UNIVERSIDAD CARLOS III DE MADRID
ESCUELA POLITÉCNICA SUPERIOR

EXAMEN DE INSTRUMENTACIÓN ELECTRÓNICA I
2º CURSO INGENIERÍA TÉCNICA EN ELECTRÓNICA INDUSTRIAL

6 de Febrero de 1996

DURACIÓN: 3 H 30 M

1. Se desea comparar las características de dos sensores de iluminancia: una LDR y un fotodiodo cuyas hojas de características se adjuntan. Para ello se propone el circuito sumador de la Figura 1 que permite obtener una salida proporcional a la suma de las señales de entrada.

![Diagrama de circuito sumador](image)

Figura 1

(2 puntos)

(a) Calcular $v_o$ en función de las corrientes $i_1$ e $i_2$. ¿Qué parámetros fijan los valores de dichas corrientes en la expresión de $v_o$? ¿Tiene $v_o$ un comportamiento lineal con la luz? de la radiación incidente? ¿Por qué?

(b) ¿Qué sensor tiene una mayor respuesta espectral?

(c) Ajuste los valores de las resistencias que sean necesarios para que $v_o$ tenga la misma contribución de ambos sensores para una iluminancia de 300 lux.

2. Se diseña un acelerómetro para la medida de aceleraciones según el esquema de la Figura 2. Los datos de la galga se encuentran en la hoja de características que se adjunta.

\[
\begin{align*}
L_y &= dx \\
L_x &= L \frac{a}{d} \\
L_y &= dx \\
L_x &= L \left(\frac{a}{d}\right)
\end{align*}
\]
mientras que los de la ménsula (probeta) son: módulo de elasticidad $E=10^8$ N/m$^2$, módulo de Poisson $\nu=0.3$, sección transversal $s=2 \times 10^{-4}$ m$^2$.

![Diagrama](image)

Figura 2

(3 puntos)

(a) Explique su principio de funcionamiento de forma breve y concisa.

(b) Calcule la sensibilidad del acelerómetro en $\Omega/g$.

(c) Diseñe un circuito acondicionador de la señal para el acelerómetro de la Figura 2 utilizando un puente de Wheatstone y el amplificador de instrumentación AD620 cuyas hojas de características se adjuntan:

   c.1 Especificque la orientación de las galgas extensométricas en la ménsula y su colocación en el puente. El montaje en el puente ha de ser tal que permita máxima sensibilidad y compensación de la temperatura. Explique razonadamente su diseño.

   c.2. Calcule la sensibilidad del puente en mv/g. Si no se calculó la sensibilidad del acelerómetro en el apartado (b), suponga $S_a=2 \times 10^2$ $\Omega/g$. La alimentación del puente es de 12 v. ¿Cómo afecta dicho valor de la tensión de alimentación a la sensibilidad del puente?. ¿Cómo influye en el funcionamiento de la galga?

   c.3 Determine los valores exactos que deben tener las resistencias del puente para que se anule la tensión de desequilibrio del puente cuando no se aplica aceleración.

   c.4 Calcule el valor de la resistencia que fija la ganancia del amplificador de instrumentación para obtener un rango de señal de salida de 0 a 10v en la medida de aceleraciones de 0 a 200 g. Si no calculó antes la sensibilidad del puente suponga $S_a=0,65$ mv/g.

   c.5 ¿Qué ventajas presenta el utilizar el puente de Wheatstone frente a un circuito potenciométrico?. Mencione 3 razones que exijan el uso de un amplificador de instrumentación a la salida del puente de Wheatstone.

3. Se desea medir la temperatura dentro de una cubeta en un rango de 20 a 80°C, de forma que la tensión de salida varie de 0 a -10v. Para ello se propone el circuito de la Figura 3.
(2 puntos)

(a) Calcule la tensión de salida $v_o$ en función de $v_1$ y de la tensión $v(T)$ a la salida del sensor de temperatura. ¿Se obtiene una función lineal si se supone que $v(T)$ varía linealmente con la temperatura? ¿Qué fija la posición del potenciómetro $P_1$? ¿Cómo se consiguen los -10V de fondo de escala para la temperatura de 80°C? ¿Qué función tiene cada etapa con amplificador operacional?

(b) Si se utiliza como sensor de temperatura una RTD lineal que tiene una resistencia de 141 Ω a 50 °C, un coeficiente de variación con la temperatura de 0.004/°C y que disipa una potencia de $30\text{mW}/°C$:

b.1 ¿Cuál es la corriente máxima que puede circular por la RTD para poder medir con un error inferior a 0.1°C?

b.2 ¿Cuáles deben ser los valores de $R_1$, $R_2$, $R_E$ para que la fuente de corriente suministre un 50% de dicha corriente máxima? (Suponga $I_{MAX}=1.5\text{mA}$ si no fue calculada en el apartado anterior).

b.3 Supuesta la red de polarización diseñada en la etapa anterior, ¿qué ganancia debe suministrar la etapa inversora para conseguir el rango de señal de salida deseado? ¿Cuáles han de ser los valores de $R_1$ y $R_2$? ¿Cuál ha de ser la posición del cursor $P_1$?

(c) Sea un termistor NTC con una variación de -10%/°C, una resistencia de 3.5KΩ a 20 °C y una potencia disipada de $P_D=5\text{mW}/°C$. Si se coloca esta NTC en lugar de la RTD en el montaje diseñado en el apartado anterior (con los mismos valores para todos los componentes), ¿qué error mínimo se cometería en la medida de temperatura?

(d) ¿Qué otros sensores de temperatura eléctricos conoce? Enumérelos y especifique una de sus características más sobresaliente frente a los otros.

4. Se utiliza un sensor de posición potenciométrico para medir desplazamientos de 0 a 10cm de una pieza móvil, como se muestra en la Figura 4, la resistencia varía linealmente en este rango de 0 a 2KΩ.
(1 punto)

(a) Diseñe un circuito acondicionador que proporcione una salida lineal de 0 a 5v.

(b) ¿Qué otro tipo de transductores pasivos basados en la variación de impedancia se pueden utilizar en la medida de desplazamientos? Enumérelos y describálos brevemente.

5. Explique cualitativamente las variaciones de las tensiones y corrientes indicadas en la Figura 5, ante un aumento de la tensión $E$.

(1 punto)

6. Explicar brevemente el funcionamiento del circuito mostrado en la Figura 6, indicando de qué etapas está compuesto.

-Sabiendo que la resistencia de salida del sensor de Efecto Hall es 50Ω, ¿qué constante de tiempo rige la carga del condensador C1?, ¿Qué tipo de filtro es?, ¿Cuál es su frecuencia de corte?

(1 punto)
Light dependent resistors

Two cadmium sulphide (cdS) photoconductive cells with spectral response similar to that of the human eye. The cell resistance falls with increasing light intensity. Applications include smoke detection, automatic lighting control, batch counting and burglar alarm systems.

Guide to source illuminations

<table>
<thead>
<tr>
<th>Light source</th>
<th>Illumination (lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moonlight</td>
<td>0.1</td>
</tr>
<tr>
<td>60W bulb at 1m</td>
<td>50</td>
</tr>
<tr>
<td>1W MCB bulb at 0.1m</td>
<td>100</td>
</tr>
<tr>
<td>Fluorescent lighting</td>
<td>500</td>
</tr>
<tr>
<td>Bright sunlight</td>
<td>30,000</td>
</tr>
</tbody>
</table>

Circuit symbol

Light memory characteristics

Light dependent resistors have a particular property in that they remember the lighting conditions in which they have been stored. This memory effect can be minimised by storing the LDRs in light prior to use. Light storage reduces equilibrium time to reach steady resistance values.

NORP12 (RS stock no. 651-507)

Absolute maximum ratings

- Voltage, a.c. or d.c. peak: 320V
- Current: 75mA
- Power dissipation at 35°C: 350mW
- Operating temperature range: -50°C to +75°C

Electrical characteristics

T = 25°C 2854K tungsten light source

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell resistance</td>
<td>100 lux</td>
<td>0.1</td>
<td>4.0</td>
<td>12</td>
<td>kΩ</td>
</tr>
<tr>
<td></td>
<td>10 lux</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>kΩ</td>
</tr>
<tr>
<td>Dark resistance</td>
<td>-</td>
<td>3.5</td>
<td>1.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Dark capacitance</td>
<td>-</td>
<td>3.5</td>
<td>1.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Dark time 1</td>
<td>1000 lux</td>
<td>-</td>
<td>2.0</td>
<td>-</td>
<td>ms</td>
</tr>
<tr>
<td></td>
<td>10 lux</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>ms</td>
</tr>
<tr>
<td>Dark time 2</td>
<td>1000 lux</td>
<td>-</td>
<td>4.0</td>
<td>-</td>
<td>ms</td>
</tr>
<tr>
<td></td>
<td>10 lux</td>
<td>-</td>
<td>2.0</td>
<td>-</td>
<td>ms</td>
</tr>
</tbody>
</table>

1. Dark to 110% R
2. To 10 x R
R = photocell resistance under given illumination

Features

- Wide spectral response
- Low cost
- Wide ambient temperature range

Dimensions
Absolute maximum ratings
- Voltage at no load peaks: 100V
- Current: 5mA
- Power dissipation at 25°C: 50mW
- Operating temperature range: -25°C to 75°C

Electrical characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Usual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell resistance</td>
<td>10 lux</td>
<td>20</td>
<td>%</td>
<td>100</td>
<td>kΩ</td>
</tr>
<tr>
<td></td>
<td>100 lux</td>
<td>%</td>
<td></td>
<td></td>
<td>kΩ</td>
</tr>
<tr>
<td>Dark resistance</td>
<td>10 lux after 10 sec</td>
<td>%</td>
<td>20</td>
<td></td>
<td>nΩ</td>
</tr>
<tr>
<td>Spectral response</td>
<td></td>
<td>99%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emitter</td>
<td>100 Ωc</td>
<td>45</td>
<td>ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collector</td>
<td>100 Ωc</td>
<td>95</td>
<td>ms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 4: Resistance as a function of illumination](image)

![Figure 5: Spectral response](image)
<table>
<thead>
<tr>
<th>Gauge Pattern Leads Attached</th>
<th>Type</th>
<th>Dimensions (mm)</th>
<th>Nominal Resistance (Ω)</th>
<th>Gauge Factor (approx.)</th>
<th>Gauges per Package</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gauge Length</td>
<td>Gauge Width</td>
<td>Backing</td>
<td></td>
</tr>
<tr>
<td><strong>PFL-10-II</strong></td>
<td>10</td>
<td>0.9</td>
<td>18 x 6</td>
<td>120 ± 0.3</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>PFL-20-II</strong></td>
<td>20</td>
<td>1.4</td>
<td>28 x 6</td>
<td>120 ± 0.3</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>PFC-10-II</strong></td>
<td>10</td>
<td>0.9</td>
<td>18 x 18</td>
<td>120 ± 0.5</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>PFC-20-II</strong></td>
<td>20</td>
<td>1.4</td>
<td>28 x 28</td>
<td>120 ± 0.5</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>PFCS-10-II</strong></td>
<td>10</td>
<td>0.9</td>
<td>21 x 21</td>
<td>120 ± 0.5</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>PFR-10-II</strong></td>
<td>10</td>
<td>0.9</td>
<td>18 x 18</td>
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</tr>
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<td>10</td>
<td>0.9</td>
<td>21 x 21</td>
<td>120 ± 0.5</td>
<td>2.1</td>
</tr>
</tbody>
</table>

*"P" series gauges are temperature compensated by m/si steel only.*
HIGH ACCURACY A/D CONVERTERS

For high accuracy and high resolution, sampling point A/D converters are limited by the combination of offset and gain calibration errors. There are two basic techniques available for calibration: a hardware method, as shown in Figure 43, and a software technique, as shown in Figure 44. In this application, the microprocessor is hardwired into the monitoring circuit, ensuring software calibration. Therefore, a hardware calibration was applied which limited the software handoff. The software is used to set the gain of the A/D converter, and the MSB of the AD526 is in error as a polarity bit, the gain is increased to the maximum value. This maximizes the full scale range of the conversion process and results in a low dynamic range.

The calibration technique uses two point correction, offset and gain. The hardware is simplified by the use of programmable data tables, the AD526, which can be "burned".

![Diagram of AD526 A/D Converter](image-url)

Figure 43. High Accuracy A/D Converter

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ANALOG DEVICES

LOW COST, LOW POWER INSTRUMENTATION AMPLIFIER

AD620

FEATURES
- EASY TO USE
- Gain Set with One External Resistor
- Gain Ramp (1 to 1000)
- Wide Power Supply Range (+3.3 V to 18 V)
- High Performance with Three Op Amp IA Designs
- Available in 8-Pin DIP and SOIC Packaging
- Low Power, 1.3 mA max Supply Current
- Excellent DC Performance ("A Grade")
- ±150 μV max Input Offset Voltage (50 μV max "B" Grade)
- 1 μV/°C max Input Offset Drift
- 20 mA max Input Bias Current
- 93 dB min Common Mode Rejection Ratio (G = 1)

LOW NOISE
- 5 nV/V/Hz at 1 kHz, Input Voltage Noise
- 624 nV/p-p Noise (1 kHz to 10 Hz)

EXEMPLARY AC SPECIFICATIONS
- 120 kHz Bandwidth (G = 100)
- 15 μA Setting Time to 0.01%

APPLICATIONS
- ECG and Medical Instrumentation
- Data Acquisition Systems
- Industrial Process Controls
- Portable Equipment

PRODUCT DESCRIPTION

The AD620 is a low-cost, high accuracy instrument amplifier which requires only one external resistor to set gains of 1 to 1000. Furthermore, the AD620 features low offset and drift characteristics of ±150 μV max and ±0.6 μV/°C max, ideal for use in precision data acquisition systems, such as weigh scales and transfer interface. Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications such as ECGs and monitoring blood pressure.

The low input bias current of 1.0 mA max is made possible with the use of superbeta processing in the input stage. The AD620 works in a preamplifier due to its low input voltage noise of 5 nV/√Hz at 1 kHz, 0.1 Vp-p in ±1 kHz bandwidth, 0.1 μV/p-p input current noise. Also, the AD620 is well suited for multiphase applications with its setting time of 15 μs to 0.01% and can be used in low cost to enable designs with one input per channel.

![Typical Standard Input Drift](image-url)

![Typical Standard Input Voltage Noise](image-url)

INSTRUMENTATION AMPLIFIERS 4-61
<table>
<thead>
<tr>
<th>Condition</th>
<th>Input Range ±5 V</th>
<th>Input Range ±10 V</th>
<th>Input Range ±20 V</th>
<th>Input Range ±100 V</th>
<th>Input Range ±200 V</th>
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</thead>
<tbody>
<tr>
<td>Average IC</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
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<tr>
<td>Over Temperature</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Input Current</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Over Temperature</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Input Current</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Over Temperature</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Current Draw</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Over Temperature</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Current Draw</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Note: For more information, please refer to the manual or contact the manufacturer.
THEORY OF OPERATION

The AD620 is a monolithic instrumentation amplifier based on a modification of the classic three-op-amp approach. Absolute value scaling allows the user to program gains accurately to ±5% in G = 100 with only one resistor. Monolithic construction and low noise filtering allow the input matching and tracking of circuit components, thus ensuring the highest level of performance inherent in this circuit.

The input transistors Q1 and Q2 provide a single-differential input pair for high precision (Figure 11), yet offer the lower input bias currents typical of low power operation. Feedback through the Q3-A1 pair and Q2-A2-A3 loop assist constant offset currents of the input devices Q1, Q2 thereby rendering the input voltage across the current setting resistor Rs. This creates a differential gain from the input in the A1A2 outputs given by G = (B1 + B2)/B1, + 1. The unity gain A2 provides A3 a constant common-mode signal, yielding a single-ended output referenced to the REF pin potential.

The transconductance of the three transistors (Q1, Q2, and Q3) determine the common-mode rejection of the input stage. This gain is critical for larger gains. At high gains, the offset cannot be reduced to the same level as for lower gains, thus requiring additional compensation. The gain bandwidth product (determined by B1, B2, and C1) can be increased by using a higher voltage, thus increasing the frequency response. The gain of the second stage is determined by the offset current of the input devices.

The internal gain resistors, R1 and R2, are trimmed to an average value of 21.5 kΩ, allowing the gain to be programmed accurately with a single external resistor.
The BPW 34 is a silicon planar PIN photodiode incorporating in a transparent plastic package. Its terminals are soldering tabs arranged in 8.00 mm (2/10") spacing. Due to its design, the diode can also very easily be assembled on PC boards. The planar reverse side of the plastic package provides for stable fixation. Arrays can be implemented by multiple arrangements. This versatile photodetector can be used as a diode as well as a solar cell. The signal/noise ratio is particularly favorable, even at low illuminance. The open-circuit voltage at low illuminance is higher than with comparable mesa photovoltaic cells. The PIN photodiode is outstanding for low junction capacitance, high cut-off frequency and fast switching times. The photodiode is particularly suitable for IR sound transmission. The cathode is marked by a projection at the soldering tab.

### Maximum ratings
- 

#### Reversing voltage

*Vₐ* 32

#### Operating and storage temperature range
- Operating temperature 230°C
- Storage temperature -40 to +80°C

#### Total power dissipation
- **Pₚ** 6.8 x 10⁻⁵ W
- **Ω** 4.2 x 10⁻¹⁴ W/Hz

### Characteristics (Tₑ = 25°C)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral sensitivity (S)</td>
<td>70 (±50) nA/W</td>
</tr>
<tr>
<td>Wavelength of max. sensitivity (λ)</td>
<td>850 nm</td>
</tr>
<tr>
<td>Quantum yield (η)</td>
<td>0.88 electrons/Photon</td>
</tr>
<tr>
<td>Spectral sensitivity (S₃)</td>
<td>0.60 A/W</td>
</tr>
<tr>
<td>Open-circuit voltage (Uₑ) = 100 kV</td>
<td>256 mV</td>
</tr>
<tr>
<td>Open-circuit voltage (Uₑ) = 100 kV</td>
<td>385 mV</td>
</tr>
<tr>
<td>Short-circuit current (Iₛ)</td>
<td>5.5 μA</td>
</tr>
<tr>
<td>Rise and fall time of the photocurrent</td>
<td>128 ns</td>
</tr>
<tr>
<td>Temperature coefficient of Vₑ</td>
<td>-2.8 mV/K</td>
</tr>
<tr>
<td>Temperature coefficient of Iₛ</td>
<td>0.18 %/K</td>
</tr>
<tr>
<td>Capacitance</td>
<td>72 pF (Cₑ)</td>
</tr>
<tr>
<td>Radiant sensitive area</td>
<td>2.3 x 10⁻⁴ cm²</td>
</tr>
<tr>
<td>Dark current (Vₑ = 10 V)</td>
<td>7.0 pA</td>
</tr>
<tr>
<td>Noise equivalent power (Vₑ = 10 V)</td>
<td>4.2 x 10⁻¹⁴ W/Hz</td>
</tr>
</tbody>
</table>

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**Note:** The spectral sensitivity indicated refers to unfiltered radiation at a temperature of 20°C and 2.0 mm from a Planckian source (1 mW).
MEDIUM POWER LINEAR AND SWITCHING APPLICATION

DESCRIPTION
The BD433, BD435 and BD437 are silicon epitaxial-base NPN power transistors in Jedeo TO-126 style package, intended for use in medium power linear and switching applications.

The BD433 is especially suitable for use in cascade output stages.

The complementary PNP types are the BD434, BD436 and BD438 respectively.

INTERNAL SCHEMATIC DIAGRAMS

ABSOLUTE MAXIMUM RATINGS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>NPN</th>
<th>PNP*</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Collector-base Voltage (I_E = 0)</td>
<td>BD433: 22</td>
<td>BD434: 32</td>
<td>BD435: 45</td>
<td>V</td>
</tr>
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<td>Collector-emitter Voltage (V_BE = 0)</td>
<td>BD433: 22</td>
<td>BD434: 32</td>
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<td>Emitter-base Voltage (I_CE = 0)</td>
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<td>Collector Peak Current (I_CE ≤ 10 ms)</td>
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<td>Total Power Dissipation at T_case ≤ 25 ºC</td>
<td>BD433: 36</td>
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<td>Junction Temperature</td>
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* PNP types voltage and current values are negative

December 1988
### THERMAL DATA

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### ELECTRICAL CHARACTERISTICS (Tcase = 25 °C unless otherwise specified)

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<td>VCE(sat)</td>
<td>Collector-emitter Saturation Voltage</td>
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* Pulsed: pulse duration = 300 µs, duty cycle = 1.5%.

For PNP types voltage and current values are negative.