

3-D Printed Quadrupole Mass Filters for CubeSat Mass Spectrometry



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We are developing compact, monolithically 3D-printed RF quadrupole mass filters that operate in the MHz range to collect gas concentration climate data in the ionosphere

MOTIVATION

Mass spectrometry is the gold standard for quantitative chemical analysis. Mass spectrometers employ mass filters that generate electromagnetic fields to sort out in vacuum the ionized constituents of a sample based on their mass-to-charge ratio (Fig. 1), making it possible to determine the chemical composition of the sample.

However, mass spectrometers are typically large, heavy, and power hungry, restricting their ability to be deployed into in-situ, portable, and hand-held scenarios, e.g., CubeSats. Miniaturization has been attained at the expense of great loss in performance, caused in part by fabricating unideal electrode shapes and losing assembly resolution via post-assembly. Via additive manufacturing, it is possible to create monolithically and more precisely electrode shapes.

RESULTS

We are developing compact, monolithically 3D-printed RF quadrupole mass filters that operate in the MHz range. Fig. 2 shows early-stage prototypes of this filter, while Fig. 3 shows more advanced prototypes.

The work includes developing compact, low-power, precision electronics for running the quadrupole and reading the current transmitted by the mass filter (Fig. 4, 5). We are also exploring ideas for improving the performance of the mass filter.

The specifications of the circuit are:

- Compact 3D-printed RF quadrupole mass filter for chemical analysis of the ionosphere (1 to 100 Da range) that operates in the MHz range (<1 amu peak width across 1-100 Da, i.e., 100:1 resolution)
- 2 to 200 V sinusoids with 0.2 V voltage steps, 10 cm length and 4 mm diameter rods mass filter, w/ 0.33 to 33 V DC voltage offsets
- Full Bridge Class D amplifier to maximize power efficiency @ 2.65MHz

For sinusoids at maximum amplitude (200 V, Fig. 5a), we get secondary harmonics that are more than 10X less than the driving frequency (Figure 5b).

FUTURE WORK

With the 3D prototypes complete & the electronics simulated, next steps are testing the devices in vacuum with existing electronics, and then our own circuits.

Further Reading

- L. F. Velásquez-García et al, *J. Microelectromech. Syst.*, vol. 16, no. 6, pp. 1430-1438, 2008.
- K. Cheung et al, *J. Microelectromech. Syst.*, vol. 19 no. 3, pp. 469-483, 2010.
- Z. Sun et al, *J. Microelectromech. Sys.*, vol. 27, no. 6, pp. 1171-1185, 2018.

RF waves applied to conductive rods generate electromagnetic fields that filter ions based on amplitude input

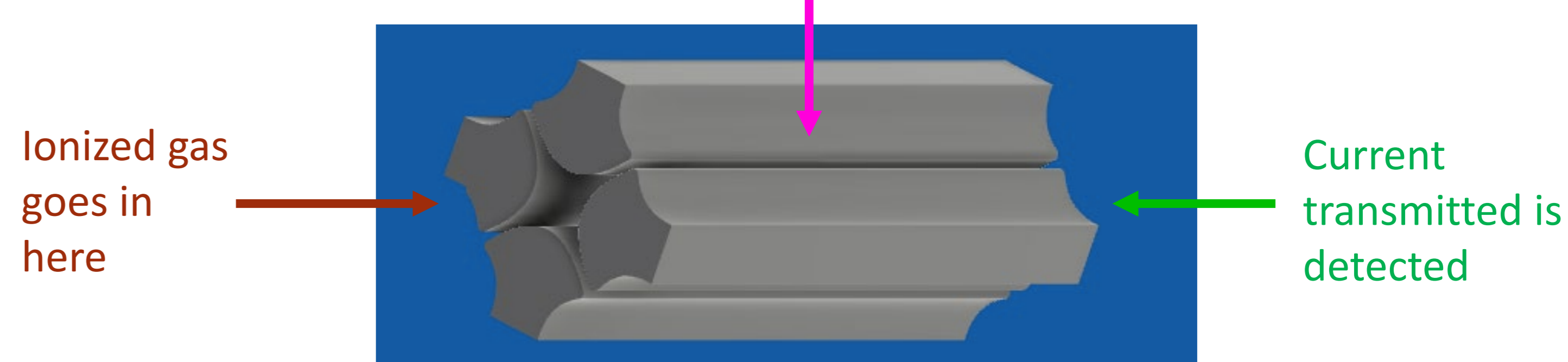


Fig. 1 Conceptual schematic of a quadrupole mass filter

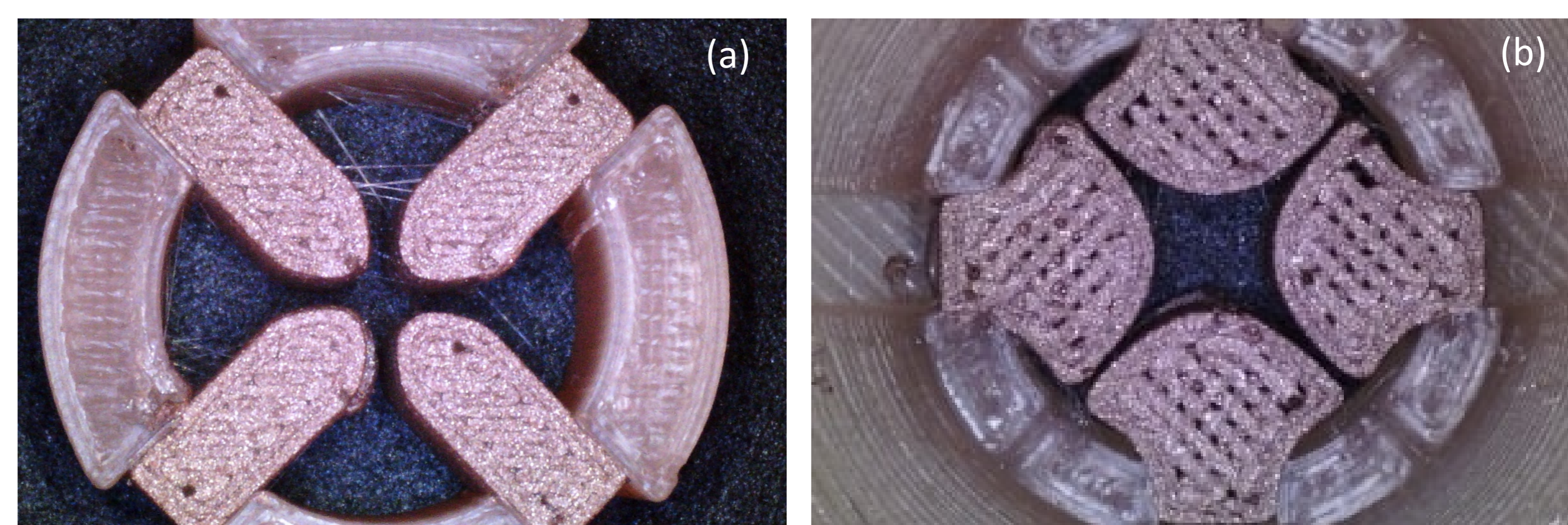


Fig. 2 3D-printed quadrupoles: (a) early version, (b) later version with advanced hyperbolic electrodes. As reference, the diameter of the central hole surrounded by the electrodes is 4 mm

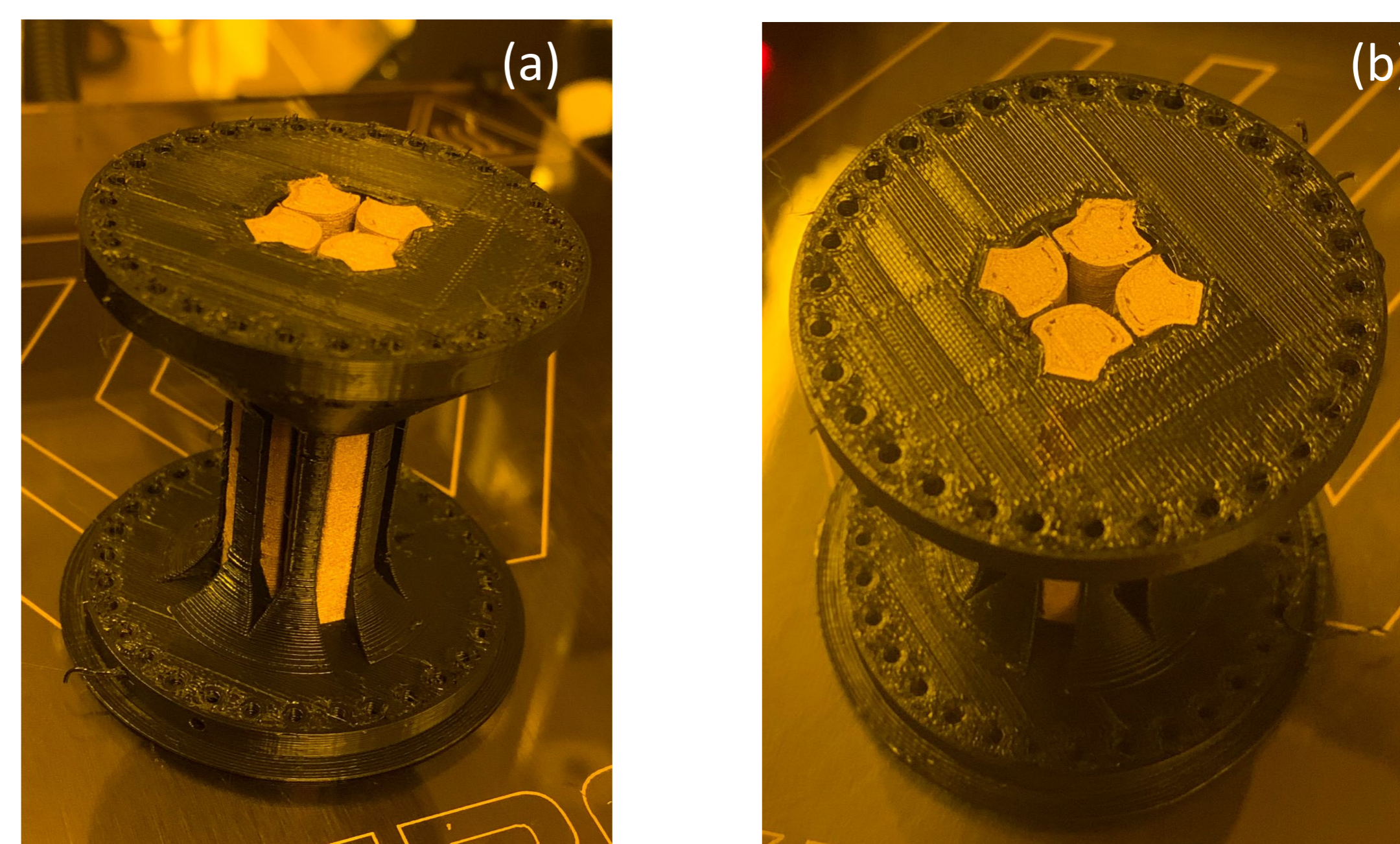


Fig. 3 Side view (a) and top view (b) of recent 3D-Printed quadrupole prototype. As reference, the diameter of the central hole surrounded by the electrodes is 4 mm

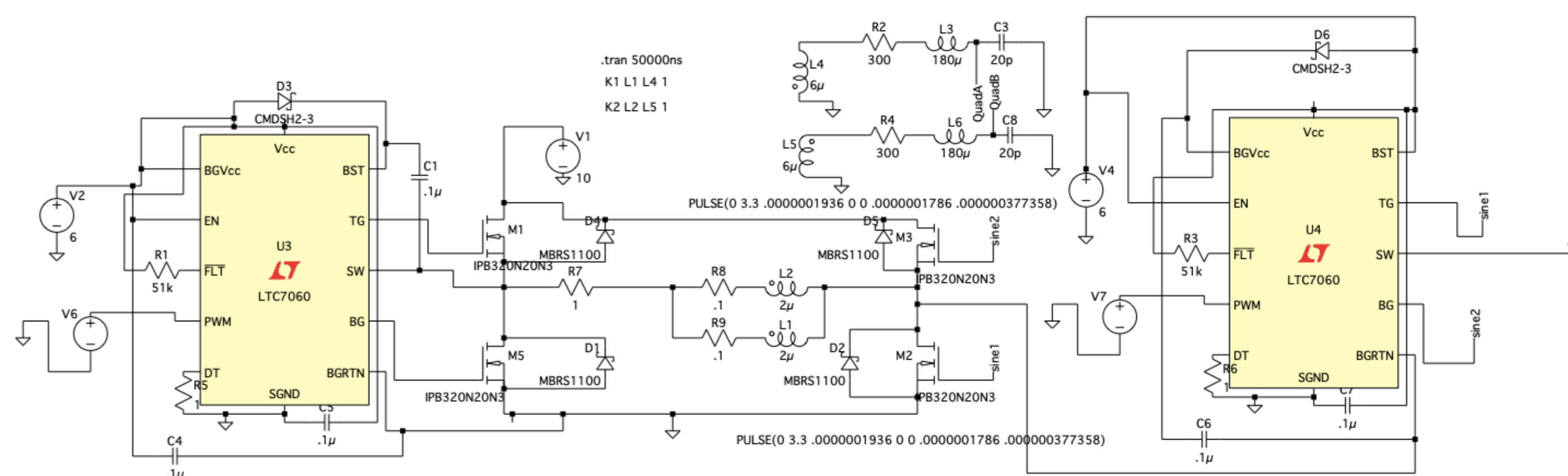


Fig. 4 Synthesized circuitry to drive at low power a miniaturized quadrupole

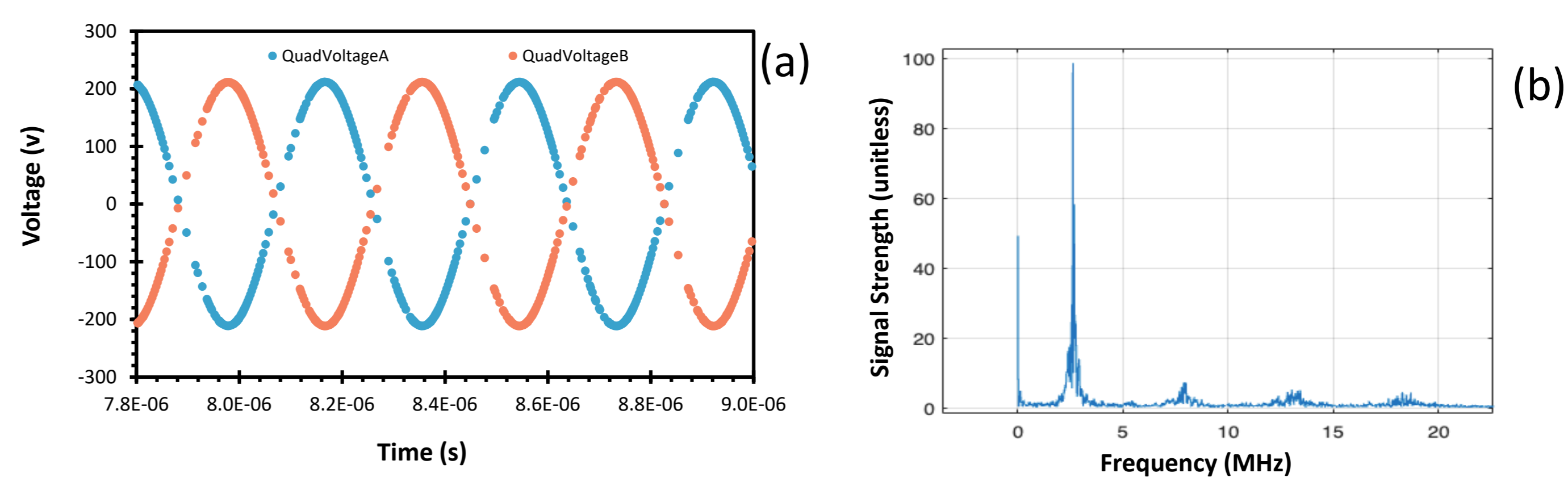


Fig. 5 Generated Sinusoidal wave @ 2.65 MHz (a) and Fourier transform of the RF wave (b)

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