Specifications for TES-ETF bolometers for SPIRE

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1 Introduction

The purposes of this note are

(i) to review the basic theory of the TES-ETF bolometer;
(ii) to investigate the influence of background power on the operation of the device.

The second question is particularly important for SPIRE. Given an expected background power level, a bolometer can be designed to be tailored for best performance under that background. If however, the *actual* background turns out to be substantially different, then the achieved sensitivity can be significantly degraded. This must be viewed as a potential danger for filled arrays in SPIRE due to possible difficulties in eliminating stray light and the possibility that the effective telescope emissivity may be higher that the figure assumed. In the case of TES arrays, it is necessary to guard against the possibility that the background could make the detctors inoperable.

2 Definitions

T_o	Temperature of heat sink	
k	Thermal conductivity of material constituting the thermal link	
T	Temperature of bolometer at operating point	$T = T_B + \delta T e^{i\omega t}$
ϕ	Normalised operating temperature	$\phi = T/T_o$
Q	Radiant power absorbed by detector	$Q = Q_o + \delta Q e^{i\omega t}$
Q_{des}	Value of Q for which bolometer is designed	
P	Bias power	$P = P_o + \delta P e^{i\omega t}$
W	Total power dissipated in bolometer	$W = P + Q$
W_o	Steady state value of W	$W_o = P_o + Q_o$
U	Power conducted along thermal link	
G_s	Static thermal conductance between bolometer and heat sink	$G_s = W/(T - T_o)$
G_d	Dynamic thermal conductance between bolometer and heat sink	$G_d = \delta W/\delta T$
V_B	Bias voltage	
R	Bolometer resistance at operating point	
C	Heat capacity of bolometer at operating point	
α	Temperature coefficient of resistance	$\alpha = dLogR/dLogT$
S	Bolometer responsivity	$S(\omega) = S_o(1 + \omega\tau)^{-1}$
S_o	DC responsivity	
τ	Physical time constant	$\tau = C/G_d$
τ_e	Effective time constant	

3 ETF theory

3.1 Response to modulated signal

When the bolometer is voltage biased with extreme electrothermal feedback, the bias voltage, V_B, and the operating resistance, R, are held essentially constant.

The steady state heat balance equation is $$W_O = P_O + Q_O = G_S(T - T_O)\,. \qquad (1)$$

Dynamic case: $$P_O + \delta P e^{i\omega t} + Q_O + \delta Q e^{i\omega t} = G_S(T - T_O) + \delta U e^{i\omega t} + C\frac{\delta T}{\delta t} \quad (2)$$

δP and δU can be expressed in terms of δT: $$P = \frac{{V_B}^2}{R} \Rightarrow \frac{\delta P}{\delta R} = -\frac{{V_B}^2}{R^2}$$

$$\alpha = \frac{T}{R}\frac{dR}{dT} \Rightarrow \delta R = \frac{\alpha R \delta T}{T} \Rightarrow \delta P = -\frac{\alpha {V_B}^2 \delta T}{RT}$$

and $\delta U = \frac{\delta W}{\delta T}\delta T = G_d \delta T$

Therefore

$$Q_O + \delta Q e^{i\omega t} + \frac{{V_B}^2}{R} - \frac{\alpha {V_B}^2}{RT}\delta T e^{i\omega t} = G_S(T - T_O) + G_d \delta T e^{i\omega t} + i\omega C \delta T e^{i\omega t} \quad (3)$$

This is equivalent to Lee *et al.* Equation 1.

Subtracting the steady state values from both sides, we get:

$$\delta Q e^{i\omega t} - \frac{\alpha {V_B}^2}{RT}\delta T e^{i\omega t} = G_d \delta T e^{i\omega t} + i\omega C \delta T e^{i\omega t}$$

$$\delta Q e^{i\omega t} = \left[G_d + i\omega C + \frac{\alpha {V_B}^2}{RT}\right]\delta T e^{i\omega t} \quad (4)$$

3.2 Responsivity and time constant

By definition, $S = \frac{\delta I}{\delta Q} = \frac{\delta I / \delta T}{\delta Q / \delta T}$

Now $$\frac{\delta I}{\delta T} = \frac{\delta}{\delta T}\left[\frac{V_B}{R}\right] = -\frac{V_B}{R^2}\frac{\delta R}{\delta T} \quad \text{and} \quad \frac{\delta R}{\delta T} = \frac{\alpha R}{T}$$

$$\Rightarrow \frac{\delta I}{\delta T} = -\frac{\alpha V_B}{RT}$$

$$S = \frac{\delta I / \delta T}{\delta Q / \delta T} = -\frac{\alpha V_B}{RT}\left[\frac{1}{G_d + i\omega C + \frac{\alpha {V_B}^2}{RT}}\right] = -\frac{\alpha V_B}{RT}\left[\frac{1}{G_d + \frac{\alpha P_O}{T}}\right]\left[\frac{1}{G_d + \frac{i\omega C}{G_d + \frac{\alpha P_O}{T}}}\right]$$

Letting $S(\omega) = S_O \left[\dfrac{1}{1 + i\omega\tau_e}\right]$, we have

$$\tau_e = \frac{C}{G_d\left[1 + \dfrac{\alpha P_O}{G_d T}\right]} \tag{5}$$

and $$S_O = -\left[\frac{\alpha V_B}{RTG_d + \alpha P_O R}\right] = -\frac{1}{V_B}\left[\frac{\alpha}{\dfrac{RTG_d}{V_B^2} + \alpha}\right] = -\frac{1}{V_B}\left[\frac{1}{1 + \dfrac{RTG_d}{\alpha V_B^2}}\right]$$

Let $$L = \frac{\alpha P_O}{G_d T} = \frac{\alpha V_B^2}{RTG_d} \quad \text{(L} \equiv \text{ loop gain of ETF feedback system)} \tag{6}$$

Therefore $$S_O = -\frac{1}{V_B}\left[\frac{L}{L + 1}\right], \tag{7}$$

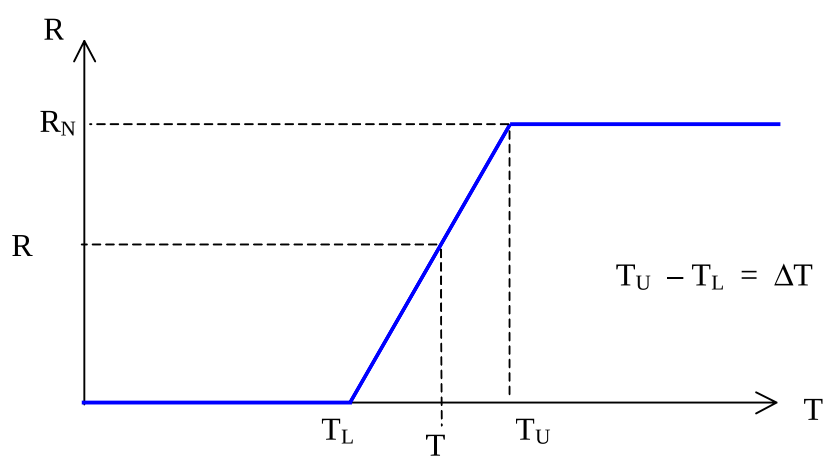
and $$\tau_e = \frac{C}{G_d[1 + L]} = \frac{\tau}{[1 + L]}, \tag{8}$$

so that $$S(\omega) = -\frac{1}{V_B}\left[\frac{L}{L + 1}\right]\left[\frac{1}{1 + i\omega\tau}\right] \tag{9}$$

(this is the same as Lee *et al*. Equation 6).

3.3 Simple characterisation of the R vs. T characteristic

Assume that the bolometer resistance is zero on the lower side of the transition and R_N on the upper, with a linear variation in between and a transition width of ΔT.



Therefore $R = \left[\frac{R_N}{\Delta T}\right]\left[T - T_L\right] \quad \Rightarrow \quad \frac{\delta R}{\delta T} = \frac{R_N}{\Delta T}$

and $\alpha = \frac{T}{R}\frac{\delta R}{\delta T} = \frac{T}{T - T_L}$.

If the bolometer is biased at the mid-point of the transition where $T = (T_U + T_L)/2$ then

$$\alpha = 2T/\Delta T. \tag{10}$$

If the bias point is closer to the lower temperature, then α is higher. For a 3-mK transition width with $T = 450$ mK, $\alpha = 300$.

4 Design of ETF-TES bolometers for SPIRE background power levels

The bolometer must be biased so that the operating temperature is on the superconducting transition, which occurs at a temperature that depends on the properties of the film and so cannot be adjusted for a given device. Assume also that the bath temperature cannot be adjusted. The steady state thermal conductance between the bolometer and the heat sink depends on the device design, the bath temperature and the transition temperature, and is therefore also fixed. The heat balance equation

$$W_O = P_O + Q = G_S(T - T_O)$$

therefore requires that the total dissipation W_o be a constant, and that the bias power P_o be adjusted to achieve the required operating point. Ideally, the absorbed background power, $Q = Q_{des}$, the background level for which the bolometer has been designed. Provided that a stable bias point exists, the electrothermal feedback maintains a constant operating temperature by automatically adjusting P_o to compensate for changes in Q.

If the actual value of the background power is larger than expected, then the electrical bias power can be reduced to compensate. However, if Q is too large, then even if P_o is reduced to zero the equilibrium temperature will still exceed the transition temperature and it will not be possible to bias the bolometer at all. Therefore some margin must be included to ensure that a higher-than-expected background will not make it impossible to operate the detector. This requires designing a reasonably large value of P_o to provide a wide enough range of adjustment. The problem of excess background must be regarded as a major danger in the case of SPIRE. The background in the instrument might in reality be greater than designed for various reasons (e.g., the overall emissivity of the telescope may be higher than expected; some source of stray light within the instrument or coming from outside may contribute excess background). Conventional semiconductor bolometers are not subject to the same catastrophic consequences if the background is too large: sensitivity would be degraded, of course, but the detectors would still work.

For the TES detector, there is another reason why P_o should not become too small: the loop gain of the device should be reasonably high to ensure fast speed of response.

So, we want a high value of P_o/Q_{des}: this can be ensured by making G_s large – but this is at the expense of sensitivity, which we want to keep within the photon noise dominated regime.

4.1 Constraints on TES design due to the need to insure against excess background

To examine the constraints on the bias power and designed thermal conductance arising from these considerations, we can proceed as follows.

(i) Assume that the photon noise NEP can be approximated by the simple shot noise formula:

$$NEP_{ph} = (2Qh\nu)^{0.5}. \tag{11}$$

Ideally, the actual power will be the same as the designed value: $NEP_{ph-des} = (2Q_{des}h\nu)^{0.5}$.

(ii) Assume that the bolometer NEP is dominated by thermal (phonon) noise and that the thermal conductance is chosen to make the thermal noise NEP less than the expected photon noise NEP by some factor θ:

$$NEP_{thermal} = \left[\gamma 4kT^2 G_d\right]^{0.5} = \frac{NEP_{ph\text{-}des}}{\theta} \qquad \Rightarrow \qquad G_d = \frac{Q_{des}h\nu}{2\theta^2\gamma kT^2}, \tag{12}$$

where γ is a factor less than one which accounts for the temperature gradient along the link between the bolometer and the heat sink (see below). It would be nice to have $\theta \geq 3$, to be strongly photon noise dominated; we assume here that a value of at least 2 is required.

(iii) Assume that the temperature variation of the thermal conductivity is described by a power law:

$$k(T) = k(T_O)\left[\frac{T}{T_O}\right]^{\beta} = k_O\phi^{\beta} \qquad \text{where } \phi = T/T_o. \tag{13}$$

In this case, the dynamic thermal conductance can be shown to follow the same power law:

$$G_d(T) = G_d(T_O)\left[\frac{T}{T_O}\right]^{\beta} = G_{do}\phi^{\beta} \tag{14}$$

and the static thermal conductance between the bolometer and the heat sink is given by

$$G_S(T) = G_{do}\left[\frac{\phi^{\beta+1}-1}{(\beta+1)(\phi-1)}\right]. \tag{15}$$

Near the bath temperature ($\phi \rightarrow 1$), $G_s(T_o) = G_{so} = G_{do}$.

For a power law variation of the thermal conductivity, the phonon noise reduction factor, γ, can be shown (Griffin and Holland, 1988) to be given by

$$\gamma = \left[\frac{1}{\phi^{\beta+2}}\right]\left[\frac{\phi^{2\beta+3}-1}{\phi^{\beta+1}-1}\right]\left[\frac{\beta+1}{2\beta+3}\right]. \tag{16}$$

For SPUD type detectors, typical values are $\beta = 3$ and $\phi = 1.5$, giving $\gamma = 0.54$.

(iv) Let the actual background power be $Q = FQ_{des}$, where F would be greater than one if there is some excess background. We can now use the static heat balance equation

$$P_O = G_S(T - T_O) - Q,$$

to find the bias power P_o:

$$P_O = G_S T\left[1 - \frac{1}{\phi}\right] - Q = G_{do} T\left[\frac{\phi^{\beta+1} - 1}{(\beta+1)(\phi-1)}\right]\left[\frac{\phi - 1}{\phi}\right] - FQ_{des}. \tag{17}$$

Now $$G_{do} = G_d(T)\left[\frac{1}{\phi}\right]^{\beta} = \frac{Q_{des} h\nu}{2\theta^2 \gamma k T^2}\left[\frac{1}{\phi}\right]^{\beta}, \tag{18}$$

so $$P_O = \frac{Q_{des} h\nu}{2\theta^2 \gamma k T}\left[\frac{1}{\phi}\right]^{\beta}\left[\frac{\phi^{\beta+1} - 1}{(\beta+1)(\phi-1)}\right]\left[\frac{\phi - 1}{\phi}\right] - FQ_{des}.$$

Therefore $$\frac{P_O}{Q_{des}} = \frac{x}{2\theta^2\gamma}\left[\frac{\phi^{\beta+1} - 1}{(\beta+1)\phi^{\beta+1}}\right] - F \qquad \text{where } x = \frac{h\nu}{kT}. \tag{19}$$

Substituting for γ from (16), we get

$$\frac{P_O}{Q_{des}} = \frac{x}{2\theta^2}\left[\frac{\phi^{\beta+1} - 1}{(\beta+1)}\right]^2\left[\frac{\phi(2\beta+3)}{\phi^{2\beta+3} - 1}\right] - F. \tag{20}$$

If the right hand side of this equation is zero or negative, then the bolometer cannot be biased. For $\beta = 3$ and $\phi = 1.5$, we have

$$\frac{P_O}{Q_{des}} = \frac{(0.186)x}{\theta^2} - F. \tag{21}$$

For instance, for $\lambda = 500\ \mu m$, $x = 64$ giving $F \le \dfrac{11.9}{\theta^2}$. (22)

The loop gain is given by $$L = \frac{\alpha P_O}{G_d T} = \frac{P_O}{Q_O}\frac{2\theta^2\gamma\alpha k T}{h\nu}$$

Substituting from above for Po/Q_{des} and letting $\gamma = 0.54$, we have

$$L = \alpha\left[0.201 - \frac{(1.08)\theta^2 F}{x}\right]. \tag{23}$$

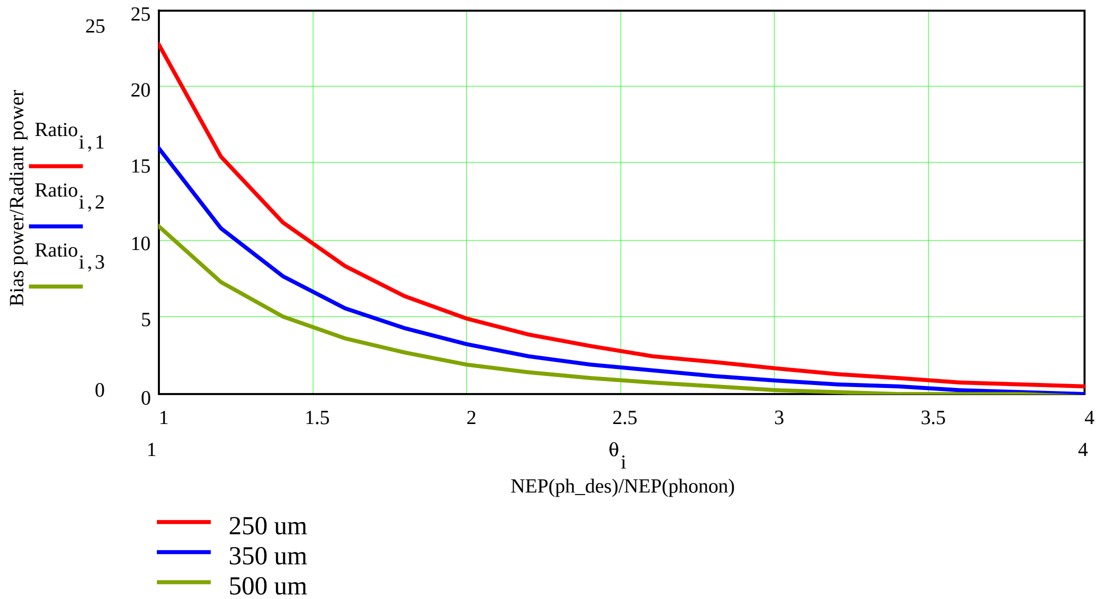


Fig. 1: Bias power/Radiant power vs. $NEP_{photon}/NEP_{phonon}$ for $\beta = 3$, $\phi = 1.5$, and F = 1

Fig. 1 shows how P_o/Q_{des} varies with the factor θ for the three SPIRE photometer channels for the case of F = 1 (i.e., background power as expected). The designed backgrounds, Q_{des} (from the in-band telescope emission) are 1.5, 1.1 and 1.0 pW for the 250, 350 and 500 μm bands, respectively. These values correspond to the power absorbed per 0.5Fλ pixel in a filled array with 80% quantum efficiency. A value of $\theta = 1$ means that the detector NEP is equal to the photon noise NEP (under the idealised assumption that the detector NEP is completely dominated by the phonon noise contribution). If we assume that we need to have $\theta \geq 2$, then the bias power is greater than the designed radiant power by a factor of 4.9 at 250 μm, 3.2 at 350 μm and 2.0 at 500 μm. Taking the 500-μm channel as the worst case, the bolometer could still be biased (in principle) even if the actual background power turned out to be larger than expected by a factor of 1 + 2.0 = 3.0 - in agreement with the inequality derived above for F (equation 22). If greater "insurance" against the disastrous effects of excess background is required, it must be at the expense of reduced sensitivity: it can only be achieved by reducing the value of θ and moving out of the strongly photon noise dominated regime for the designed background.

The loop gain, L, is plotted against θ in Fig. 2, where we assume $\alpha = 300$. A large value of θ (i.e., strongly photon noise dominated) corresponds to a low value of L which is undesirable from the point of view of speed of response and well-calibrated responsivity (are there any other ill effects of low L?). However, $\theta = 2$ corresponds to $L \approx 40$ even in the worst case (500 μm).

The required dynamic thermal conductance is plotted against θ in Fig. 3. For $\theta = 2$, values of 98, 50 and 32 nW K^{-1} are required for the 250, 350 and 500 μm bands, respectively. The corresponding values of the static thermal conductance are smaller by a factor of

$$\frac{\phi^{\beta}(\beta + 1)(\phi - 1)}{(\phi^{\beta+1} - 1)} = 1.7\,. \qquad (24)$$

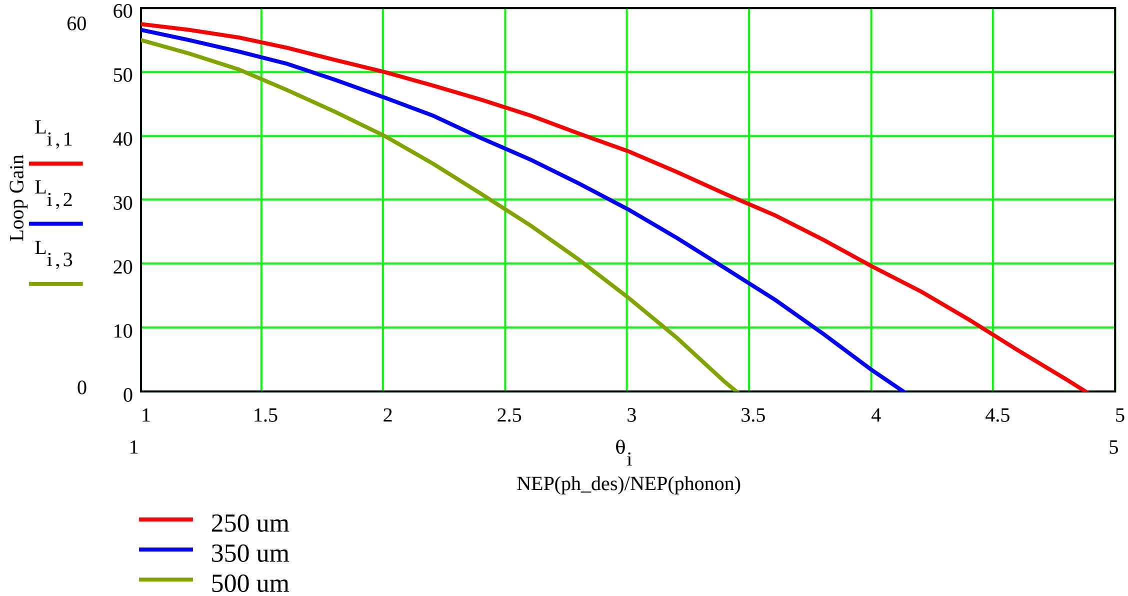


Fig. 2: Loop Gain vs. $NEP_{photon}/NEP_{phonon}$ for $\beta = 3$, $\phi = 1.5$, and F = 1

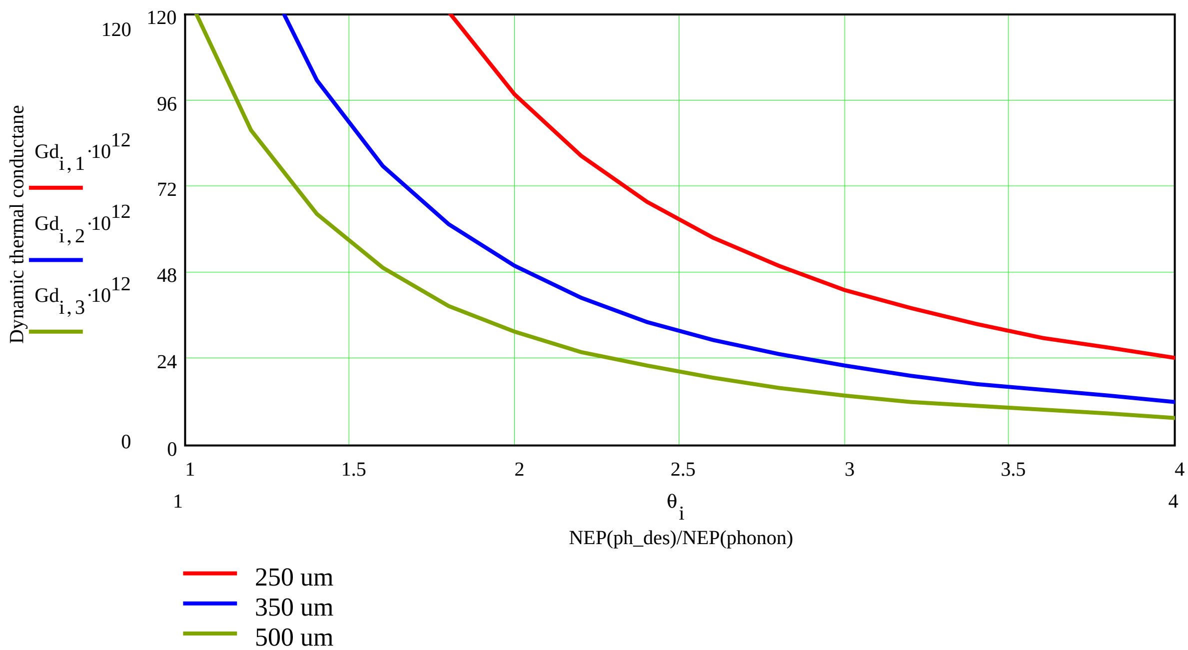


Fig. 3: Dynamic thermal conductance vs. $NEP_{photon}/NEP_{phonon}$ for $\beta = 3$, $\phi = 1.5$, F = 1, and $\alpha = 300$.

4.2 How does the sensitivity of the TES vary as a function of background?

Assume that the only contributions to the NEP are photon noise, Johnson noise in the detector and thermal (phonon) noise. We then have:

$$NEP_{tot}^{\ 2} = NEP_{ph}^{\ 2} + NEP_{thermal}^{\ 2} + NEP_{Johnson}^{\ 2} \ , \tag{25}$$

where $$NEP_{ph}^{\ 2} = 2FQ_{des}h\nu \ , \tag{26}$$

$$NEP_{thermal}^{\ 2} = \gamma 4kT^2G_d = \frac{NEP_{ph\text{-}des}}{\theta^2} = \frac{2Q_{des}h\nu}{\theta^2} \ , \tag{27}$$

$$NEP_{Johnson}^{\ 2} = \frac{4kT/R}{S^2}\left[\frac{\tau_e}{\tau}\right]^2\left[\frac{1 + \omega\tau^2}{1 + \omega\tau_e^{\ 2}}\right] . \tag{28}$$

The third term, due to Johnson noise, is as in Mather (1982). Let us consider only the low frequency limit ($\omega \approx 0$), and substitute for S and τ_e/τ from (7) and (8) above:

$$NEP_{Johnson}^{\ 2} = \frac{4kTV_B^{\ 2}}{R}\left[\frac{L+1}{L}\right]^2\left[\frac{1}{L+1}\right]^2 = \frac{4kT_O\phi P}{L^2} \ . \tag{29}$$

We have $L = \dfrac{\alpha P_O}{G_d T} \quad \Rightarrow \quad NEP_{Johnson} = \dfrac{4kT_O^{\ 3}\phi^3 G_d^{\ 2}}{\alpha^2 P}$.

Now $G_d = \dfrac{Q_{des}h\nu}{2\theta^2\gamma kT^2} \quad \Rightarrow \quad NEP_{Johnson} = \dfrac{Q_{des}^{\ 2}h\nu x}{\alpha^2\gamma^2\theta^4 P}$.

Substituting $P_O = Q_{des}\dfrac{x}{2\theta^2\gamma}\left[\dfrac{\phi^{\beta+1} - 1}{(\beta+1)\phi^{\beta+1}}\right] - FQ_{des}$ we get:

$$NEP_{Johnson}^{\ 2} = \frac{2Q_{des}h\nu}{\gamma\alpha^2\theta^2\left[\dfrac{\phi^{\beta+1} - 1}{(\beta+1)\phi^{\beta+1}}\right] - \dfrac{2\theta^4\gamma^2\alpha^2 F}{x}} ,$$

$$\Rightarrow \quad NEP_{Johnson}^{\ 2} = \frac{2Q_{des}h\nu}{\gamma\alpha^2\theta^2\left[\left[\dfrac{\phi^{\beta+1} - 1}{(\beta+1)\phi^{\beta+1}}\right] - \dfrac{2\theta^2\gamma F}{x}\right]} .$$

Using $\gamma = \left[\dfrac{1}{\phi^{\beta+2}}\right]\left[\dfrac{\phi^{2\beta+3} - 1}{\phi^{\beta+1} - 1}\right]\left[\dfrac{\beta + 1}{2\beta + 3}\right]$, we can rewrite this as:

$$NEP_{Johnson}^{\ 2} = \frac{2Q_{des}h\nu}{\alpha^2\theta^2\left[\left[\dfrac{\phi^{2\beta+3} - 1}{\phi^{2\beta+3}(2\beta + 3)}\right] - \dfrac{2\theta^2\gamma^2 F}{x}\right]} . \tag{30}$$

When the denominator in the Johnson noise term becomes zero or negative, then the bolometer cannot be biased on the superconducting-normal transition and the Johnson noise NEP is effectively infinite. Therefore

$$\mathrm{NEP_{tot}}^2 = (2Q_{des}h\nu)\left[F + \frac{1}{\theta^2} + \frac{1}{\alpha^2\theta^2\left[\left[\dfrac{\phi^{2\beta+3}-1}{\phi^{2\beta+3}(2\beta+3)}\right] - \dfrac{2\theta^2\gamma^2 F}{x}\right]}\right], \qquad (31a)$$

$$\text{for } F \prec \frac{x}{2\theta^2\gamma^2}\left[\frac{\phi^{2\beta+3}(2\beta+3)}{\phi^{2\beta+3}-1}\right];$$

$$\mathrm{NEP_{tot}}^2 = \infty \quad \text{otherwise.} \qquad (31b)$$

The first term in equation (31a) represents photon noise from the background, the second term gives the phonon noise contribution and the third term is the Johnson noise component. We may rewrite this equation in terms of mapping speed (normalised to the case where the actual background is equal to the designed value):

$$\text{Speed} = \left[\frac{\mathrm{NEP_{ph\text{-}des}}}{\mathrm{NEP_{tot}}}\right]^2.$$

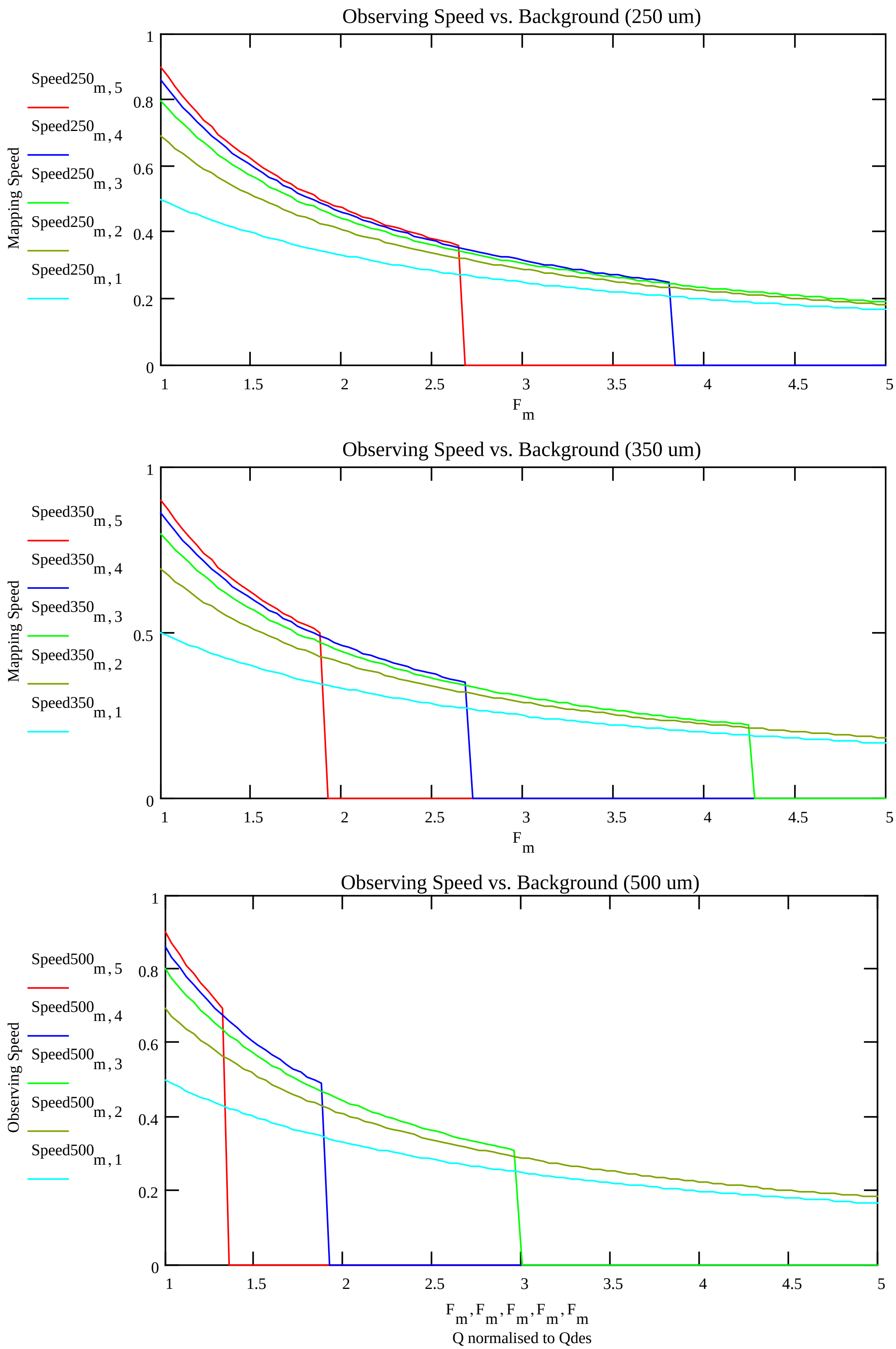
$$\text{Speed} = \left[F + \frac{1}{\theta^2} + \frac{1}{\alpha^2\theta^2\left[\left[\dfrac{\phi^{2\beta+3}-1}{\phi^{2\beta+3}(2\beta+3)}\right] - \dfrac{2\theta^2\gamma^2 F}{x}\right]}\right]^{-1}, \qquad (32a)$$

$$\text{for } F \prec \frac{x}{2\theta^2\gamma^2}\left[\frac{\phi^{2\beta+3}(2\beta+3)}{\phi^{2\beta+3}-1}\right]; \qquad \text{Speed} = 0 \quad \text{otherwise.} \qquad (32)$$

For reasonable values of the detector parameters, such as those assumed here, the third (Johnson noise) term can be made negligible. We then have:

$$\text{Speed} \approx \left[F + \frac{1}{\theta^2}\right]^{-1} \quad \text{for} \quad F \prec \frac{x}{2\theta^2\gamma^2}\left[\frac{\phi^{2\beta+3}(2\beta+3)}{\phi^{2\beta+3}-1}\right]; \qquad \text{Speed} = 0 \quad \text{otherwise.}$$

This is plotted in Fig. 4 for the values of ϕ, β etc. assumed here. These plots illustrate the trade-off between achieving photon noise limited performance and ensuring that the bolometer will not be saturated by any excess background power: a high value of θ is necessary for sensitivity comparable to the photon noise limit at the designed background, but a low value is required to provide a high thermal conductance and so to ensure that the bolometer can be biased over a wide range of Q. The compromise is most difficult at the longest SPIRE wavelength (500 µm), where the minimum acceptable value of $\theta = 2$ corresponds to a mapping speed equal to 80% of the photon noise limited speed for $Q = Q_{des}$. With $\theta = 3$, a background only 1.3 times higher than Q_{des} would saturate the detectors. For $\theta = 2$, we can tolerate $Q = 3Q_{des}$ (in agreement with the figure above).



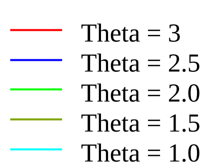


Fig. 4: Observing speed vs. normalised background power for the three SPIRE bands for different values of θ.

5 Comparison with behaviour of a semiconductor bolometer in similar circumstances

In the case of a traditional semiconductor bolometer, the sensitivity is degraded in a monotonic fashion by increasing background power. Unlike the TES sensor, there is no point at which the detector ceases to operate at all. The loss in sensitivity is due to three effects: (a) additional photon noise; (b) increase in the inherent detector NEP; (c) increase in the relative contribution of the amplifier chain arising from loss in detector responsivity. To investigate the manner in which the sensitivity declines as a function of background, a numerical simulation has been carried out using the following assumptions which could apply to a typical NTD ^{3}He bolometer optimised for SPIRE:

(ii) Modified Griffin & Holland bolometer model
(iii) Ideal NTD Ge bolometer
(iv) $T_o = 0.3$ K
(v) Designed absorbed background power = 3.8 pW (SPIRE 500 μm channel; feedhorn option)
(vi) Bolometer tailored to give resistance of around 5 MΩ at operating point
(vii) Bolometer parameters:
- Tg = 35 K
- $\beta = 1.5$
- n = 0.5
- R* = 970 Ω (to give Rop ≈ 5 MΩ)
- Gs_o = 25 pW K-1 (this value of Gs_o corresponds to $\theta = 3.3$ - i.e., strongly photon noise limited if Q = Qdes)

(viii) Signal chain input short noise = 6 nV Hz-1/2
(ix) Load resistance R_L = 30 MΩ
(x) Bias voltage can be adjustable to the optimal value at the actual background

The observing speed is plotted against background power for this case in Fig. 5. Shown for comparison are the same curves for the TES bolometer as in the bottom panel of Fig. 4.

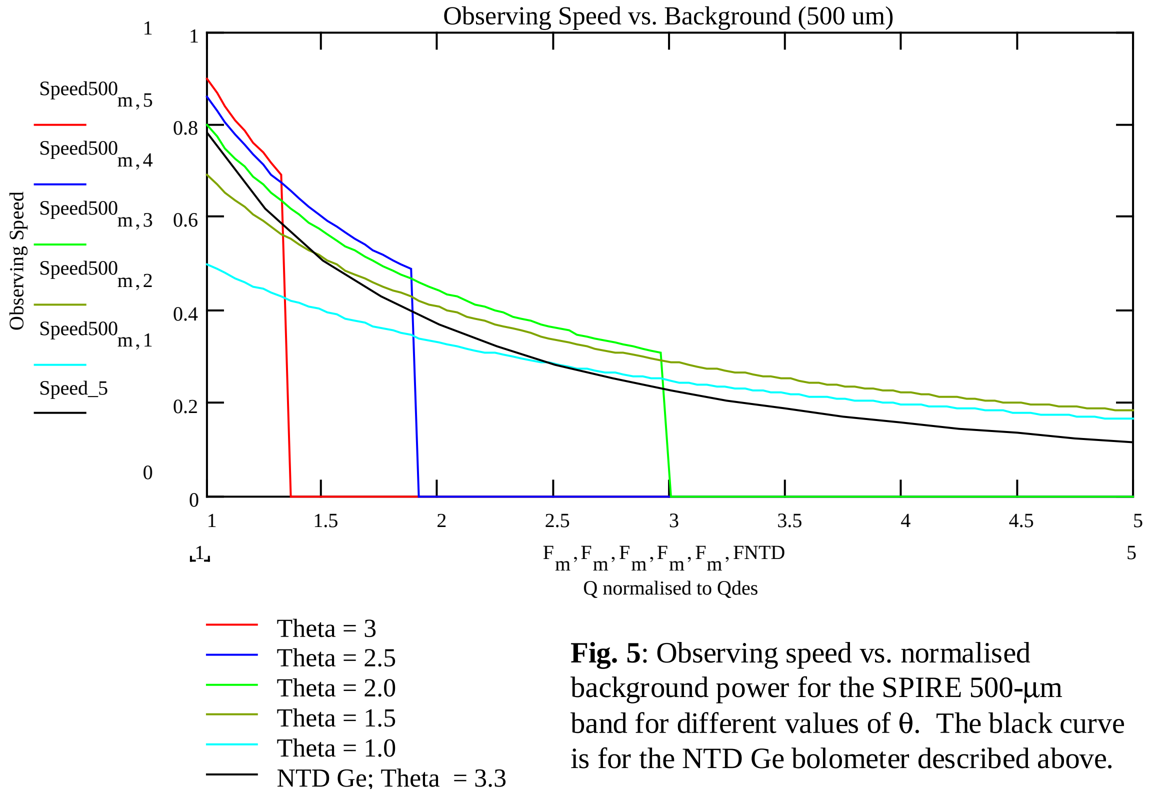


Fig. 5: Observing speed vs. normalised background power for the SPIRE 500-μm band for different values of θ. The black curve is for the NTD Ge bolometer described above.

There are several things to be noted from Fig. 5.

- For $Q = Q_{des}$, the TES is slightly better for a given value of θ because it suppresses the Johnson noise component more heavily and because we are assuming that there is no amplifier noise for the TES.

- The observing speed of the semiconductor bolometer drops slightly faster than for the TES because of the increasing NEP component from the amplifier noise - however, this is a rather small effect.

- Overall, the semiconductor bolometer is much less vulnerable to excess background that the TES: the decline in speed with background is similar, but with no catastrophic loss of the detector if the power exceeds a certain value as in the case of the TES. In addition, larger values of θ can be used, giving equal of slightly better performance (relative to the photon noise limited mapping speed) than the TES for Q = Qdes.

6 Conclusions

1 For the SPIRE photometer, adopting the criterion that the detector phonon noise NEP be at least a factor of 2 less than the photon noise limited NEP provides an “insurance” factor against a higher-than-designed radiant background of a factor of about 3 at 500 μm (greater for the other two bands). Given the anticipated difficulties in suppressing stray radiation, this is not a very large margin (and does not make any allowance for non-ideal effects such as excess noise).

2 With the assumptions made above:

$\beta = 3$
$T_o = 300$ mK
$T/T_o = 1.5$
$\theta = 2$
$\alpha = 300$

we require TES detectors with dynamic thermal conductances of around 100, 50 and 30 nW K^{-1} for the 250, 350 and 500 μm bands, respectively (static thermal conductances about 1.7 times smaller than these values).

3 A suitably designed semiconductor bolometer has a sensitivity (relative to the photon noise limit) which decreases at a similar rate as for the TES sensor, but it is not prone to catastrophic loss of the detector array in the event of excess background.

7 References

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