NEP
« Noise Equivalent Power » Calculation

MenloSystems GmbH

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Content

1 Introduction

1.1 Definition of NEP

Contrary of what could be thought regarding the wide use of the Noise Equivalent Power in literature to characterize the measurements limits of detectors, it is not easy to find a clear mathematical definition of the NEP in the literature!
The first definition given here comes from the Federal Standard 1037C (telecom glossary 2000) of the United State Government. “*Noise-equivalent power (NEP) is the radiant power that produces a signal-to-noise ratio of unity at the output of a given optical detector, operating wavelength, and effective noise bandwidth. Some manufacturers and authors define NEP as the minimum detectable power per square root bandwidth [W/Hz1/2].*”

Noise Equivalent Power, or NEP, is a basic indicator of detector performance. NEP is the noise floor of a detector, normalized to a 1Hz bandwidth. NEP is expressed in Watts per square root bandwidth. To derive NEP, two parameters must be measured: the detector responsivity at a specified frequency, and the detector voltage noise at the same frequency. NEP can then be calculated as:

$$NEP = \frac{Noise\ Voltage/\sqrt{Hz}}{Rv} \quad at\ some\ freqeuncy,\ f_o$$

If the electrical pole of the detector circuit shown in figure 1 is much less than the unity gain bandwidth of the amplifier, the responsivity for the detector is given by:

$$Rv(f) = \frac{R_i \cdot R_f \cdot \frac{f}{f_{therm}}}{\sqrt{1+\left(\frac{f}{f_{therm}}\right)^2} \cdot \sqrt{1+\left(\frac{f}{f_{pole}}\right)^2}}$$

$$f_{pole} = \frac{1}{2 \cdot \pi \cdot R_f \cdot C_f} \qquad f_{therm} = Pyroelectric\ Thermal\ Tau$$

If we specify that the frequency of measurement is higher than the thermal frequency and lower than the electrical pole, the responsivity can be simplified to:

$$Rv(f) = \frac{R_i \cdot R_f}{\sqrt{1+(f \cdot 2 \cdot \pi \cdot R_f \cdot C_f)^2}}$$

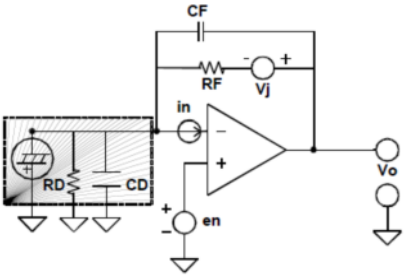


Figure 1.1-1 Current Radiometer with Noise Source Calculation

1.2 Definitions and Terms

1.2.1 Definitions

- Photo sensitivity: **S[A/W]**
  Ratio between photo current of the diode (A) and optical input power (W)

- Dark current: **I_D [A]**
  Diode noise current (Diode with voltage feed and without optical input power)

- Shunt resistance: **R_{sh} [Ohm]**
  Parallel shunt resistor of the diode – between 10^8 Ohm und 10^{11} Ohm

- Noise figure: **NF [dB], F(figure)**
  Noise figure → NF= 10log F

1.2.2 Terms

Absolute terms:

- Electron charge $e = 1{,}602 \times 10^{-19}$ C
- Boltzmann $k = 1{,}38 \times 10^{-23}$ J/K
- Absolute temperature $T_0 = 298{,}15$ K

Used equations:

- Shot noise: $I_S = (2eI_DB)^{1/2}$ [A];

- Johnson noise: $I_j = (4KTB/R_{sh})^{1/2}$ [A] ; B – Bandwidth [Hz]

- NEP : NEP = I_{rtot}/S [W] ; I_{rtot} – Overall noise current at amplifier input

  or

  NEP = $I_{rtot}/SB^{1/2}$ [W/Hz$^{1/2}$]

- Noise figure
  HF-Amplifier: **$F = P_{aus}/GKT_0B$**
  G – amplification
  P_{aus} – power output
  K – Boltzmann constant
  T_0 – absolute temperature
  B – Bandwidth

- Overall noise figure

  $F_{tot} = F_1 + (F_2 – 1)/ G_1 + \ldots + (F_n -1)/ G_{n-1}$
  G_1 – Gain of amplifier 1

2 Photodetector APD 210

2.1 Photodiode

Typ : C30737E-500, Perkin Elmer

Data sheet:
I_D = max. 10×10^{-9} A;
S = 50 A/W;
C_p = 0,3 pF; (parallel capacity of the diode)
$R_{sh} = 5\times10^8\ \Omega$ (no specification – value estimated)

- Shot noise: $I_S = (2eI_DB)^{1/2} = 1{,}79\times10^{-9}$ A; B = 1GHz
  $I_S = (2eI_DB)^{1/2} = 5{,}66\times10^{-11}$ A; B = 1MHz
  $I_S = (2eI_DB)^{1/2} = 5{,}66\times10^{-14}$ A; B = 1Hz
- Johnson noise: $I_j = (4KTB/R_{sh})^{1/2} = 1{,}81\times10^{-10}$ A; B = 1GHz
  $I_j = (4KTB/R_{sh})^{1/2} = 5{,}73\times10^{-12}$ A; B = 1MHz
  $I_j = (4KTB/R_{sh})^{1/2} = 5{,}73\times10^{-15}$ A; B = 1Hz

- Total current: $I_{tot} = (I_S^2 + I_j^2)^{1/2} = 1{,}80\times10^{-9}$ A; B = 1GHz
  $I_{tot} = (I_S^2 + I_j^2)^{1/2} = 5{,}68\times10^{-11}$ A; B = 1MHz
  $I_{tot} = (I_S^2 + I_j^2)^{1/2} = 5{,}68\times10^{-14}$ A; B = 1Hz
- NEP_{Diode} = I_{tot}[A]/S[A/W] = **$3{,}60\times10^{-11}$ W; B = 1 GHz**
  = **$1{,}14\times10^{-12}$ W; B = 1 MHz**
  = **$1{,}14\times10^{-15}$ W; B = 1 Hz**

or

$NEP_{Diode} = 1{,}14\times10^{-15}$ [W/Hz$^{1/2}$].

2.2 *Amplifier*

TYP: RF2360-NBB500 – two stages:

Data sheet:

RF2360 G = 20dB oder 100;

NF = 1,5dB (1GHz); **=> F = 1,41**

NBB500 G = 20dB oder 100;

NF = 3,2dB (1GHz); **=> F = 2,08**

$F_{tot} = F_1 + (F_2 - 1)/ G_1 + \ldots + (F_n - 1)/ G_{n-1}$; (in general)

$F_{tot} = 1{,}41 + (2{,}08 - 1)/100 = 1{,}43$;

$F_{tot} = P_{aus}/GKT_0B$; $\Rightarrow P_{aus} = \mathbf{F_{tot}\, GKT_0B}$;

$P_{in} = P_{aus}/G = F_{tot}\, K\, T_0B = 5{,}72 \times 10^{-12}$ W; B = 1GHz;

$P_{in} = P_{aus}/G = F_{tot}\, K\, T_0B = 5{,}72 \times 10^{-15}$ W; B = 1MHz;

$P_{in} = P_{aus}/G = F_{tot}\, K\, T_0B = 5{,}72 \times 10^{-21}$ W; B = 1Hz;

$P_{indiode} = P_{in} \times 8{,}12 = 46{,}44 \times 10^{-12}$ W; (1GHz)

with network adaptation: $R_L = 115{,}4\Omega$ (for diode) / Amplifier input = $37{,}5\Omega$

$I_{rin} = (P_{indiode} / R_L)^{1/2} = 634 \times 10^{-9}$ A; (1GHz)

$I_{rin} = (P_{indiode} / R_L)^{1/2} = 20 \times 10^{-9}$ A; (1MHz)

$I_{rin} = (P_{indiode} / R_L)^{1/2} = 20 \times 10^{-12}$ A; (1Hz)

I_{rin} – Noise current at amplifier input, R_L – Load resistance;

2.3 *Module APD 210*

$I_{rtot} = (I_{rin}^2 + I_{tot}^2)^{1/2}$ [A];

$I_{rtot} = 634 \times 10^{-9}$ A; (1 GHz)

$I_{rtot} = 20 \times 10^{-9}$ A; (1 MHz)

$I_{rtot} = 20 \times 10^{-12}$ A; (1 Hz)

NEP = I_{rtot} /S = $12{,}6 \times 10^{-9}$ W; (1 GHz)

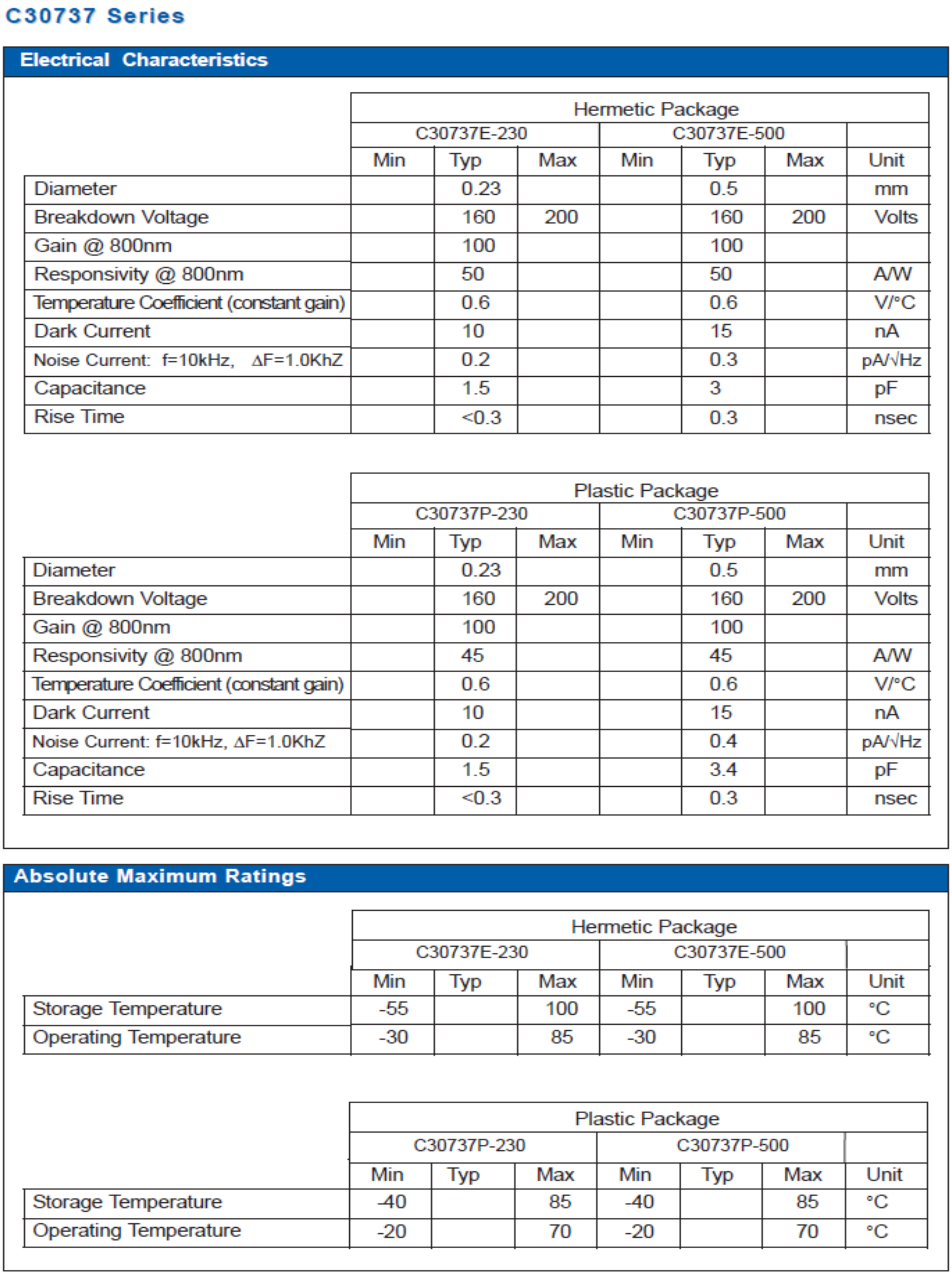
NEP = I_{rtot} /S = $2{,}00 \times 10^{-9}$ W; (1 MHz)

NEP = I_{rtot} /S = $2{,}00 \times 10^{-12}$ W; (1 Hz)

or

NEP = 0,4 [pW/Hz$^{1/2}$].

2.4 Data sheet C30737E-500, PerkinElmer



C30737 Series

Electrical Characteristics

	Hermetic Package						
	C30737E-230			C30737E-500			
	Min	Typ	Max	Min	Typ	Max	Unit
Diameter		0.23			0.5		mm
Breakdown Voltage		160	200		160	200	Volts
Gain @ 800nm		100			100		
Responsivity @ 800nm		50			50		A/W
Temperature Coefficient (constant gain)		0.6			0.6		V/°C
Dark Current		10			15		nA
Noise Current: f=10kHz, ΔF=1.0KhZ		0.2			0.3		pA/√Hz
Capacitance		1.5			3		pF
Rise Time		<0.3			0.3		nsec

	Plastic Package						
	C30737P-230			C30737P-500			
	Min	Typ	Max	Min	Typ	Max	Unit
Diameter		0.23			0.5		mm
Breakdown Voltage		160	200		160	200	Volts
Gain @ 800nm		100			100		
Responsivity @ 800nm		45			45		A/W
Temperature Coefficient (constant gain)		0.6			0.6		V/°C
Dark Current		10			15		nA
Noise Current: f=10kHz, ΔF=1.0KhZ		0.2			0.4		pA/√Hz
Capacitance		1.5			3.4		pF
Rise Time		<0.3			0.3		nsec

Absolute Maximum Ratings

	Hermetic Package						
	C30737E-230			C30737E-500			
	Min	Typ	Max	Min	Typ	Max	Unit
Storage Temperature	-55		100	-55		100	°C
Operating Temperature	-30		85	-30		85	°C

	Plastic Package						
	C30737P-230			C30737P-500			
	Min	Typ	Max	Min	Typ	Max	Unit
Storage Temperature	-40		85	-40		85	°C
Operating Temperature	-20		70	-20		70	°C