Research Highlight #155

Hyperbolic-cosine waveguide tapers and oversize rectangular waveguide for reduced broadband insertion loss in W-band electron paramagnetic resonance spectroscopy. II. Broadband characterization

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Introduction: This work[1] is a follow-up to the experimental results that were reported by us on an oversize rectangular waveguide assembly operating nominally at W-band (94 GHz).[2] Broadband response in high-frequency EPR has been an ongoing technical challenge.[3] The original assembly was formed using a commercially available WR28 waveguide as well as a pair of specially designed tapers with a hyperbolic-cosine shape from the WR28 to WR10 waveguide.[2] The oversize section reduces broadband insertion loss for an EPR probe placed in a 3.36T magnet. Hyperbolic-cosine tapers minimize the reflection of the main mode and the excitation of unwanted propagating waveguide modes. Oversize waveguide is distinguished from corrugated waveguide, overmoded waveguide, or quasi-optic techniques by minimal coupling to higher-order modes. Only the TE10 mode of the parent WR10 waveguide is propagated.

Results: In this work, a new oversize assembly with a gradual 90˚ twist was implemented. Microwave power measurements show that the twisted oversize waveguide assembly reduces the power loss in the observe and pump arms of a W-band bridge by an average of 2.35 dB and 2.41 dB, respectively, over a measured 1.25 GHz bandwidth relative to a straight length of WR10 waveguide. Network analyzer measurements confirm a decrease in insertion loss of 2.37 dB over a 4 GHz bandwidth and show minimal amplitude distortion of approximately 0.15 dB. Continuous wave EPR experiments confirm these results. The measured phase variations of the twisted oversize waveguide assembly, relative to an ideal distortionless transmission line, are reduced by a factor of two compared to a straight length of WR10 waveguide. Oversize waveguide with proper transitions is demonstrated as an effective way to increase incident power and the return signal for broadband EPR experiments. Detailed performance characteristics, including continuous wave experiments on 1 μM TEMPO in aqueous solution, served as a benchmark for other broadband low-loss probes in millimeter-wave EPR bridges. Figure 1 showcases the enhancements we have developed here, including the new oversize assembly in combination with other upgrades implemented by the Center's engineering team. In addition, the oversize waveguide and hyperbolic tapers also minimize transmission line distortions and allow for a more ideal excitation and signal return path for pulsed experiments.

Implications: In summary, the development of a twisted oversize waveguide assembly to reduce transmission line losses while minimizing amplitude and phase variations over the operational frequency range of the system increases incident power to the sample and increases the return EPR signal. The oversize assembly has been experimentally shown to be a robust low-loss transmission line for use in broadband EPR spectroscopy.

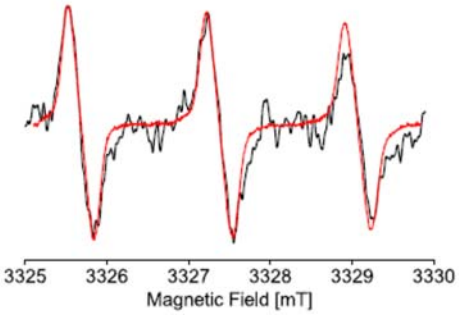

Figure 1. Comparison of a 1 μM TEMPO sample run on the set up in Ref. 4. (black) and the current W-band system with twisted oversize assembly (red). The enhanced signal to noise ratio is due to several upgrades to our home-built W-band assembly, including a custom Gunn-diode oscillator with significant (30 dB/Hz) reduction in phase noise, delay-line balancing, stable automatic frequency control, a water-bath temperature-controlled resonator and modulation coils, and the twisted oversize waveguide assembly highlighted here.

[1] Sidabras JW, Strangeway RA, Mett RR, Anderson JR, Mainali L, Hyde JS. (2016) Hyperbolic-Cosine Waveguide Tapers and Oversize Rectangular Waveguide for Reduced Broadband Insertion Loss in W-band Electron Paramagnetic Resonance Spectroscopy. II Broadband Characterization. Rev Sci Instrum. 87(3):034704. PMCID: PMC4798996

[2] Mett RR, Sidabras JW, Anderson JR, Hyde JS. (2011) Hyperbolic-Cosine Waveguide Tapers and Oversize Rectangular Waveguide for Reduced Broadband Insertion Lin W-band EPR Spectroscopy. Rev. Sci. Instrum. 82, 074704. PMCID: PMC3155584

[3] Grinberg OY, Berliner LJ (eds.). (2004) Very High Frequency (VHF) ESR/EPR. Biological Magnetic Resonance. New York: Springer Press.

[4] Sidabras JS, Mett RR, Froncisz W, Camenisch TG, Anderson JR, Hyde JS. (2007) Multipurpose EPR Loop Gap Resonator and Cylindrical TE011 Cavity for Aqueous Samples at 94 GHzRev. Sci. Instrum. 78, 034701.