UCDAVIS
DEPARTMENT OF CHEMISTRY

A 6-18 GHz Direct Digital Synthesis Tunable Segmented Chirped Pulse Fourier Transform Microwave Spectrometer

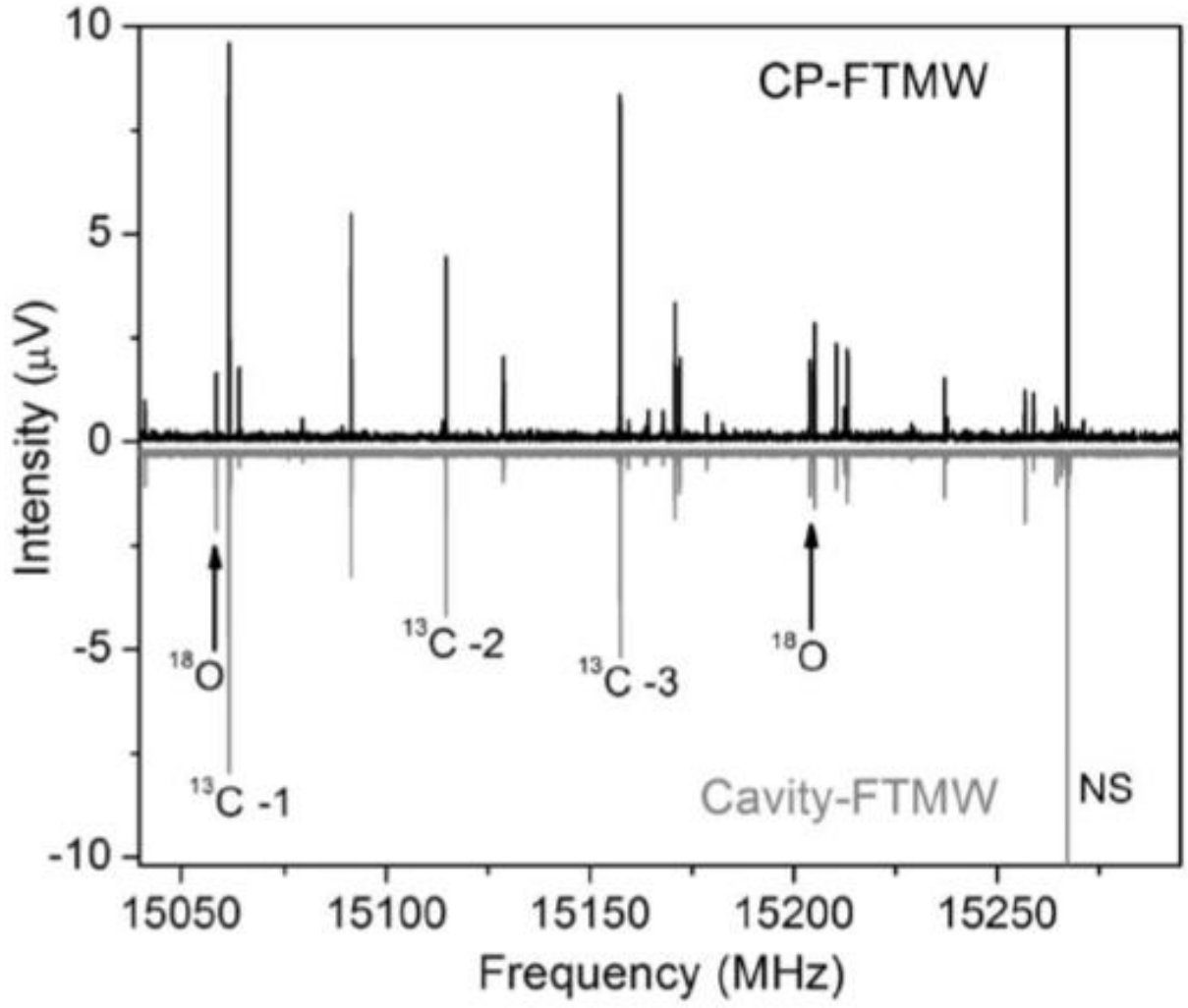
Haley N. Scolati, Sommer L. Johansen, Anna L. Pischer, Kyle N. Crabtree

Department of Chemistry, University of California, Davis

The Importance of CP-FTMW

UCDAVIS
DEPARTMENT OF CHEMISTRY

Invented in 2006 with first publication in 2008



Rotational spectrum of C_4H_6O using Cavity-FTMW vs CP-FTMW over a 250 MHz frequency range.

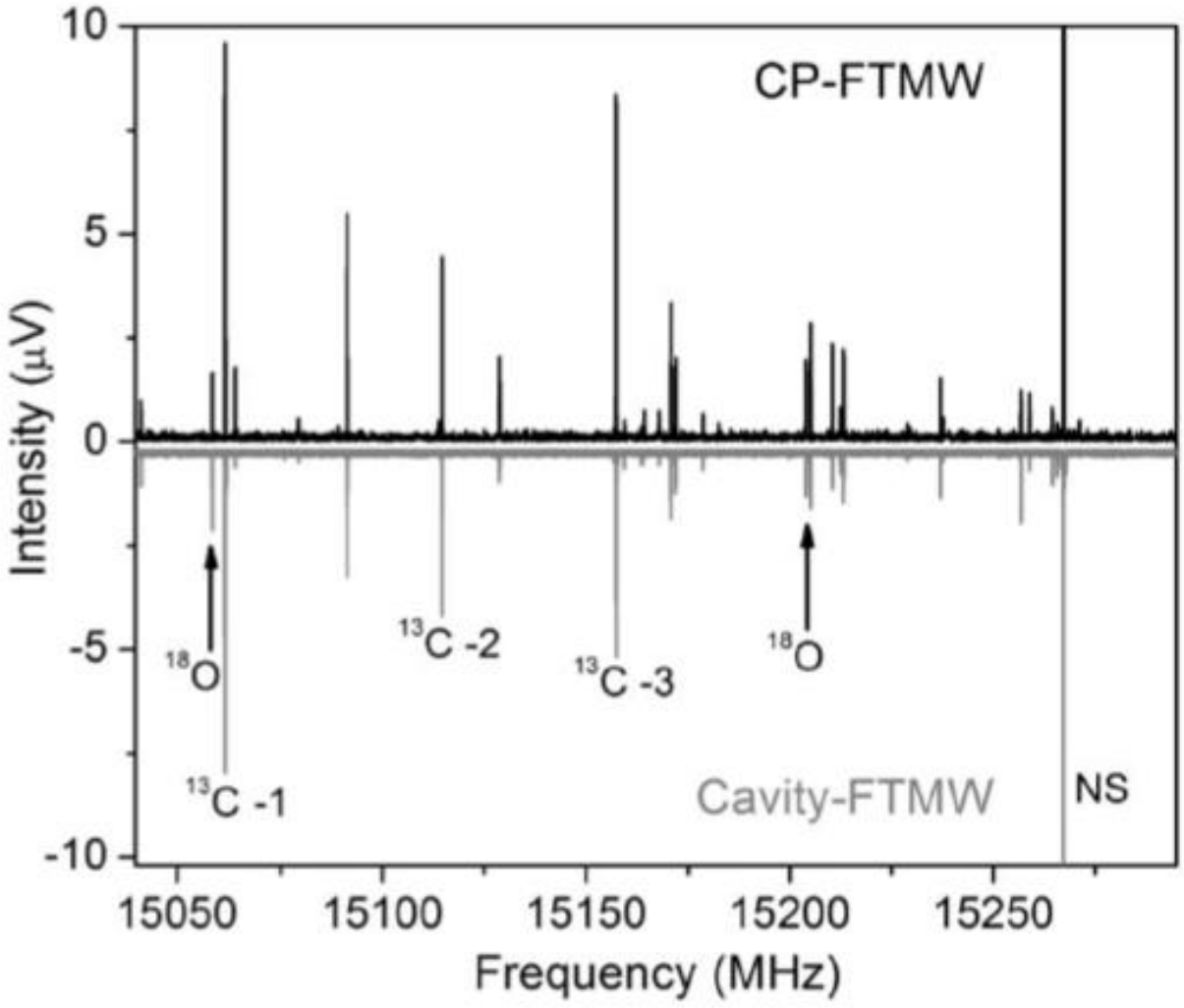
Brown, G. G.; *Rev. Sci. Instrum*. 2008, **79,** 053103-1
Park, G. B.; Field, R. W. *J. Chem. Phys.* 2016, **144**, 200901.

The Importance of CP-FTMW

UCDAVIS
DEPARTMENT OF CHEMISTRY

Invented in 2006 with first publication in 2008

Significant advancement for molecular identification and gas phase experiments



Rotational spectrum of C_4H_6O using Cavity-FTMW vs CP-FTMW over a 250 MHz frequency range.

Brown, G. G.; *Rev. Sci. Instrum*. 2008, **79,** 053103-1
Park, G. B.; Field, R. W. *J. Chem. Phys.* 2016, **144**, 200901.

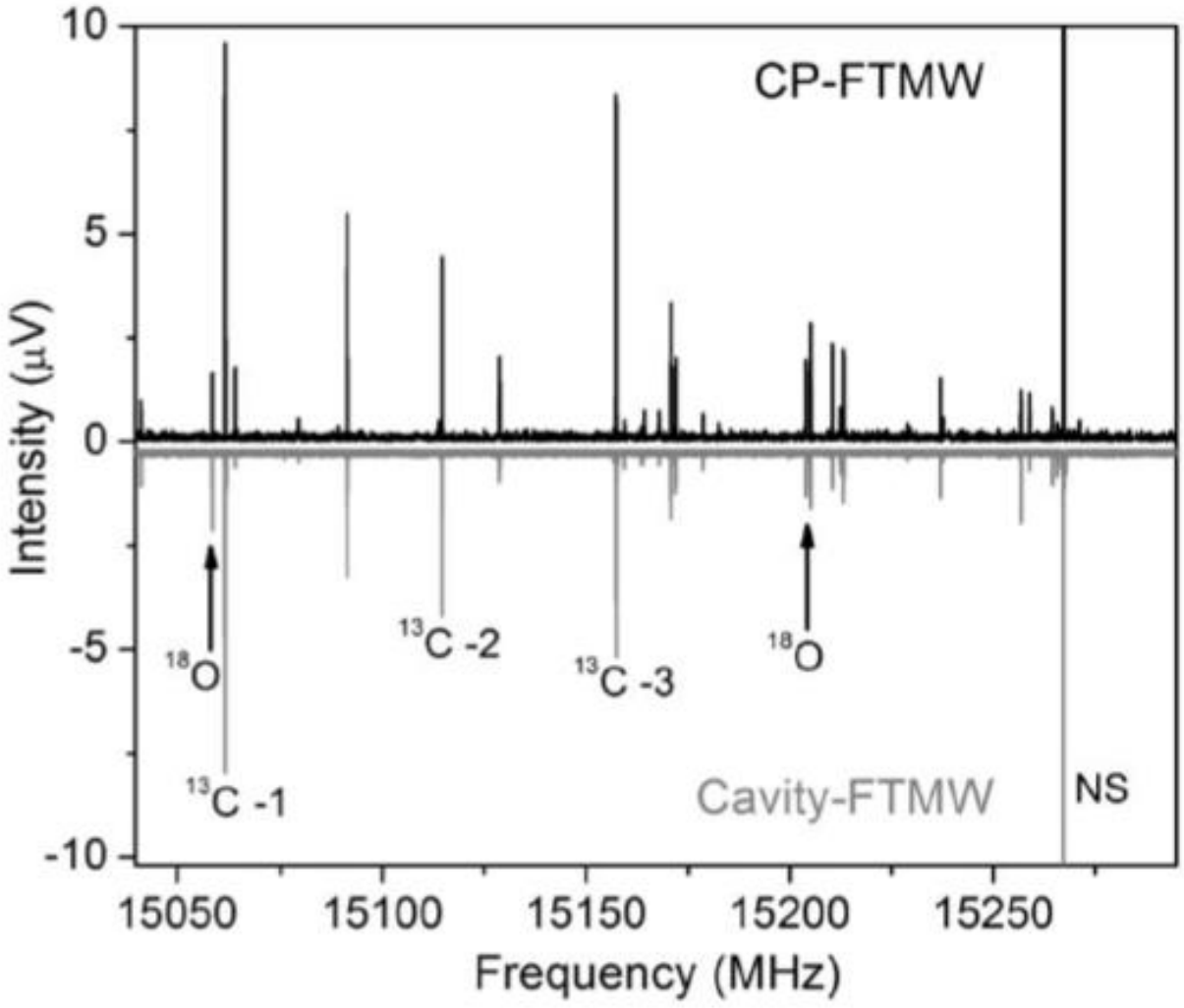
The Importance of CP-FTMW

UCDAVIS
DEPARTMENT OF CHEMISTRY

Invented in 2006 with first publication in 2008

Significant advancement for molecular identification and gas phase experiments

High resolution spectral acquisition using broadband frequency coverage



Rotational spectrum of C_4H_6O using Cavity-FTMW vs CP-FTMW over a 250 MHz frequency range.

Brown, G. G.; *Rev. Sci. Instrum*. 2008, **79,** 053103-1
Park, G. B.; Field, R. W. *J. Chem. Phys.* 2016, **144**, 200901.

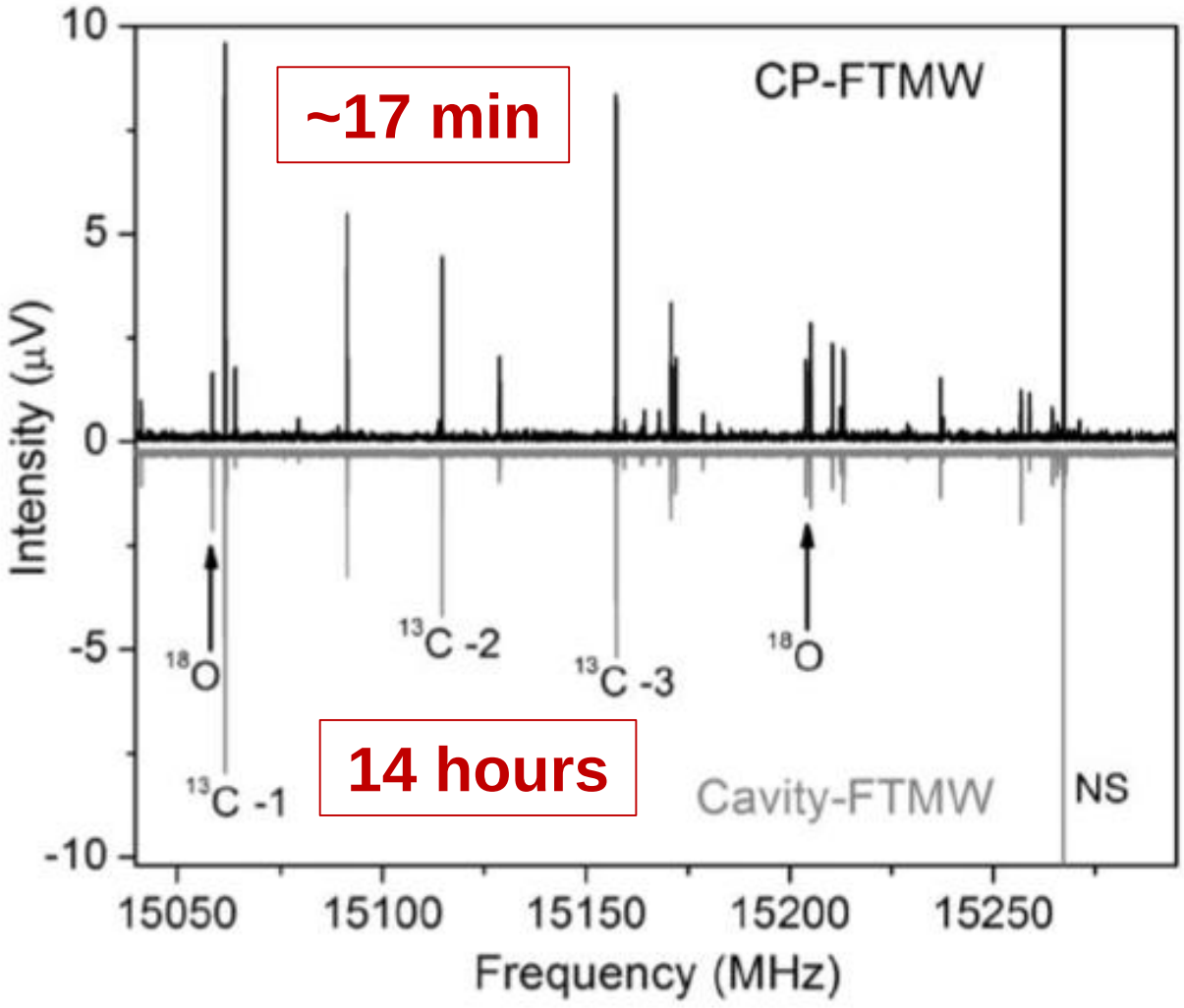
The Importance of CP-FTMW

UCDAVIS
DEPARTMENT OF CHEMISTRY

Invented in 2006 with first publication in 2008

Significant advancement for molecular identification and gas phase experiments

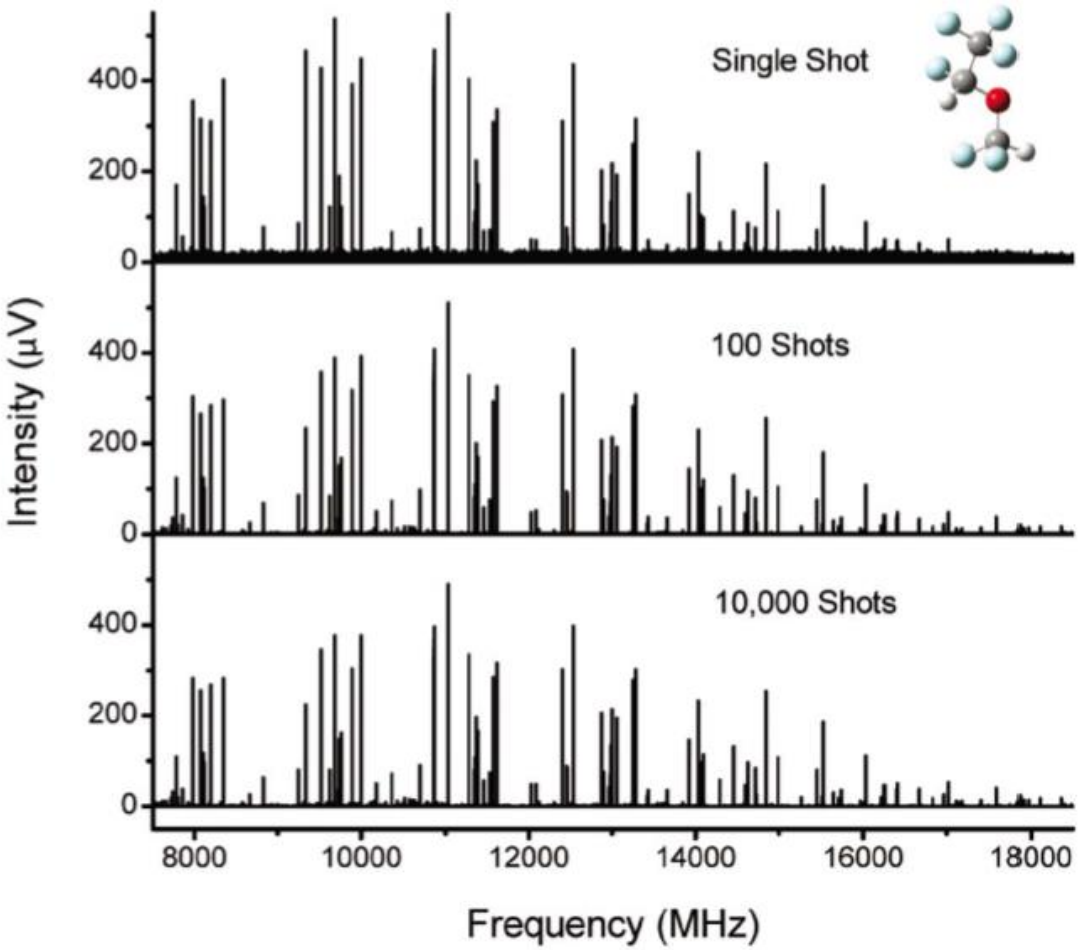
High resolution spectral acquisition using broadband frequency coverage



Rotational spectrum of C_4H_6O using Cavity-FTMW vs CP-FTMW over a 250 MHz frequency range.

Brown, G. G.; *Rev. Sci. Instrum*. 2008, **79,** 053103-1
Park, G. B.; Field, R. W. *J. Chem. Phys.* 2016, **144**, 200901.

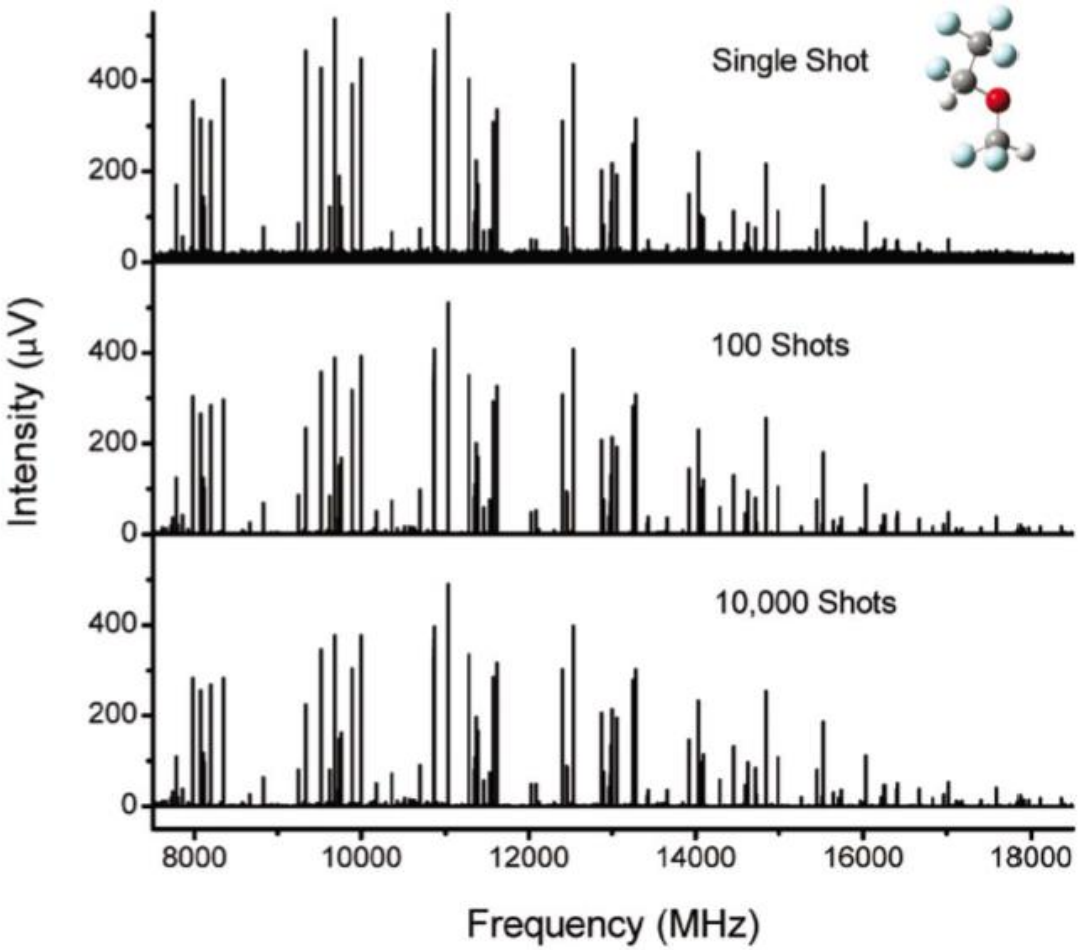
The Costly Requirements



Rotational spectrum of suprane over a 10 GHz bandwidth (~17 minute acquisition time).

Brown, G. G.; *Rev. Sci. Instrum*. 2008, **79,** 053103-1
Park, G. B.; Field, R. W. *J. Chem. Phys.* 2016, **144**, 200901.

The Costly Requirements



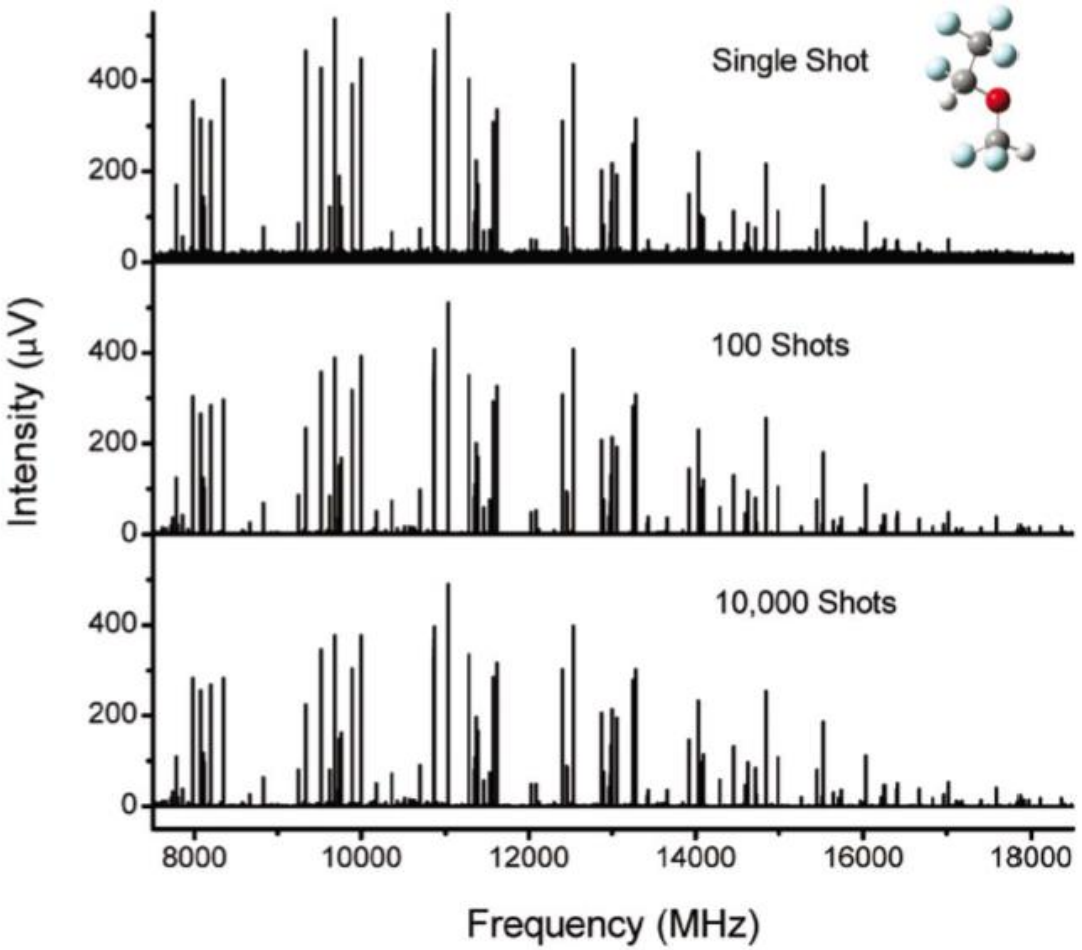
Rotational spectrum of suprane over a 10 GHz bandwidth (~17 minute acquisition time).

Requires more peak power

- No cavity (Q=1)
- No passive amplification
- Requires active amplification

Brown, G. G.; *Rev. Sci. Instrum*. 2008, **79,** 053103-1
Park, G. B.; Field, R. W. *J. Chem. Phys.* 2016, **144**, 200901.

The Costly Requirements



Rotational spectrum of suprane over a 10 GHz bandwidth (~17 minute acquisition time).

Requires more peak power

- No cavity (Q=1)
- No passive amplification
- Requires active amplification

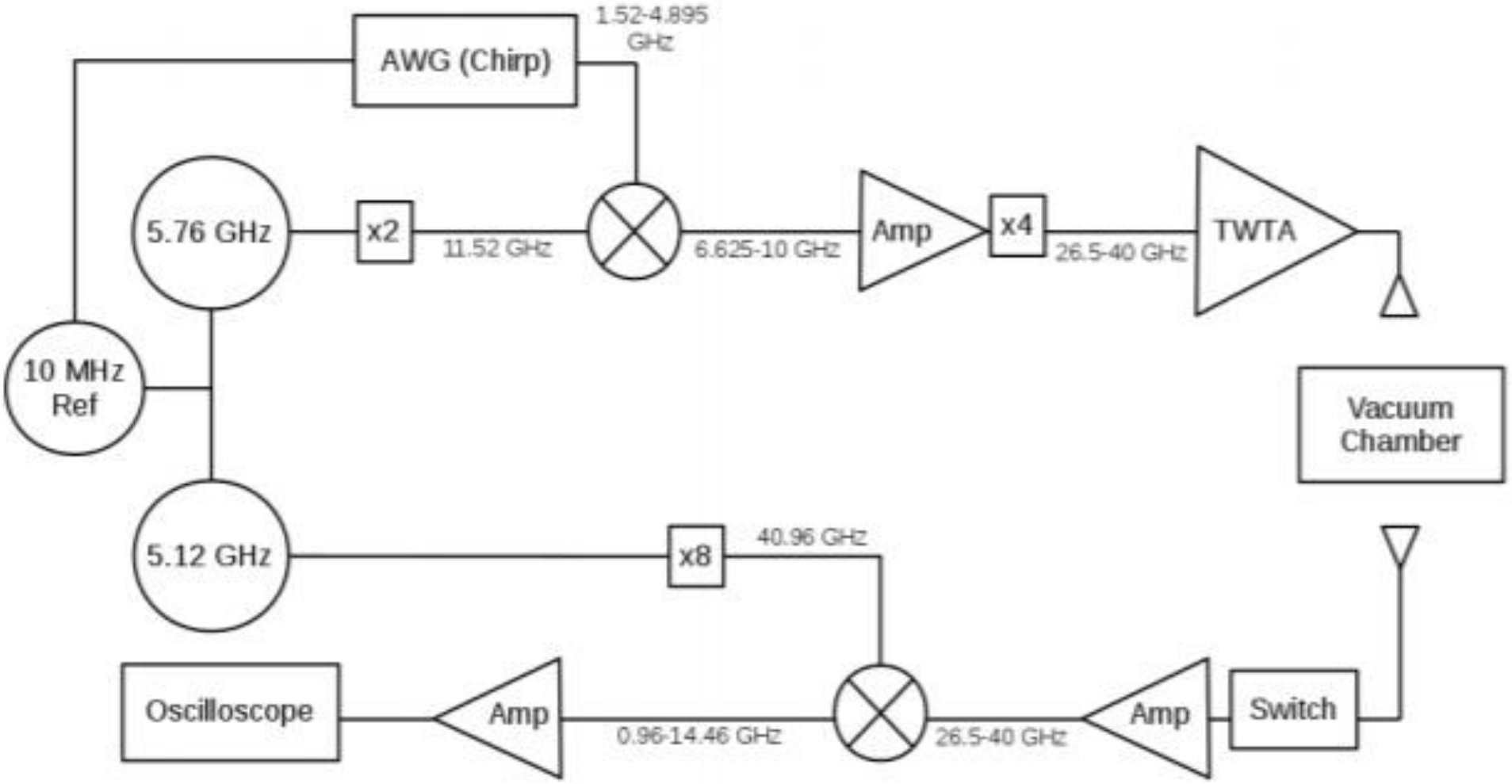
Increased bandwidth

- Increased sampling rate
- 11 GHz vs 1 MHz range

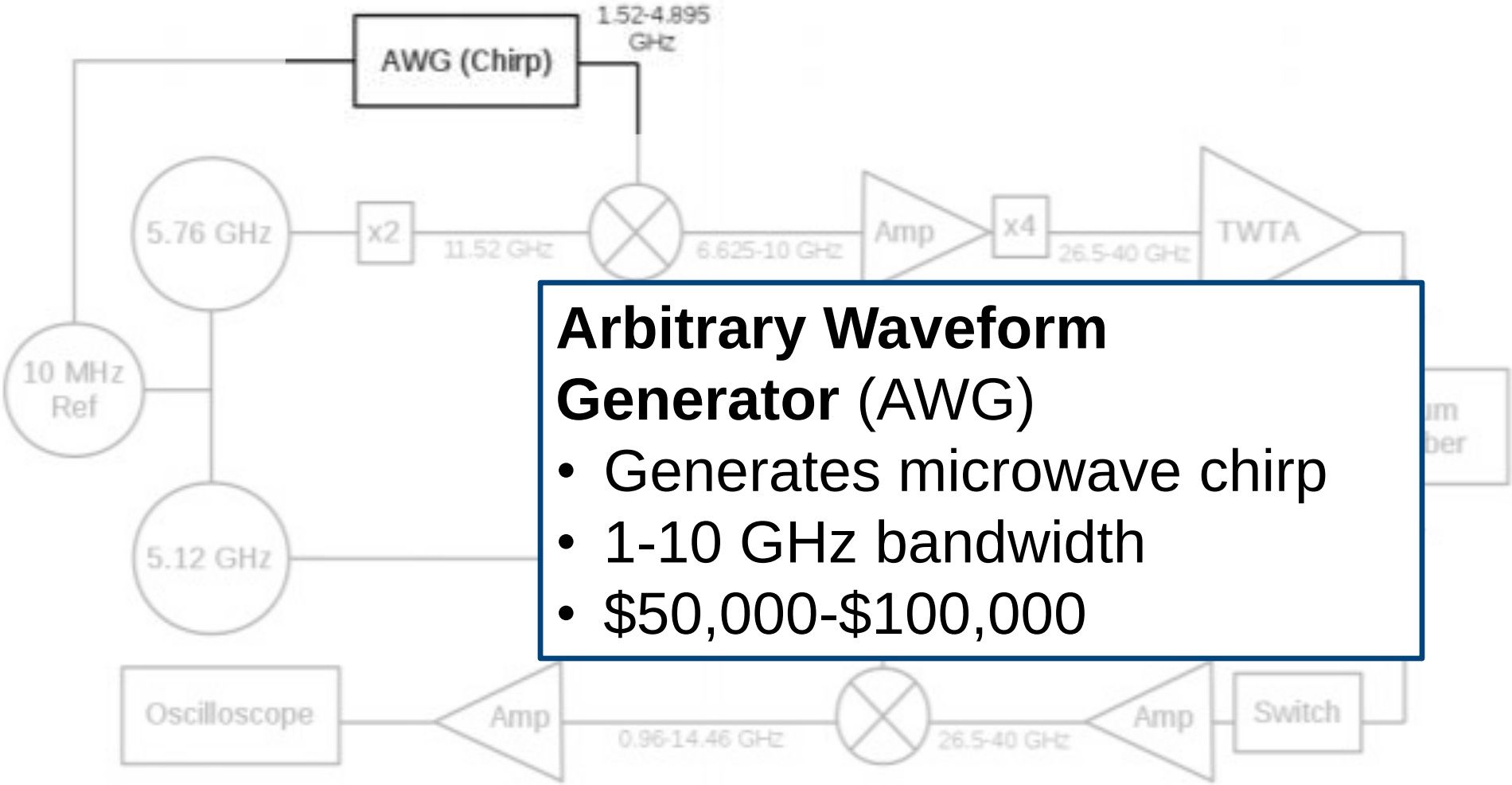
Brown, G. G.; *Rev. Sci. Instrum*. 2008, **79,** 053103-1
Park, G. B.; Field, R. W. *J. Chem. Phys.* 2016, **144**, 200901.

CP Spectrometers are Expensive

UCDAVIS
DEPARTMENT OF CHEMISTRY



CP Spectrometers are Expensive

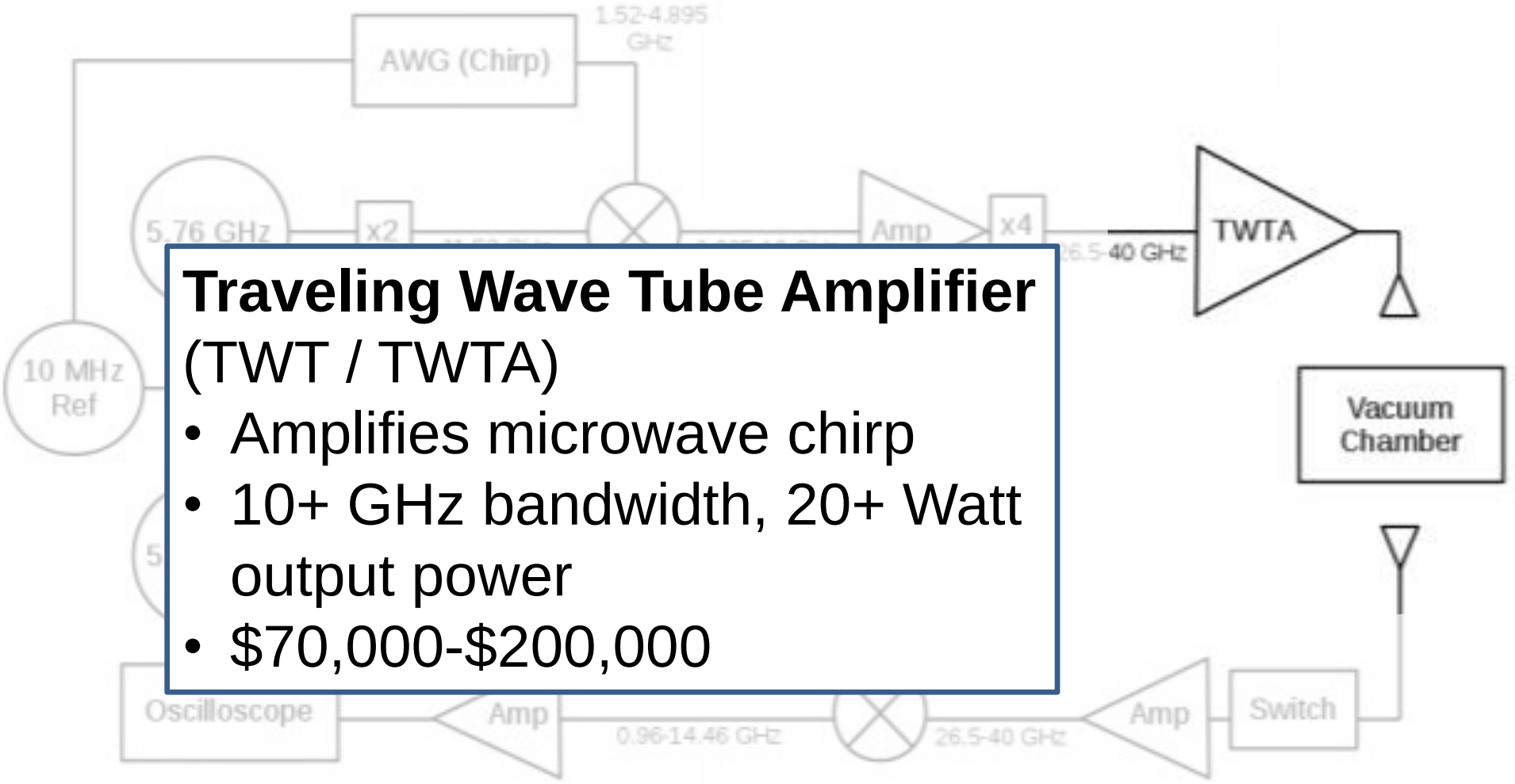


Arbitrary Waveform Generator (AWG)

- Generates microwave chirp
- 1-10 GHz bandwidth
- $50,000-$100,000

CP Spectrometers are Expensive

UCDAVIS
DEPARTMENT OF CHEMISTRY

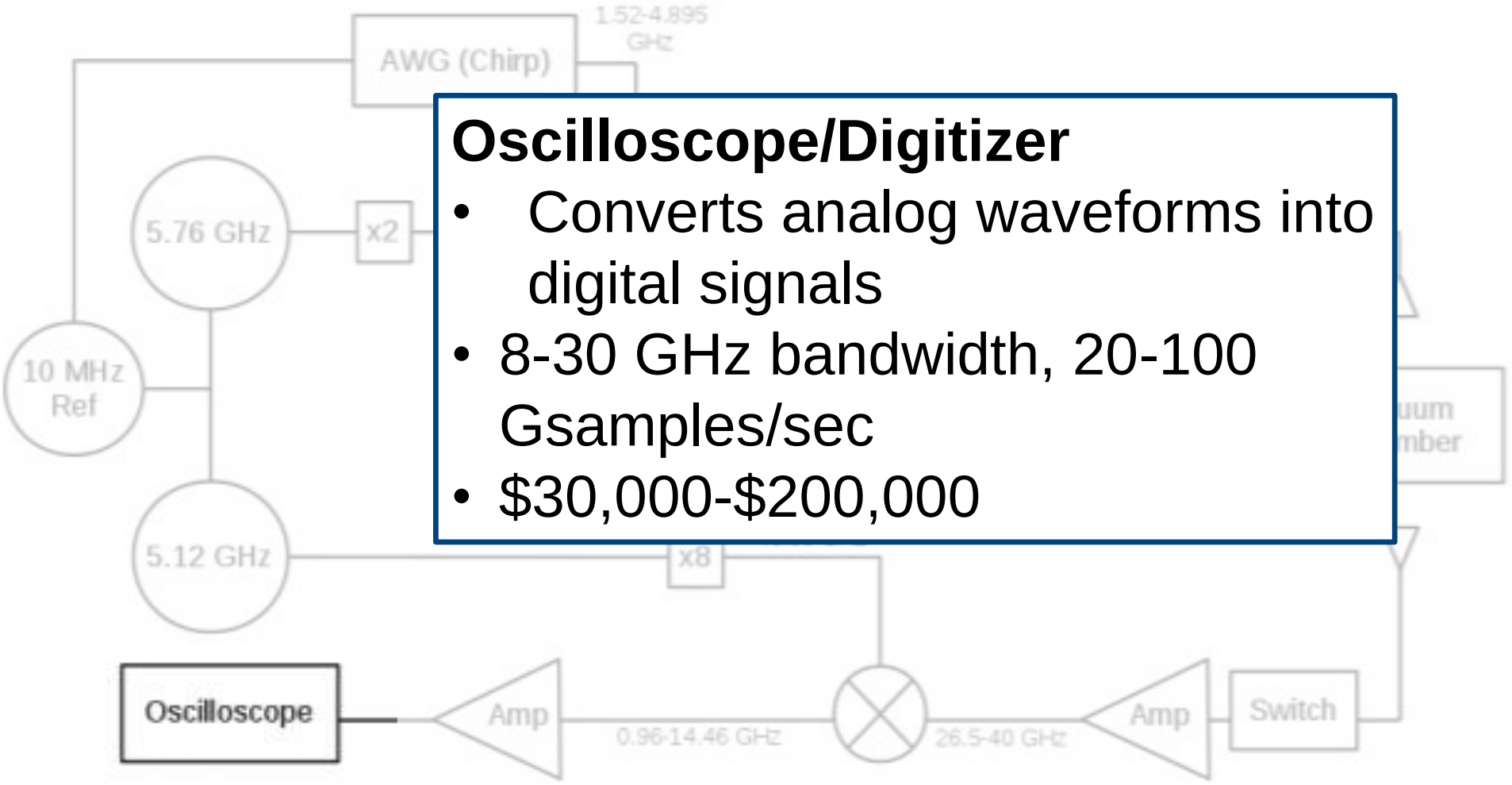


Traveling Wave Tube Amplifier
(TWT / TWTA)

- Amplifies microwave chirp
- 10+ GHz bandwidth, 20+ Watt output power
- $70,000-$200,000

CP Spectrometers are Expensive

UCDAVIS
DEPARTMENT OF CHEMISTRY



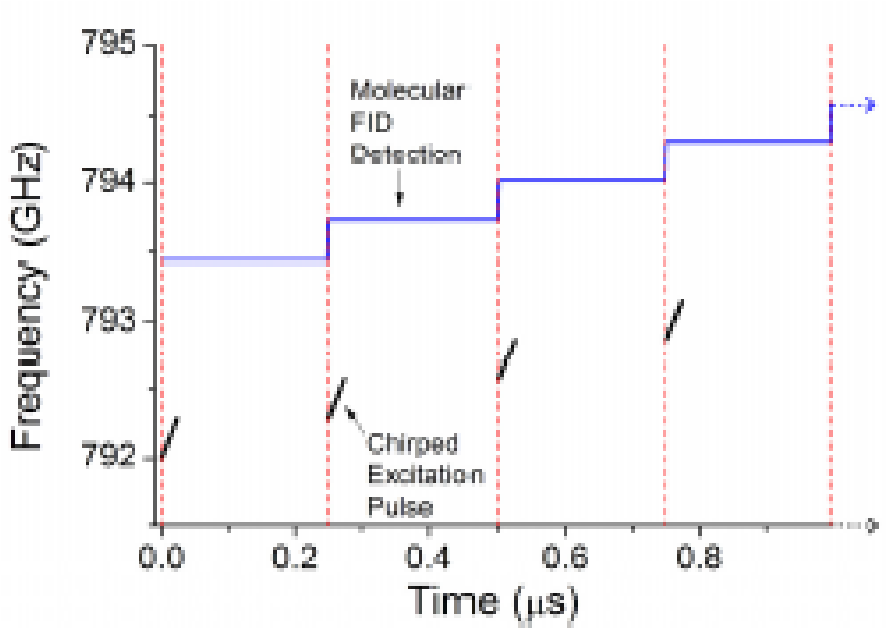
Oscilloscope/Digitizer

- Converts analog waveforms into digital signals
- 8-30 GHz bandwidth, 20-100 Gsamples/sec
- $30,000-$200,000

The Segmented Approach Uses a Tunable IF

UCDAVIS DEPARTMENT OF CHEMISTRY

- Sweeps over smaller frequency intervals
- Adds tunable Intermediate Frequency (IF)
- Requires less power, lower digitization bandwidth

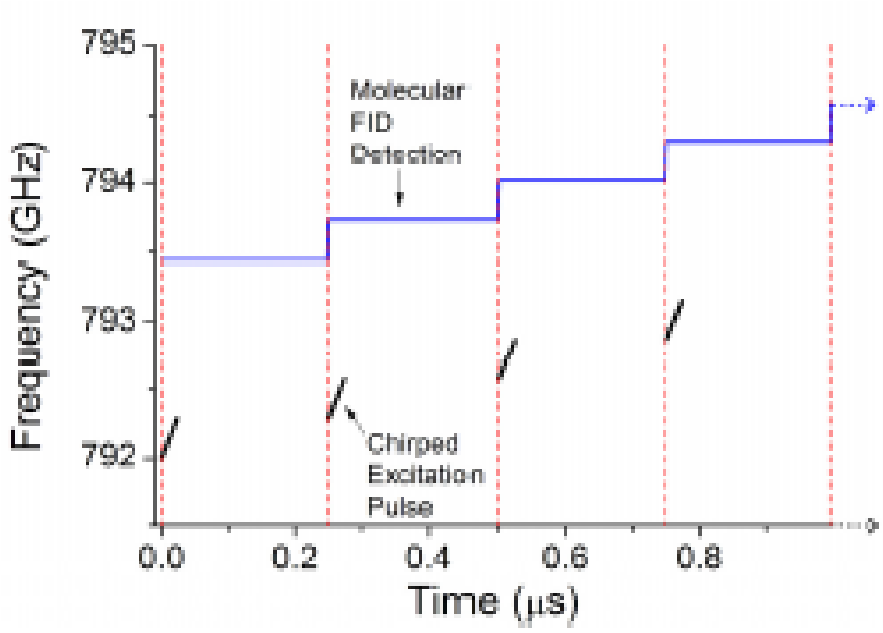


Neill, J. L.; Harris, B. J.; Steber, A. L.; Douglass, K. O.; Plusquellic, D. F.; Pate, B. H. Optics Express. 2013, **21**, 19743

The Segmented Approach Uses a Tunable IF

UCDAVIS DEPARTMENT OF CHEMISTRY

- Sweeps over smaller frequency intervals
- Adds tunable Intermediate Frequency (IF)
- Requires less power, lower digitization bandwidth



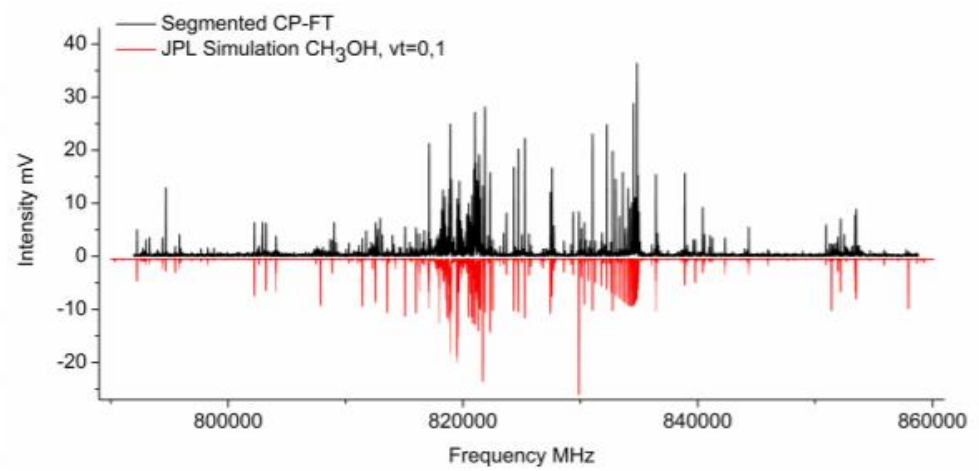


Fig. 3. Single acquisition cycle (58 μs data collection) of methanol (black) with 67 GHz bandwidth, compared to a simulation at 300 K generated using the JPL spectral catalog [22] (red).

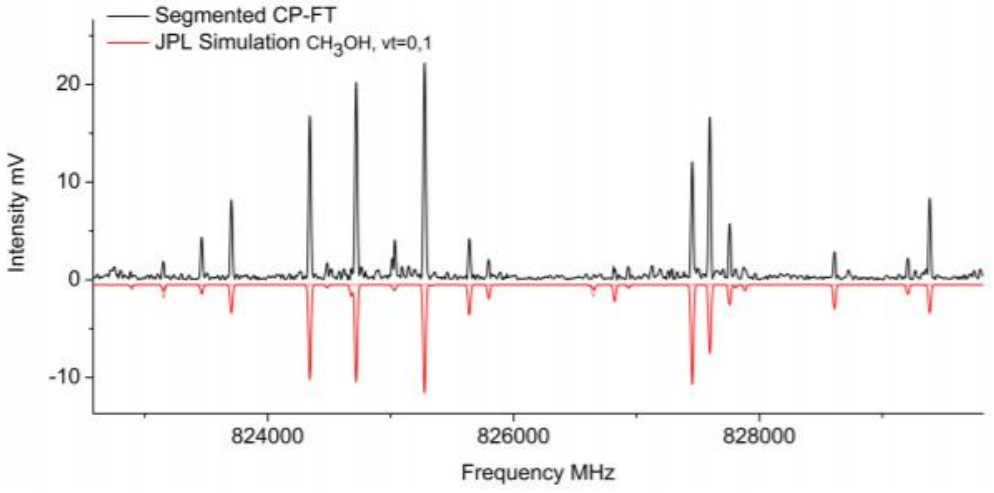


Fig. 4. Expanded view of the 67 GHz 58 μ sec single shot segmented CP-FT spectrum of methanol (black) compared to the JPL simulation.

Neill, J. L.; Harris, B. J.; Steber, A. L.; Douglass, K. O.; Plusquellic, D. F.; Pate, B. H. Optics Express. 2013, **21**, 19743

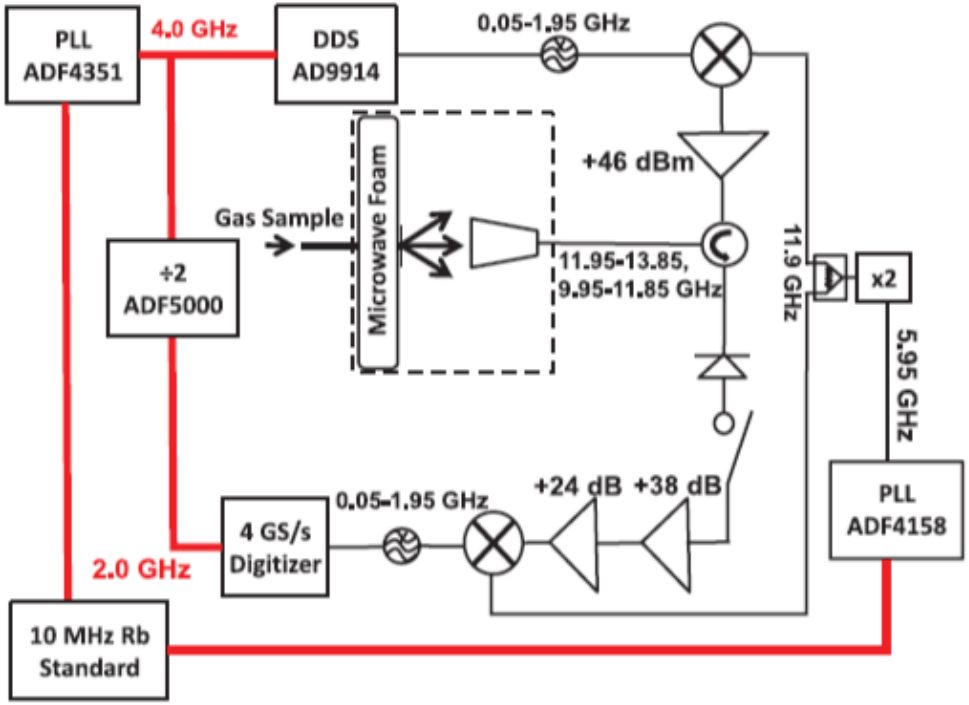
Direct Digital Synthesizer Replaces AWG

UCDAVIS DEPARTMENT OF CHEMISTRY

Same purpose as an AWG

DDS: Synthesizer whose output frequency can be changed very quickly

- Much cheaper



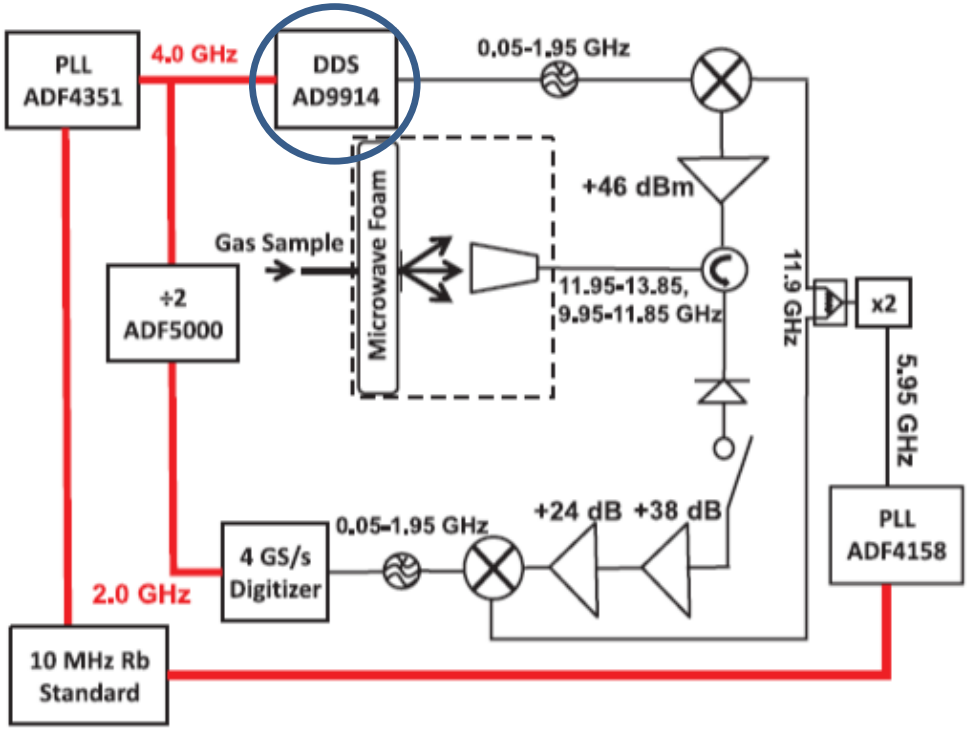
Direct Digital Synthesizer Replaces AWG

UCDAVIS DEPARTMENT OF CHEMISTRY

Same purpose as an AWG

DDS: Synthesizer whose output frequency can be changed very quickly

- Much cheaper



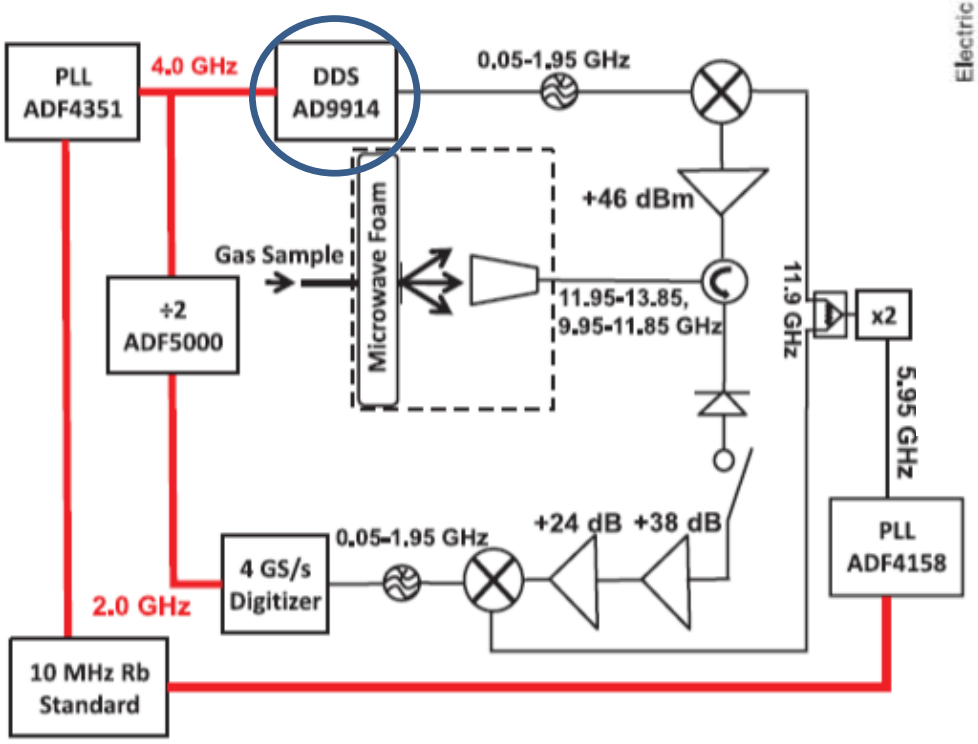
Direct Digital Synthesizer Replaces AWG

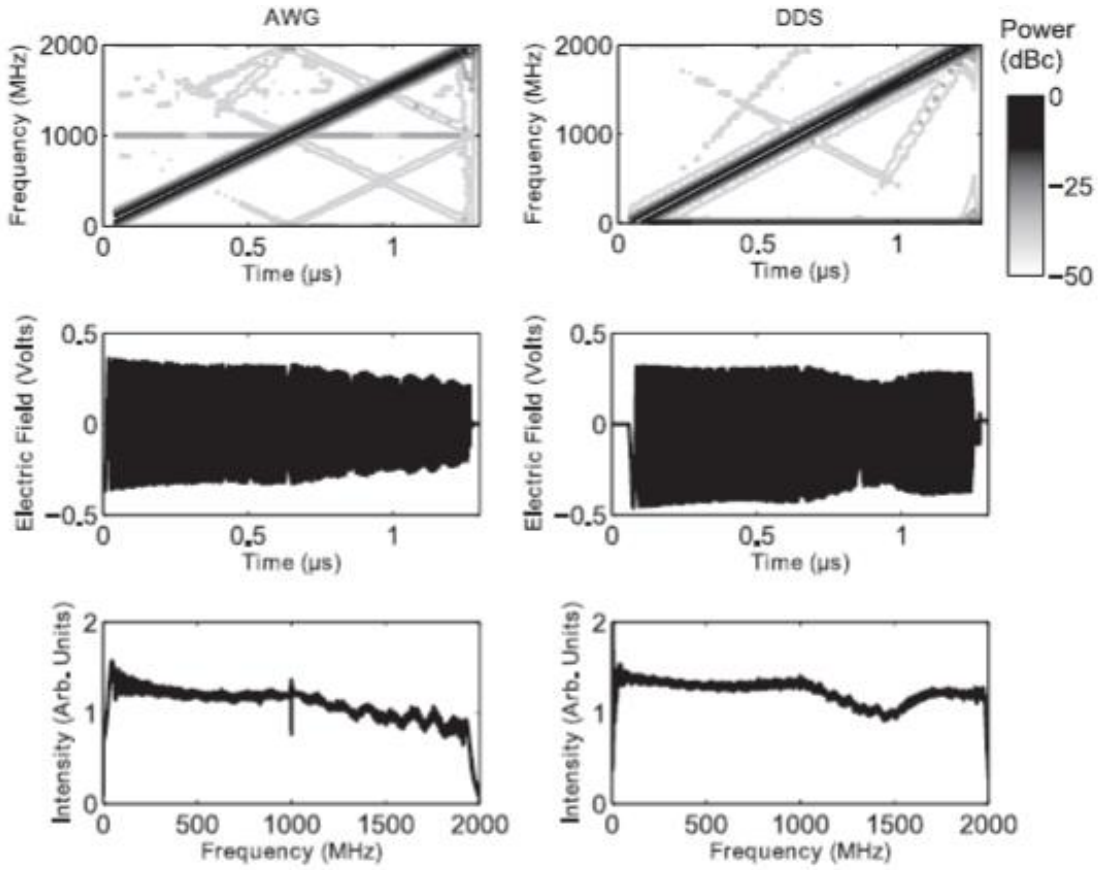
UCDAVIS DEPARTMENT OF CHEMISTRY

Same purpose as an AWG

DDS: Synthesizer whose output frequency can be changed very quickly

- Much cheaper



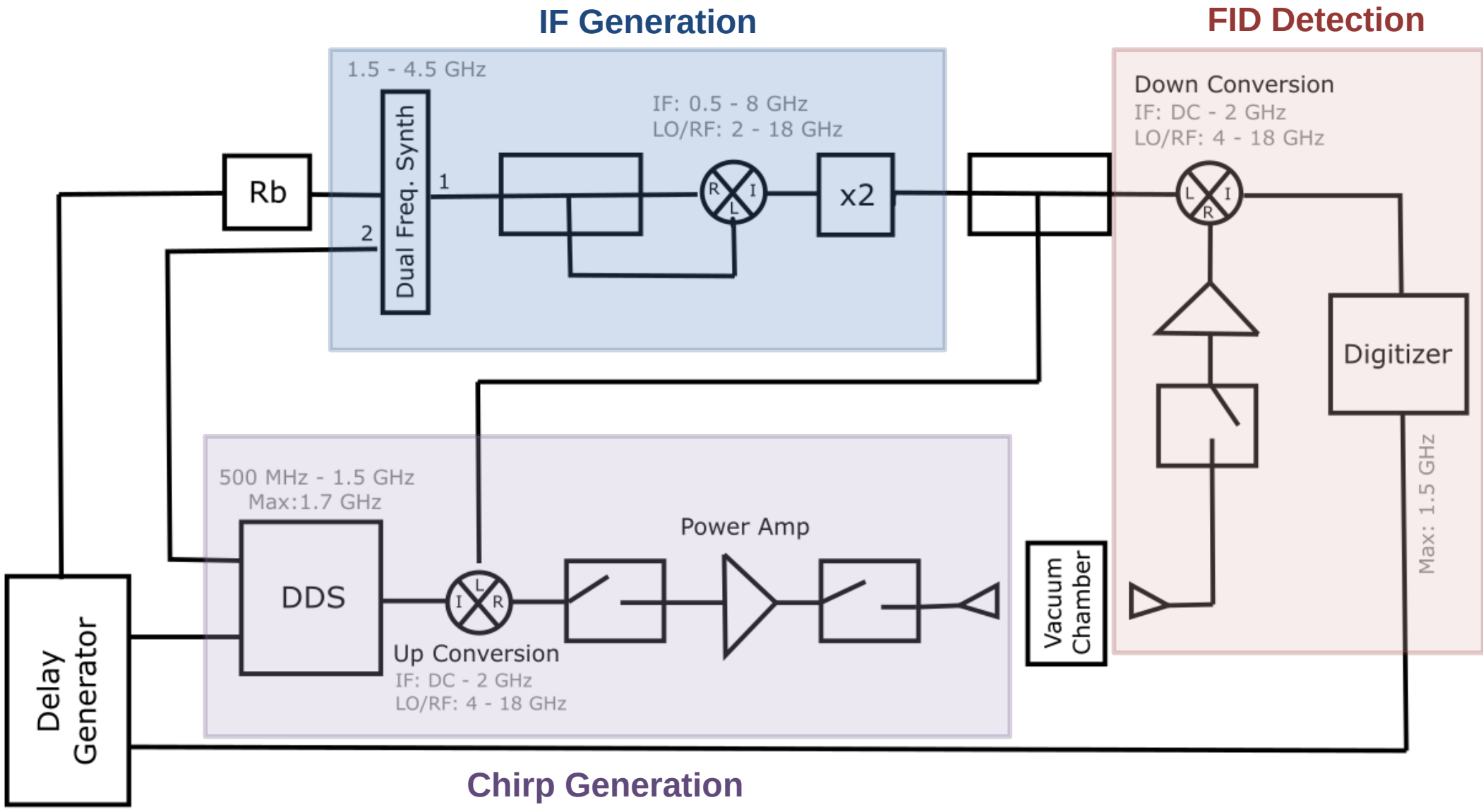


1.5 μs chirp by an AWG compared to a stepped single frequency output by a DDS over 2 GHz bandwidth.

Finneran, I. A.; et al. *Rev. Sci. Instrum*. 2013, **84**, 083104-1

UC Davis Segmented Spectrometer

UCDAVIS
DEPARTMENT OF CHEMISTRY



Cost Effective Components

UCDAVIS
DEPARTMENT OF CHEMISTRY

Direct Digital Synthesizer (DDS)

- Analog Devices
- 3.5 Gsamples/sec (max)
- Free (+$50,000)

AD9914/AD9915 Evaluation Board User Guide. Norwood: Analog Devices (2017).
M4i.22xx-x8 - 8 bit Digitizer up to 5 GS/s. Grosshansdorf: Spectrum Instrumentation (2018)
15W Solid State Power Amplifier 6GHz-18GHz.. San Diego: RF-Lambda (2018).

Cost Effective Components

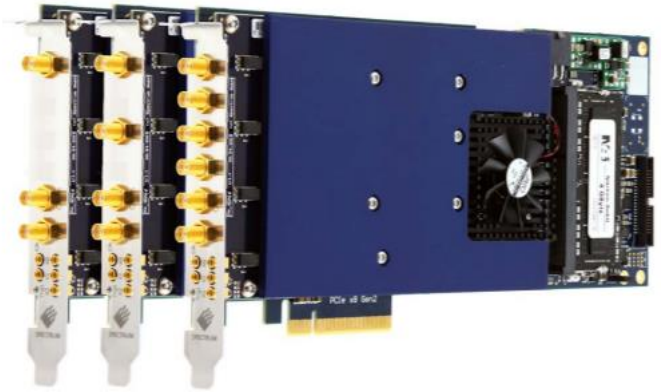
UCDAVIS
DEPARTMENT OF CHEMISTRY

Direct Digital Synthesizer (DDS)

- Analog Devices
- 3.5 Gsamples/sec (max)
- Free (+$50,000)

Digitizer

- Spectrum Instrumentation
- 1500 MHz Bandwidth
- $6500 (+$23,500)



AD9914/AD9915 Evaluation Board User Guide. Norwood: Analog Devices (2017).
M4i.22xx-x8 - 8 bit Digitizer up to 5 GS/s. Grosshansdorf: Spectrum Instrumentation (2018)
15W Solid State Power Amplifier 6GHz-18GHz.. San Diego: RF-Lambda (2018).

Cost Effective Components

UCDAVIS
DEPARTMENT OF CHEMISTRY

Direct Digital Synthesizer (DDS)

- Analog Devices
- 3.5 Gsamples/sec (max)
- Free (+$50,000)

Digitizer

- Spectrum Instrumentation
- 1500 MHz Bandwidth
- $6500 (+$23,500)

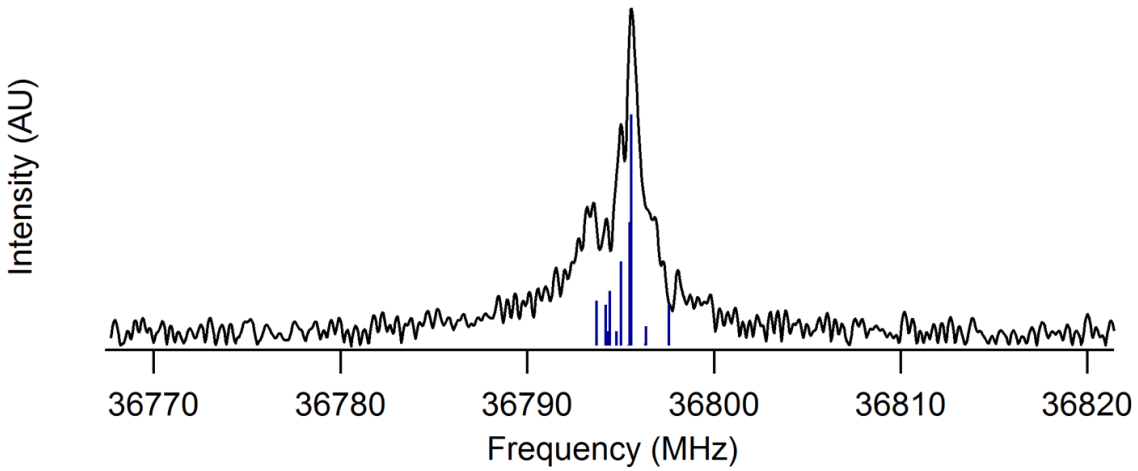
High Power Amplifier

- RF Lambda
- 6-18 GHz, 15 W
- $7800 (+$62,200)

AD9914/AD9915 Evaluation Board User Guide. Norwood: Analog Devices (2017).
M4i.22xx-x8 - 8 bit Digitizer up to 5 GS/s. Grosshansdorf: Spectrum Instrumentation (2018)
15W Solid State Power Amplifier 6GHz-18GHz.. San Diego: RF-Lambda (2018).

Acknowledgments

UCDAVIS
DEPARTMENT OF CHEMISTRY



PI:
Kyle Crabtree

Research Assistant:
Hannah Toru

Graduate Students:
Sommer Johansen
Zachary Buchanan
Zhongxing Xu
Eric Nguyen
Kelly Meyer

Undergraduate Researchers:
Anna Pischer
Brenda Erickson
Sonja Bumann