My 47 Ghz Rig

San Bernardino Microwave Society

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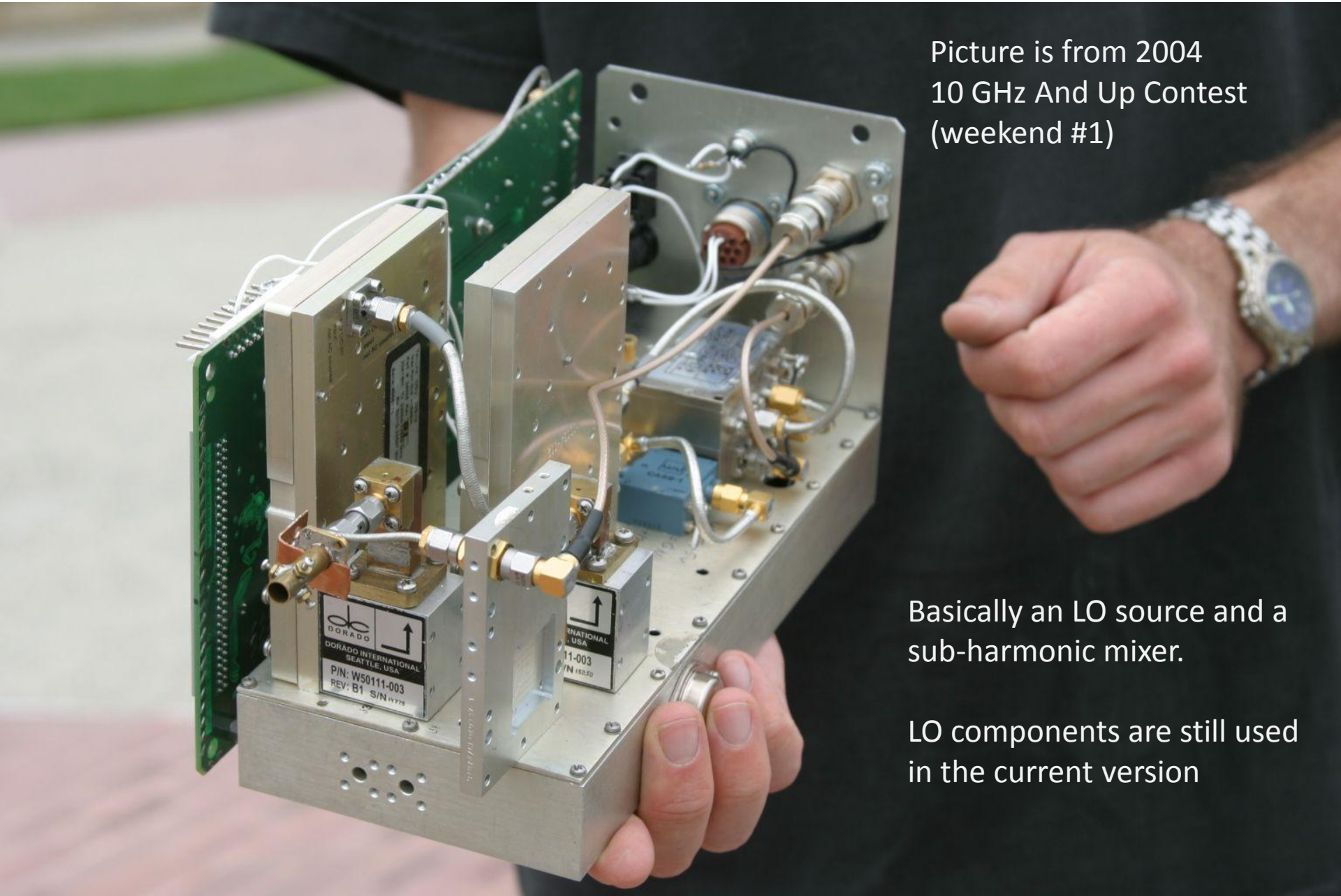
March 5, 2010

Overview

- History of this radio
- Beyond bare diode mixers
- The New Front End
- Working With Bare MMICs
- Some Special Tools
- Waveguide –Transitions, Rectangular to Round, MMIC - WG
- Waveguide Switch
- Receive Module
- Transmit Module
- A Proper Box
- Aiming at 47 Ghz

The Early Days… (2004)

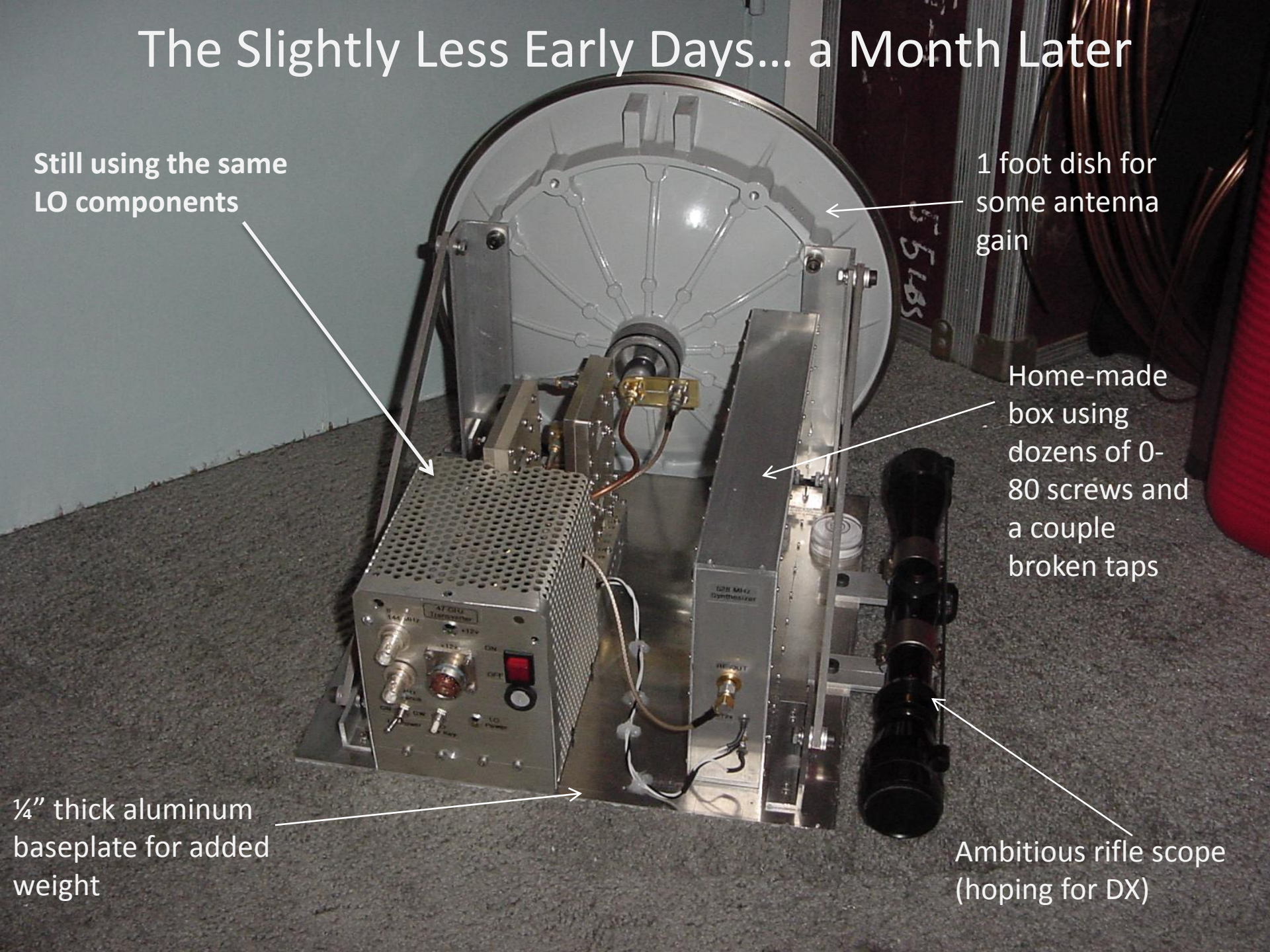


Picture is from 2004
10 GHz And Up Contest
(weekend #1)

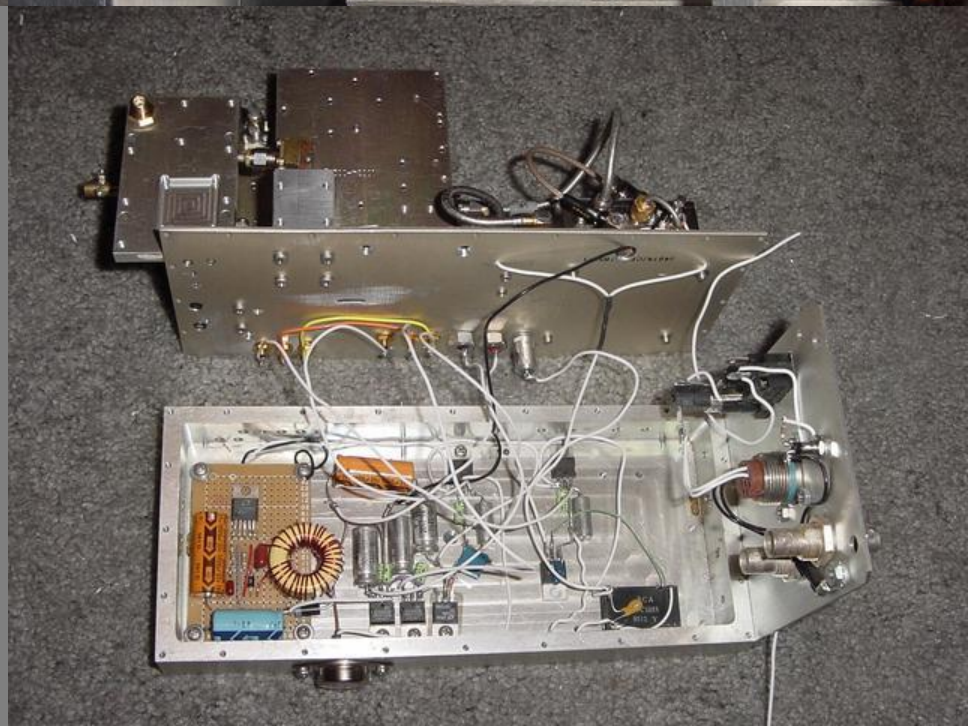
Basically an LO source and a sub-harmonic mixer.

LO components are still used in the current version

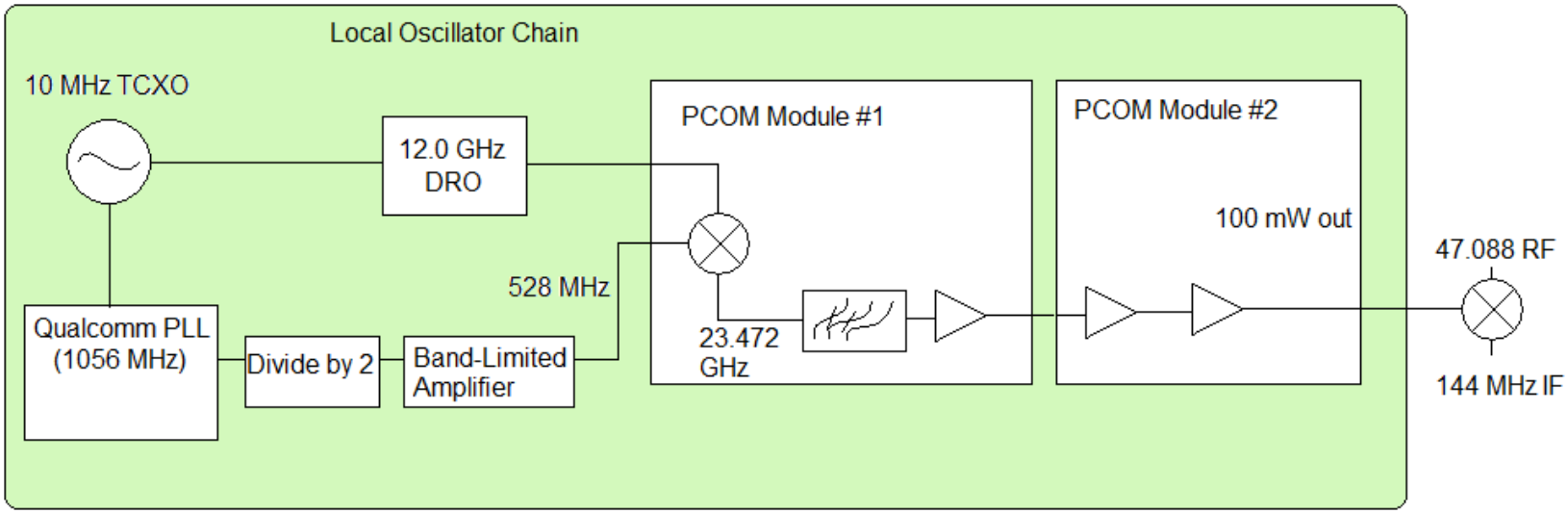
The Slightly Less Early Days… a Month Later



A Few Final Pictures of The Old Radio



Block Diagram of The Old Radio



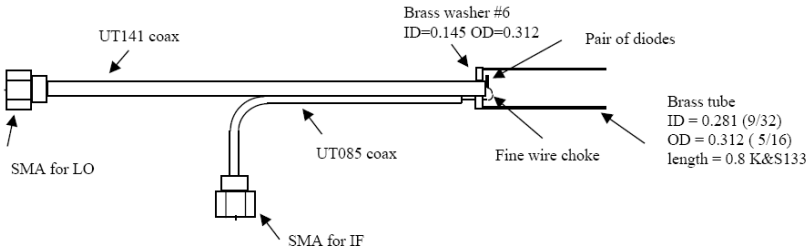
- 1 km contacts were made using this radio in 2004 and again in somewhere between 2005 and 2008 in San Diego with similarly constructed radios by members of the San Diego Microwave Group

•Performance was suitable for VERY short range, but I wanted to do more…

Beginnings of the New Radio

- I knew the LO chain was solid and would be the basis of the new radio
- I really wanted some gain on transmit and receive, and a better noise figure.
- This is where things get interesting...

Beyond Bare Mixers

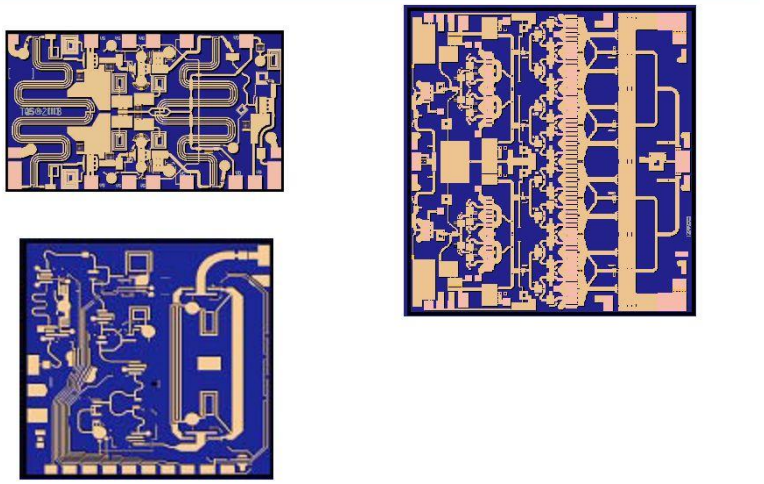


- Beyond 24 GHz, bare mixers of one kind or another have dominated amateur front ends for many years.
- There are few choices for the amateur.
  - DB6NT amplifier (expensive, but actually not a bad deal as you will soon see)
  - Mimix Broadband packaged, solderable parts (receiver, transmitter)
  - Bare MMICs (highest performance, but difficult to work with, as you will also soon see)
- The vast majority of components available for 47 Ghz are not available in packaged form.

Beyond Bare Mixers – Bare MMICs

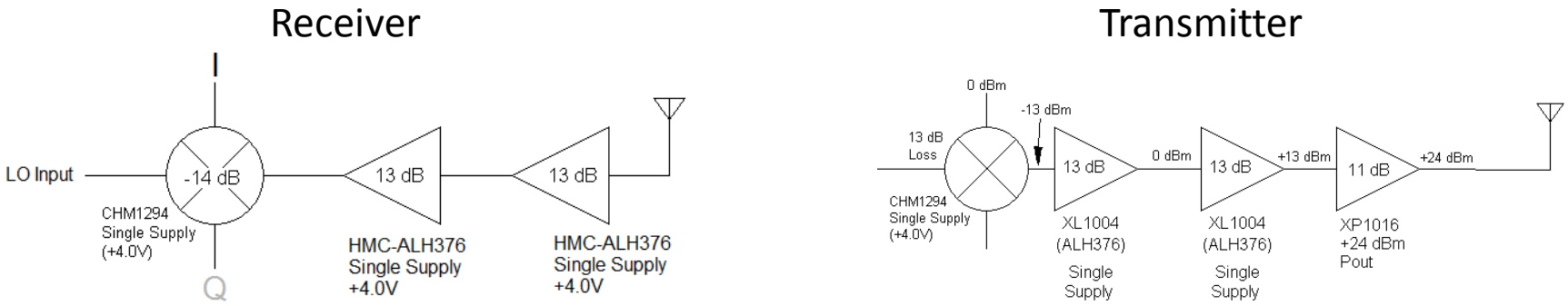
- Mixers – A few available including those with low conversion loss, some with low LO drive, sub-harmonic, image reject, etc.
- LNAs with noise figures in the 3-4 dB range
- PAs – 100 mW doable, Triquint has some higher power options)
- Several years ago, some Italian hams put together a very nice 47 GHz LNA using MMICs (see QEX)
- If you can deal with bare MMICs, the possiblities are pretty neat!

Bare MMICs



- Parts are available from:
  - Hittite
  - Avago (formerly HP)
  - Triquint
  - Mimix Broadband
  - UMS (France)
- Some parts are export controlled, okay if in U.S., hard if you are not. UMS parts are available outside the US.
- Richardson Electronics is probably the distributor of choice, given that they will deal in small quantities

The New Front End



- Receiver features ~15 dB of receive gain, ~4 dB noise figure (on paper), runs on a single +4V supply
- Transmitter features 100 mW of output power (on paper), image and carrier suppression
- Both use sub-harmonic mixers. Distributing a 23 GHz LO is a lot easier than a 47 GHz LO!

Working with Bare MMICs

- Bare MMICs are usually 4 mils thin, no more than a few millimeteres on a side
- Bare MMICs are typically made of crystalline GaAs.
- So they are TINY and extremely FRAGILE
- They like to crumble in tweezers, fall from tweezers, and fly into oblivion
- Which means…

Working With Bare MMICs

- Diet is important
- No Caffeine
- No Sugar
- You'll need a few special things
  - A good stereo microscope (zoom helps but a fixed 20x is what I have)
  - A good pair of tweezers. I have mediocre tweezers, but a set of Excelta 5-CO tweezers (~$100) are on my list of things to get.
  - Tweezers ideally should require very little force to close, the difference between crushing a die and picking it up is surprisingly small. Tweezers with a strong spring force reduce any resolution you might have for delicate maneuvers
  - A hot plate or oven capable of reaching and maintaining 150 degrees C (for curing epoxy)

Working With MMICs

- MMICs are shipped in either “Gel-Paks” or Waffle Packs.
- Waffle packs are nice, easy to get parts out.
- Gel-Paks require a vacuum or a lot of swearing to get the parts off the sticky membrane.

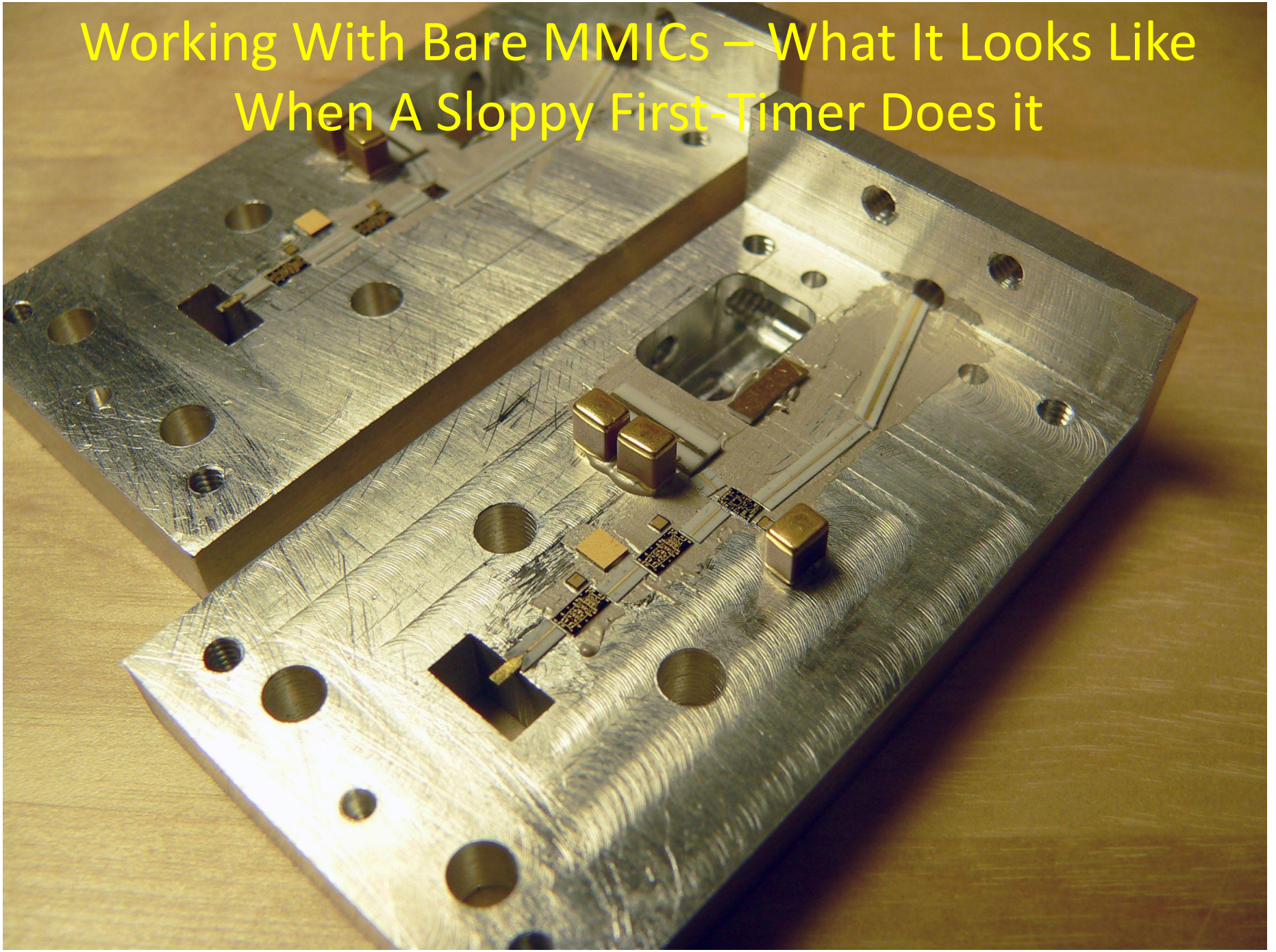
Working With Bare MMICs – Glue!

- MMICs are either epoxied or soldered to a housing in most cases.
- Soldering MMICs requires expensive equipment and costly die collets, not good for amateurs…
- Silver loaded epoxy is available in many forms including one-part, two part, some that requires -40C refrigeration, some that will last at room temperature, some that cure quickly, etc.
- I have used Circuit Works 2400 (two-part, 10 minutes of use) room temperature cure.
- I have also used and prefer a pre-measured two-part from McMaster Carr unfortunately it is $20 a pop…
- The good stuff (Epo-tek or Diemat starts at almost $200 per container) and lasts for a year or two.

Working With Bare MMICs – Other Useful Tools and Procedures

- Super sharp Exacto knives (for scraping excess cured epoxy)
- Q-tips (for slicing into sharp spears for pushing down the corners of the chips)
- Good very tiny paintbrushes (for spreading epoxy)
- Need to get a thin layer (0.5 to 1 mil) of epoxy
- Push the part into the epoxy so it rests evenly
- Cure at the prescribed temperature (usually 150C) for the required time

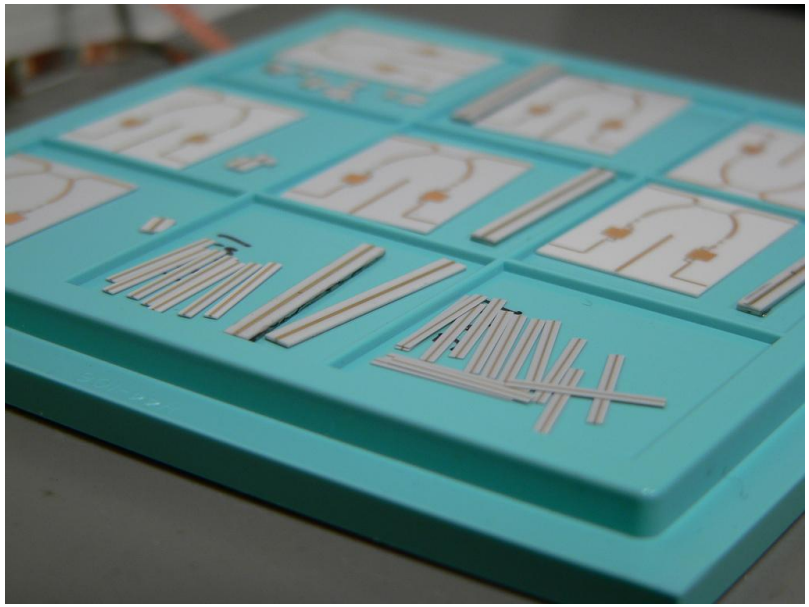
Working With Bare MMICs – What It Looks Like When A Sloppy First-Timer Does it

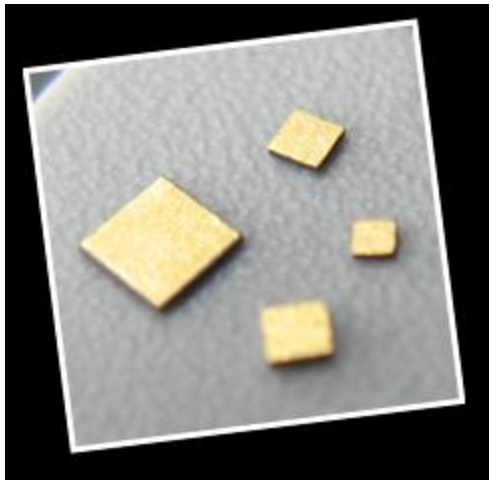


Working With MMICs – Last Thoughts

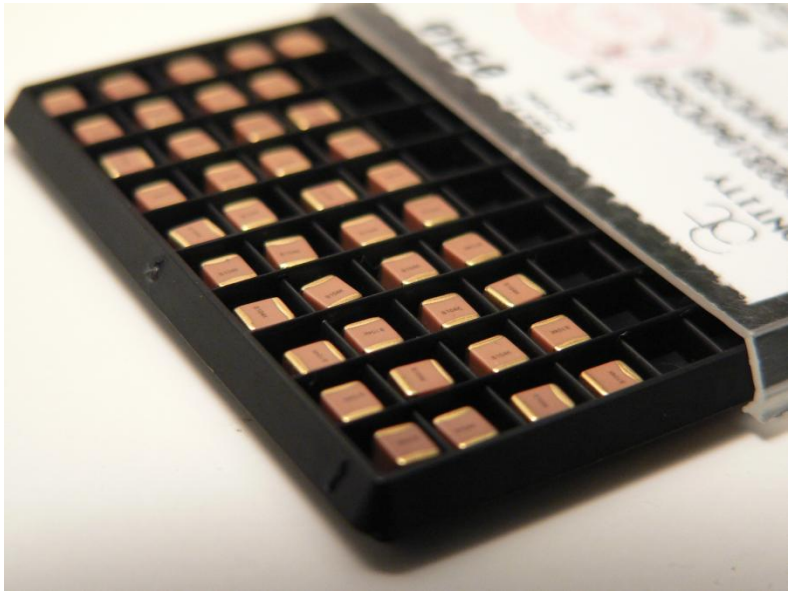
- Wire bonding is a whole ‘nother presentation so I won’t cover it here. Come to MUD 2010 and see my talk on that subject
- MMICs are hard to work with, I never look forward to working on these things, it is nerve-wracking, expensive, and full of potential pitfalls
- More experience gives better results, I have gotten better, but there is definitely room for improvement.

Other Things You Need Besides MMICs

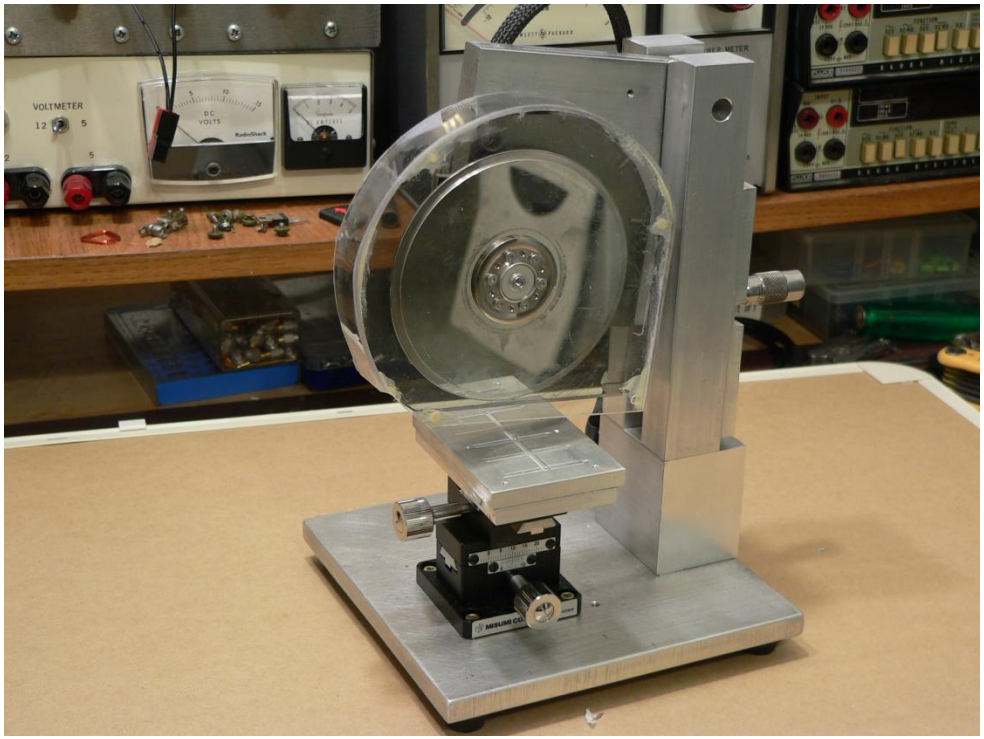




- Water
- Food
- Shelter
- Love
- A sense of purpose
- Friendship
- Single Layer chip caps
- Multi-layer porcelain caps with gold ends
- 50 ohm substrates with gold metallization
- Waveguide Transitions
- Housings

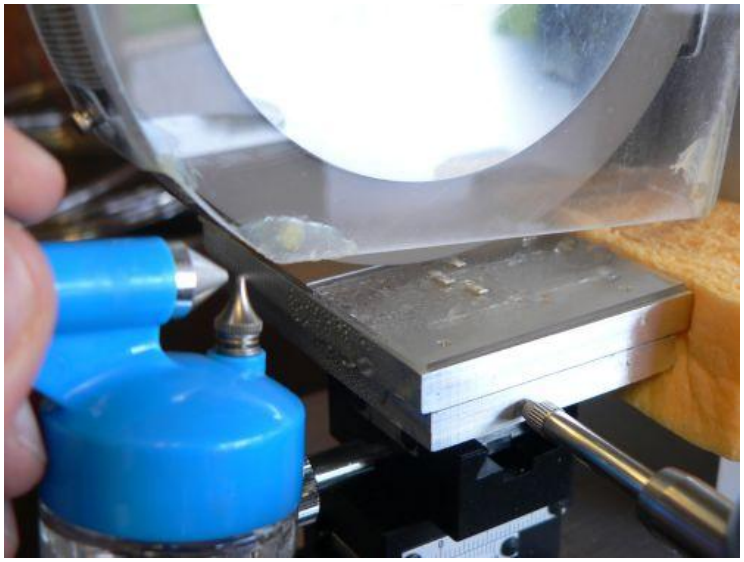


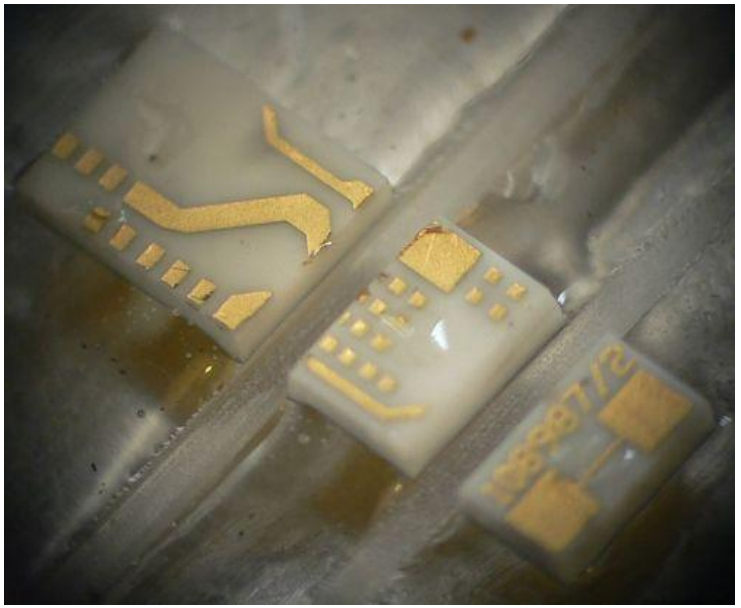
Another Special Tool



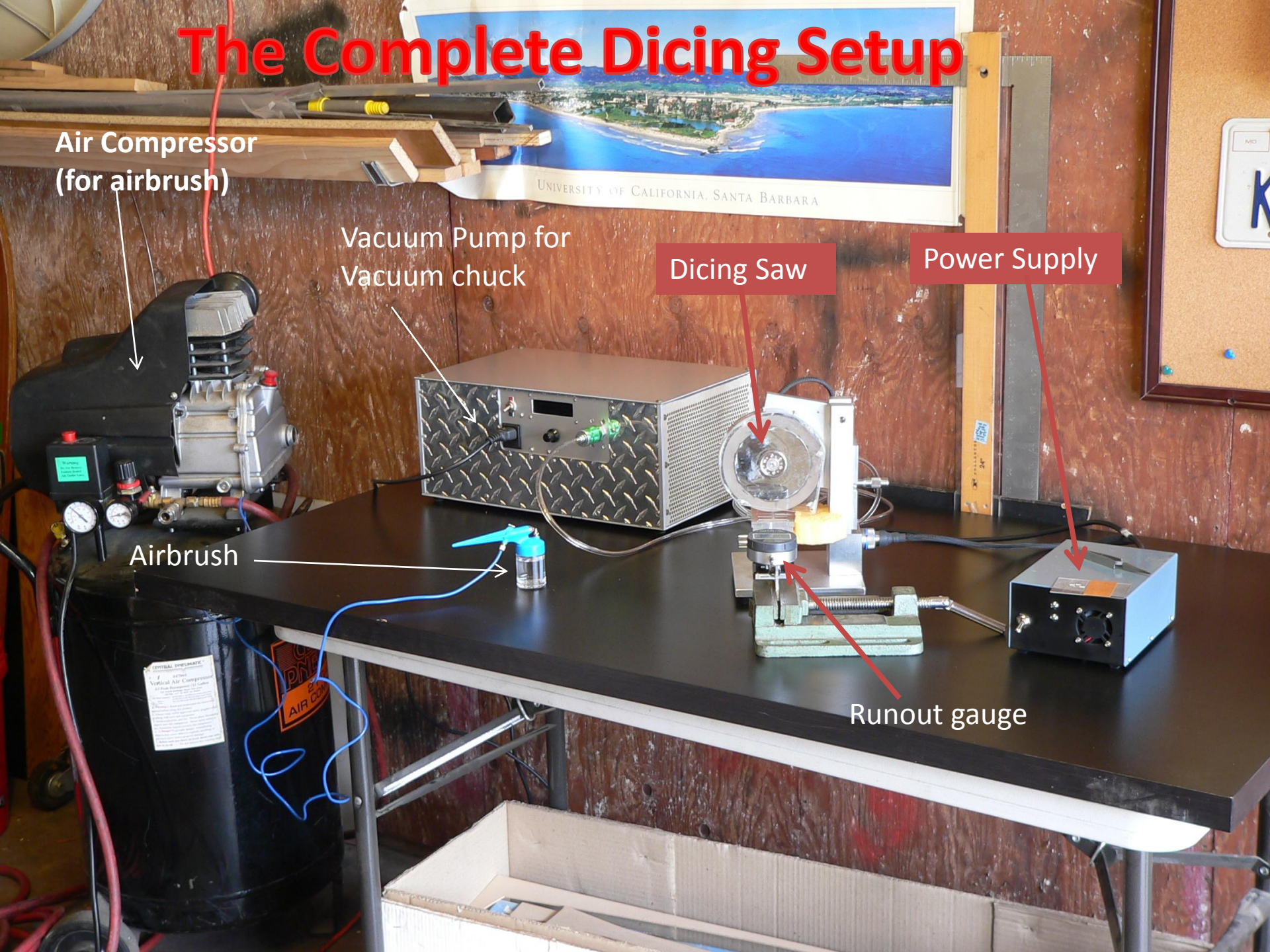
- 50 ohm substrates of the Al2O3 or Quartz variety come in standard lengths.
- For 47 GHz you can get away with 10 mil thick Al2O3 substrates, but I used 5 mil.
- Cutting them to length requires:
  - A way to cut substrates to length
  - Crystalbond (a mounting adhesive)
  - Vacuum pump
  - Vacuum chuck
- I decided to make my own dicing saw…

Another Special Tool

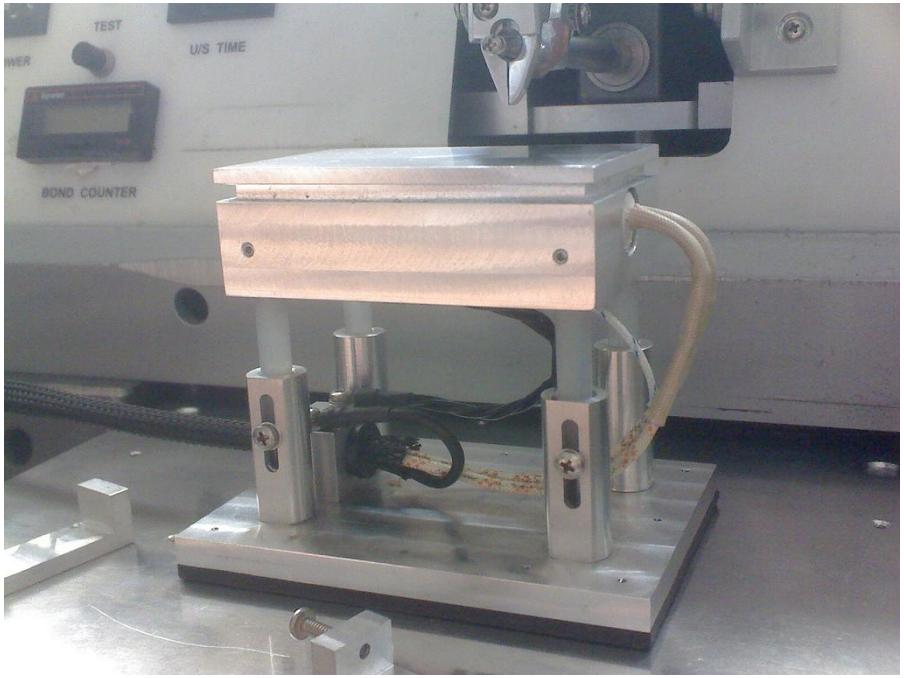




- My dicing saw uses an old hard drive motor
- Depth is set using a micrometer head
- X-Y table is from Ebay
- Vacuum chuck is home-made
- Water is sprayed using a model painting airbrush
- Dicing blade is a semiconductor wafer dicing saw blade (from Ebay)
- Can make chop cuts, slicing cuts, miter cuts, can do some rough surface grinding, etc.

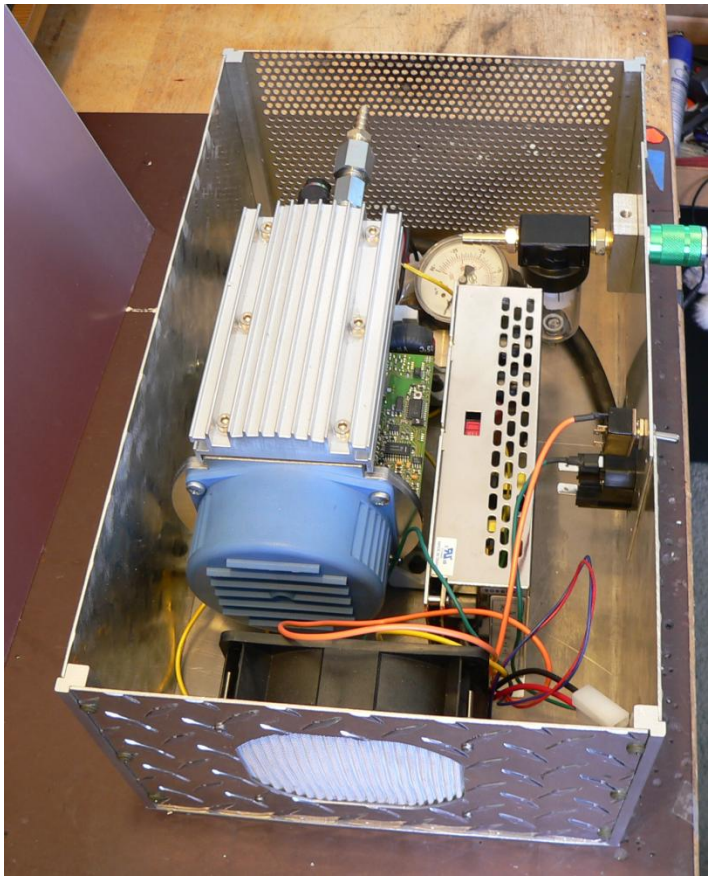

The Complete Dicing Setup
Air Compressor
(for airbrush)
Vacuum Pump for
Vacuum chuck
Dicing Saw
Power Supply
Airbrush
Runout gauge
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Yet Another Special Tool



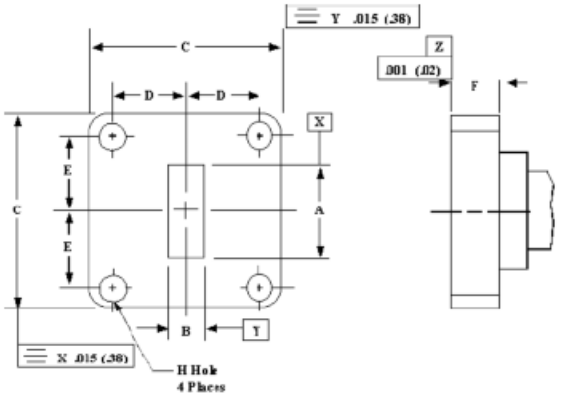
- Hot plate with PID controller
- Used for curing epoxy and wire bonding
- Adjustable height
- 50 watt heater element
- Fully ESD protected

Still Another Special Tool



- Vacuum pump is a German made precision 24 V DC pump
- Picked up at a surplus store in new condition for $20 !!
- Digitally controlled by an Arduino Microcontroller with digital vacuum readout using a MEMS vacuum sensor

Waveguide Switches, Transitions, Housings

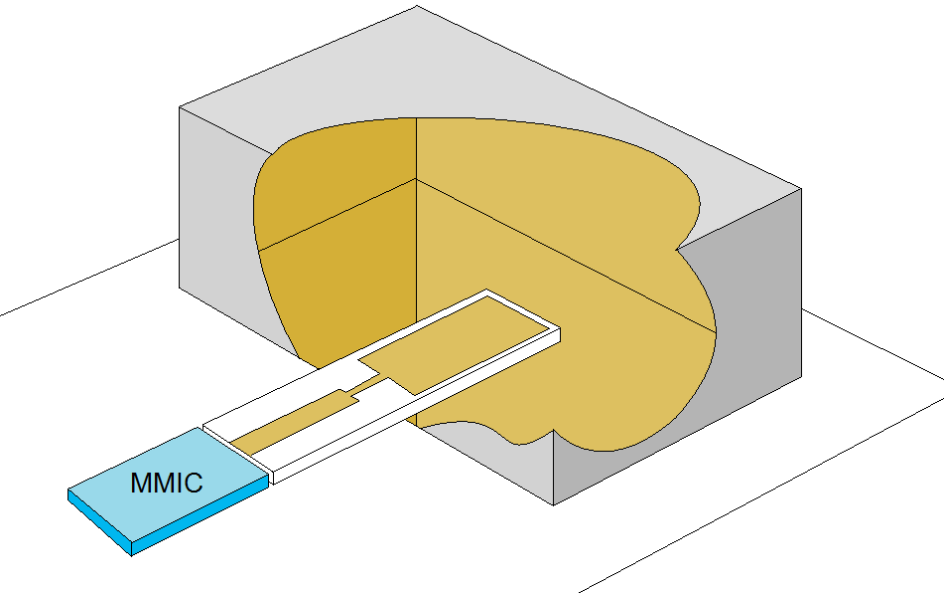


Band	Frequency Band (GHz)	A ±.0015 (.04)	B ±.0015 (.04)	C	D BSC	E BSC	F	H
Q	33.0 50.0	.2240 (5.69)	.1120 (2.84)	.750±.005 (19.05)(1.3)	.265 (6.75)	.250 (6.35)	.156±.005 (3.96)(.38)	.116±.002 (2.95)(.05)
Q	33.0 50.0	.2240 (5.69)	.1120 (2.84)	.750±.005 (19.05)(1.3)	.265 (6.75)	.250 (6.35)	.156±.005 (3.96)(.38)	.112-40 UNC-2B
U	40.0 60.0	.1880 (4.78)	.0940 (2.39)	.750±.005 (19.05)(1.3)	.265 (6.75)	.250 (6.35)	.187±.005 (4.75)(.38)	.116±.002 (2.95)(.05)
U	40.0 60.0	.1880 (4.78)	.0940 (2.39)	.750±.005 (19.05)(1.3)	.265 (6.75)	.250 (6.35)	.187±.005 (4.75)(.38)	.112-40 UNC-2B

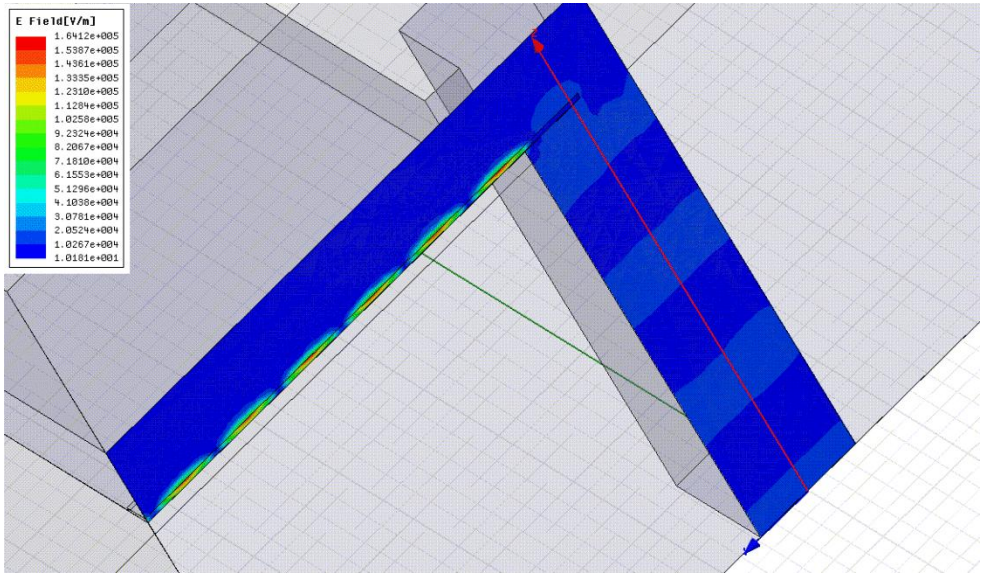
All dimensions in inch (mm)

- WR-19 or WR-22 are optimal for 47 GHz
- E-Plane waveguide transitions are a favorite of microwavers due to a relative ease of construction
- Challenge of making “dive boards” includes problems with patterning, substrates, and metallization (gold)
- WR-22 is 112 mils in height. 10 mils is nearly 10% - dimensions are critical!

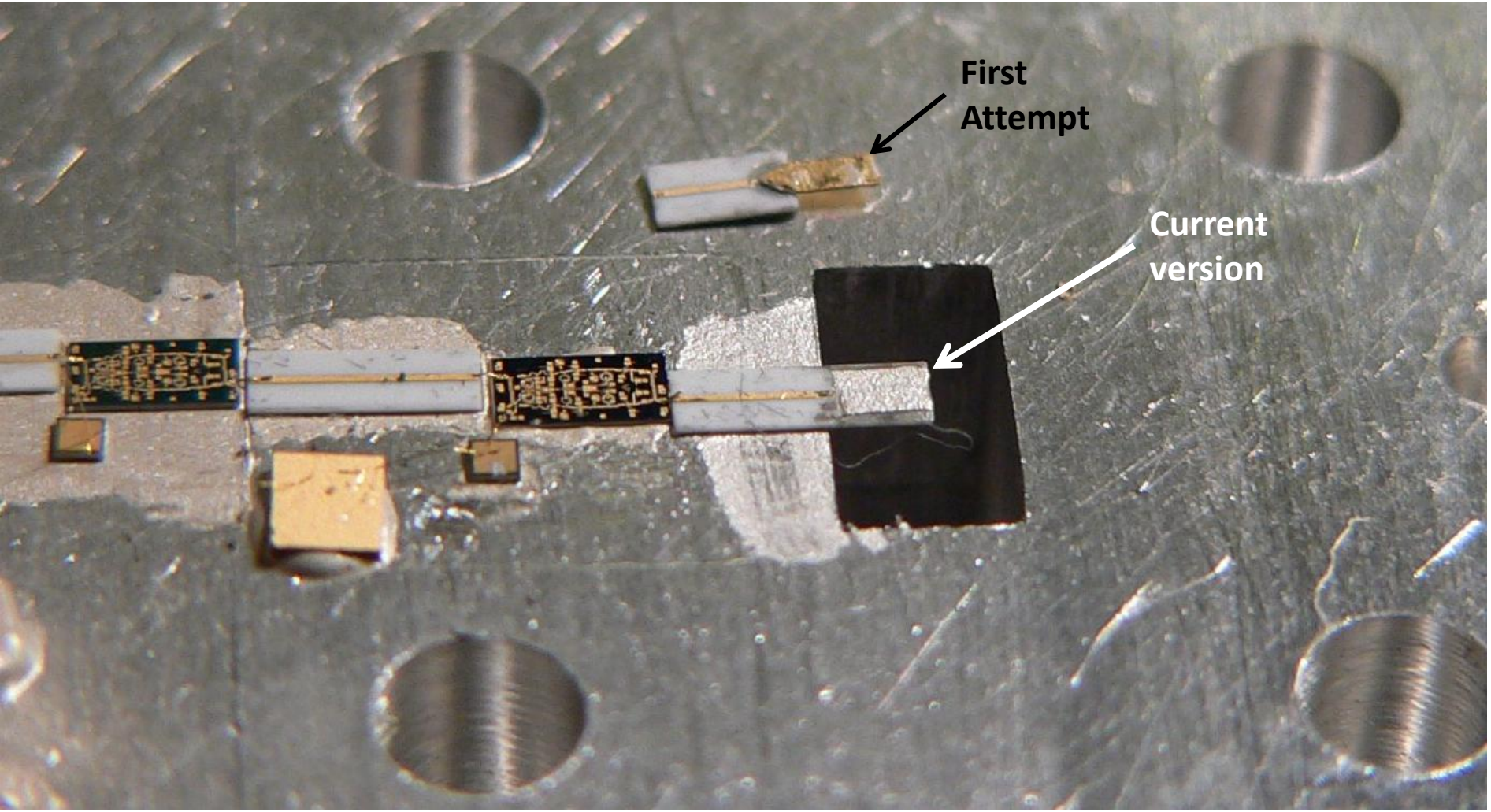
Design of Transition



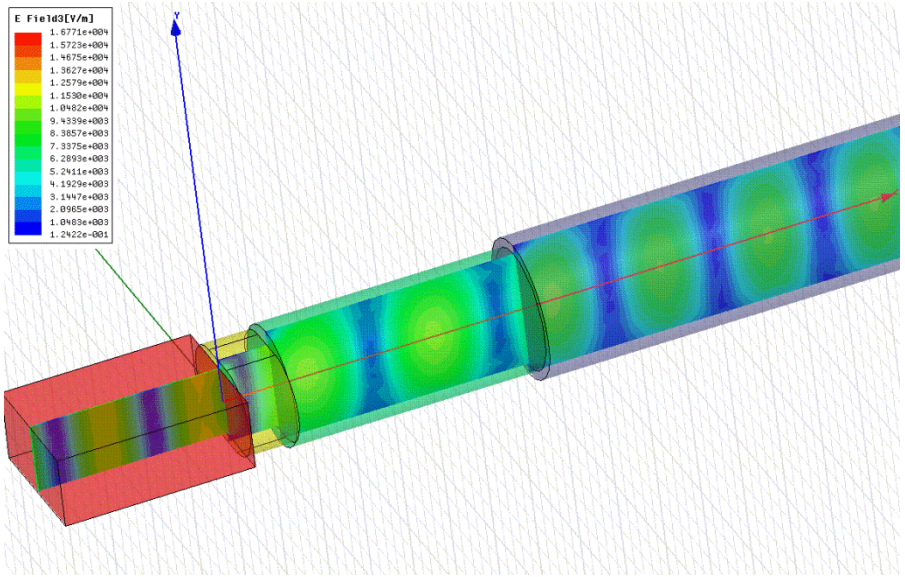
- Design was done using 3-D Simulation tool
- Dimensions of tab are pretty sensitive
- Tab is formed by smearing silver epoxy over a 50 ohm alumina strip



Actual Waveguide Transitions

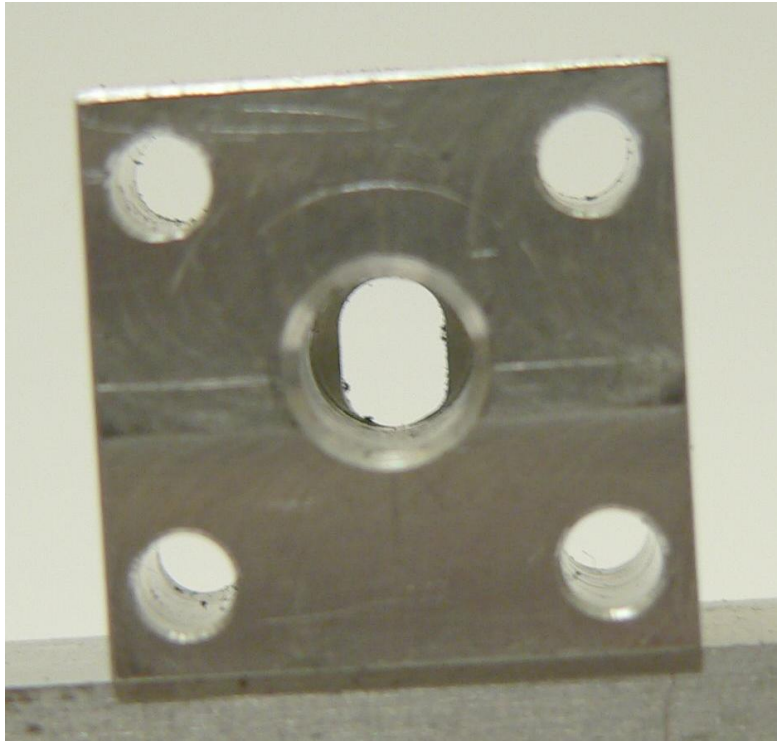


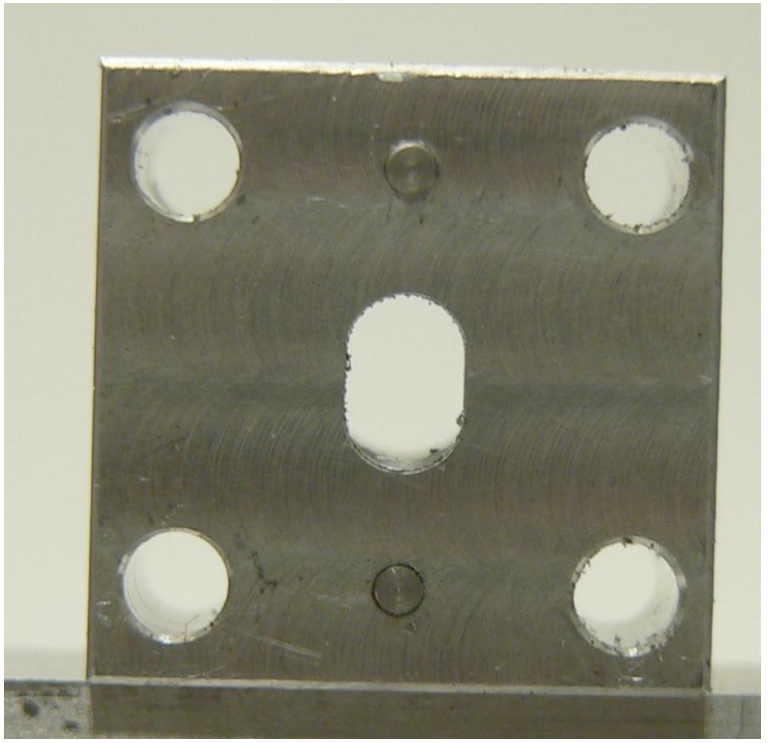
Rectangular to Round Waveguide Transition



- Two methods
  - smooth taper
  - ¼ wave transformer
- ¼ wave transformer is not TOO hard to make. Smooth taper is harder to make.

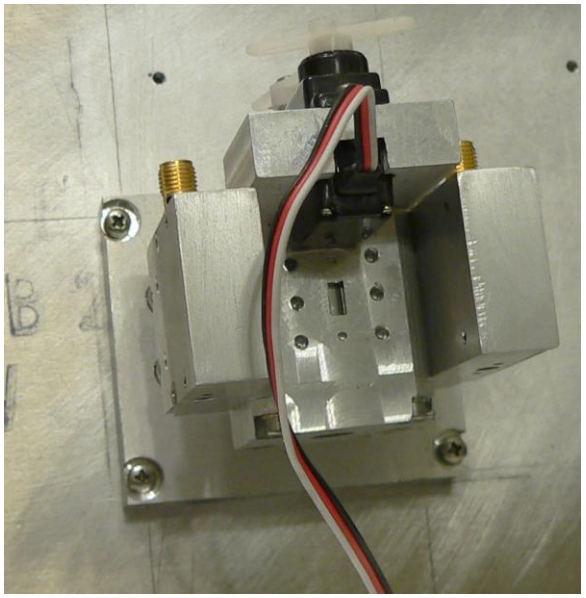
Machined WR-22 to Round Transition

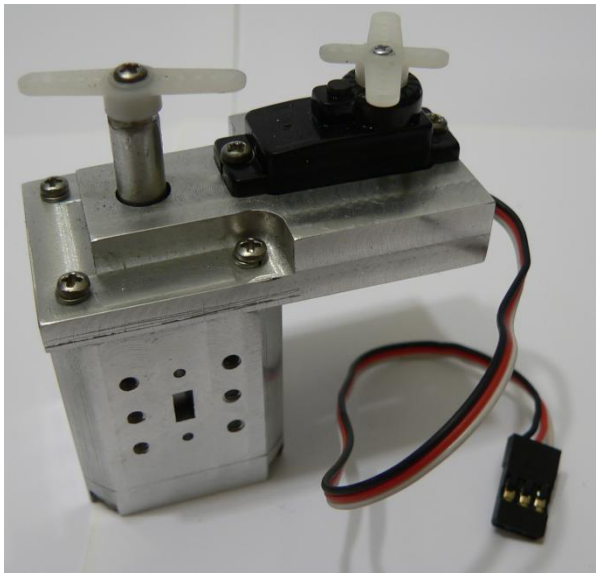




- Can be used as a really predictable dice if needed
- Gives ~15 dB return loss
- I screwed up the alignment between the round hole and the radiused rectangular hole
- CNC would be ideal, or just a mill with usable handwheels/indicators

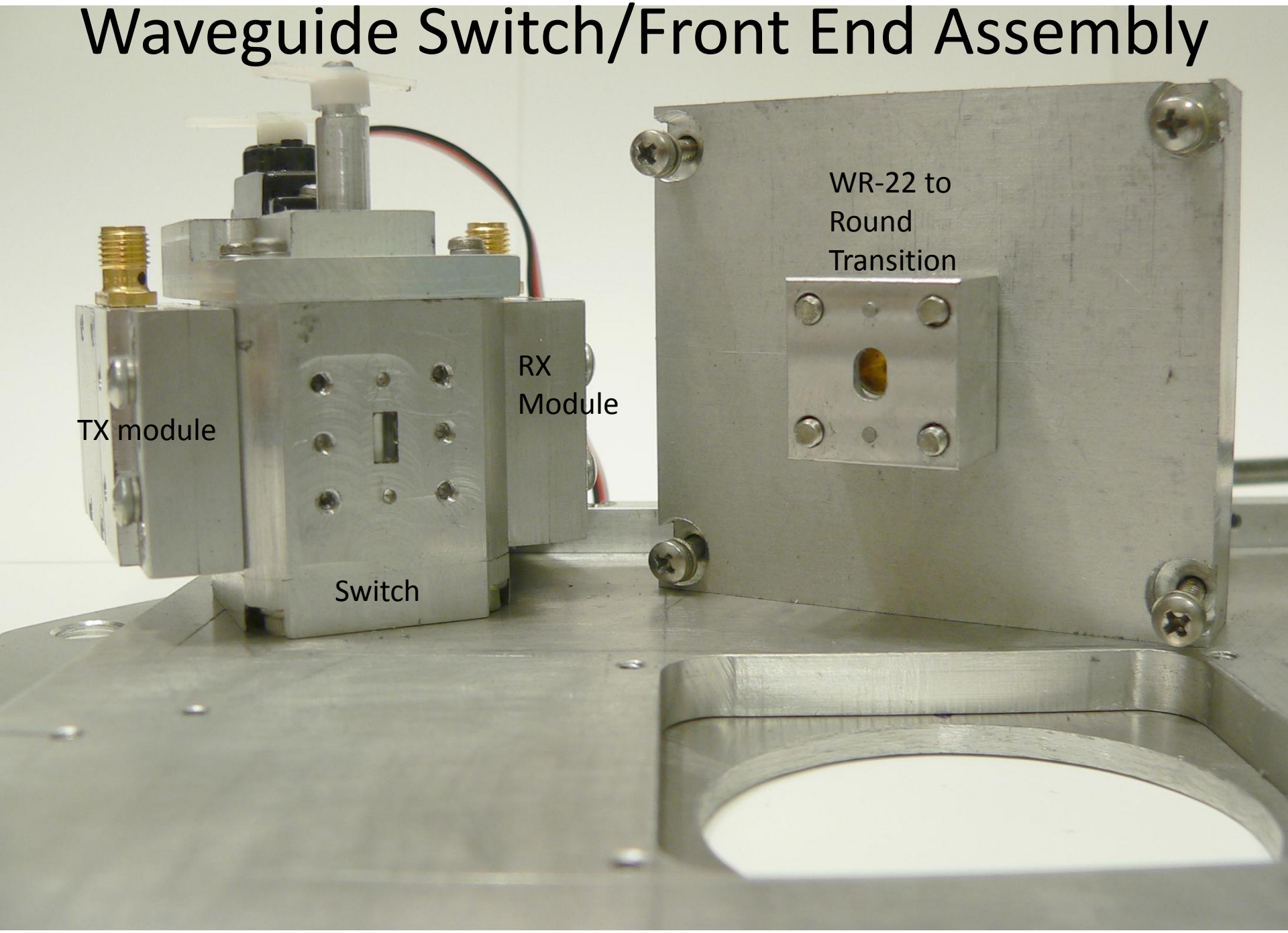
Waveguide Switch



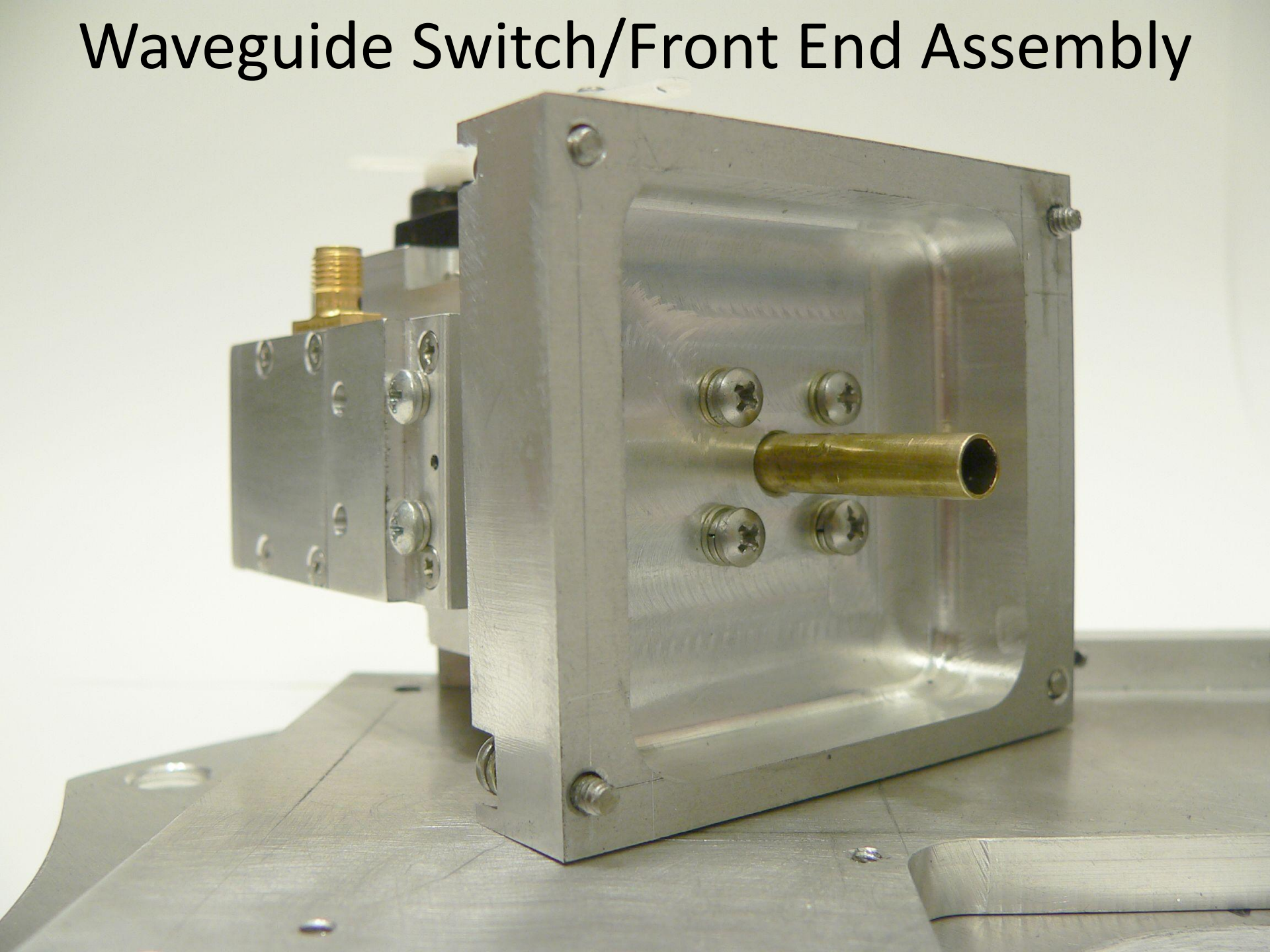


- Previous work on a successful WR-42 switch was used for this design.
- First work on the switch was completed at my Father-in-law's shop in Argentina
- Wire EDM of the waveguide ports done at The EDM Shop in Orange County, CA
- Performance is good enough, but leaves room for improvement – 20 dB return loss, but around 1 dB of insertion loss! Polishing and plating would help!

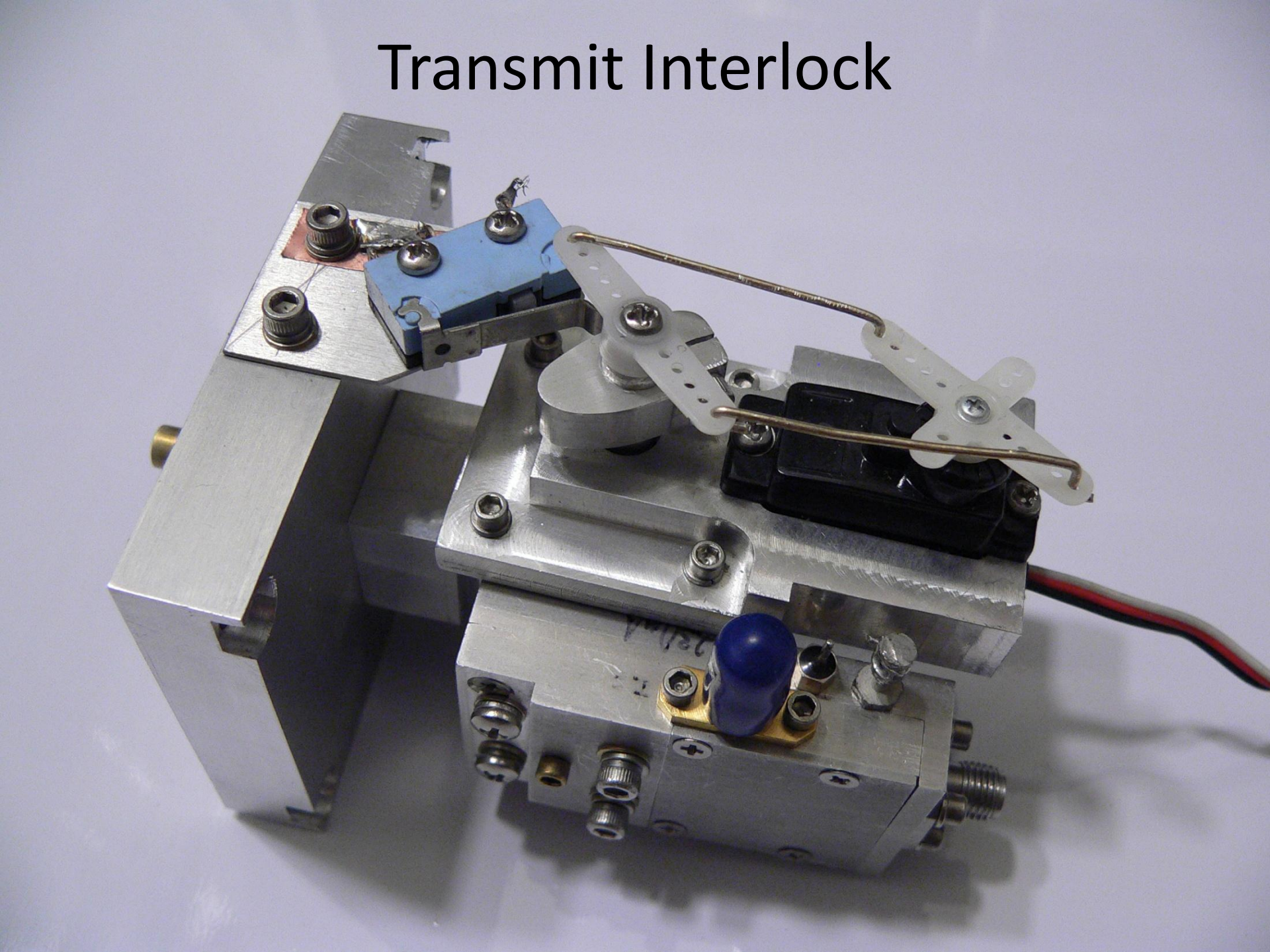
Waveguide Switch/Front End Assembly



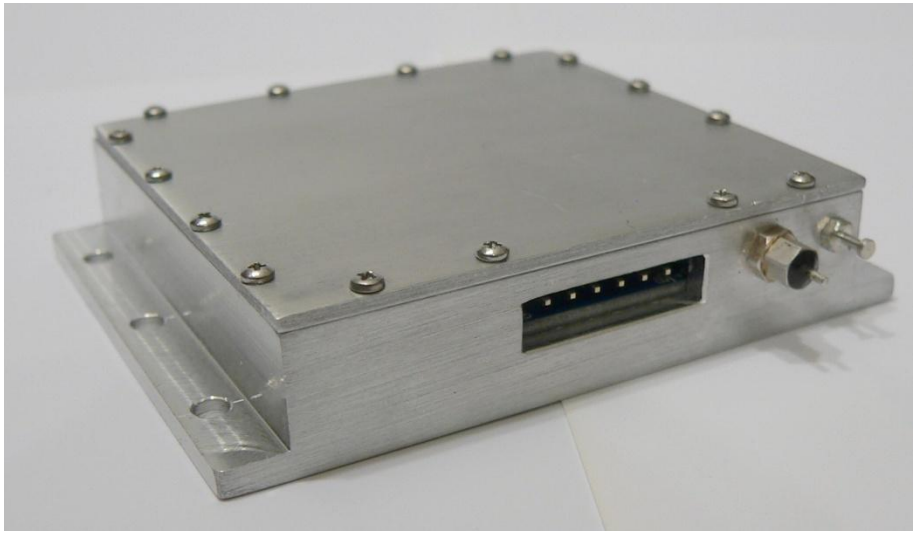
Waveguide Switch/Front End Assembly

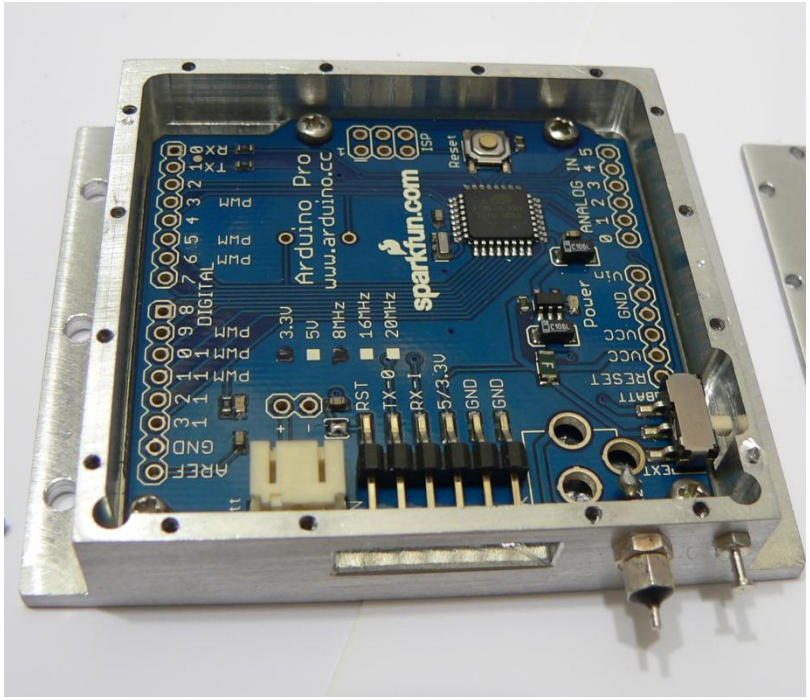


Transmit Interlock



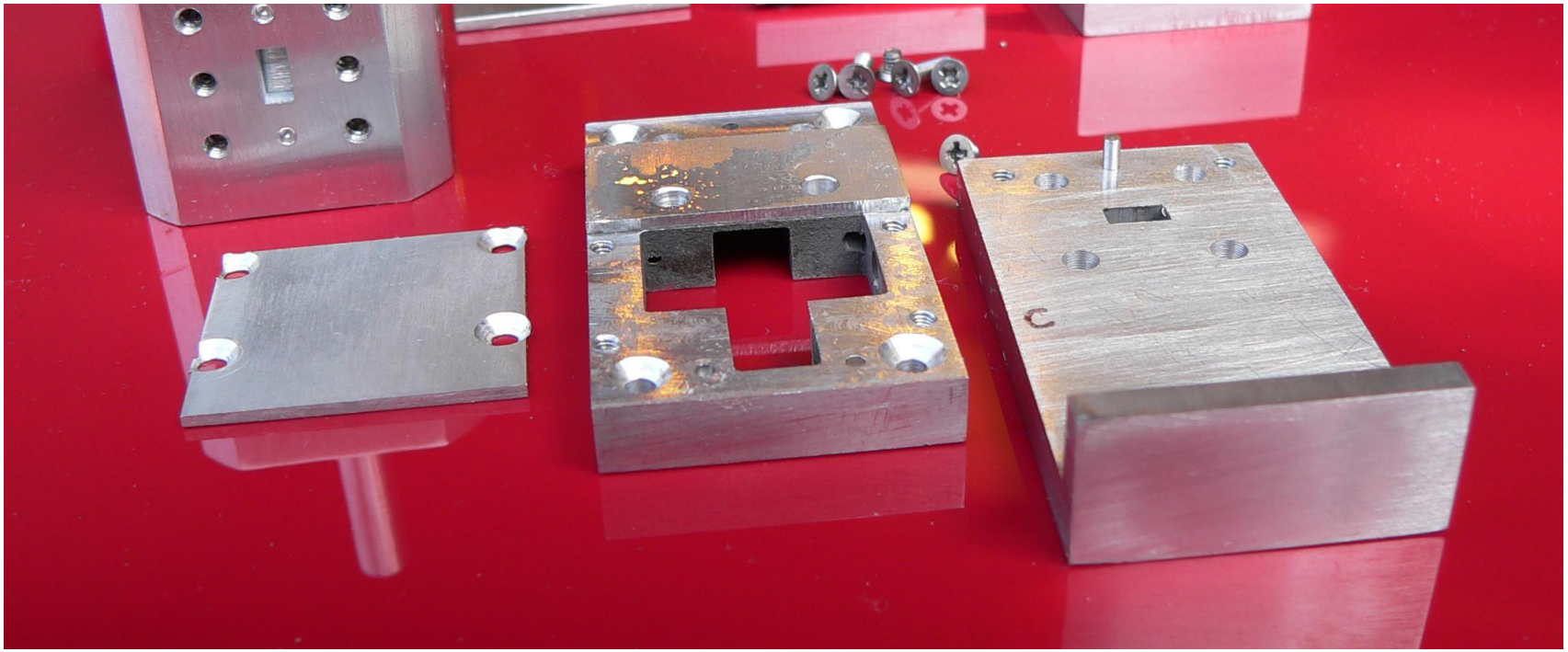
Waveguide Switch Controller and T/R Sequencer





- Off the shelf Arduino (Atmega168) microcontroller
- Easy to program
- Analog and digital inputs
- PWM, digital outputs
- Easily reprogrammed with a USB cable, can be done in the field!
- Transmit/Receive positions encoded by 10-turn pots
- Cheap! ~$25

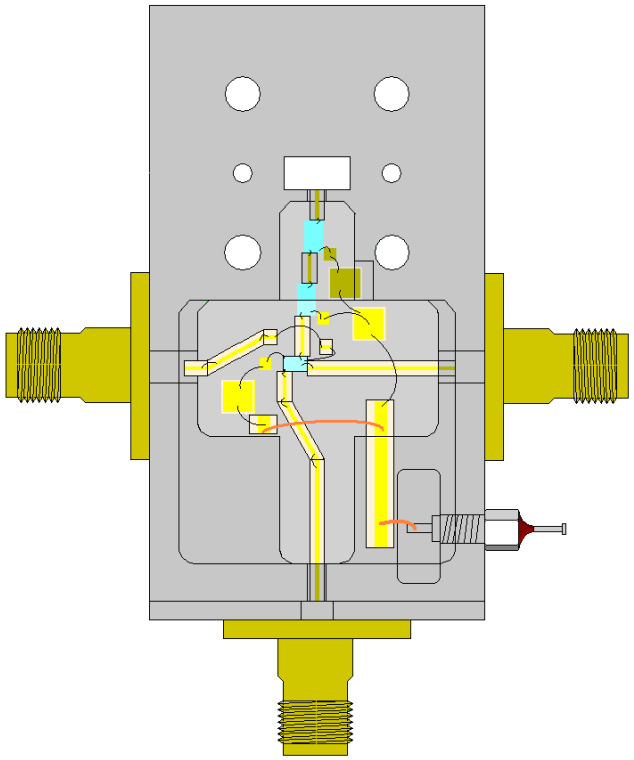
Transmit/Receive Modules



- Initial work began in late 2007, again while on Christmas break in Argentina
- Modules were originally designed to work with packaged Mimix parts
- Little change was required to work with bare MMICs
- Housings are made from three pieces
  - Baseplate (where components go)
  - Upper frame (forms the cavity, holds IF connectors, waveguide backshort
  - Lid (to allow access for final attachment of wires to IF and DC connectors
- Combination of traditional milling, wire EDM, die-sinker EDM

Transmit/Receive Modules

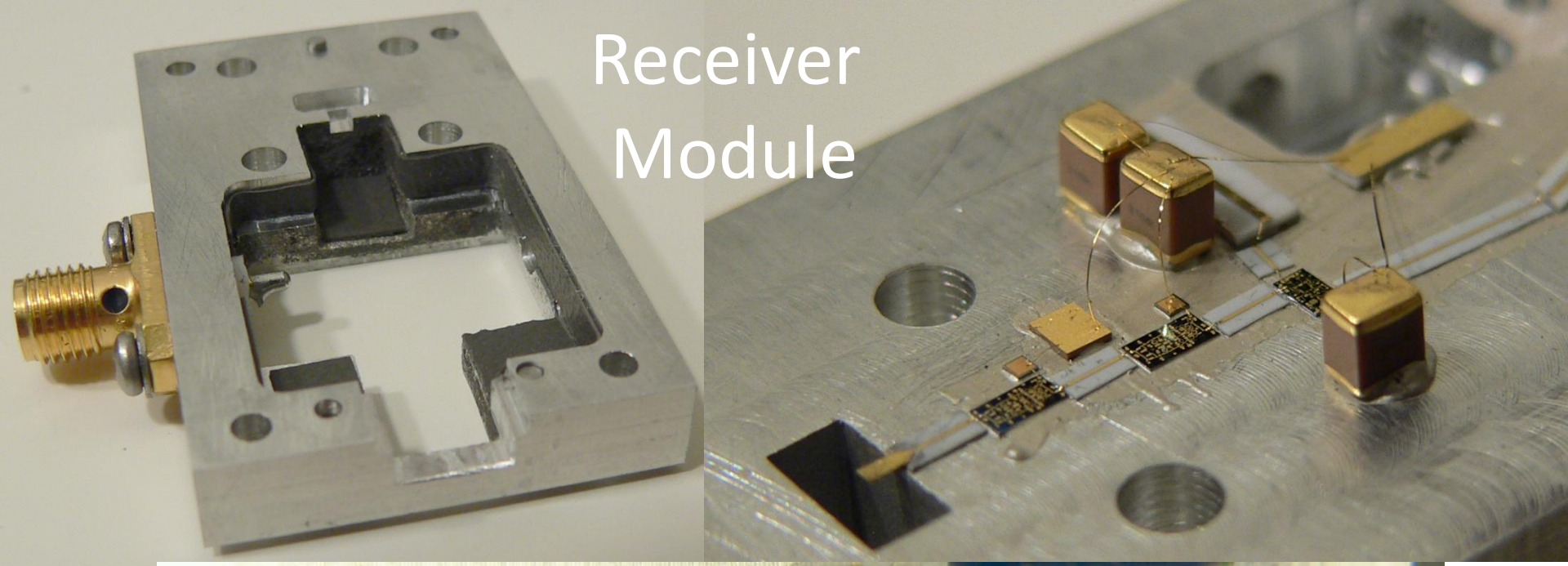
Receiver Module

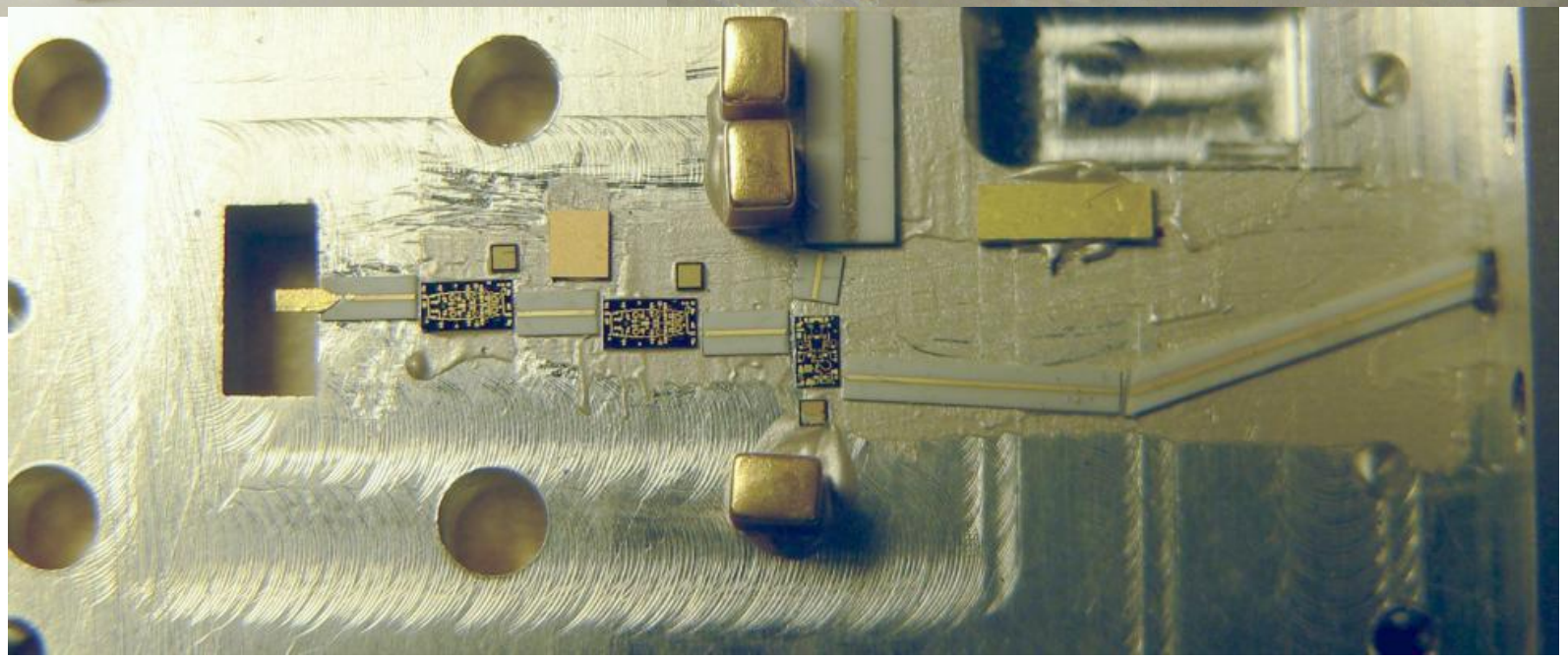


- Ended up being single-IF connection (take a 3 dB hit in noise figure ☹
- Gain came out to be 10 dB
- Noise Figure (double sideband) is 6 dB, so around 9 dB SSB, not superb, but better than a mixer
- Would like to improve the transition still. Possibly using gold leaf to improve conductivity.
- Or if anyone has $5k, we could do a run through a real substrate fab house….

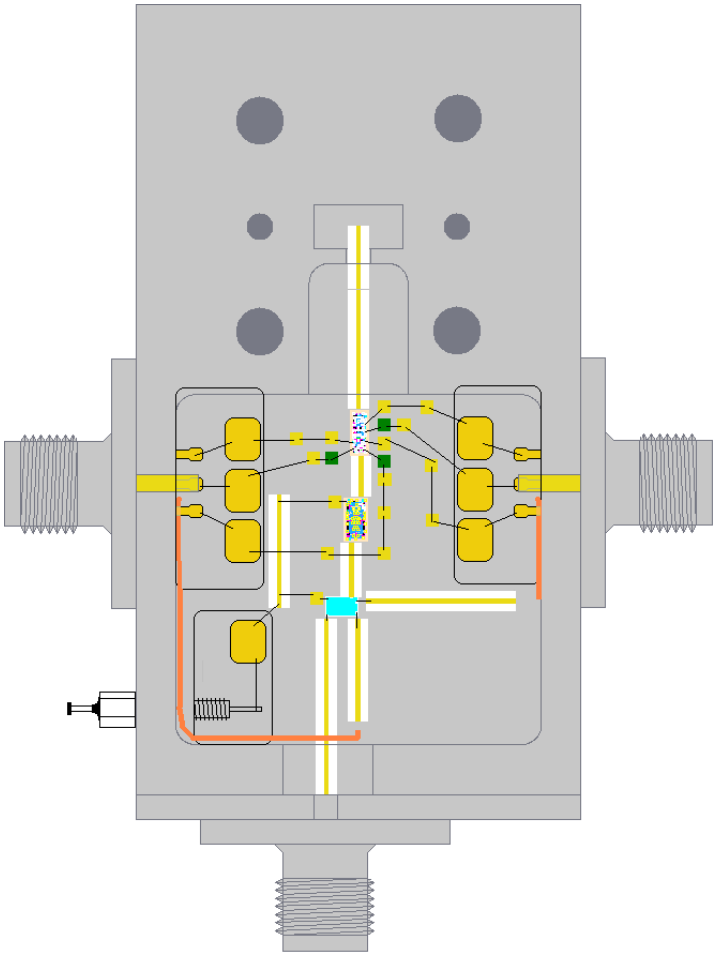
+10 dBm LO Drive required

Receiver Module





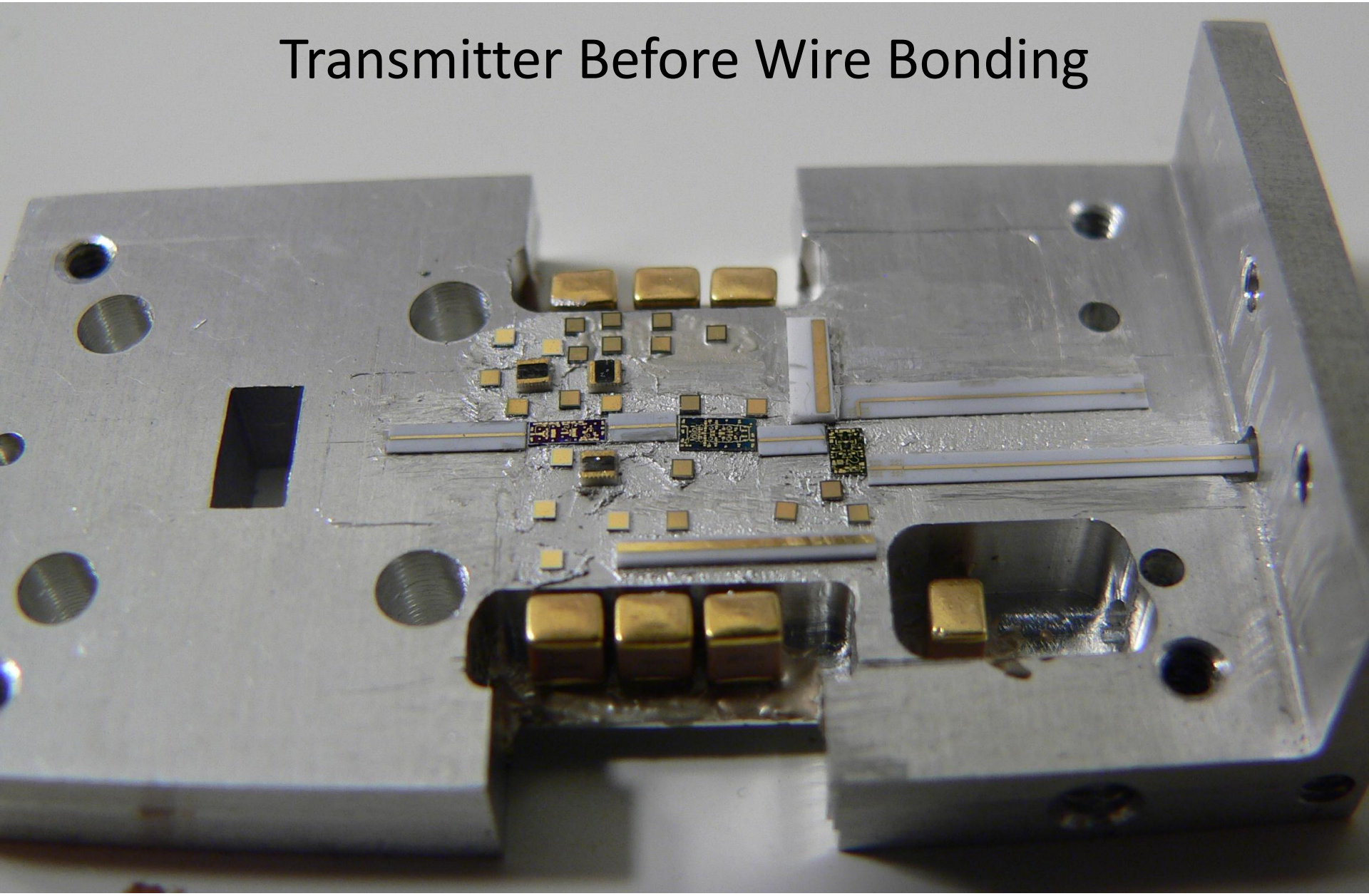
Transmitter Module



- Substantially more complex than receiver
  - Many more bias lines
  - More complex biasing (resistors on gates)
- Puts out just 10 mW – Should put out 100 mW
- Measurements were made with one IF signal, should be 3 dB or more increase with second IF signal
- Final amplifier does not seem to be saturating, meaning that there may be insufficient gain before.
- Could potentially add another gain stage….

+10 dBm LO Drive required

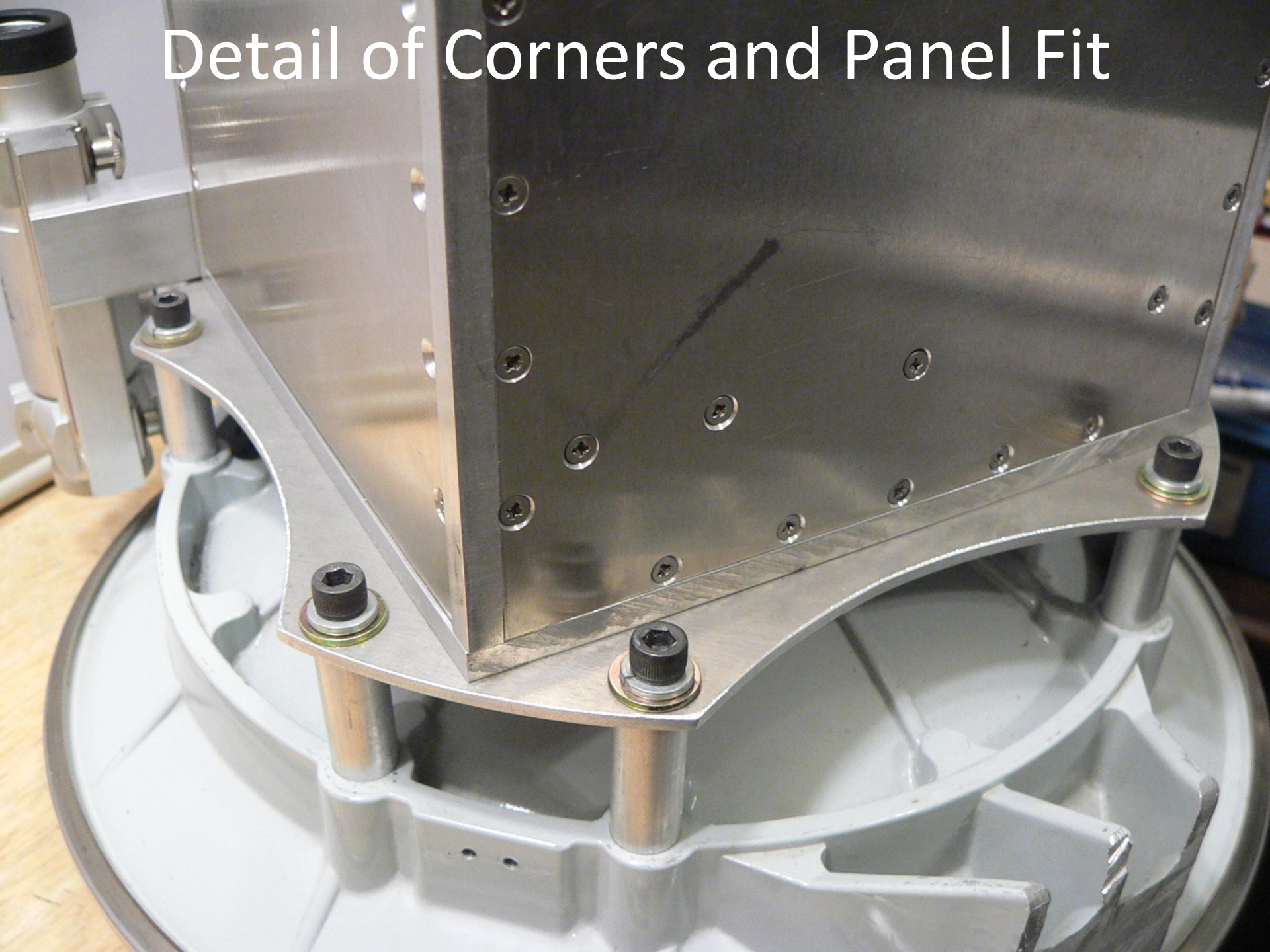
Transmitter Before Wire Bonding



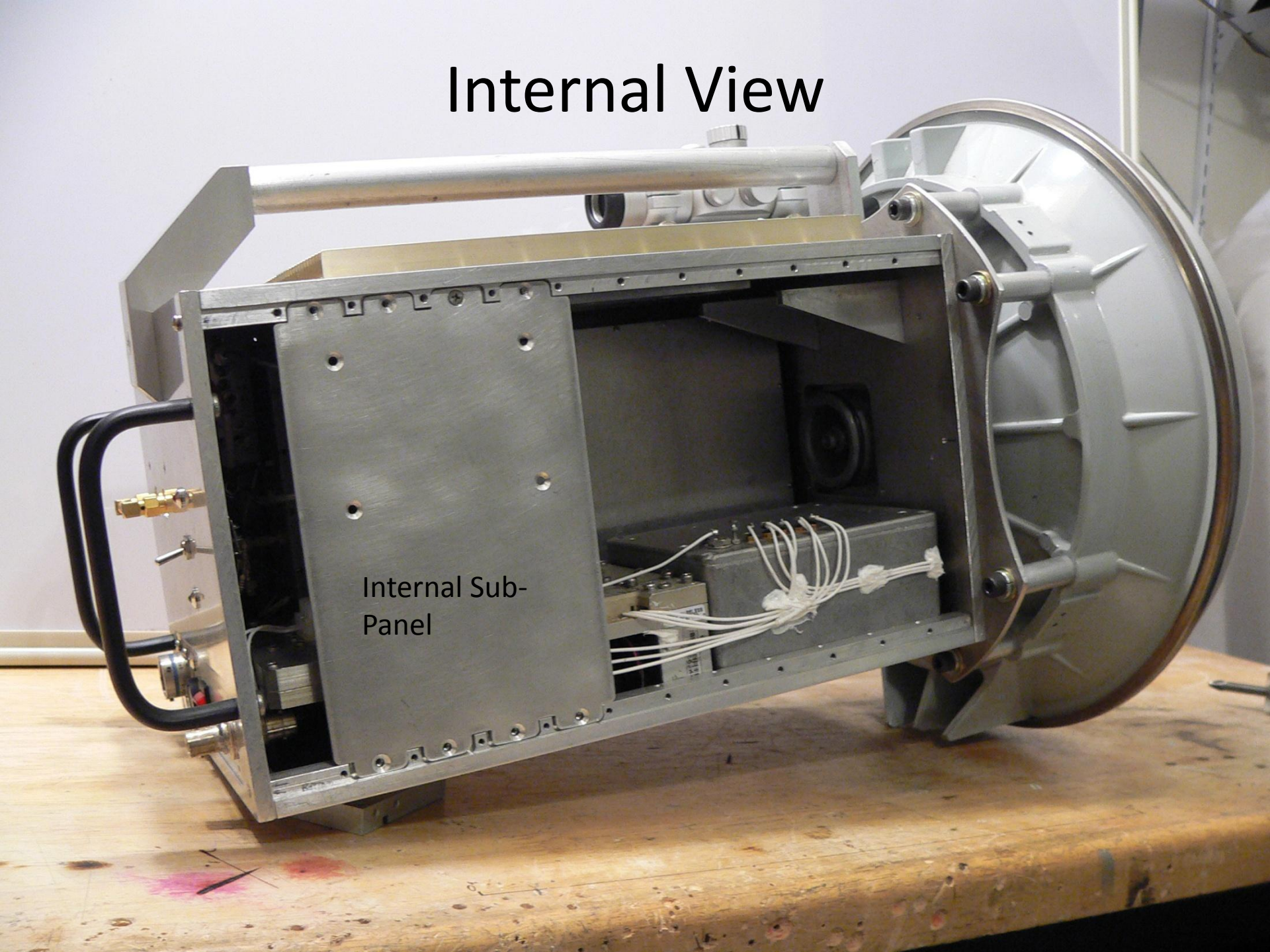
A Proper Box

- This project called for a special box.
- Completely aluminum
- Scalable in many ways
- All panels independently removable
- Waaaaay too many screws!

Detail of Corners and Panel Fit

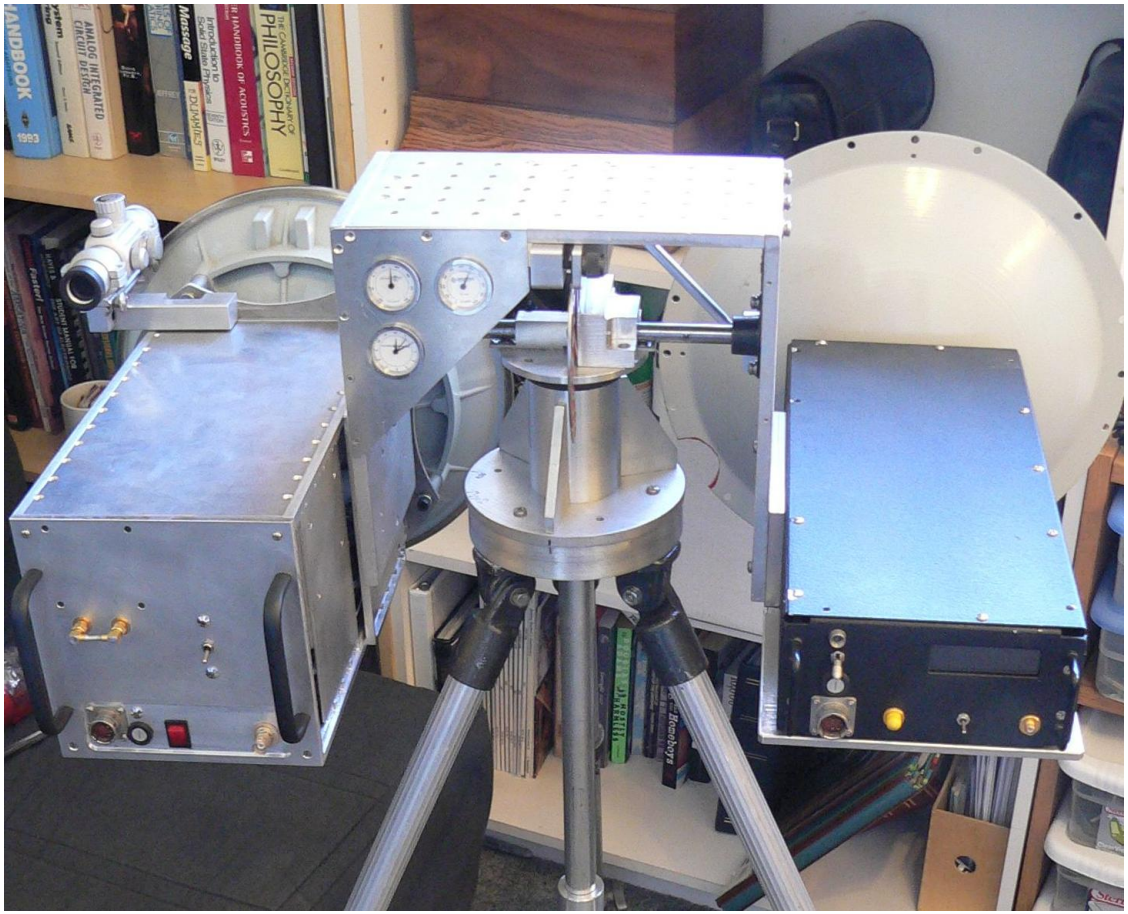


Internal View



Scope Mount With Level

Pointing at 47 GHz



- 1 foot dish gives less than 1 degree beamwidth at 47 GHz
- Need a very stable platform
- Must have smooth movement

Details of Tripod Head

Elevation Brake

Tripod Improvements

Original central section left much to be desired… Flimsy, crummy bushings (screws in many cases)

- New aluminum downtube
- New slider and arms
- Wider stance (better stability)
- Shoulder bolts used for bearings
- Smoother movement
- Added thick aluminum mounting plate on top.

Conclusion

- Still have a few things to finish
  - Switching regulators for RF parts
  - Current regulators for transmitter
  - Try to get a little more out of the transmitter
  - Put it all together and test
- I have learned a LOT
- Now your turn, we need more 47 GHz operators!!!