1. Simple explanation of quantum radar range limitations

In order to explain the range limitations of every quantum radar (QR) in simple terms, we remind that the detection probability of a target depends on the radar receiver's signal-to-noise ratio (SNR). The commonly used correlation receiver provides a maximum SNR equal to $2E/N_0$, i.e., twice the echo's signal energy (E) divided by the *noise power spectral density* $N_0 = k_B T_s$, where $k_B = 1.38 \cdot 10^{-23}\, J/K$ is the Boltzmann's constant and T_s the "system noise temperature".

In a QR, the transmitted signal, of duration T, is made up by a number M of "modes" each one of duration $1/B$, where B is the operation bandwidth, hence, $M = B \cdot T$.

A single QR mode, ideally transmitting an average number of photons N_s at the frequency f directly into the receiver antenna, has an average energy $E = N_s hf$, hence the SNR is:

$$SNR = \frac{2N_s hf}{k_B T_s} \tag{1}$$

where $h = 6.62 \cdot 10^{-34}\, J \cdot s$ is the Planck's constant.

In a real-world operation, one must consider the round-trip attenuation, related to the distance R of the target (the R^{-4} effect) and the target's radar cross section, leading to the celebrated radar equation [1].

Simply put, an attenuation figure a_R (another symbol κ is used in most QR literature) takes care of these effects. Typical values of a_R are plotted in **Figure 1** (from [2]) at X-band ($f = 9.375\, GHz$).

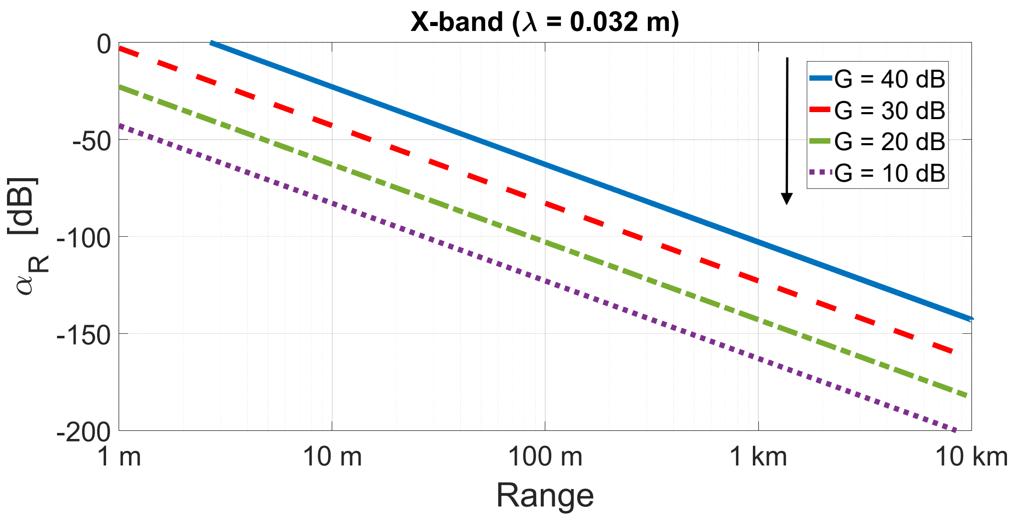

Figure 1. A Free-space attenuation a_R [dB], versus Range at X-band ($\lambda = 0.032\, m$, $f = 9.375\, GHz$), with Radar target Radar Cross Section $\sigma = 1\, m^2$ and an antenna gain (the same for Tx and Rx) $G = 10, 20, 30, 40\, dB$ (from [2]).

The coherent integration of M modes gives an SNR gain equal to M; hence, the corresponding SNR:

$$SNR = M \frac{2N_s\, hf}{k_B T_S} a_R \tag{2}$$

From Eq. (2):

$$M = \frac{SNR}{2a_R} \cdot \frac{k_B T_s}{N_s\, hf} \tag{3}$$

Remembering that $M = B \cdot T$, one gets a time duration:

$$T = \frac{SNR}{2a_R} \cdot \frac{k_B T_s}{N_s\, hfB} \tag{4}$$

For the typical applications of medium-range surveillance, at X-band a_R is of the order of 10^{-12}.

To get a significant quantum advantage, a small value of $\boldsymbol{N_s}$ is required (in many publications on QR, $\boldsymbol{N_s}$ is set to 0.1), while radar detection calls for $SNR \gg 1$ (in many studies, $SNR = 20$, i.e., $13\ dB$).

At X-band $f = 10\ GHz$, with $SNR = 20$, $N_s = 0.1$, $T_s = 290\ K$, $a_R = 10^{-12}$ and assuming a bandwidth $B = 1\ GHz$ (about $10\ \%$ of f), the time duration is of the order $T \cong 6 \cdot 10^7\ s$, i.e., approximately 1.9 years!

When the $-120\ dB$ attenuation is changed into a $-20\ dB$ attenuation, which is standard in most published articles on QR (especially before 2022), the fictitious increase in the radar range is by $\sqrt[4]{10^{10}} \cong 316.2$ times, and a realistic maximum range of $5\ m$ for a QR would become as large as a fictitious $1.6\ km$.

2. The stealth target case

The link budget—and the pertaining radar equation—is obviously related to the detection of stealth (low-observable) targets. In an article [3], we read: “In 2018 China’s Electronic Technology Group Corporation presented the world’s first long-range quantum radar worked up to 61 miles out”. About this statement, there is no evidence or any refereed publication, but only some advices and ads on the WEB (e.g., [4, 5]).

Moreover, on the same topic, in [6], we read: “In mid-September 2016, however, researchers from China’s Electronic Technology Group Corporation revealed the world’s first long-range quantum radar… . Thanks to the quirky rules of quantum entanglement, anything these emitted particles encountered—including the radar-numbing F-35—would create an immediate reaction in their entangled partners back at the sensor”.

An example of clickbait is available on Internet [7], where Chinese Scientists say, “Quantum Radar Could End Stealth Advantage. A new quantum radar technology developed by a team of Chinese researchers would be able to detect stealth planes, the South China Morning Post is reporting. The news service reports that the radar technology generates a mini electromagnetic storm to detect objects".

In reality, simple reasoning tells us that a **QR cross section does not exist**, i.e., the radar cross section (RCS) of an object is the same irrespectively of the type of radar, either conventional (i.e., "classical") or of the quantum type. The target "cannot know" whether a photon impinging on it has an "idler" stored somewhere, or not, and the backscatter is the same in both cases. Of course, in principle, it is possible to compute the RCS "photon by photon" by the quantum mechanics methods in place of Maxwell's equations, but the result cannot be different when the operating conditions are the same. The, hopefully final, word is due to *ad hoc* detailed analysis in an earlier study [8], where it is shown that the photon's position uncertainty makes its path not well defined, and this causes quantum interference. The result of this interference exactly replicates the classical scattering behavior of the electromagnetic waves. In other words, it is possible to exactly derive the classical electric field scattering integral using a purely quantum construction. In spite of this, very clear paper, some authors, for instance [9], neglecting or ignoring it, have continued to write on a non-existent quantum RCS.

3. References

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