Classical vs Quantum: Which Antenna Performs Better at Extremely Low Frequencies

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In recent years, with the advent of quantum computers, related quantum research has begun to flourish due to quantum computing's initial success. Now, many labs around the world (including our own) have started to work with Rydberg atoms, which are promising for revolutionizing sensors and quantum computers. They can make quantum entanglement in quantum computers much easier and create calibration free sensors of all types. However, some people have taken an interest in its unique properties that allow it to act like an antenna. What's even more exciting is that it could act as an antenna across the entirety of the Radiofrequency (RF) spectrum, but is that true? In this work, we determine whether the Rydberg antenna is a better option as compared to the tried-and-true classical antenna at Extremely Low Frequencies (ELF). To do this, we measured the classical 1 cm dipole antenna's Signal-to-Noise Ratio (SNR) over the frequency spectrum from near DC to 100 kHz to establish a baseline. This gave us insight into whether a dipole could even operate at these frequencies due to its extremely low radiation resistance. Once confirming that the dipole antenna could operate at these frequencies, a very precise experiment was set up to determine the Noise Equivalent Field (NEF) of the dipole antenna. The Noise Equivalent Field is a metric used to determine how large the strength of a signal must be for our antenna to read it. Fortunately, another team at ARL South recently measured the Noise Equivalent Field from DC to 1 kHz for a Rydberg Atomic Sensor. This provided data that could be used to compare the classical dipole antenna to the quantum sensor. Once collecting the data using a calibrated Transverse Electromagnetic (TEM) cell, which is used for testing electronics, it was then compared to the quantum sensor. The results were that the 1 cm dipole antenna had a NEF that was on average 1 magnitude higher than the quantum sensor over the same frequency range. This means that the dipole performed worse than the quantum sensor. While the results would seem to indicate that the quantum sensor is simply better than the classical dipole, one must remember that the quantum sensor setup costs magnitudes more than the dipole to create, power, and maintain. Moreover, the dipole's performance can be increased by simply increasing the length of the antenna. On the other hand, quantum sensing is a young and very new subfield of quantum theory, and it should be noted that improvements will take place. While the debate for which can perform better holistically may still be open, this research has given light to a clearer picture of these two technologies.

References

- Backes, K. M., Elgee, P. K., LeBlanc, K.-J, Fancher, C. T., Meyer, D. H., Kunz, P. D, Malvania, N., Nicolich, K. L., Hill, J. C., Marlow, B. L. S., & Cox, K. C. (2024). Performance of antenna-based and Rydberg quantum RF sensors in the electrically small regime. Applied Physics Letters, 125(14).
- Low Noise Amplifier Electrical Sensor for VLF Signals. – Kyle Jiun-Guei Wu
- B. Volkan Gurses, Whitmore, K. T., & Cohen, M. B. (2021). Ultra-sensitive broadband “AWESOME” electric field receiver for nanovolt low-frequency signals. Review of Scientific Instruments Online/Review of Scientific Instruments, 92(2).
- Scandurra, G., Cannatà, G., & Ciofi, C. (2011). Differential ultra low noise amplifier for low frequency noise measurements. AIP Advances, 1(2).
- Glick, J., Dickson, J. R., Wood, J., & Kunz, P. (2026). Low-frequency electric field sensing with a Rydberg beam. Physical Review A, 114(1).