0.8 | 1.2 | ns |

NOTES:

1. Package parasitic capacitance amounts to about 0.2pF
2. PSRR is output referenced and is circuit board layout dependent at higher frequencies. For best performance use RF filter in V_{CC} line.
3. Guaranteed by linearity and overload tests.
4. t_R defined as 20-80% rise time. It is guaranteed by a -3dB bandwidth test.

TEST CIRCUITS

Test Circuit 1

| SINGLE-ENDED | DIFFERENTIAL |
|---|---|
| $R_T \approx \frac{V_{OUT}}{V_{IN}} R = 2 \cdot S_{21} \cdot R$ | $R_T = \frac{V_{OUT}}{V_{IN}} R = 4 \cdot S_{21} \cdot R$ |
| $R_O \approx Z_O \frac{ 1 + S_{22} }{ 1 - S_{22} } - 33$ | $R_O = 2Z_O \frac{ 1 + S_{22} }{ 1 - S_{22} } - 66$ |

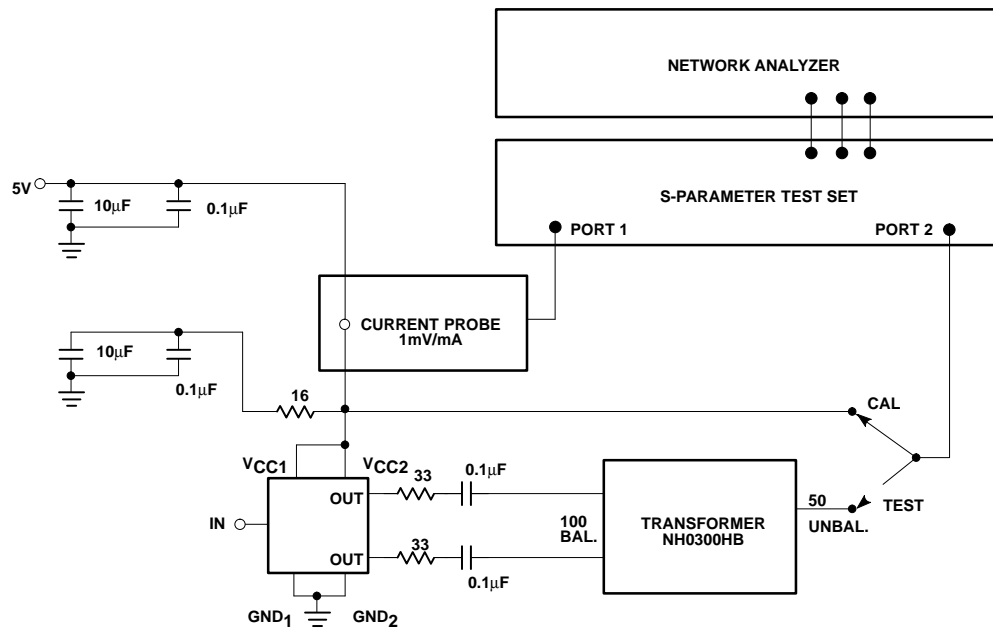
Test Circuit 2

SD00319

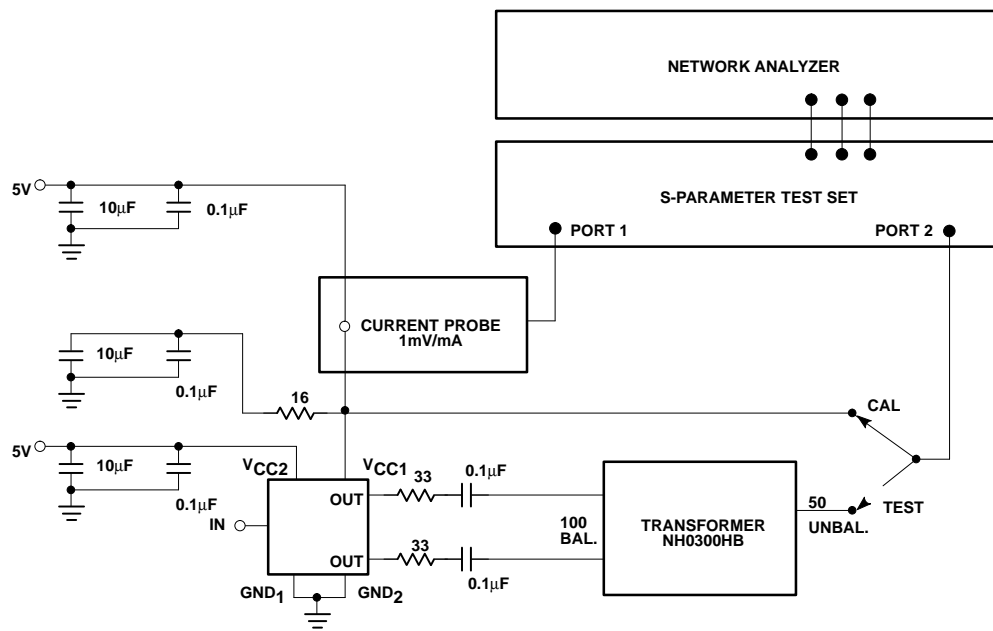
Transimpedance amplifier (280MHz)

NE5210

TEST CIRCUITS (Continued)



Test Circuit 3



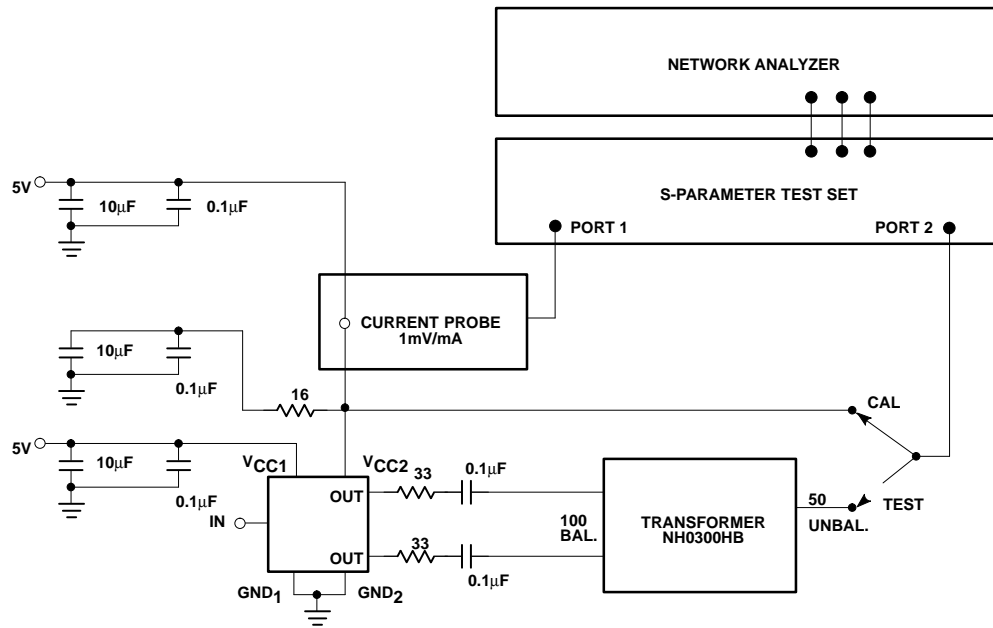
Test Circuit 4

SD00320

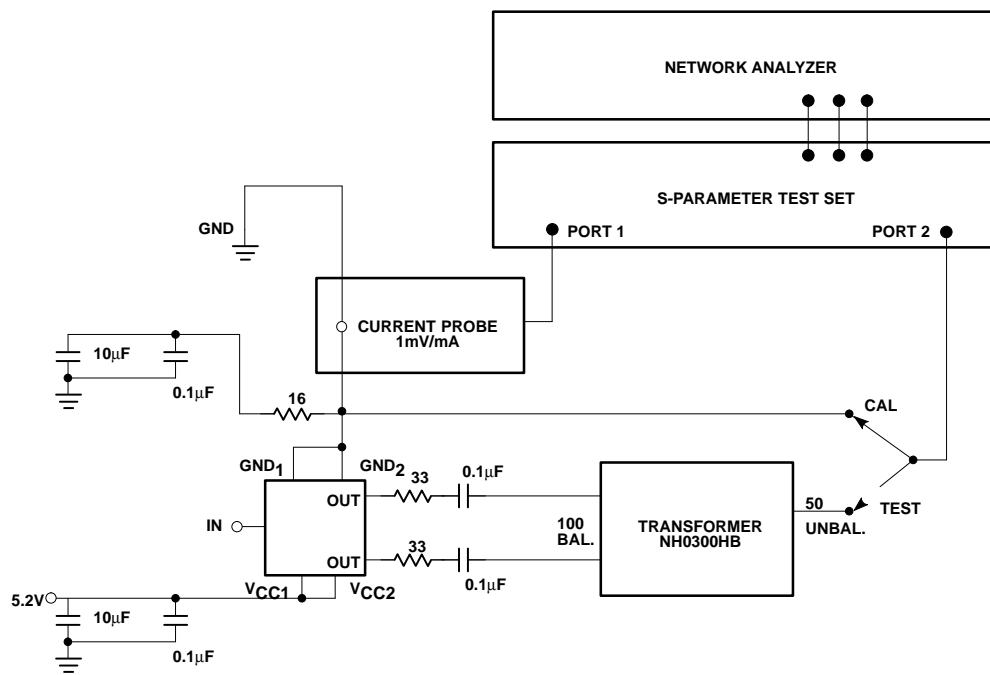
Transimpedance amplifier (280MHz)

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TEST CIRCUITS (Continued)



Test Circuit 5



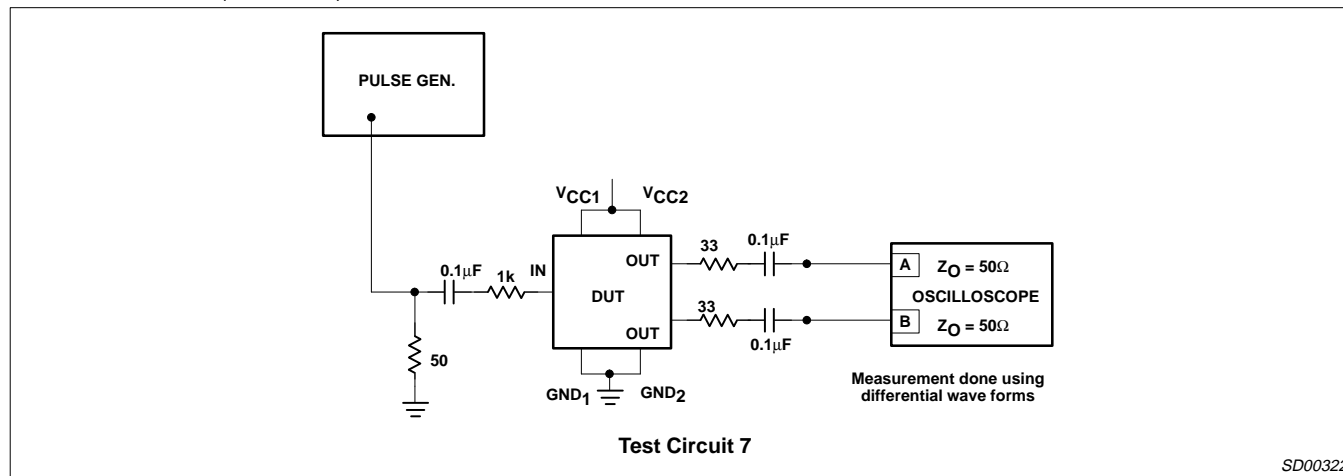
Test Circuit 6

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NE5210

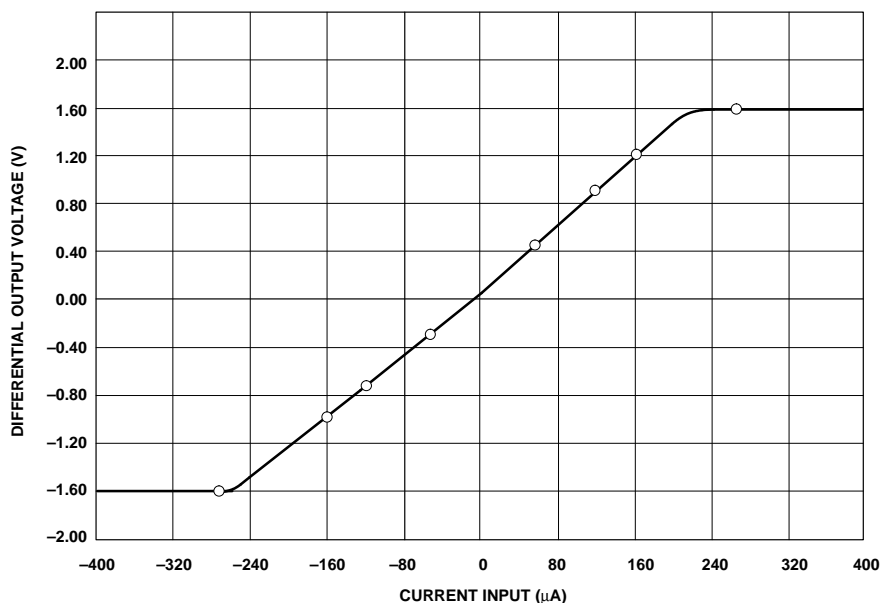
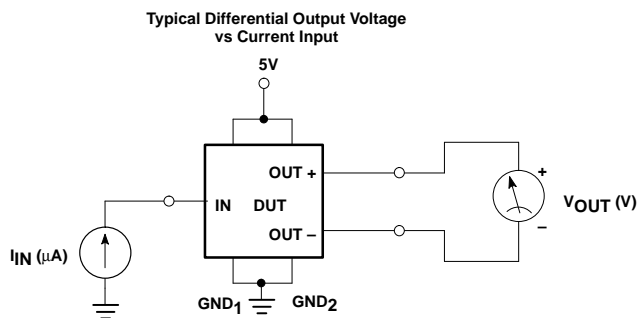
TEST CIRCUITS (Continued)



Transimpedance amplifier (280MHz)

NE5210

TEST CIRCUITS (Continued)



NE5210 TEST CONDITIONS

- Procedure 1 R_T measured at $60\mu A$
 $R_T = (V_{O1} - V_{O2}) / (+60\mu A - (-60\mu A))$
 Where: V_{O1} Measured at $I_{IN} = +60\mu A$
 V_{O2} Measured at $I_{IN} = -60\mu A$
- Procedure 2 $Linearity = 1 - ABS((V_{OA} - V_{OB}) / (V_{O3} - V_{O4}))$
 Where: V_{O3} Measured at $I_{IN} = +120\mu A$
 V_{O4} Measured at $I_{IN} = -120\mu A$
 $V_{OA} = R_T \cdot (+120\mu A) + V_{OB}$
 $V_{OB} = R_T \cdot (-120\mu A) + V_{OB}$
- Procedure 3 $V_{OMAX} = V_{O7} - V_{O8}$
 Where: V_{O7} Measured at $I_{IN} = +260\mu A$
 V_{O8} Measured at $I_{IN} = -260\mu A$
- Procedure 4 I_{IN} Test Pass Conditions:
 $V_{O7} - V_{O5} > 20mV$ and $V_{O6} - V_{O5} > 20mV$
 Where: V_{O5} Measured at $I_{IN} = +160\mu A$
 V_{O6} Measured at $I_{IN} = -160\mu A$
 V_{O7} Measured at $I_{IN} = +260\mu A$
 V_{O8} Measured at $I_{IN} = -260\mu A$

Test Circuit 8

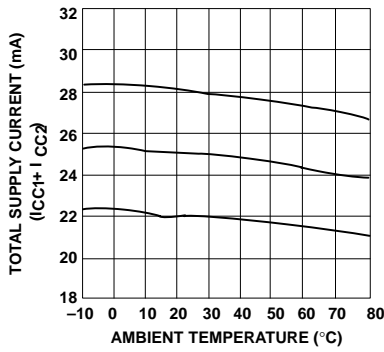
SD00323

Transimpedance amplifier (280MHz)

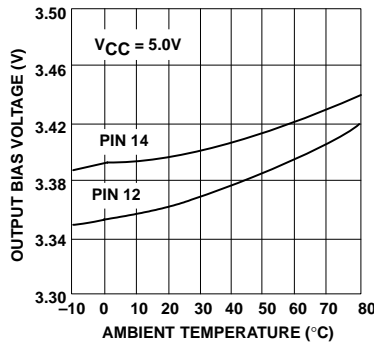
NE5210

TYPICAL PERFORMANCE CHARACTERISTICS

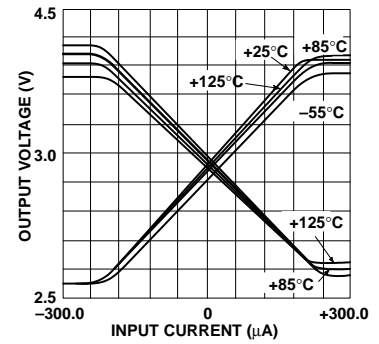
NE5210 Supply Current vs Temperature



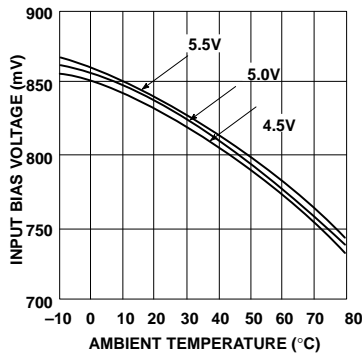
NE5210 Output Bias Voltage vs Temperature



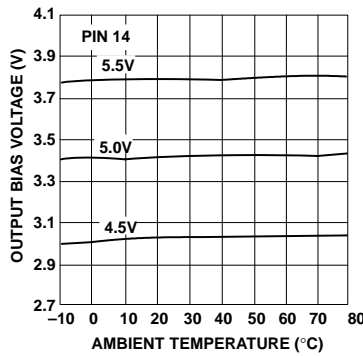
Output Voltage vs Input Current



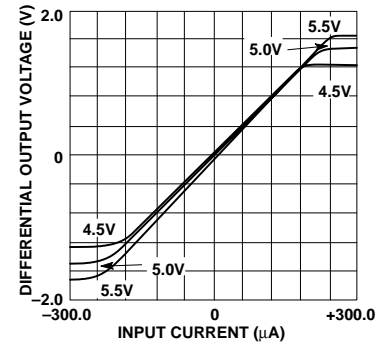
NE5210 Input Bias Voltage vs Temperature



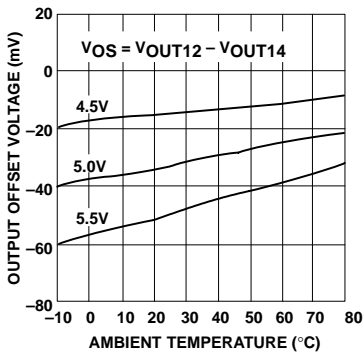
NE5210 Output Bias Voltage vs Temperature



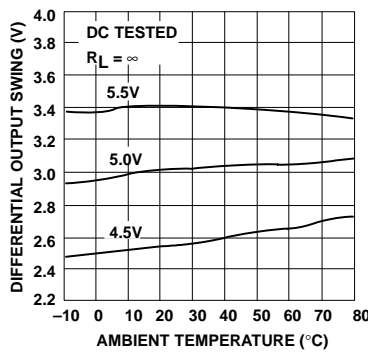
Differential Output Voltage vs Input Current



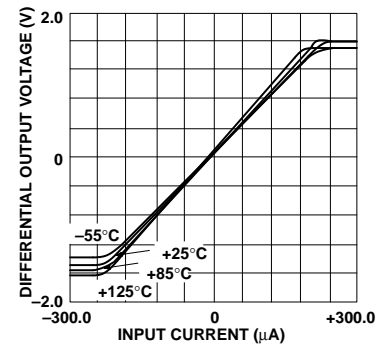
NE5210 Output Offset Voltage vs Temperature



NE5210 Differential Output Swing vs Temperature



Differential Output Voltage vs Input Current

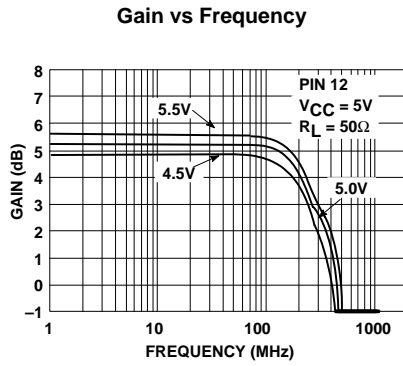
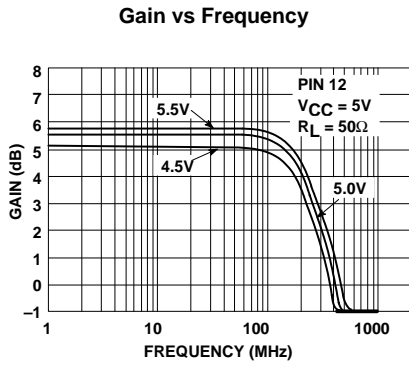


SD00324

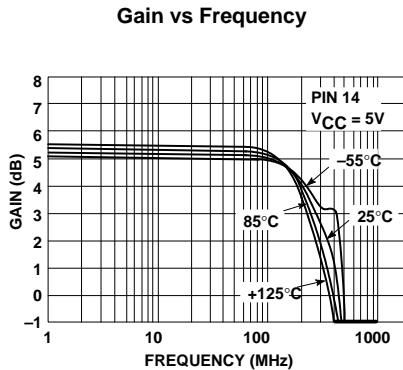
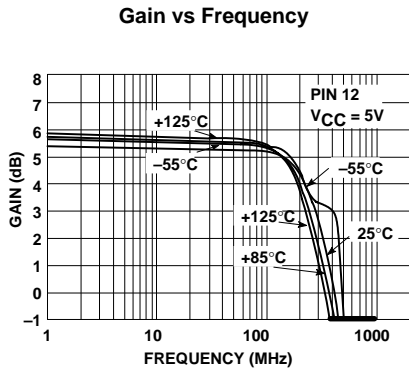
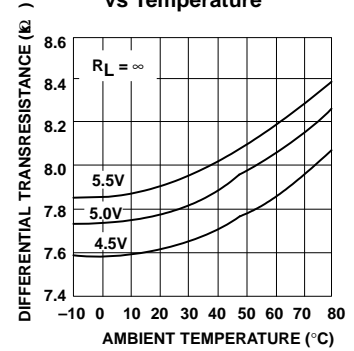
Transimpedance amplifier (280MHz)

NE5210

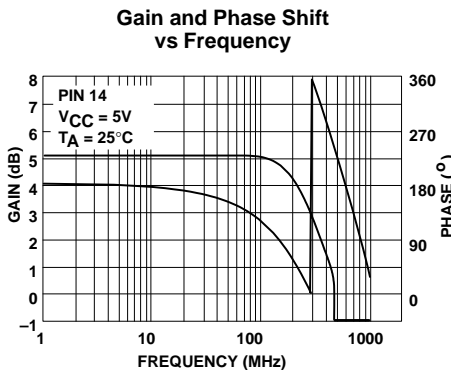
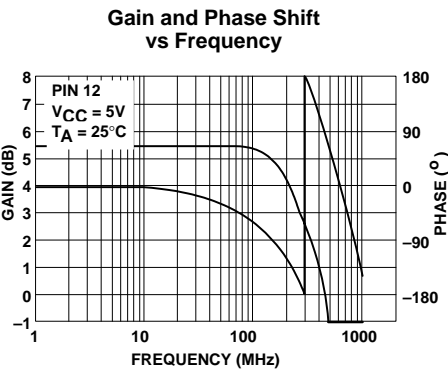
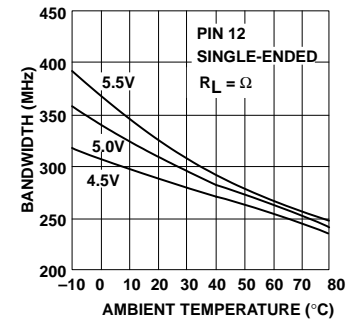
TYPICAL PERFORMANCE CHARACTERISTICS (Continued)



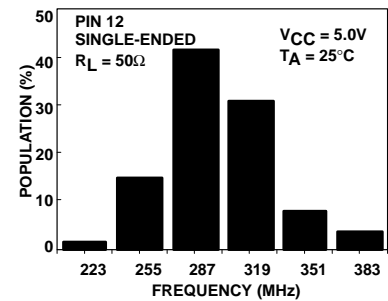
NE5210 Differential Transresistance vs Temperature



NE5210 Bandwidth vs Temperature



NE5210 Typical Bandwidth Distribution (70 Parts from 4 Wafer Lots)

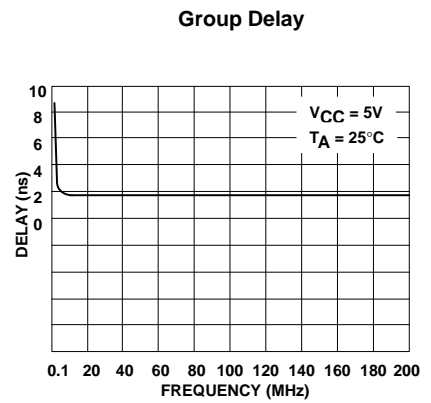
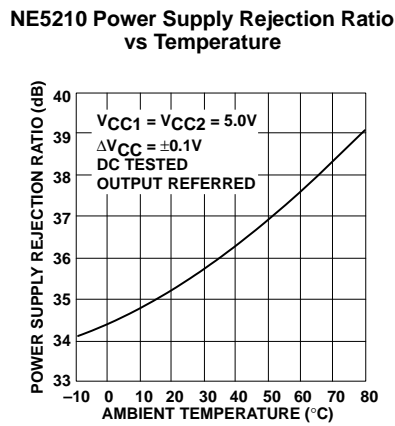
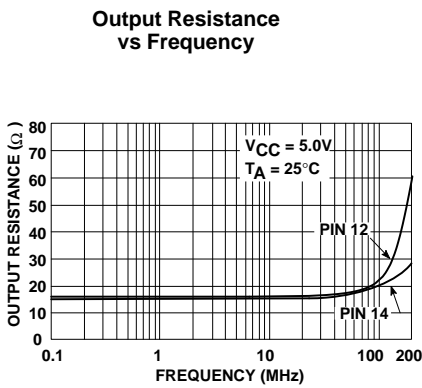
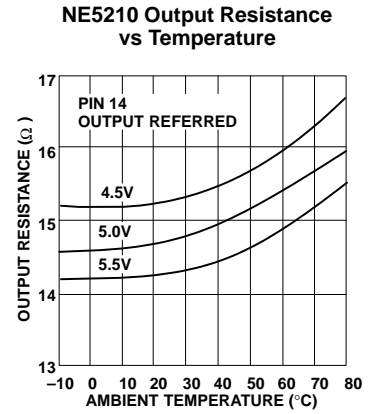
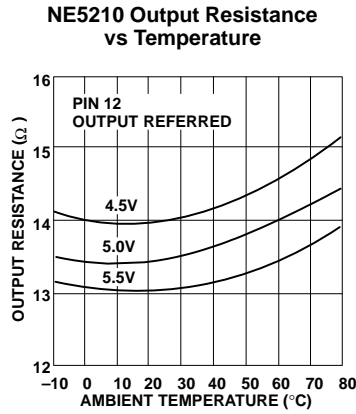
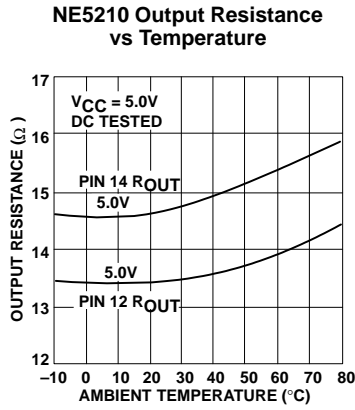


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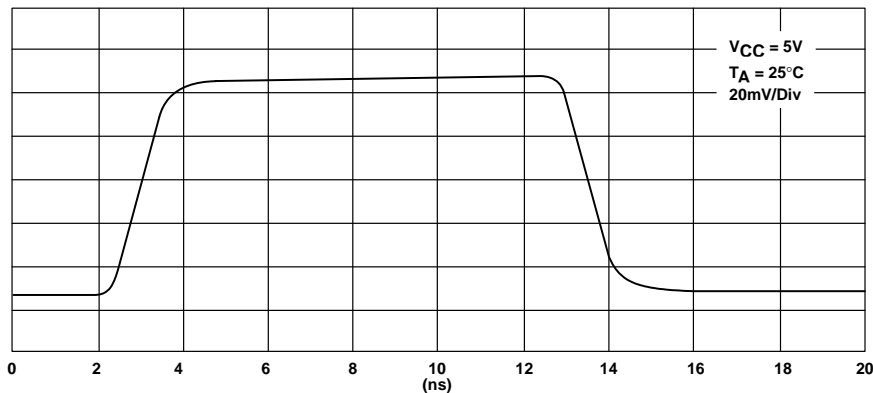
Transimpedance amplifier (280MHz)

NE5210

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)



Output Step Response



SD00326

Transimpedance amplifier (280MHz)

NE5210

THEORY OF OPERATION

Transimpedance amplifiers have been widely used as the preamplifier in fiber-optic receivers. The NE5210 is a wide bandwidth (typically 280MHz) transimpedance amplifier designed primarily for input currents requiring a large dynamic range, such as those produced by a laser diode. The maximum input current before output stage clipping occurs at typically 240µA. The NE5210 is a bipolar transimpedance amplifier which is current driven at the input and generates a differential voltage signal at the outputs. The forward transfer function is therefore a ratio of the differential output voltage to a given input current with the dimensions of ohms. The main feature of this amplifier is a wideband, low-noise input stage which is desensitized to photodiode capacitance variations. When connected to a photodiode of a few picoFarads, the frequency response will not be degraded significantly. Except for the input stage, the entire signal path is differential to provide improved power-supply rejection and ease of interface to ECL type circuitry. A block diagram of the circuit is shown in Figure 1. The input stage (A1) employs shunt-series feedback to stabilize the current gain of the amplifier. The transresistance of the amplifier from the current source to the emitter of Q₃ is approximately the value of the feedback resistor, R_F=3.6kΩ. The gain from the second stage (A2) and emitter followers (A3 and A4) is about two. Therefore, the differential transresistance of the entire amplifier, R_T is

$$R_T = \frac{V_{OUT(diff)}}{I_{IN}} = 2R_F = 2(3.6K) = 7.2k$$

The single-ended transresistance of the amplifier is typically 3.6kΩ.

The simplified schematic in Figure 2 shows how an input current is converted to a differential output voltage. The amplifier has a single input for current which is referenced to Ground 1. An input current from a laser diode, for example, will be converted into a voltage by the feedback resistor R_F. The transistor Q1 provides most of the open loop gain of the circuit, A_{VOL}≈70. The emitter follower Q₂ minimizes loading on Q₁. The transistor Q₄, resistor R₇, and V_{B1} provide level shifting and interface with the Q₁₅ - Q₁₆ differential pair of the second stage which is biased with an internal reference, V_{B2}. The differential outputs are derived from emitter followers Q₁₁ - Q₁₂ which are biased by constant current sources. The collectors of Q₁₁ - Q₁₂ are bonded to an external pin, V_{CC2}, in order to reduce the feedback to the input stage. The output impedance is about 17Ω single-ended. For ease of performance evaluation, a 33Ω resistor is used in series with each output to match to a 50Ω test system.

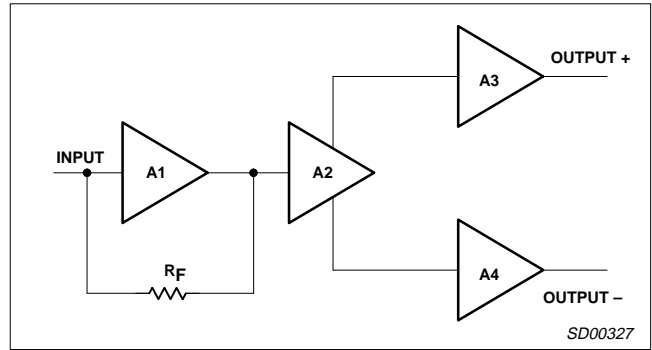


Figure 1. NE5210 – Block Diagram

BANDWIDTH CALCULATIONS

The input stage, shown in Figure 3, employs shunt-series feedback to stabilize the current gain of the amplifier. A simplified analysis can determine the performance of the amplifier. The equivalent input capacitance, C_{IN}, in parallel with the source, I_S, is approximately 7.5pF, assuming that C_S=0 where C_S is the external source capacitance.

Since the input is driven by a current source the input must have a low input resistance. The input resistance, R_{IN}, is the ratio of the incremental input voltage, V_{IN}, to the corresponding input current, I_{IN} and can be calculated as:

$$R_{IN} = \frac{V_{IN}}{I_{IN}} = \frac{R_F}{1 + A_{VOL}} = \frac{3.6K}{71} = 51$$

More exact calculations would yield a higher value of 60Ω.

Thus C_{IN} and R_{IN} will form the dominant pole of the entire amplifier;

$$f_{-3dB} = \frac{1}{2 R_{IN} C_{IN}}$$

Assuming typical values for R_F = 3.6kΩ, R_{IN} = 60Ω, C_{IN} = 7.5pF

$$f_{-3dB} = \frac{1}{2 \cdot 7.5pF \cdot 60} = 354MHz$$

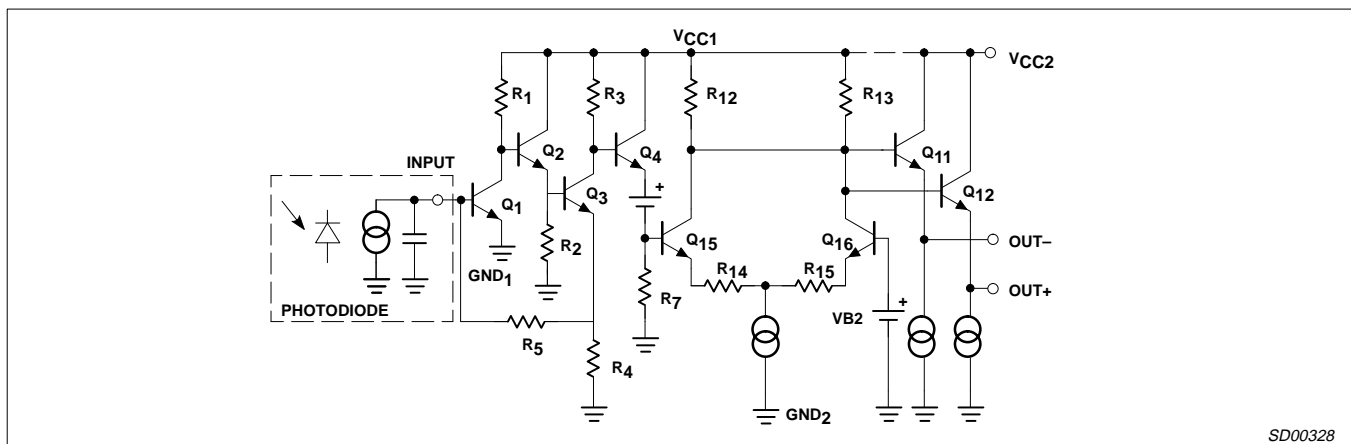


Figure 2. Transimpedance Amplifier

Transimpedance amplifier (280MHz)

NE5210

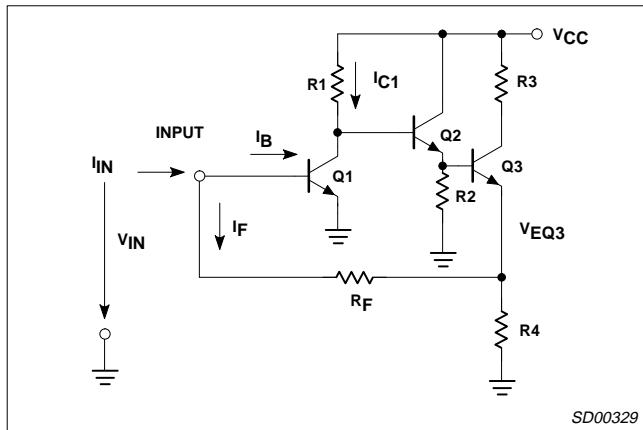


Figure 3. Shunt-Series Input Stage

The operating point of Q1, Figure 2, has been optimized for the lowest current noise without introducing a second dominant pole in the pass-band. All poles associated with subsequent stages have been kept at sufficiently high enough frequencies to yield an overall single pole response. Although wider bandwidths have been achieved by using a cascode input stage configuration, the present solution has the advantage of a very uniform, highly desensitized frequency response because the Miller effect dominates over the external photodiode and stray capacitances. For example, assuming a source capacitance of 1pF, input stage voltage gain of 70, $R_{IN} = 60\Omega$ then the total input capacitance, $C_{IN} = (1+7.5) \text{ pF}$ which will lead to only a 12% bandwidth reduction.

NOISE

Most of the currently installed fiber-optic systems use non-coherent transmission and detect incident optical power. Therefore, receiver noise performance becomes very important. The input stage achieves a low input referred noise current (spectral density) of $3.5 \text{ pA}/\sqrt{\text{Hz}}$. The transresistance configuration assures that the external high value bias resistors often required for photodiode biasing will not contribute to the total noise system noise. The equivalent input R_{MS} noise current is strongly determined by the quiescent current of Q1, the feedback resistor R_F , and the bandwidth; however, it is not dependent upon the internal Miller-capacitance. The measured wideband noise was 66 nA_{RMS} in a 200MHz bandwidth.

DYNAMIC RANGE CALCULATIONS

The electrical dynamic range can be defined as the ratio of maximum input current to the peak noise current:

Electrical dynamic range, D_E , in a 200MHz bandwidth assuming $I_{INMAX} = 240\mu\text{A}$ and a wideband noise of $I_{EQ} = 66 \text{ nA}_{RMS}$ for an external source capacitance of $C_S = 1 \text{ pF}$.

$$D_E = 20 \log \frac{(\text{Max. input current}) (\text{PK})}{(\text{Peak noise current}) (\text{RMS}) \cdot \sqrt{2}}$$

$$= 20 \log \frac{(240 \cdot 10^{-6})}{(\sqrt{2} \cdot 66 \cdot 10^{-9})} = 68 \text{ dB}$$

In order to calculate the optical dynamic range the incident optical power must be considered.

For a given wavelength λ ; (meters)
 Energy of one Photon = $\frac{hc}{\lambda}$ watt sec (Joule)

Where h = Planck's Constant = 6.6×10^{-34} Joule sec.

c = speed of light = 3×10^8 m/sec

c / λ = optical frequency (Hz)

No. of incident photons/sec = $\frac{P}{\frac{hc}{\lambda}}$ where P = optical incident power

$$\text{No. of incident photons/sec} = \frac{P}{\frac{hc}{\lambda}}$$

where P = optical incident power

$$\text{No. of generated electrons/sec} = \eta \cdot \frac{P}{\frac{hc}{\lambda}}$$

where η = quantum efficiency

$$= \frac{\text{no. of generated electron hole pairs}}{\text{no. of incident photons}}$$

$$I = \eta \cdot \frac{P}{\frac{hc}{\lambda}} \cdot e \text{ Amps (Coulombs sec.)}$$

where e = electron charge = 1.6×10^{-19} Coulombs

$$\text{Responsivity } R = \frac{\eta \cdot e}{\frac{hc}{\lambda}} \text{ Amp/watt}$$

$$I = P \cdot R$$

Assuming a data rate of 400 Mbaud (Bandwidth, $B=200\text{MHz}$), the noise parameter Z may be calculated as:¹

$$Z = \frac{I_{EQ}}{qB} = \frac{66 \cdot 10^{-9}}{(1.6 \cdot 10^{-19})(200 \cdot 10^6)} = 2063$$

where Z is the ratio of R_{MS} noise output to the peak response to a single hole-electron pair. Assuming 100% photodetector quantum efficiency, half mark/half space digital transmission, 850nm lightwave and using Gaussian approximation, the minimum required optical power to achieve 10^{-9} BER is:

$$P_{avMIN} = 12 \frac{hc}{\lambda} B Z = 12 \cdot 2.3 \cdot 10^{-19}$$

$$= 200 \cdot 10^6 \cdot 2063$$

$$= 1139 \text{ nW} = -29.4 \text{ dBm}$$

where h is Planck's Constant, c is the speed of light, λ is the wavelength. The minimum input current to the NE5210, at this input power is:

$$I_{avMIN} = q P_{avMIN} \frac{\lambda}{hc}$$

$$= \frac{1139 \cdot 10^{-9} \cdot 1.6 \cdot 10^{-19}}{2.3 \cdot 10^{-19}}$$

$$= 792 \text{ nA}$$

Choosing the maximum peak overload current of $I_{avMAX} = 240\mu\text{A}$, the maximum mean optical power is:

$$P_{avMAX} = \frac{hc I_{avMAX}}{q \lambda} = \frac{2.3 \cdot 10^{-19} \cdot 240 \cdot 10^{-6}}{1.6 \cdot 10^{-19}}$$

Thus the optical dynamic range, D_O is:

$$D_O = P_{avMAX} - P_{avMIN} = -4.6 - (-29.4) = 24.8 \text{ dB.}$$

Transimpedance amplifier (280MHz)

NE5210

This represents the maximum limit attainable with the NE5210 operating at 200MHz bandwidth, with a half mark/half space digital transmission at 850nm wavelength.

APPLICATION INFORMATION

Package parasitics, particularly ground lead inductances and parasitic capacitances, can significantly degrade the frequency response. Since the NE5210 has differential outputs which can feed back signals to the input by parasitic package or board layout capacitances, both peaking and attenuating type frequency response shaping is possible. Constructing the board layout so that Ground 1 and Ground 2 have very low impedance paths has produced the best results. This was accomplished by adding a ground-plane stripe underneath the device connecting Ground 1, Pins 8–11, and Ground 2, Pins 1 and 2 on opposite ends of the SO14 package. This ground-plane stripe also provides isolation between the output return currents flowing to either V_{CC2} or Ground 2 and the input photodiode currents to flowing to Ground 1. Without this ground-plane stripe and with large lead inductances on the board, the part may be unstable and oscillate near 800MHz. The easiest way to realize that the part is not functioning normally is to measure the DC voltages at the outputs. If they are not close to their

quiescent values of 3.3V (for a 5V supply), then the circuit may be oscillating. Input pin layout necessitates that the photodiode be physically very close to the input and Ground 1. Connecting Pins 3 and 5 to Ground 1 will tend to shield the input but it will also tend to increase the capacitance on the input and slightly reduce the bandwidth.

As with any high-frequency device, some precautions must be observed in order to enjoy reliable performance. The first of these is the use of a well-regulated power supply. The supply must be capable of providing varying amounts of current without significantly changing the voltage level. Proper supply bypassing requires that a good quality 0.1µF high-frequency capacitor be inserted between V_{CC1} and V_{CC2} , preferably a chip capacitor, as close to the package pins as possible. Also, the parallel combination of 0.1µF capacitors with 10µF tantalum capacitors from each supply, V_{CC1} and V_{CC2} , to the ground plane should provide adequate decoupling. Some applications may require an RF choke in series with the power supply line. Separate analog and digital ground leads must be maintained and printed circuit board ground plane should be employed whenever possible.

Figure 4 depicts a 50Mb/s TTL fiber-optic receiver using the BPF31, 850nm LED, the NE5210 and the NE5214 post amplifier.

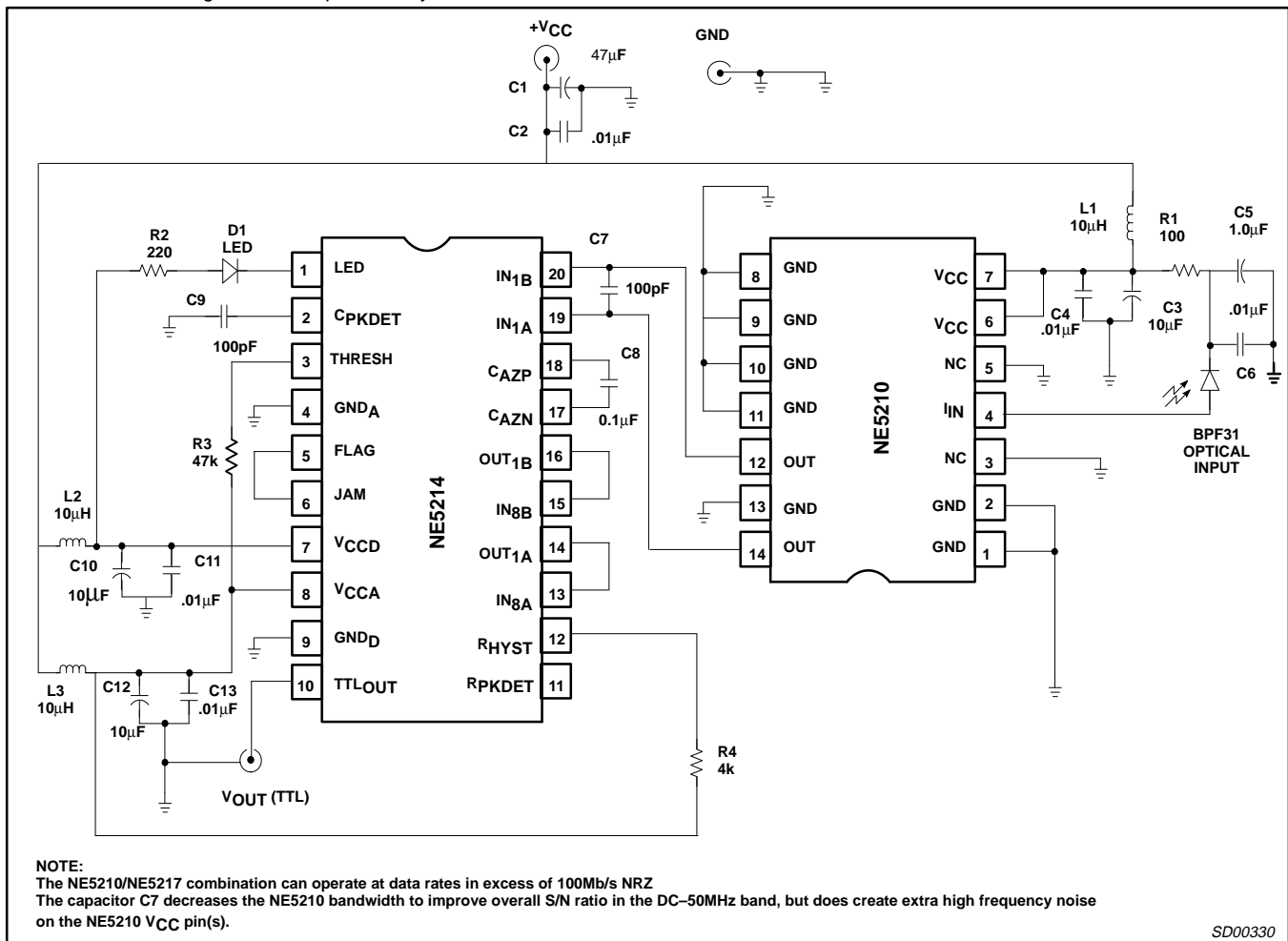


Figure 4. A 50Mb/s Fiber Optic Receiver

Transimpedance amplifier (280MHz)

NE5210

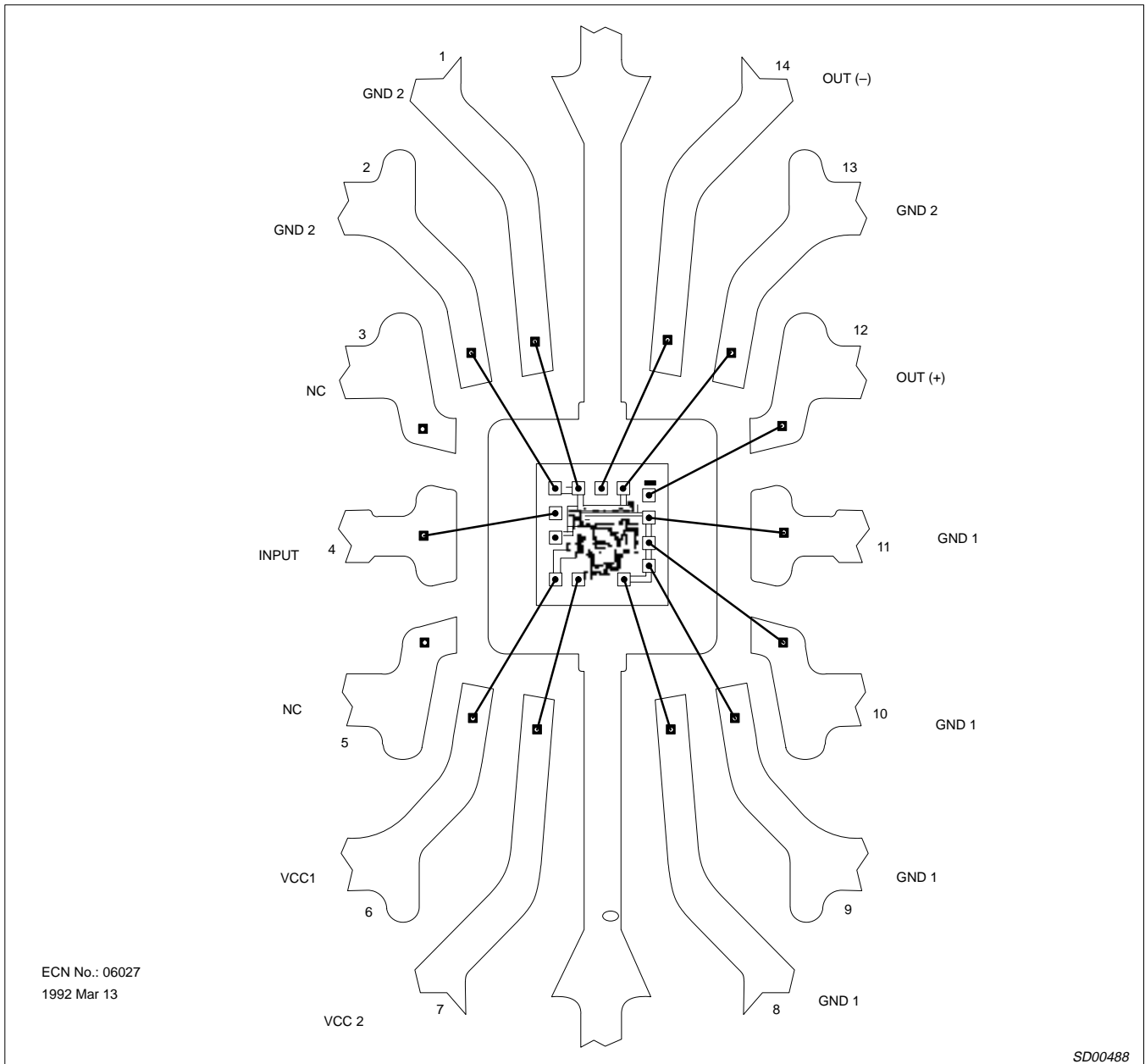


Figure 5. NE5210 Bonding Diagram

Die Sales Disclaimer

Due to the limitations in testing high frequency and other parameters at the die level, and the fact that die electrical characteristics may shift after packaging, die electrical parameters are not specified and die are not guaranteed to meet electrical characteristics (including temperature range) as noted in this data sheet which is intended only to specify electrical characteristics for a packaged device.

All die are 100% functional with various parametrics tested at the wafer level, at room temperature only (25°C), and are guaranteed to be 100% functional as a result of electrical testing to the point of wafer sawing only. Although the most modern processes are utilized for wafer sawing and die pick and place into waffle pack

carriers, it is impossible to guarantee 100% functionality through this process. There is no post waffle pack testing performed on individual die.

Since Philips Semiconductors has no control of third party procedures in the handling or packaging of die, Philips Semiconductors assumes no liability for device functionality or performance of the die or systems on any die sales.

Although Philips Semiconductors typically realizes a yield of 85% after assembling die into their respective packages, with care customers should achieve a similar yield. However, for the reasons stated above, Philips Semiconductors cannot guarantee this or any other yield on any die sales.