Fast Multi-Harmonic Kickers

Electrodynamic, DOE SBIR DE-SC0020566 SBIR Phase II, NCE.

PI: Brock F. Roberts, PhD

DOE Phase II SBIR Topic: 33c, Nuclear Physics Accelerator Technology, Particle Beam Sources and Techniques.

Collaborators: The Thomas Jefferson National Laboratory's (JLAB) Superconducting Radio Frequency Research and Development Group (SRF R&D) and Center for Injectors and Sources (CIS).

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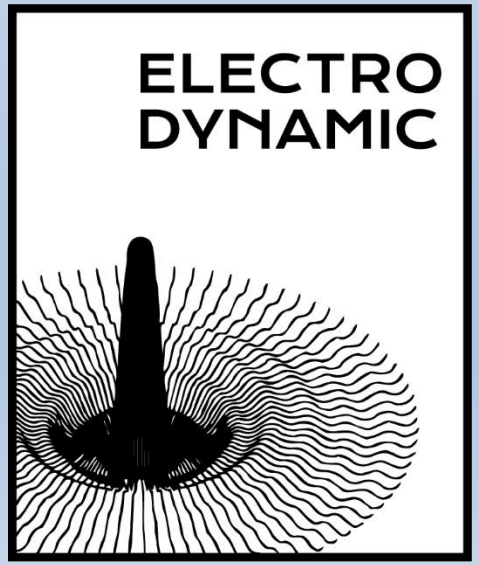

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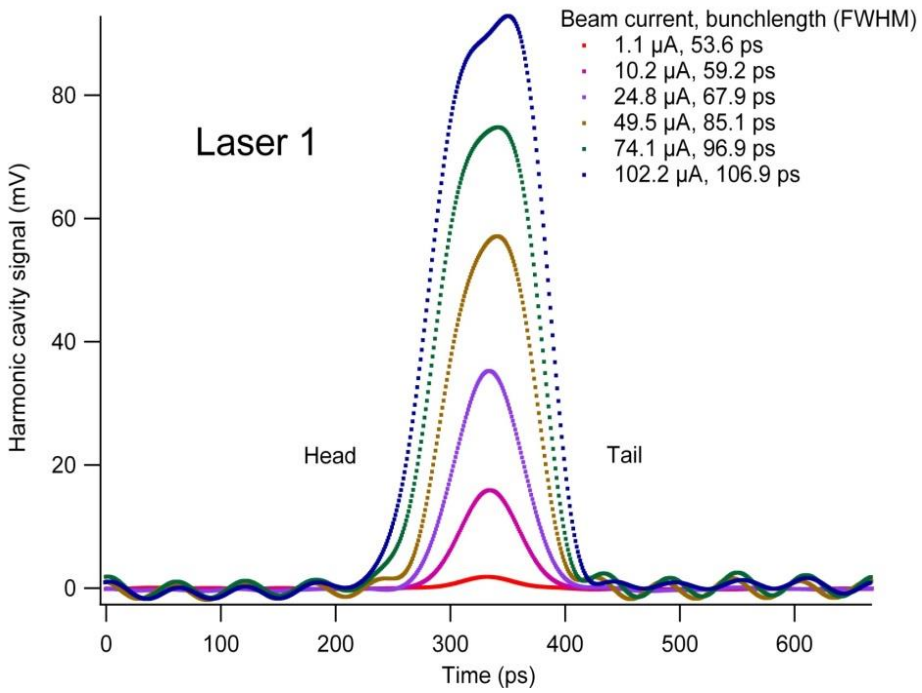
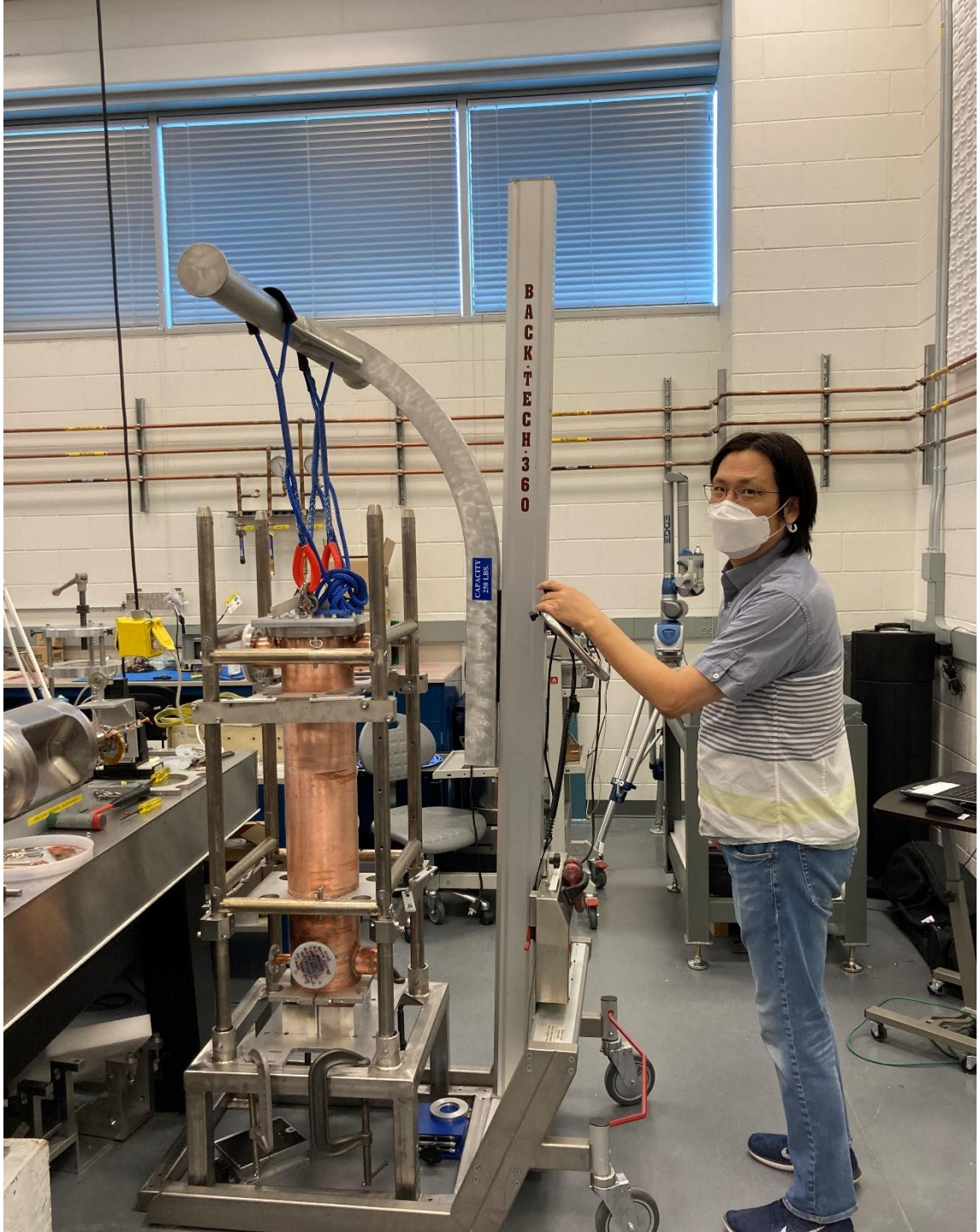
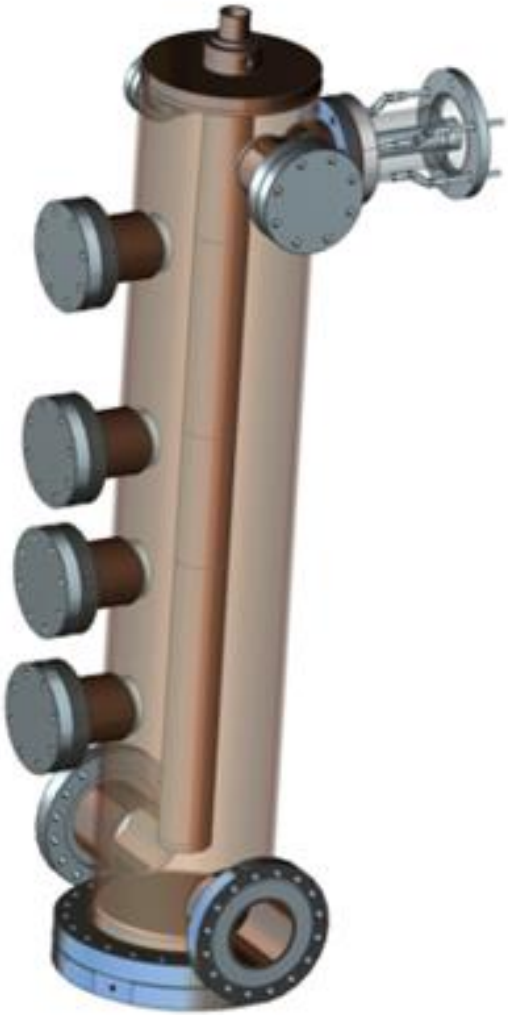



BACK-TECH-360
CAPACITY
250 LBS.



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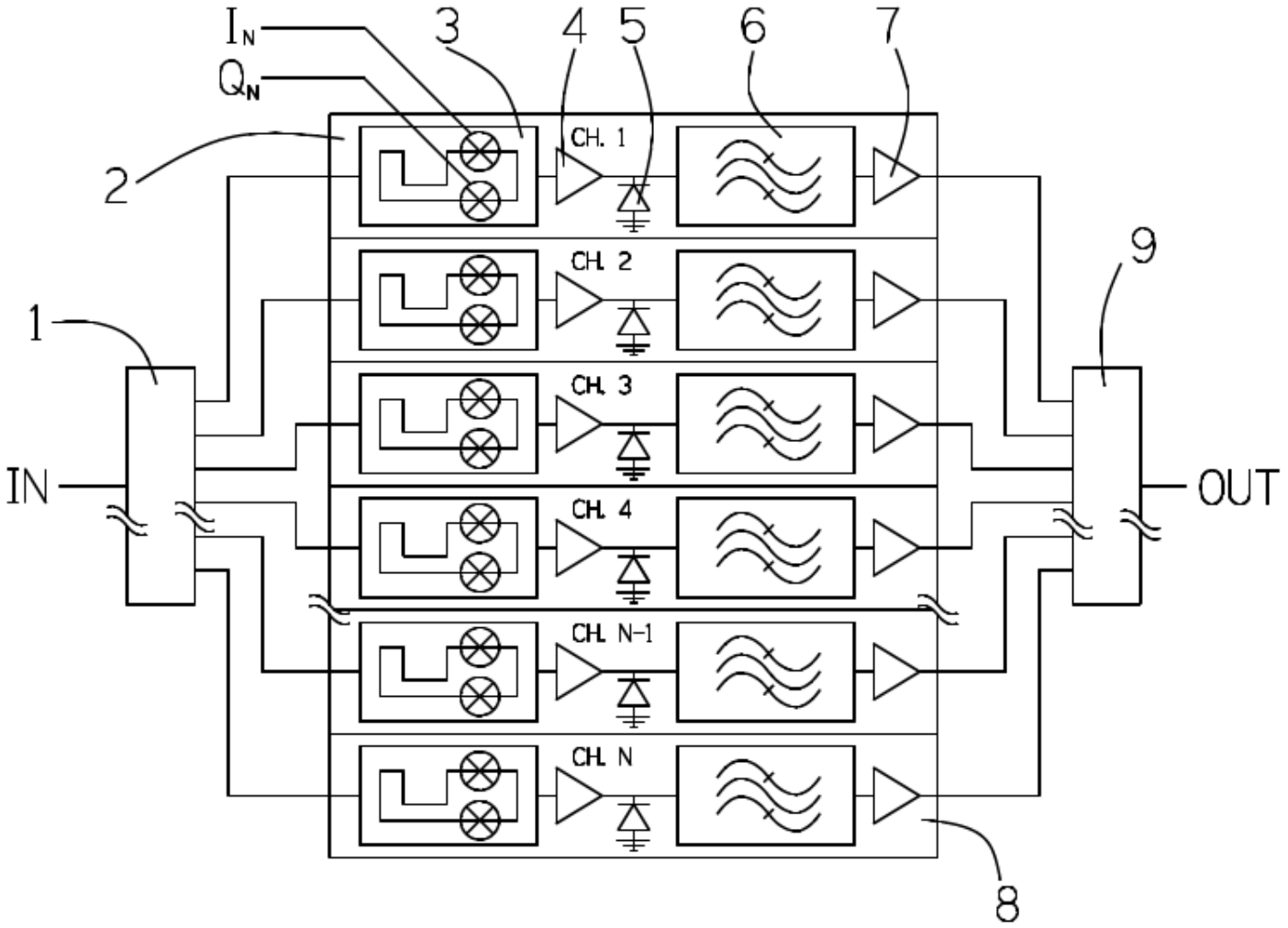
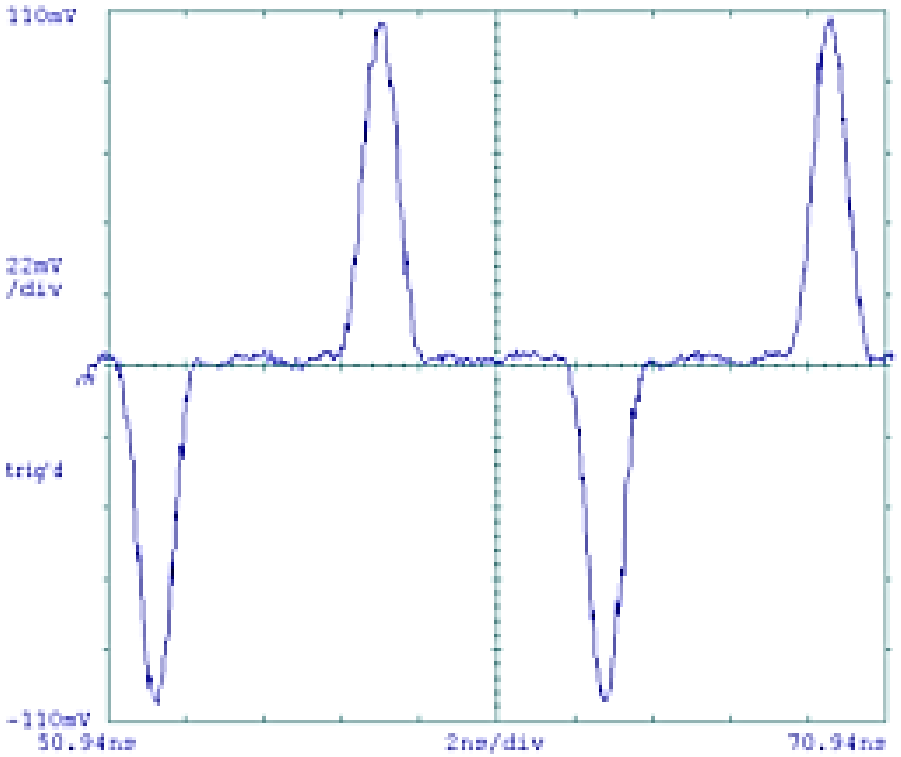
Harmonic Arbitrary Waveform Generator, the HAWG

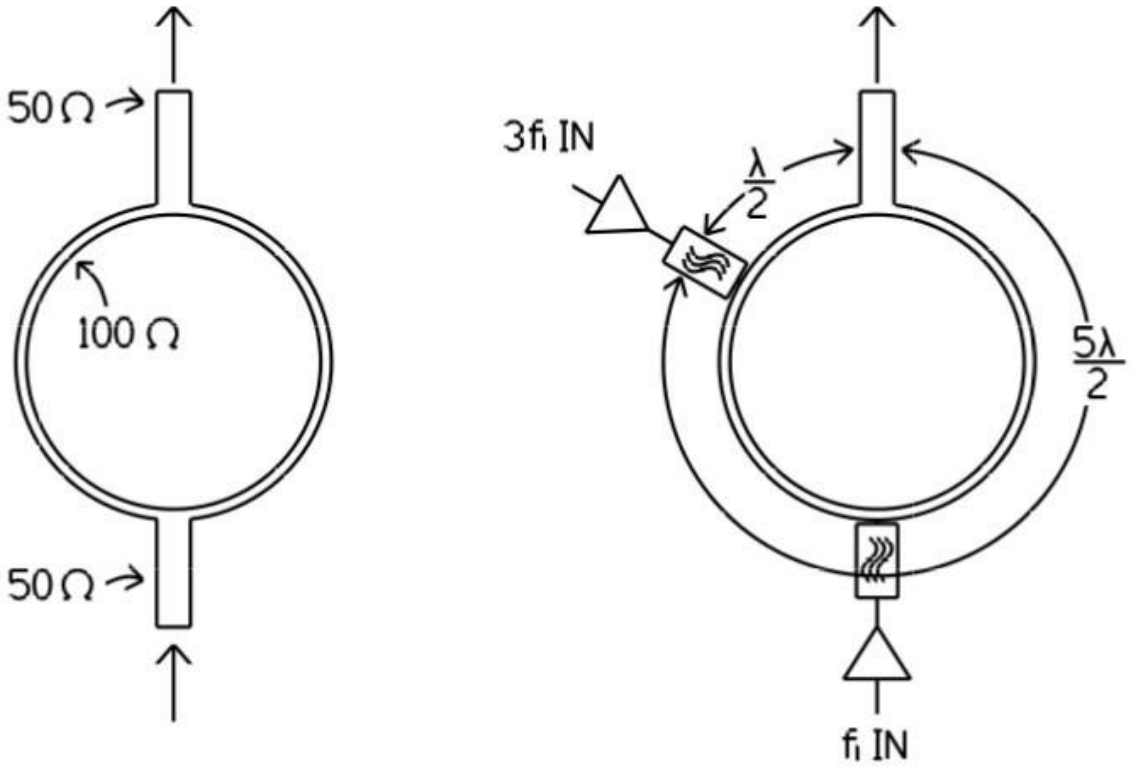


86.6 MHz HAWG

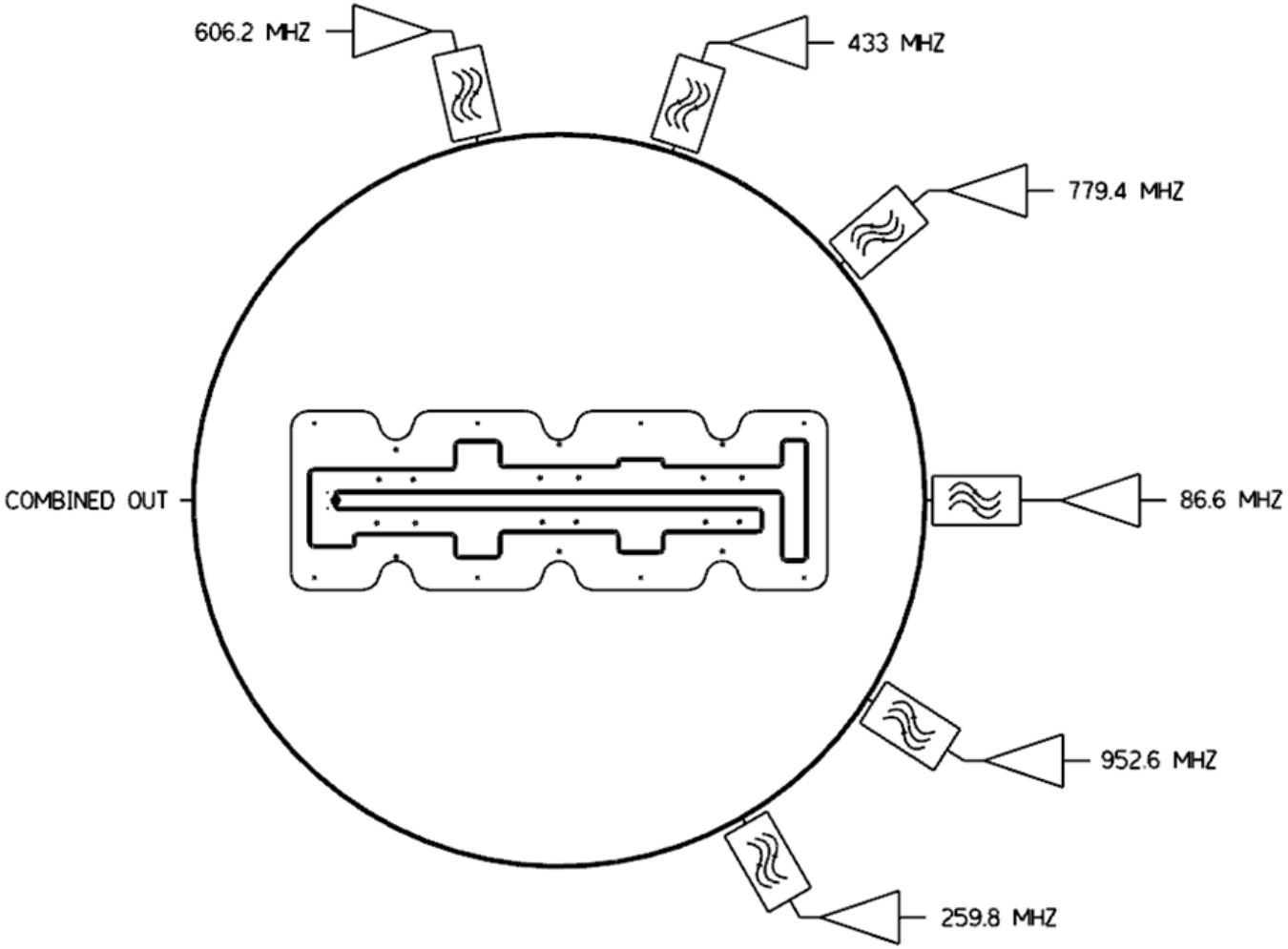
Harmonic Arbitrary Waveform Generator (HAWG) (left), 20ns of 86.6 MHz kicks (right)

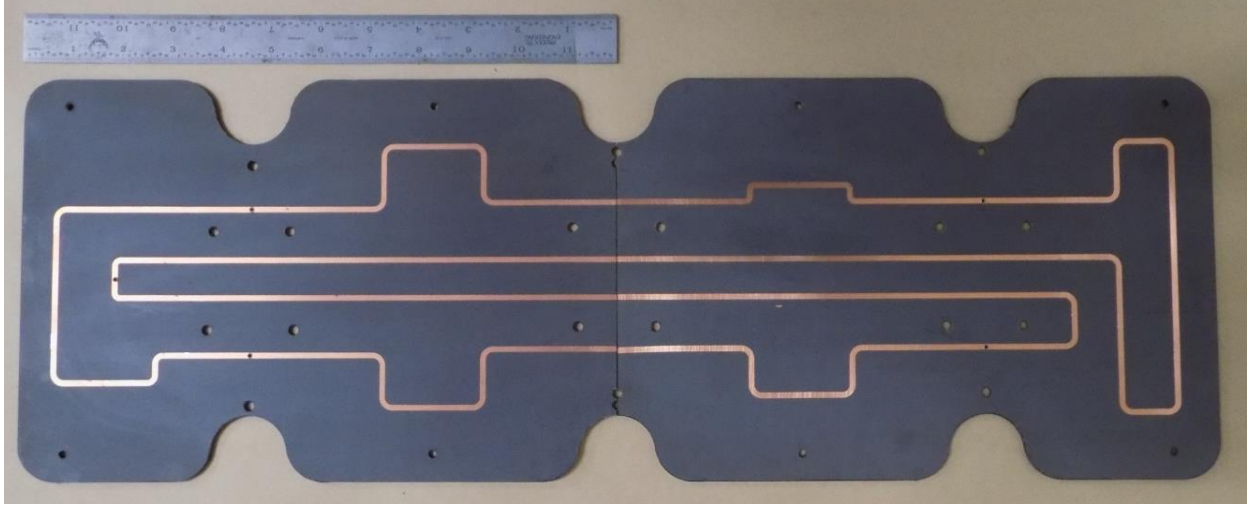


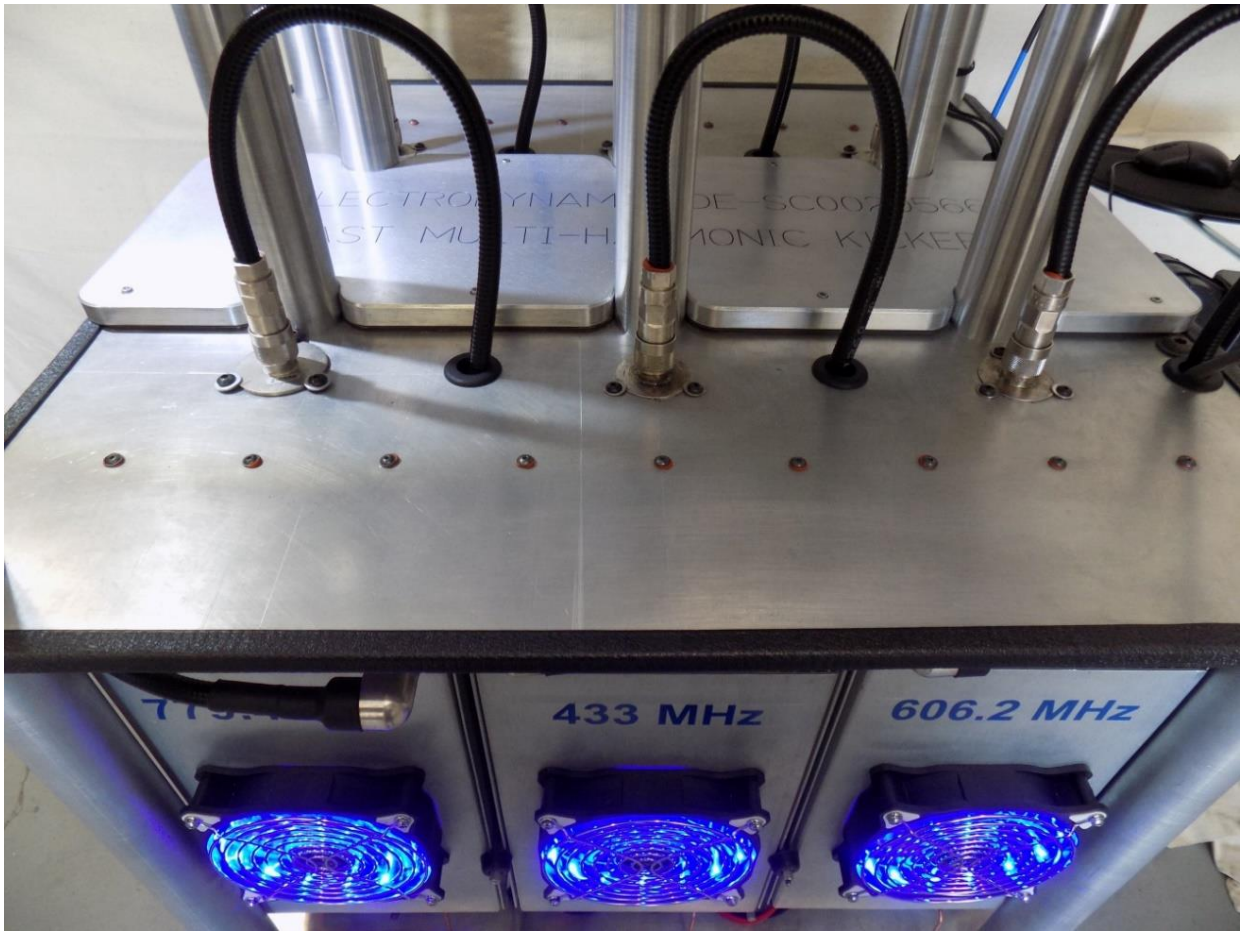
The Harmonic Amplifier and Waveform Combiner (HAWC)

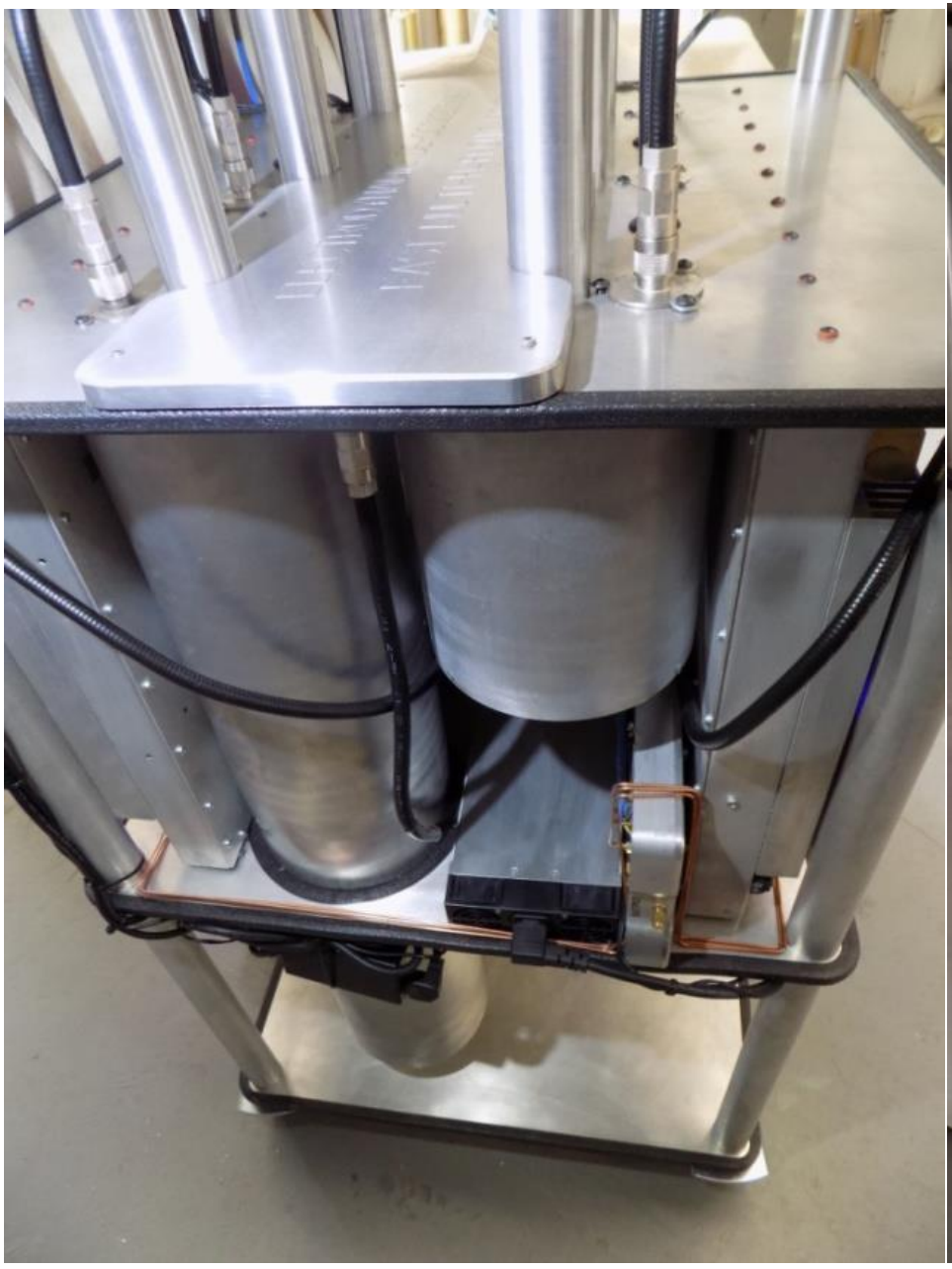


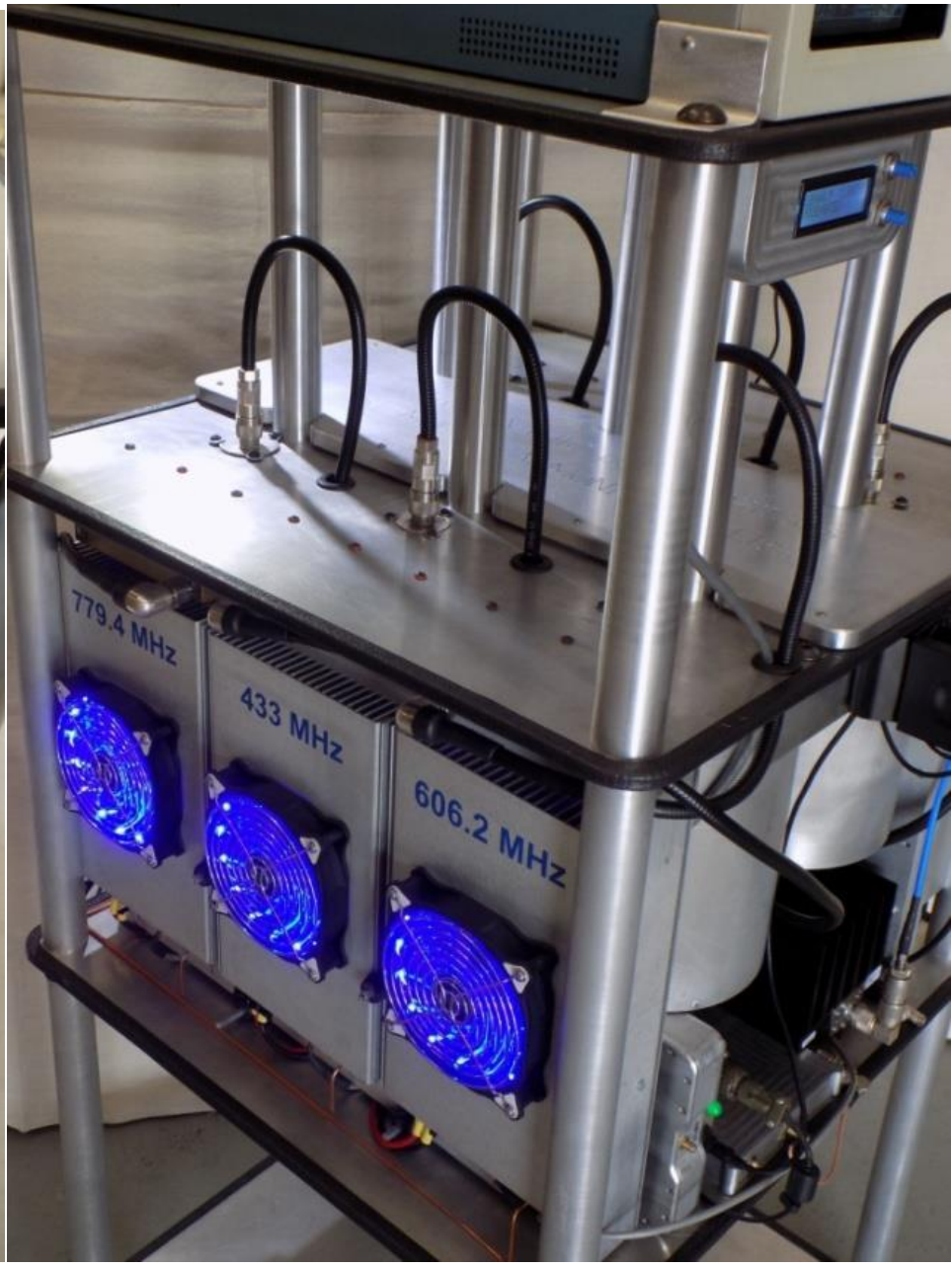
86.6 MHz Harmonic Amplifier and Waveform combiner (HAWC)



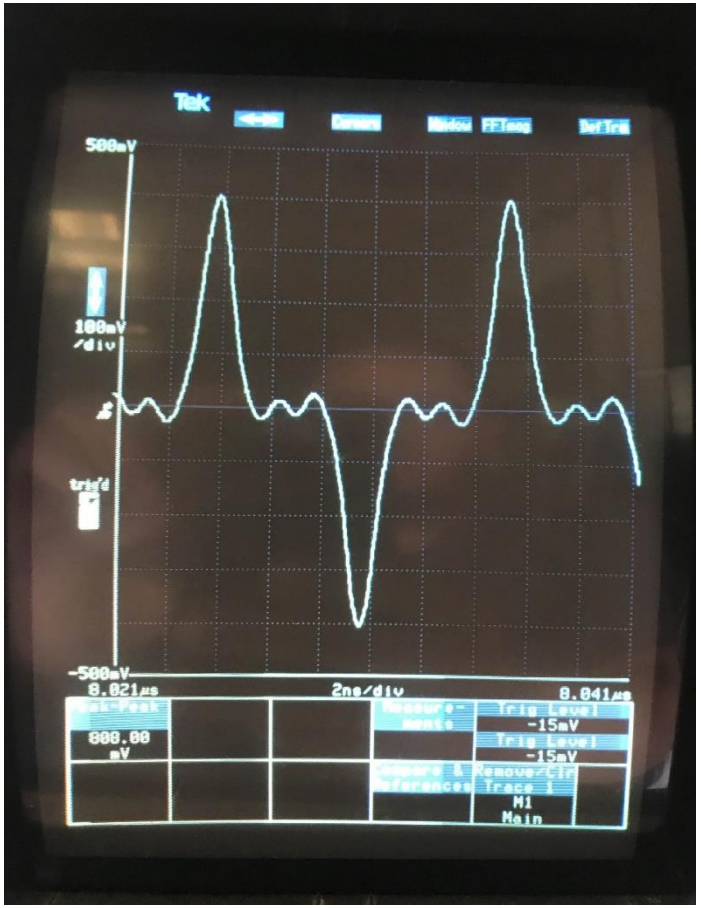



433 MHz
606.2 MHz



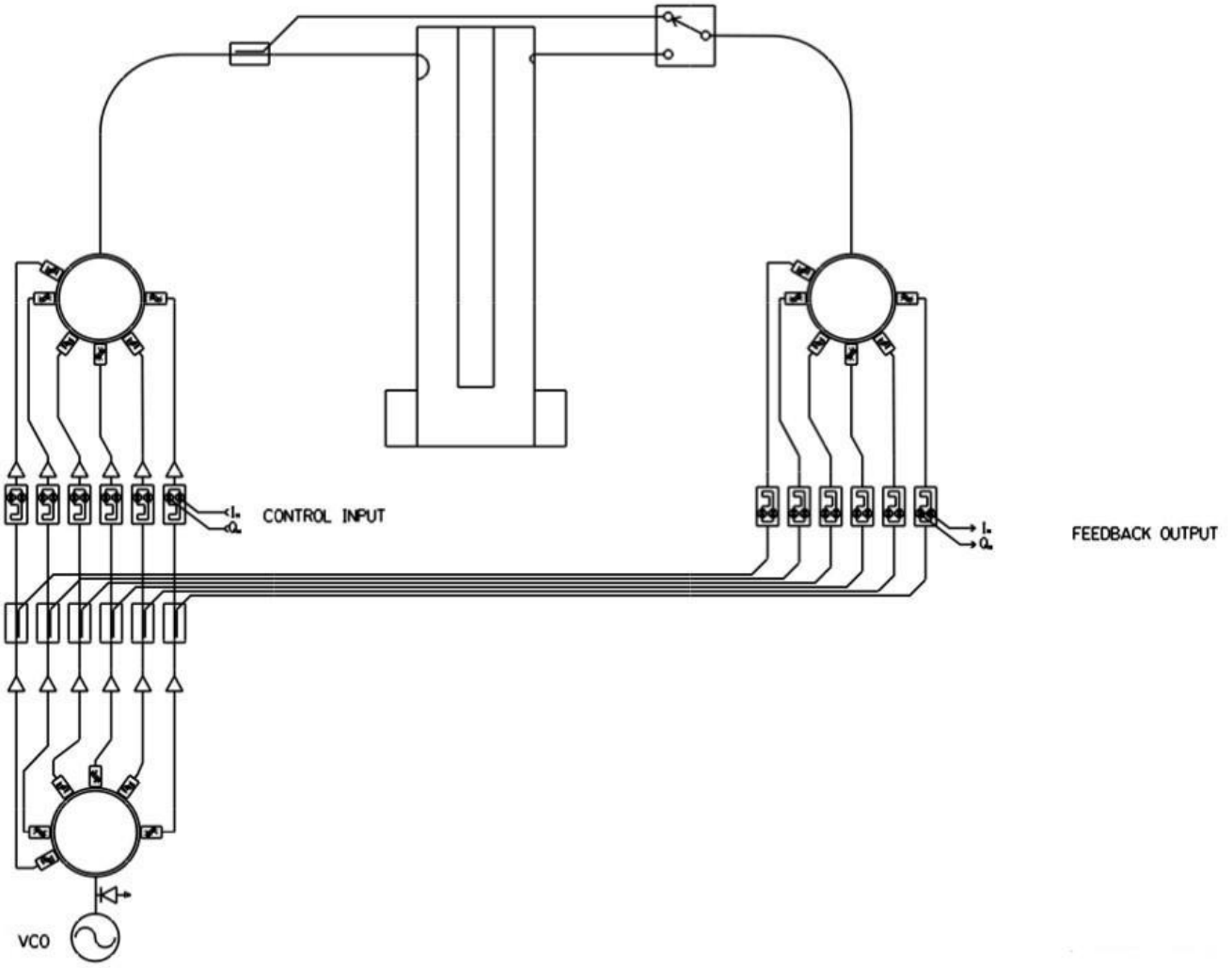

779.4 MHz
433 MHz
606.2 MHz

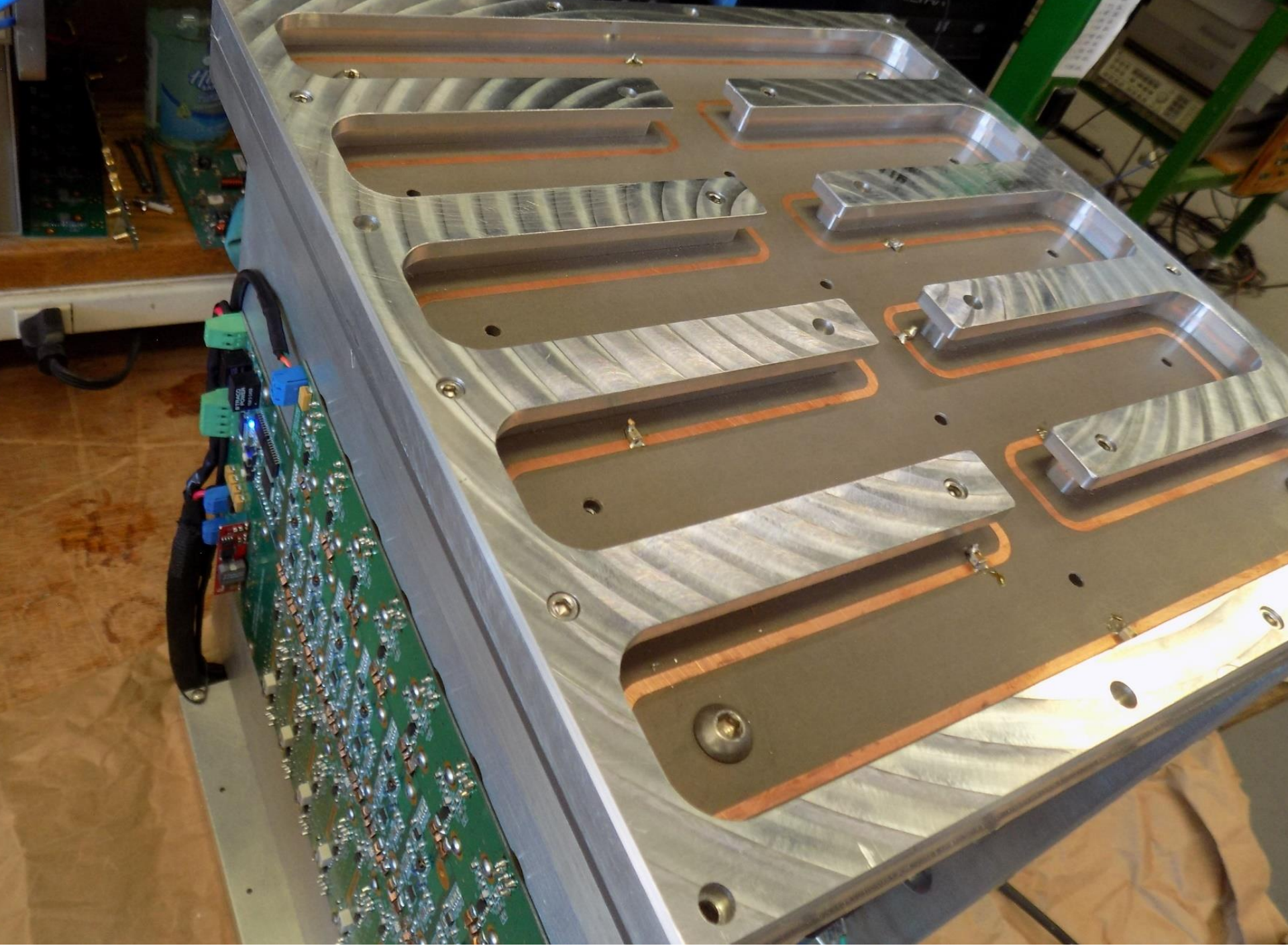
400 V peak to peak waveforms on 50 Ohm transmission line.

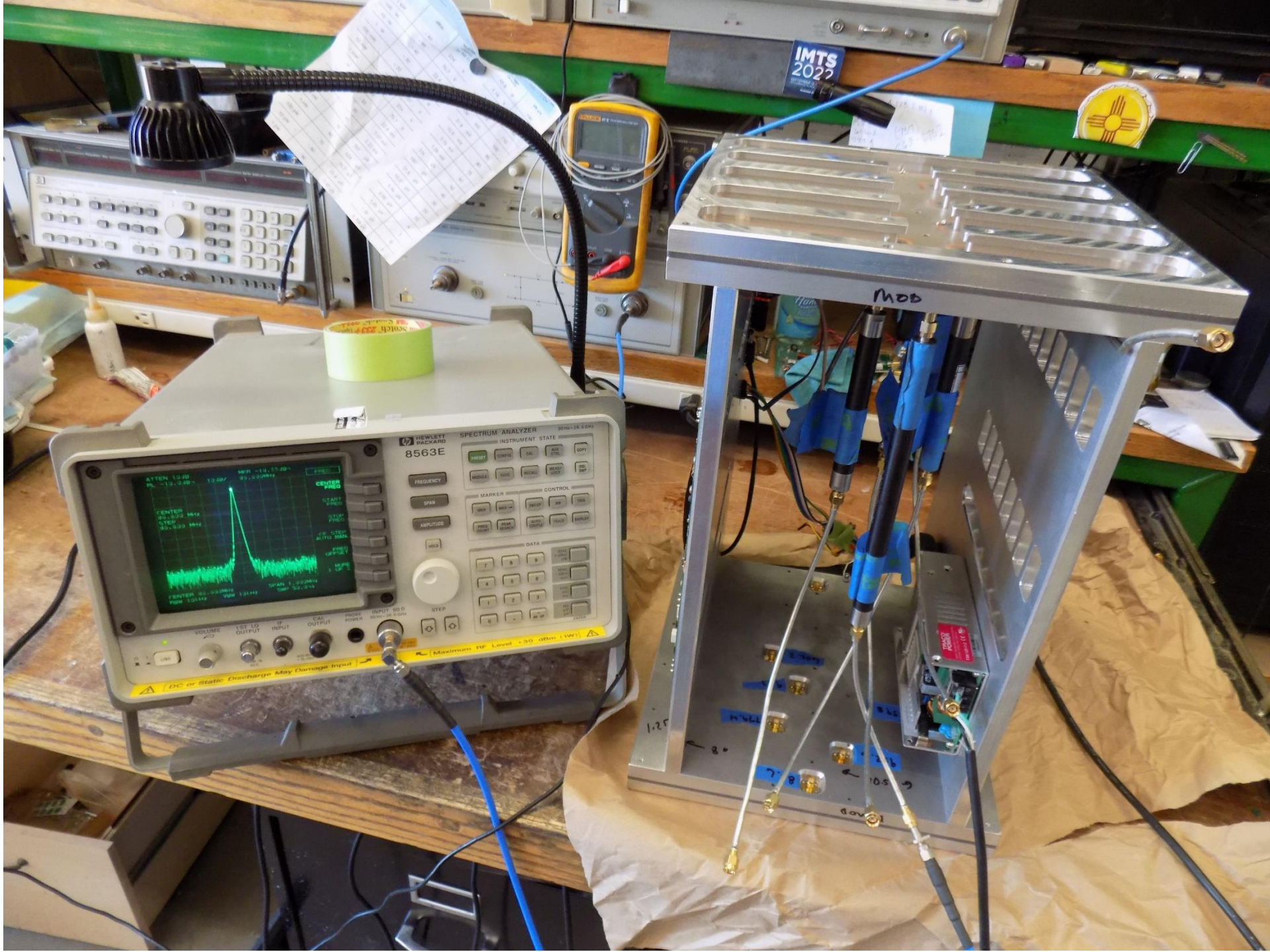


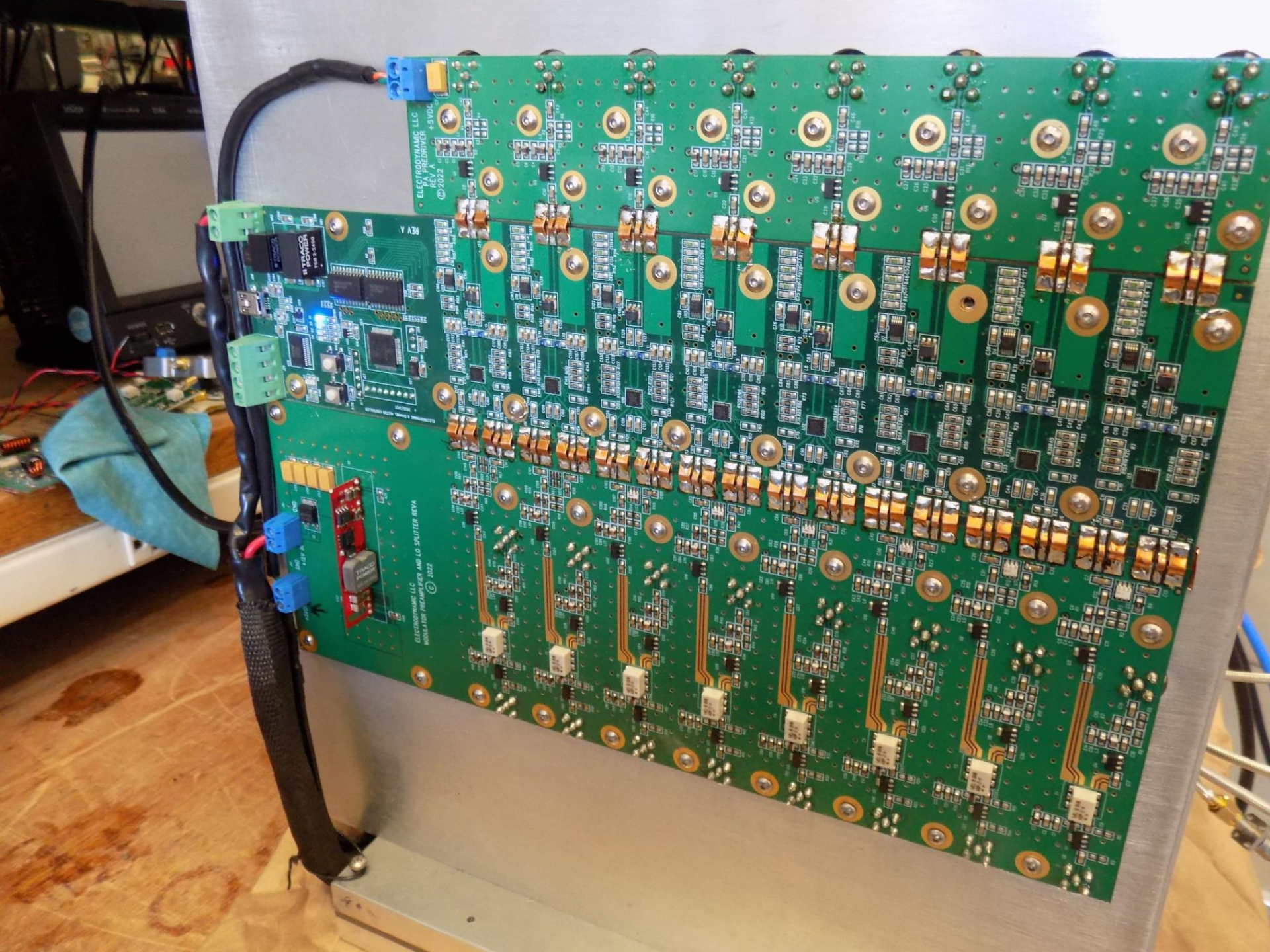
Frequency MHz	Port 1 to 0	Port 2 to 0	Port 3 to 0	Port 4 to 0	Port 5 to 0	Port 6 to 0
86.6	-.93	-60	-67	-67	-56	-70
259.8	-36	-.98	-54	-52	-70	-72
433.0	-34	-70	-1.0	-65	-49	-60
606.2	-41	-64	-56	-1.1	-49	-62
779.4	-40	-65	-51	-38	-1.9	-58
952.6	-45	-23	-62	-42	-35	-1.7

HAWG and HAWC with feedback for automatic control.






IMTS 2022
MOD
HEWLETT PACKARD
SPECTRUM ANALYZER
8563E
INSTRUMENT STATE
FREQUENCY
SPAN
AMPLITUDE
MARKER
CONTROL
DATA
STEP
Maximum RF Level +30 dBm (1W)
DC or Static Discharge May Damage Input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LO DRIVER +5VDC
REV A
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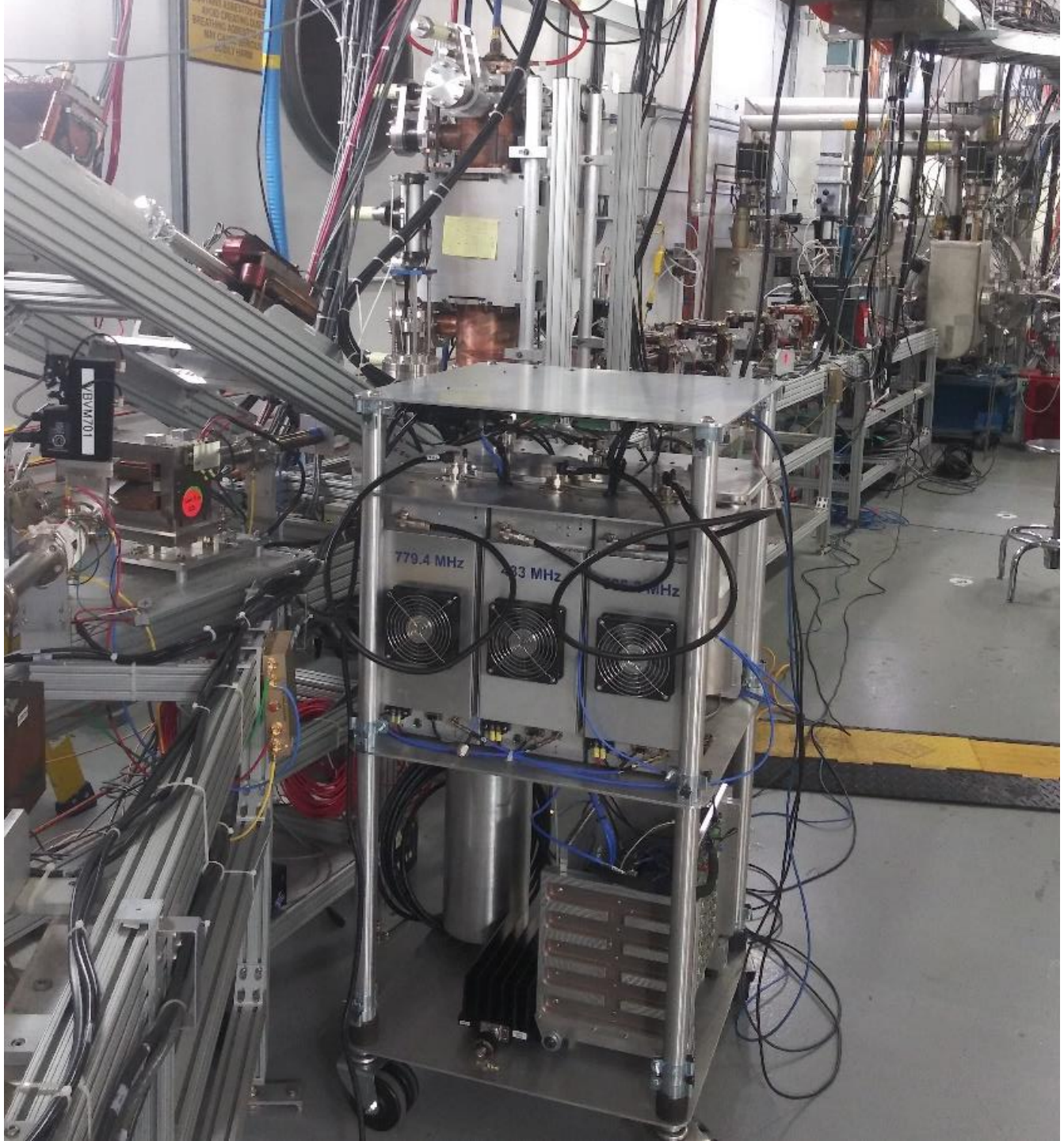
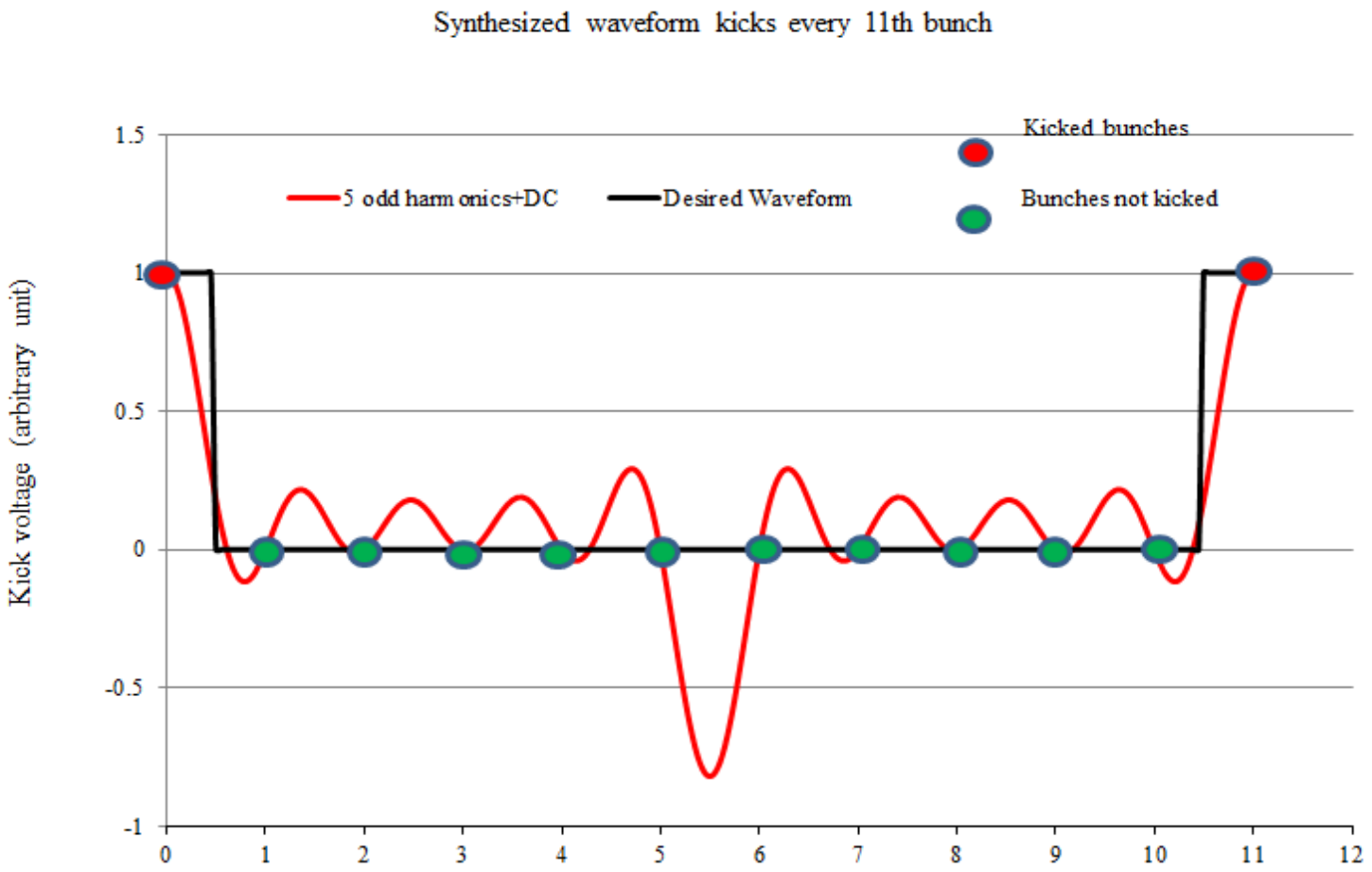
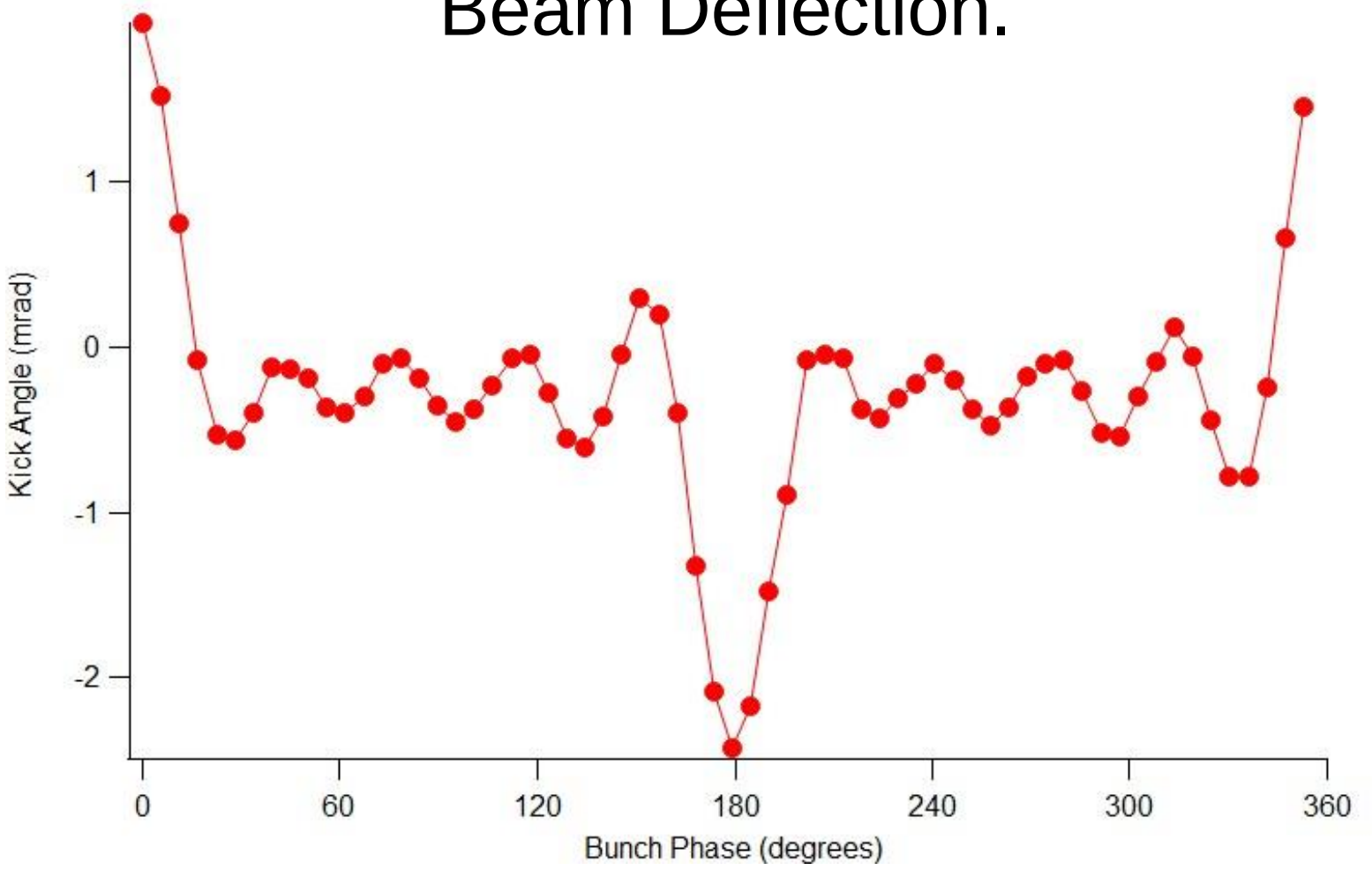

779.4 MHz

Goal: To Kick One of Eleven Electron Bunches from a 952 MHz Beam.



Synthesized Waveform as Measured by Beam Deflection.



Jlab's Fast Multi-Harmonic Kicker

Kicker Drive Frequencies: 86.6 MHz, 259.8 MHz, 433 MHz, 606.2 MHz, and 779.4 MHz

UITF Frequency: 1497 MHz and subharmonics.

Beam Energy: 6.5 MeV

Bunch Frequency: 136 MHz = 1497MHz/11 and 952.6 MHz/7

Kick Frequency: 86.6 MHz = (7(1497 MHz))/121

Bunch Scan Frequency : 12.4 MHz = 1497 MHz/121

RF synchronization reference: 12.4 MHz

Deflection: +/-2 mrad or 1/8 degree, +/-2 mm offset at 1m.

Jlab has submitted a paper to IBIC and is preparing a 2nd.

BEAM TEST OF A HARMONIC KICKER CAVITY*

M. W. Bruker†, J. Grames, J. Guo, J. Musson, S. A. Overstreet, G. T. Park,
T. Plawski, M. Poelker, R. Rimmer, H. Wang, C. Wilson, S. Zhang,
Thomas Jefferson National Accelerator Facility, Newport News, VA, USA
M. Pablo, B. Roberts, D. Speirs, Electrodynamic, Albuquerque, NM, USA

Abstract

A harmonically resonant kicker cavity designed for beam exchange in a circulator cooler was built and successfully tested at the Upgraded Injector Test Facility (UITF) at Jefferson Lab. This type of cavity is being considered for the injection scheme of the Rapid Cycling Synchrotron at the Electron-Ion Collider, where the spacing of neighboring bunches demands very short kicks. Operating with five transversely deflecting modes simultaneously that resonate at 86.6 MHz and consecutive odd harmonics thereof, the prototype cavity selectively deflects 1 of 11 electron bunches while leaving the others unperturbed. An RF driver was developed to synthesize phase- and amplitude-controlled harmonic signals and combine them to drive the cavity while also separating the modes from a field-probe antenna for RF feedback and dynamic tuning. Beam deflection was measured by sweeping the cavity phase; the deflection waveform agrees with expectations, having subnanosecond rise and fall times. No emittance increase is observed. Harmonically resonant cavities like the one described provide a new capability for injection and extraction at circulators and rings.

INTRODUCTION

In circulating accelerators, the minimum bunch spacing needed to accommodate the rise/fall time of a kicker can limit the design options for the bunch train. Originally developed for the Circulating Cooler Ring, a hypothetical ring with 11 revolutions driven by an energy-recovery linac that was intended to be part of the Jefferson Lab Electron-Ion Collider [1], the harmonic kicker cavity offers a new option for applications where every nth bunch must be deflected [2]. One such application is the injection into the Rapid Cycling Synchrotron at the Electron-Ion Collider [3], where one out of four consecutive bunches is injected at a time; here, the bunch spacing is 1.6 ns, and each set of four bunches is followed by a gap of 12 µs, encouraging the use of a pulsed device but out of reach for a stripline due to the short bunch spacing.

A harmonic kicker is a transversely deflecting cavity that can be excited at multiple harmonic frequencies at the same time, allowing one to Fourier-synthesize any deflection waveform containing only these frequencies; the high Q of the modes compared to a stripline makes the drive power manageable, while pulsed drive is still possible if the gap between sets of bunches is sufficiently long. Figure 1 shows a model of the prototype reduced to the most important parts.

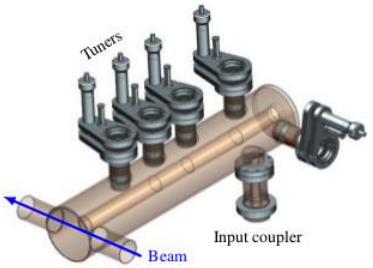


Figure 1: CAD model of a 5-mode harmonic kicker cavity. Five stub tuners are needed to tune all modes. The RF signal is coupled in through a single port; another port serves as the field probe (not shown here).

An example waveform providing a kick to 1 out of 11 bunches is shown in Fig. 2. The usefulness of this type of waveform is not characterized by its absolute flatness outside of the main peak but by the locations of its zero crossings or minor peaks, depending on design. While conceptually flexible, the mode structure of such cavities must be chosen according to the bunch timing of the intended application.

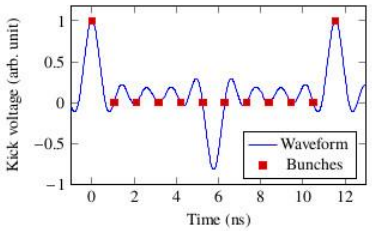
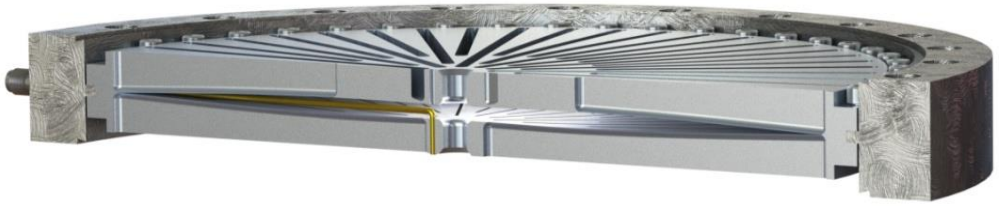
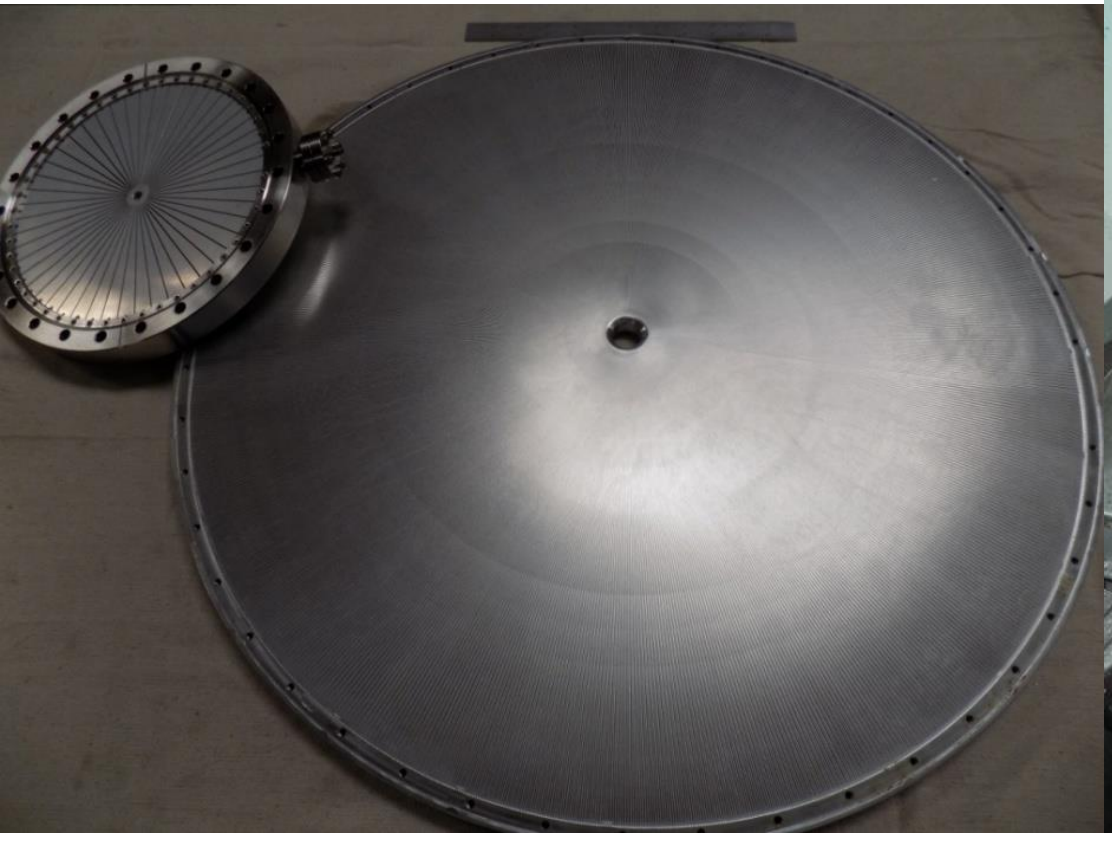


Figure 2: Kick action only on bunches at a bunch frequency equal to the fundamental of the kick waveform, f_{HK} = 86.6 MHz; in this example, all 11 buckets are filled at a bunch frequency of $11 f_{HK}$ = 952.6 MHz.

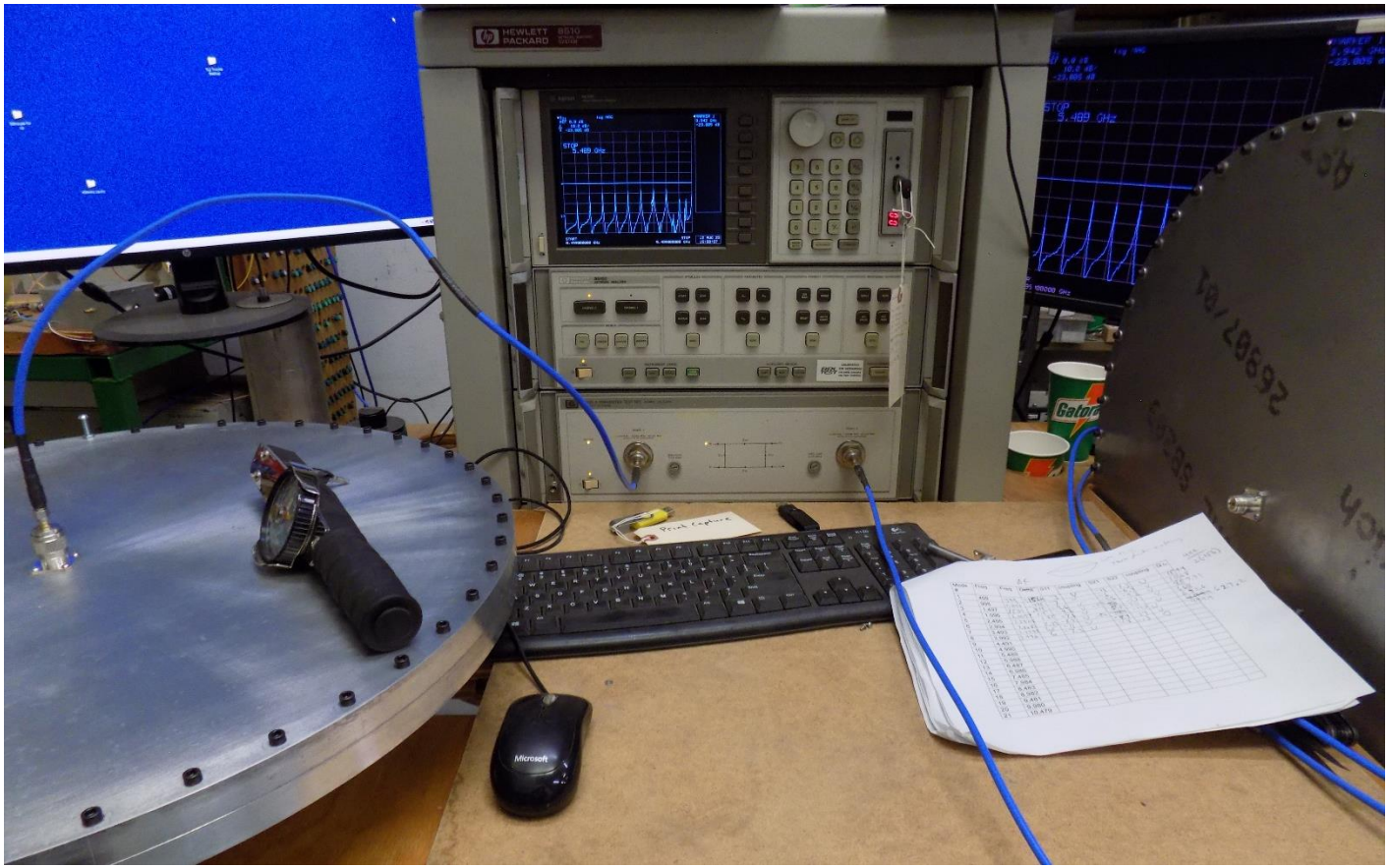
* Work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract DE-AC05-06OR23177. Multi-Harmonic driver development has been supported by DOE's NP SBIR program (DE-SC0020566).
† bruker@jlab.org

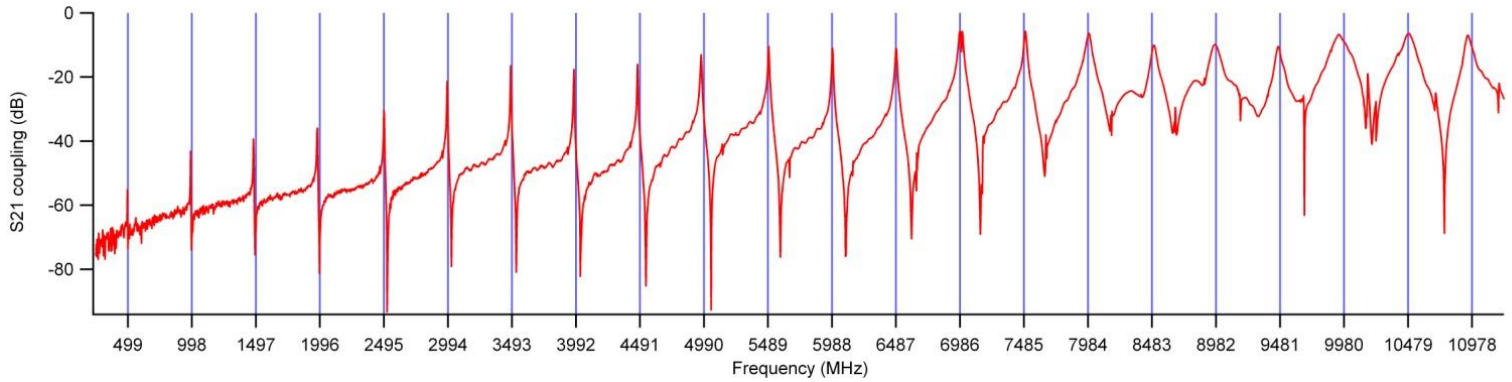
499 MHz Harmonic Cavity Fabrication



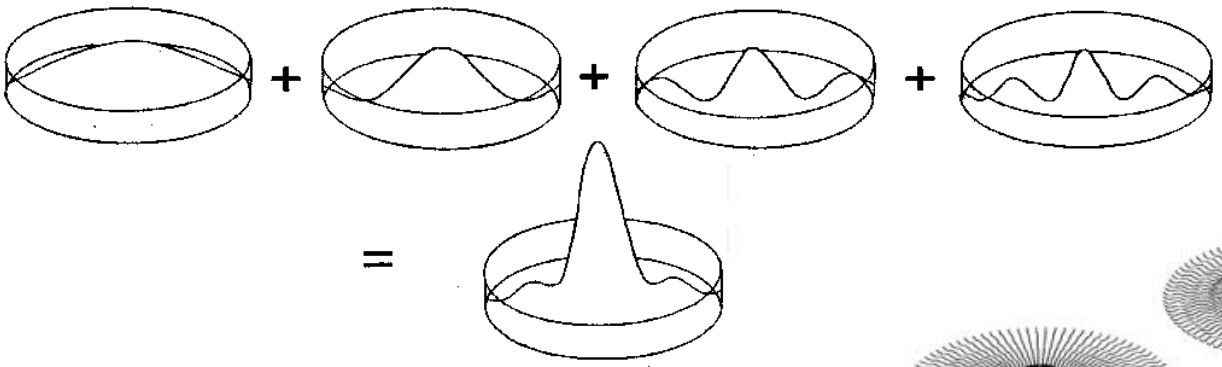


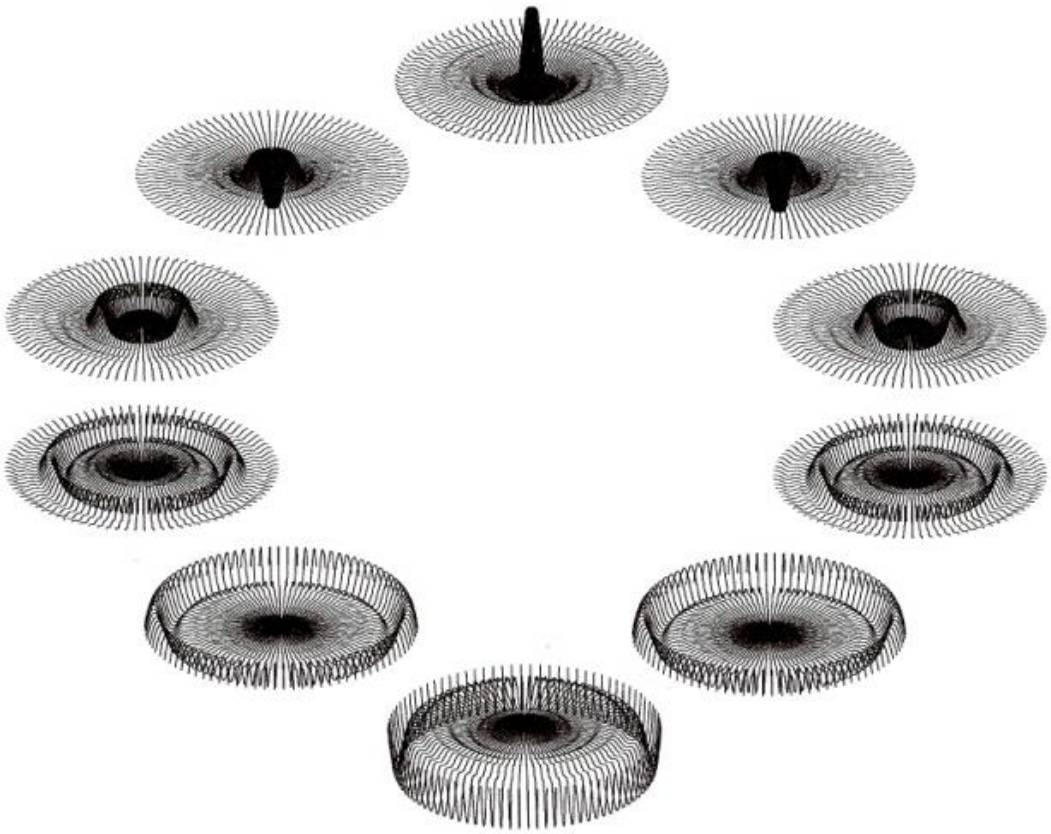
499 Mhz Harmonic Cavity Testing and Antenna Development.



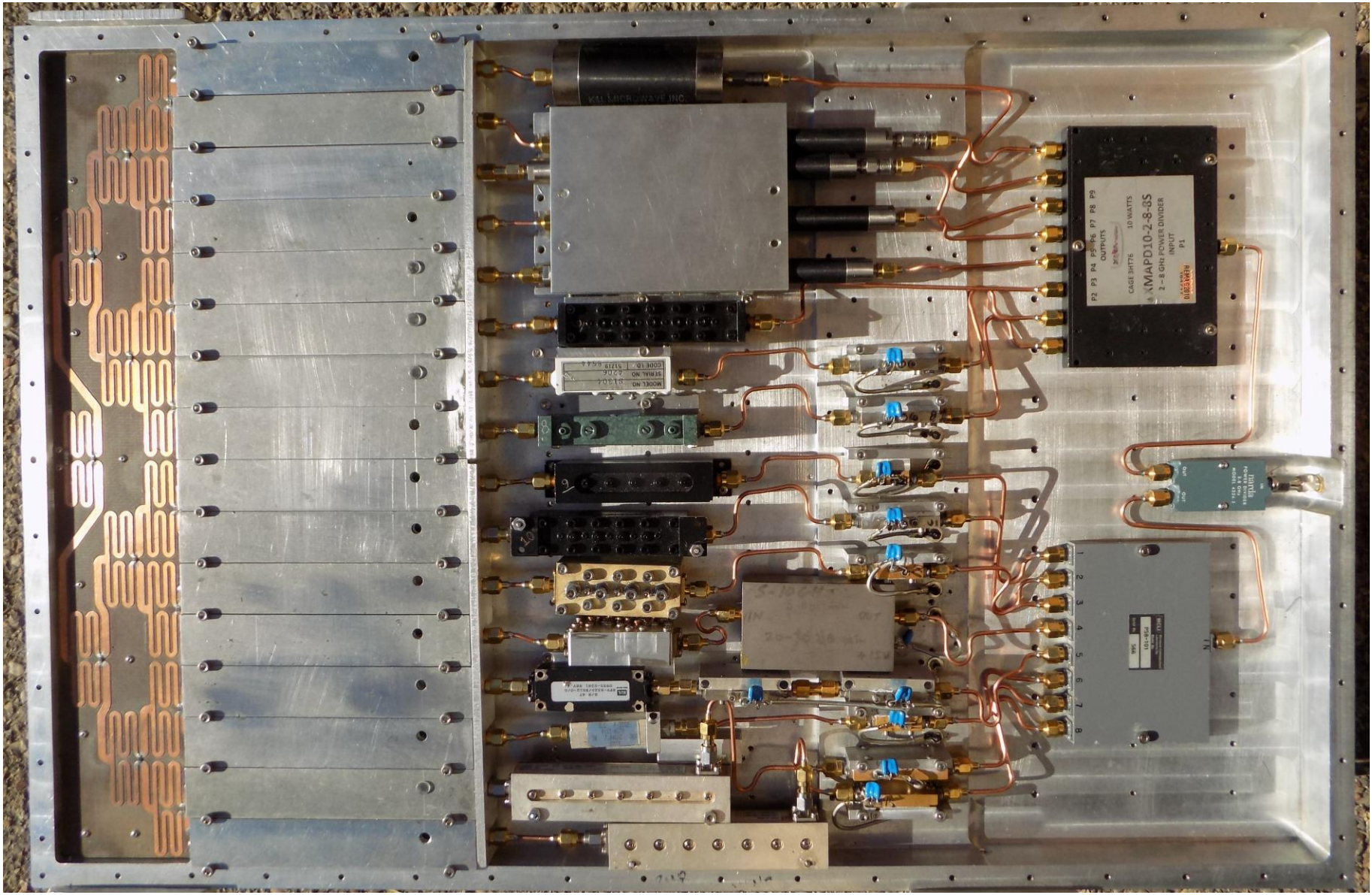


Superposition and Time Evolution



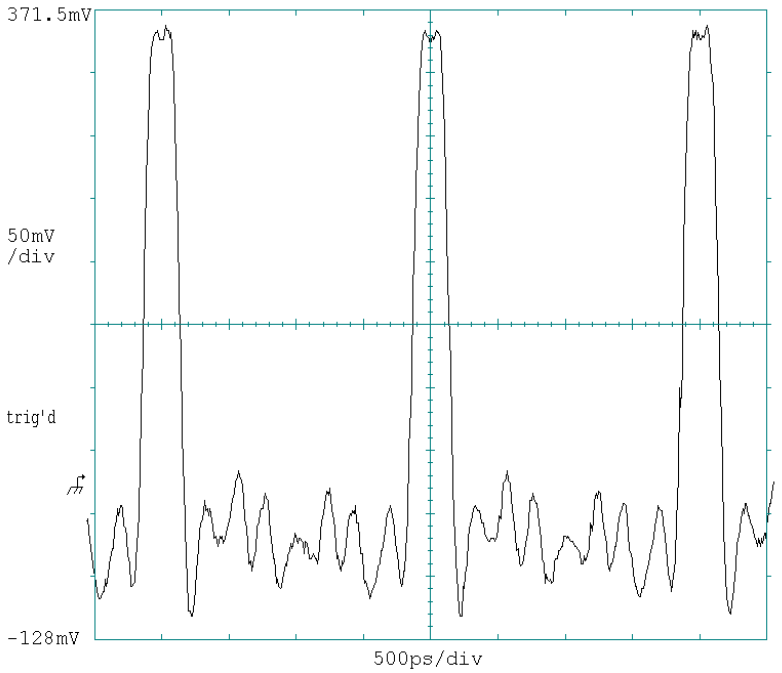


499 MHz HAWG


MAPD10-2-8-8S
2 - 8 GHz POWER DIVIDER
10 WATTS
CAGE 3HT76
INPUT
OUTPUTS

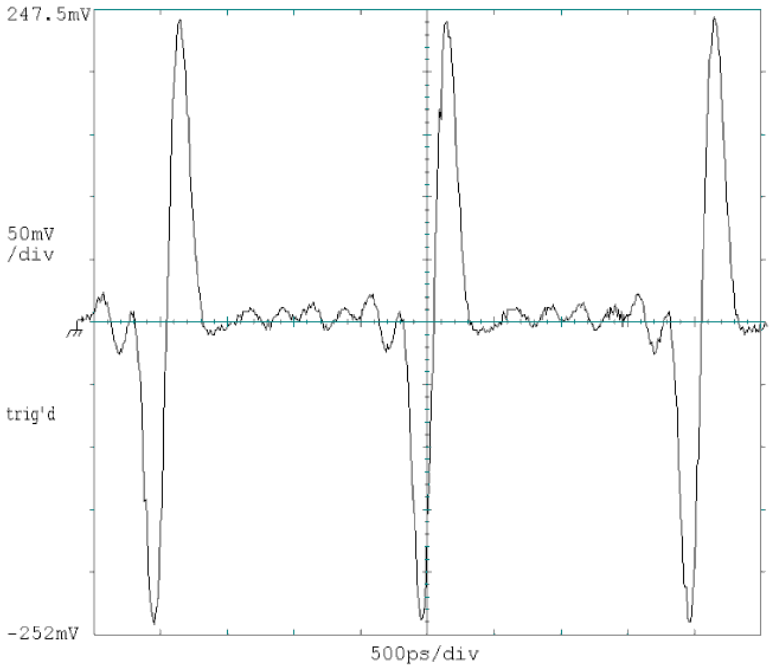
5 ns of 499 MHz Rectangular Drive Pulses

Channel #	Amplitude	Phase
1	1	0
2	.89	0
3	.78	0
4	.62	0
5	.46	0
6	.29	0
7	.13	0
8	0	0
9	.29	180
10	.16	180
11	.18	180
12	.17	180



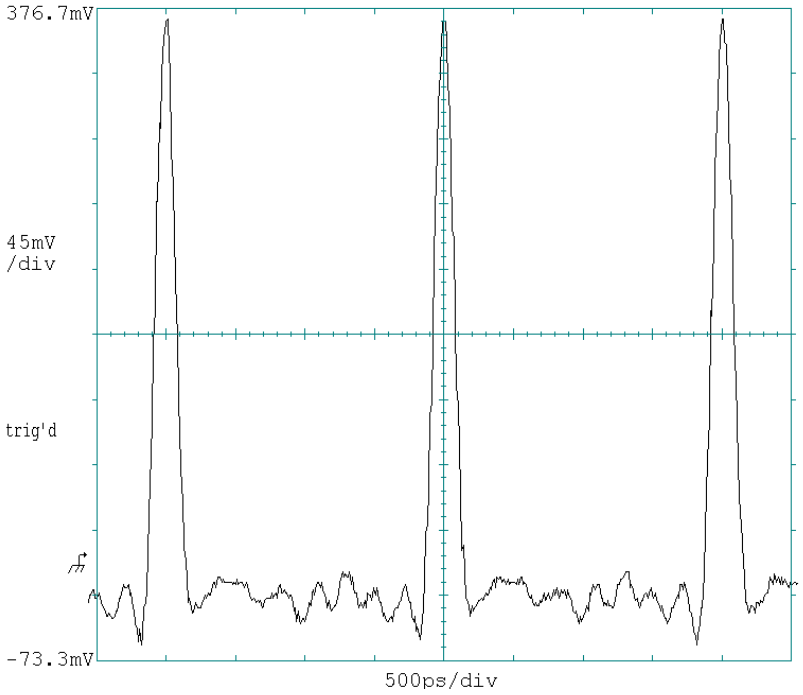
5 ns of 499 MHz Bipolar Drive Pulses

Channel #	Amplitude	Phase
1	.37	0
2	.69	0
3	.9	0
4	1	0
5	.96	0
6	.81	0
7	.61	0
8	.38	0
9	.16	0
10	0	0
11	0	0
12	0	0

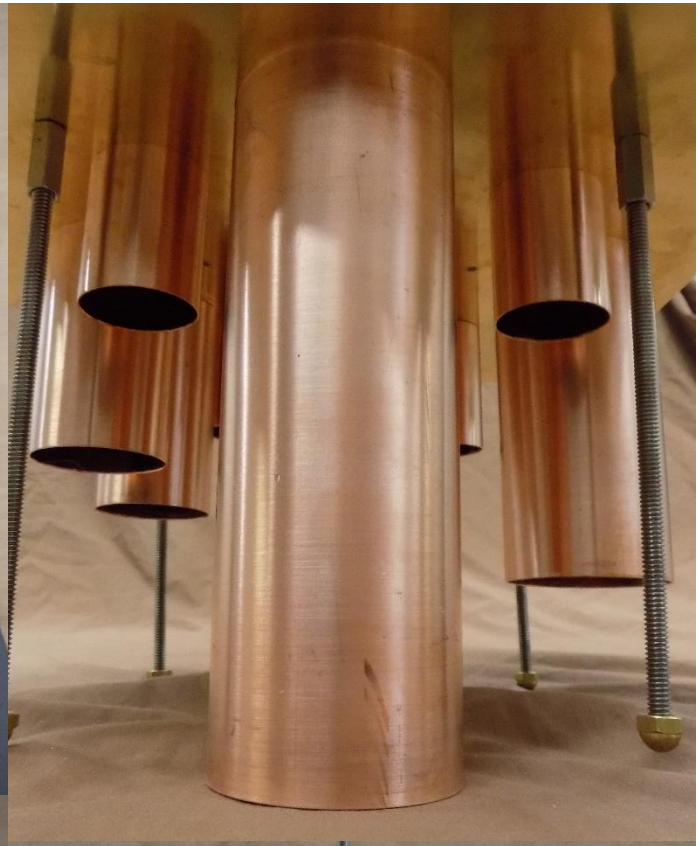


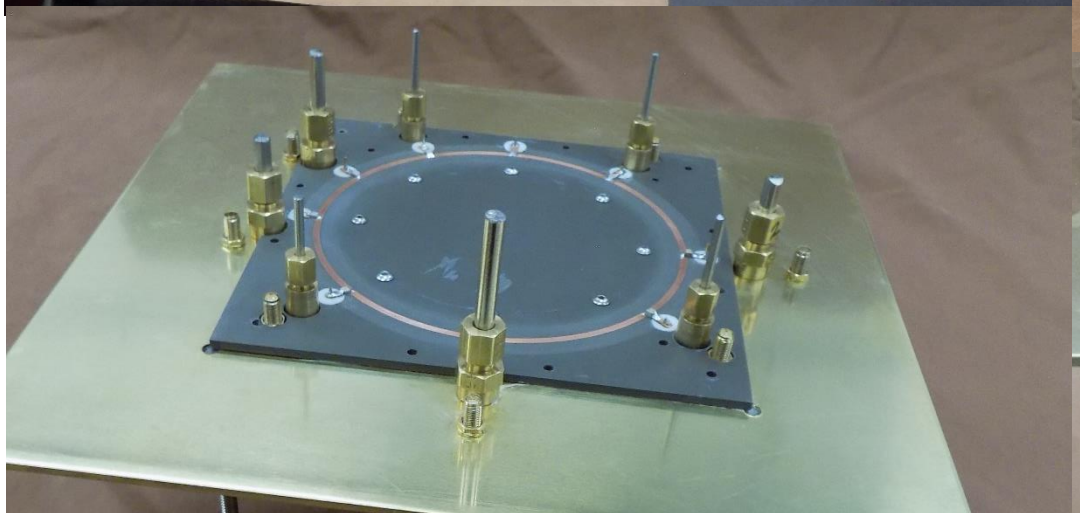
5 ns of 499 MHz Gaussian Drive Pulses

Channel #	Amplitude	Phase
1	1	0
2	.96	180
3	.91	0
4	.84	180
5	.72	0
6	.57	180
7	.44	0
8	.31	180
9	.21	0
10	.14	180
11	.1	0
12	0	180

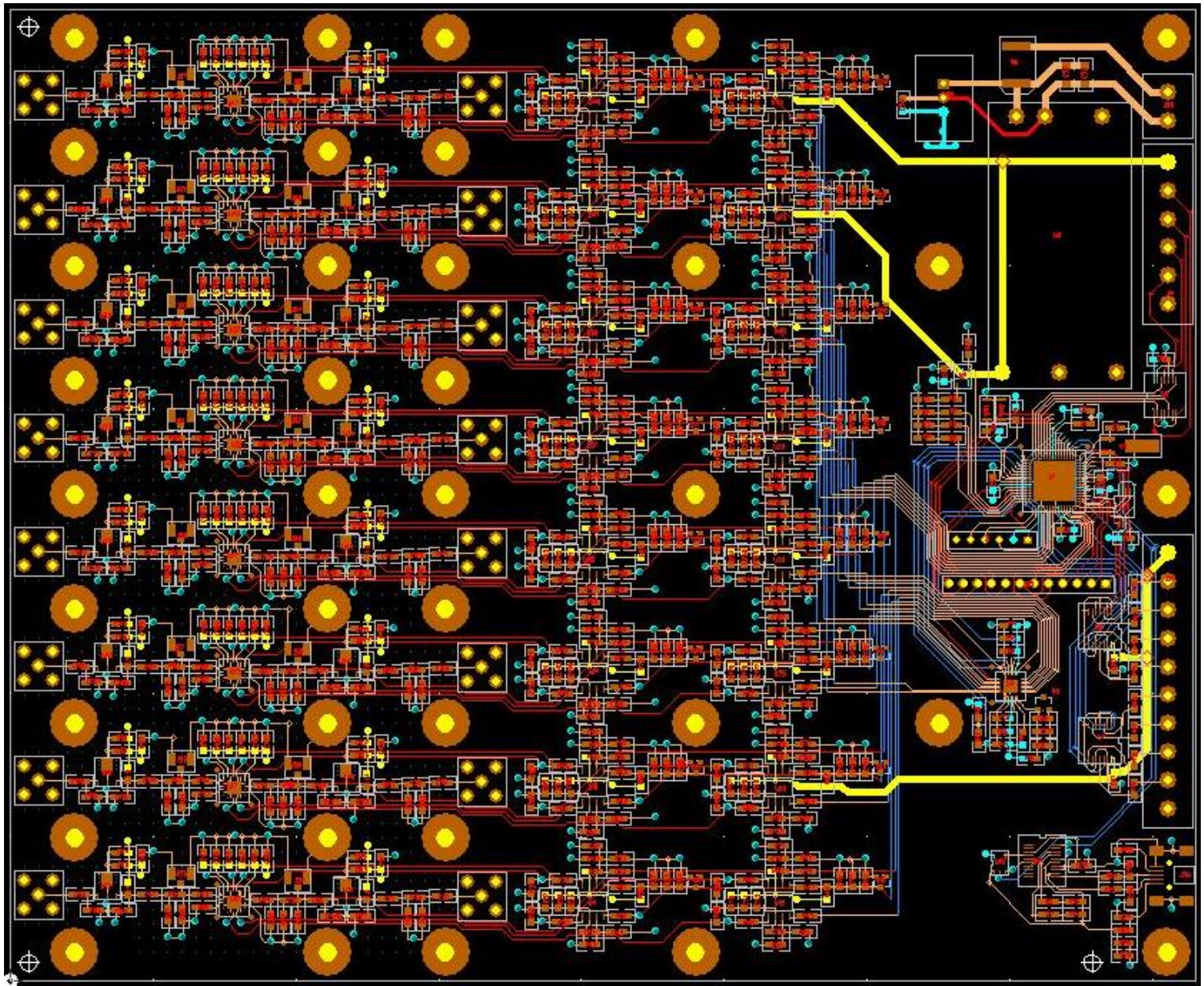


499 MHz HAWC Development.





New 499 MHz HAWG PCB in Progress.



Thank You for Supporting the SBIR Program

- Beamline installation and testing of JLAB's harmonic kicker cavity was a success, kicking one of eleven bunches of a 952.6 (136) MHz bunch stream .
- A 499 HAWC, new HAWG, and driven harmonic TM_{0N0} cavities are proceeding smoothly.
- Multi-Harmonic Drivers; HAWG +HAWC could be used for stripline kickers? What are your voltage requirements?
- Got bunch length monitors? Electrodynamic can provide non-invasive bunch length monitors, fast high power waveform generators, visit for talk. Please send me an e-mail, Brock.electro@outlook.com or give me a call: 505-225-9279. Our website is launching soon:
- www. Electrodynamic.tech