

Have a Software Defined Radio? Design and make your own antennas

Demystifying the dark arts of antenna design

Erwin Karincic
Cyber Security Researcher

Problem Statement

Many researchers indicated that having a better antenna would make their discoveries work at a better range

higher antenna gain

environment. A more sophisticated attacker, could use better equipment with a lower noise floor and higher antenna gain to undertake such an attack from an even further distance. This should open the discussion about what

Even though the units have the intended functionality, there are still some improvement to be done concerning the range of the units. Here, a further investigation regarding a better antenna is something we would recommend. Another area that we would

better antenna

better antenna

for R and determine that he can only be at 35.48 cm away. Thus for practical attacks, he will have to get a better antenna or significantly increase his transmit power. In

10 cm is not a sufficient defense against eavesdropping attacks. While neither experiment achieved the predicted eavesdropping range of 10 meters, better antenna design increases the maximum eavesdropping range significantly. In [72], Hancke was able to eavesdrop at

better antenna design

I do not think this would be a factor at all if I had better antenna directional gain capability, but I do not and for now am looking forward to any improvements to a selectivity that is already the best that I have ever used in a radio's receiver.

better antenna directional gain

Software Defined Radio (SDR)

A radio communication system which uses software for the modulation and demodulation of radio signals

The goal of this design is to produce a radio that can receive and transmit a new form of radio protocol just by running new software configuration

| SDR | Frequency |
|-------------|-------------------|
| Ettus B210 | 70 MHz - 6 GHz |
| HackRF One | 1 MHz - 6 GHz |
| BladeRF x40 | 300 MHz - 3.8 GHz |
| RTL-SDR | 22 MHz - 2.2 GHz |



Commonly Included Antennas

ANT500 from Great Scott Gadgets is a telescopic antenna designed for operation from 75 MHz to 1 GHz. Its total length is configurable from 20 cm to 88 cm. ANT500 is constructed of stainless steel and features an SMA male connector, rotating shaft, and adjustable elbow.

75 MHz to 1 GHz.

VERT2450 Antenna - \$ 63.00 USD
783075-01 | VERT2450 Vertical Antenna (2.4-2.5 and 4.9-5.9 GHz) Dualband
Includes one VERT2450 Dual Band 2.4 to 2.48 GHz and 4.9 to 5.9 GHz omni-directional vertical antenna, a 3dBi Gain.
QTY: 1

VERT900 Antenna - \$ 63.00 USD
782773-01 | VERT900 Vertical Antenna (824-960 MHz, 1710-1990 MHz) Dualband
Includes one VERT900 824 to 960 MHz, 1710 to 1990 MHz Quad-band Cellular/PCS and ISM Band omni-directional vertical antenna, a 3dBi Gain.
QTY: 1

VERT400 Antenna - \$ 110.00 USD
783074-01 | VERT400 Vertical Antenna (144 MHz, 400 MHz, 1200 MHz) Triband
Includes one VERT400 144 MHz, 400 MHz, and 1200 MHz Tri-band omni-directional vertical antenna
QTY: 1

2.4 to 2.48 GHz and 4.9 to 5.9 GHz

3dBi Gain.

824 to 960 MHz, 1710 to 1990 MHz

3dBi

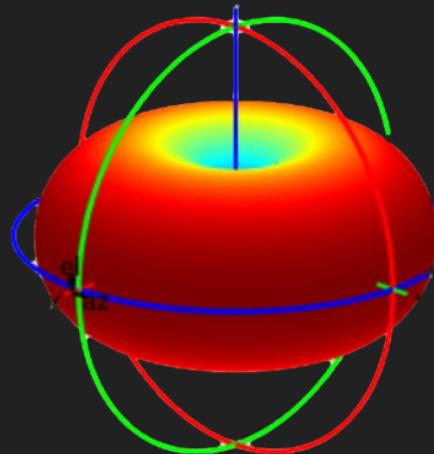
144 MHz, 400 MHz, and 1200 MHz

omni-directional vertical antenna

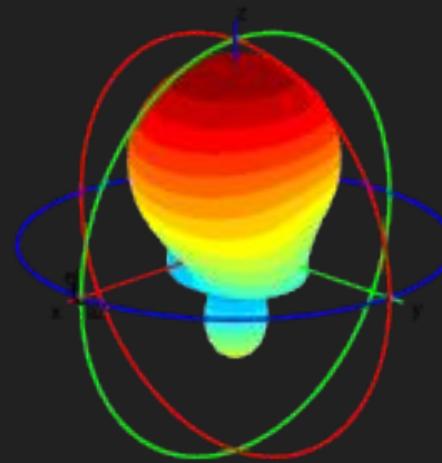


Directivity

Directivity is a ratio between antenna's radiation intensity in a given direction and the radiation intensity averaged over all directions



Omni-Directional

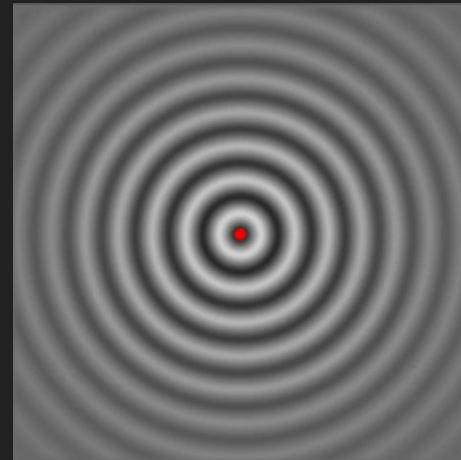


Directional

Antenna Gain

Antenna Gain is a measure of power radiated in a particular direction

| Antenna | Gain |
|-------------------------------|-----------------|
| Loops Dipoles Monopoles | 5 dBi or less |
| Microstrip Patches | 5 dBi to 8 dBi |
| Yagi-Uda Log Periodic | 8 dBi to 15 dBi |
| Horns Reflectors | 15 dBi and more |

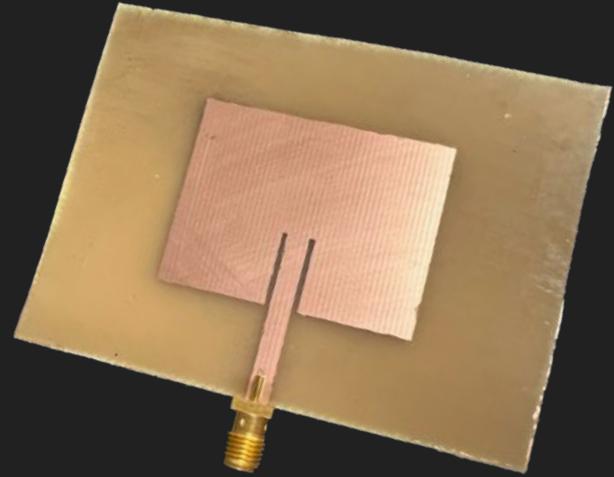
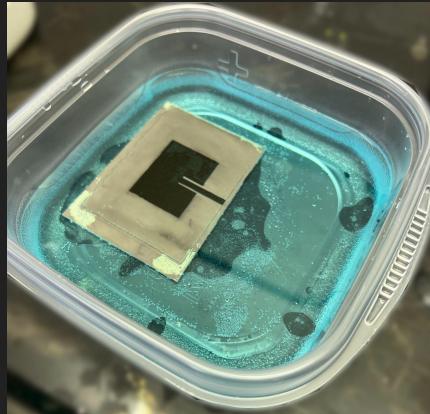
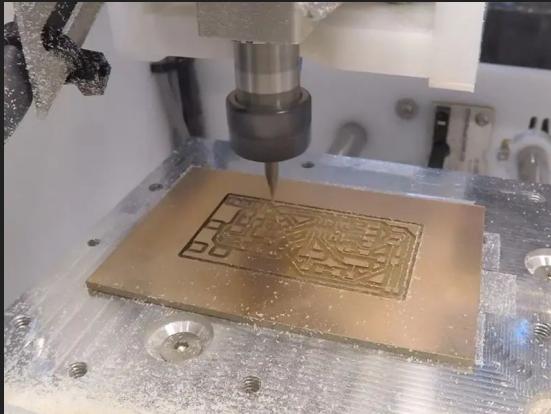


Solution

Design your own rectangular patch antenna

Use the tool from this presentation for measurements

Manufacture it using outlined methods



#whoami

Senior Security Consulting Engineer - Cisco Systems

PhD student - Virginia Commonwealth University

Experience with Reverse Engineering, Exploit Development, Pentesting, TCP/IP Networking, and Software Defined Radios

Certifications: OSCP/OSCE/OSWP/OSWE/OSEE/CCIE EI (#64597)

Part of WhatTheFreq! CTF team

Acknowledgments

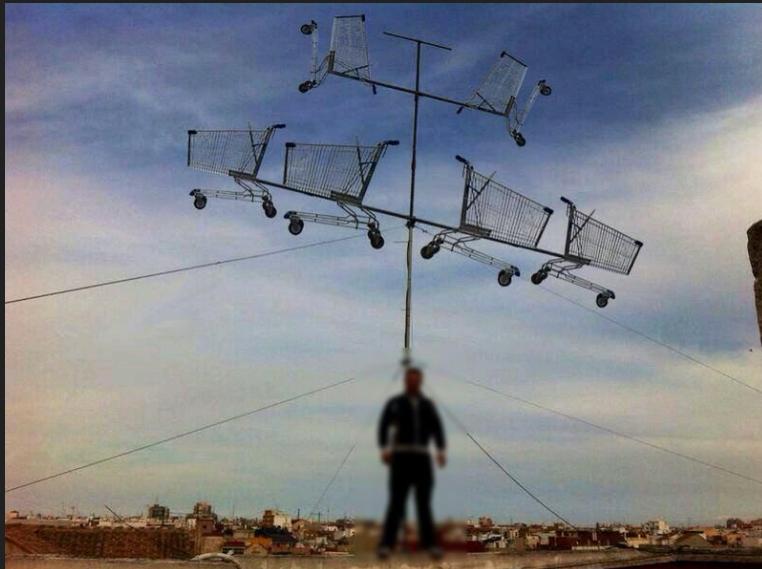
Jonathan Lundquist - PhD student (Virginia Commonwealth University)

Lauren Linkous - PhD student (Virginia Commonwealth University)

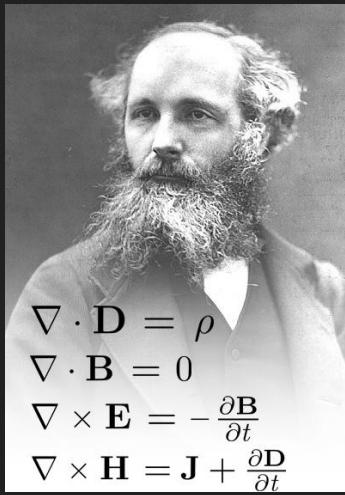
Dr. Erdem Topsakal - PhD advisor (Virginia Commonwealth University)

What's an Antenna?

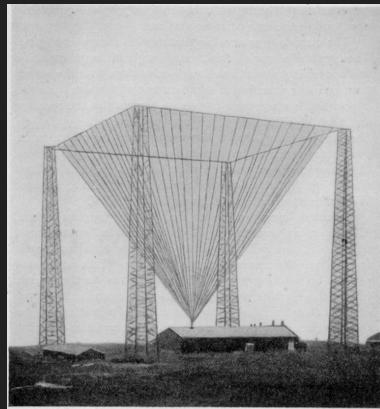
An antenna is a device that is used to efficiently transmit and receive electromagnetic waves.



History of Antennas



1864



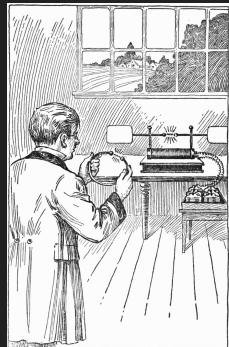
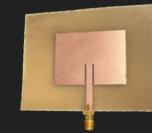
1901



1960s



1970s



1886



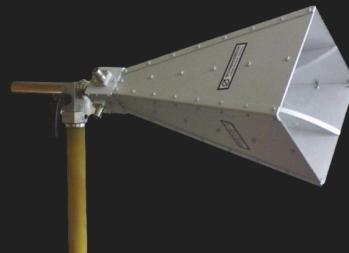
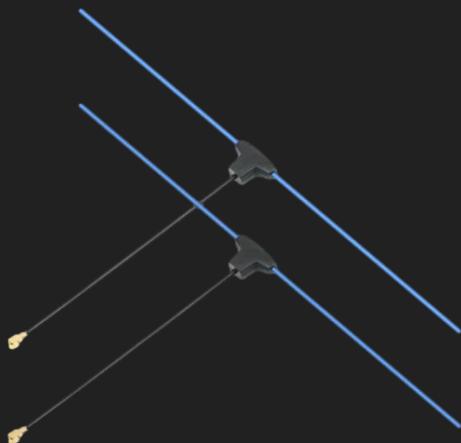
1935



1980s

Common Antenna Types

- Wire antennas
- Microstrip antennas
- Antenna arrays
- Aperture antennas
- Reflector antennas

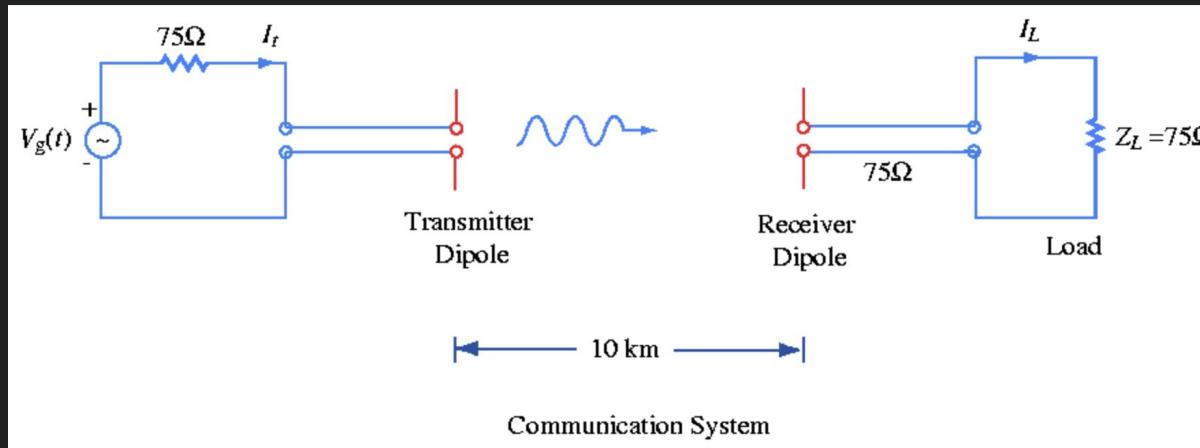


Dipole Antenna Example



Dipoles consist of two equal length conductors fed by a transmission line

The half wave dipole is named such because it is half a wavelength long



$$\lambda = \frac{v}{f}$$

λ = wavelength

v = velocity

f = frequency

Dipole Antenna Example

Designing a Dipole Antenna for local TV

| | | | | |
|--|-------------------------------------|----|-----------------|----------------|
| ● WCVW + 1 subchannel | PBS RICHMOND, VA | 57 | W (15 miles) | UHF 560 Mhz |
|--|-------------------------------------|----|-----------------|----------------|

```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py half_wave_dipole --frequency 560e6 --unit centimeter
[*] Total Dipole Length = 26.79 centimeter
[*] Each Dipole Element Length = 13.39 centimeter
```

```
usage: antenna_calculator.py half_wave_dipole [--help] [--verbose] -f FREQUENCY
                                                [-u {meter,centimeter,millimeter,inch}]
```

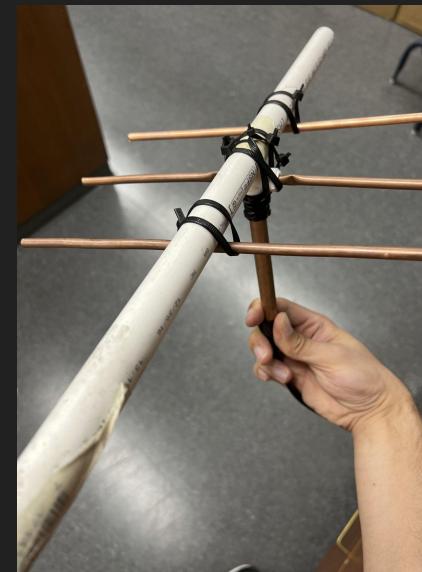
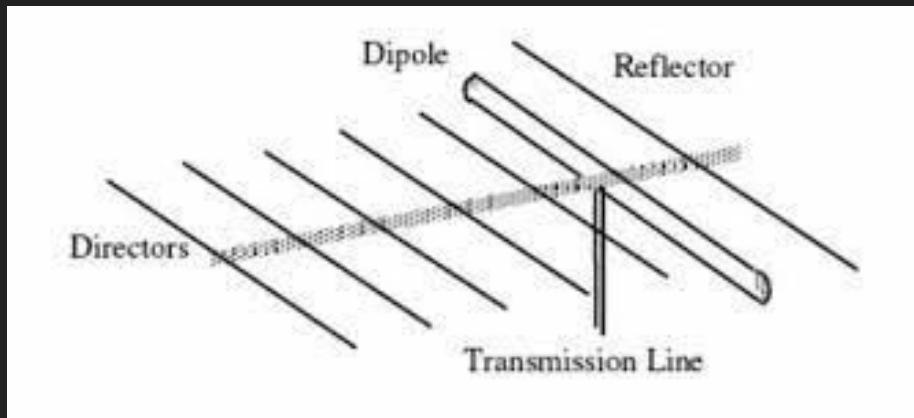
optional arguments:

```
--help            Show this help message and exit
--verbose
-f FREQUENCY, --frequency FREQUENCY
                  Frequency in Hz
-u {meter,centimeter,millimeter,inch}, --unit {meter,centimeter,millimeter,inch}
                  Unit of measurement
```



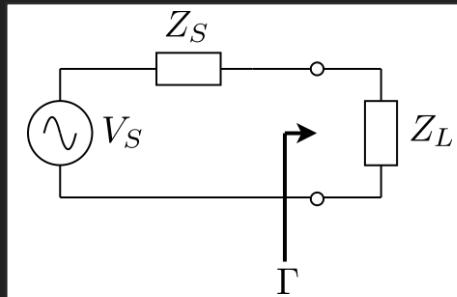
Yagi-Uda Example

Yagi-Uda Antennas are commonly used TV antennas



Reflection Issues

Using Yagi-Uda antenna with SDRs will usually not result in advertised gain



$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Receive crystal clear digital 4K 1080p, 1080i HD broadcast local channel over the air. Built-in upgraded smart chip provides advanced VHF/UHF HD channels. Extended length and multi-element design allows stronger reception. Long range reach up to 200 mile (based on how far away from your local broadcast tower). Superior and durable construction to withstand tough outdoor weather conditions. Can be mounted in attic, roof, chimney, eave, mast or higher place to receive better signal. Easily Assemble required: antenna comes pre-assembled for some parts, fully assemble needed

- Specification
Frequency: VHF:45~230MHz UHF:470~860MHz
Actual Gain: VHF:8dB UHF:12dB
VSWR: VHF:<3dB UHF:<2.5dB
Output Impedance: 75Ω
Transmission Distance: 200+ Miles
- Package Included:
one Antenna
one 40ft cable
one 4-way splitter
one J-pole

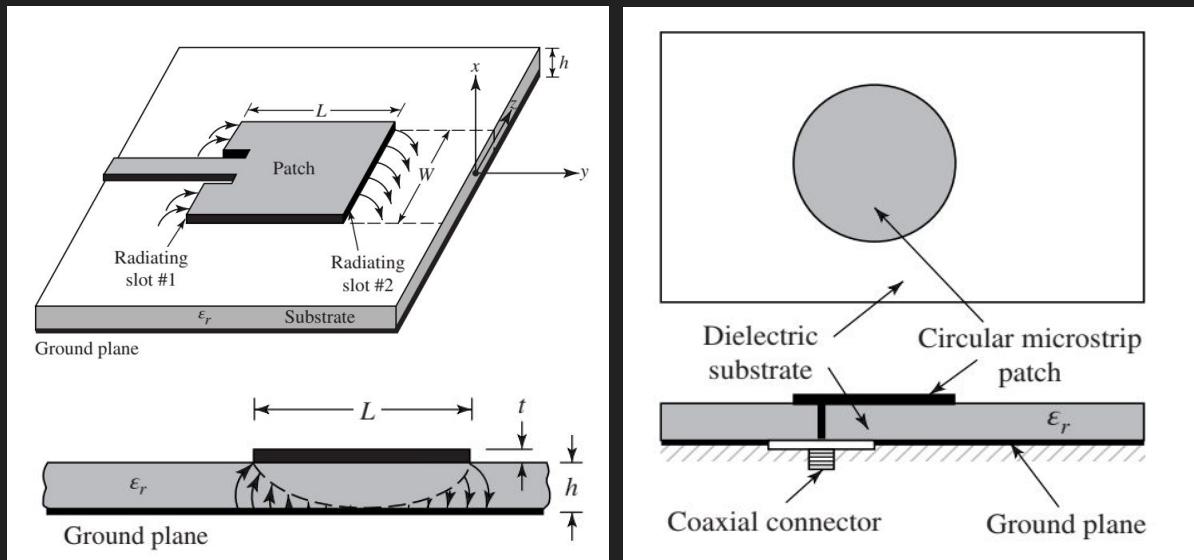
Actual Gain: VHF:8dB UHF:12dB

Output Impedance: 75Ω



Patch Antennas

- High directivity
- High gain
- Low power
- Low profile
- Easy to manufacture



Patch Antenna Math

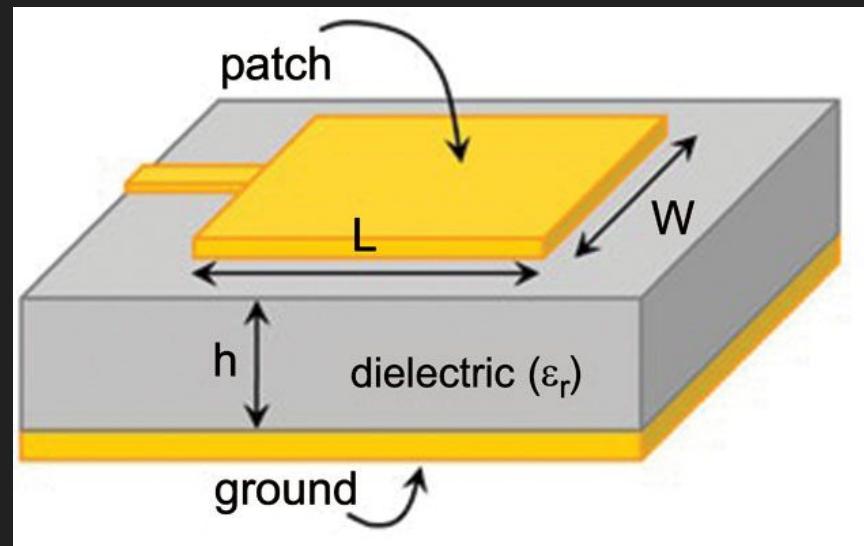
Transmission-Line Model

Given the following:

- Frequency
- Dielectric constant of the substrate
- Height of the substrate

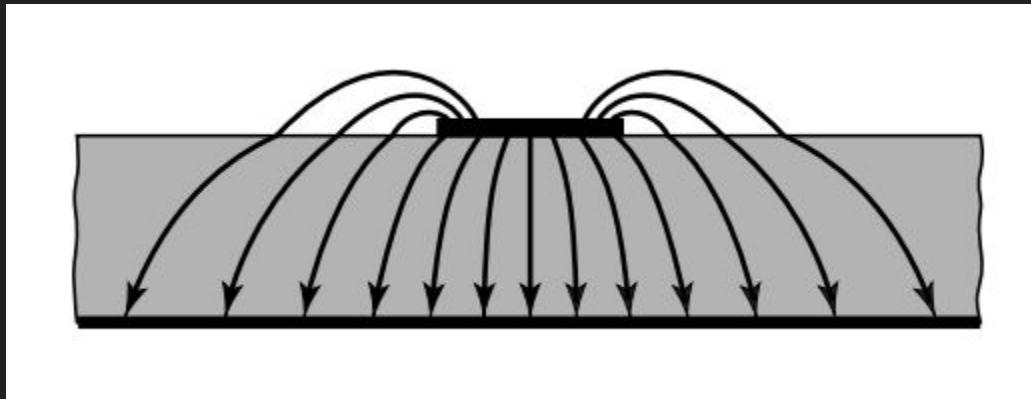
Most commonly used substrate is FR4:

- Dielectric constant of 4.4
- Height of 1.6 mm



Patch Antenna Math

The fields at the edge of the patch undergo fringing



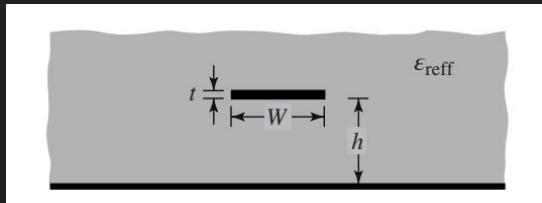
Patch Antenna Math

Width of the patch can be find with following formula

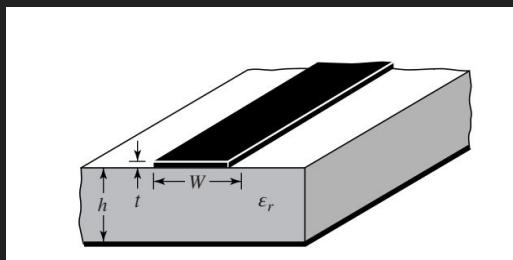
$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}}$$

Patch Antenna Math

Effective Dielectric Constant ϵ_{eff} is the dielectric constant of the uniform dielectric material so that following figure has identical electrical characteristics as actual line



Effective Dielectric Constant

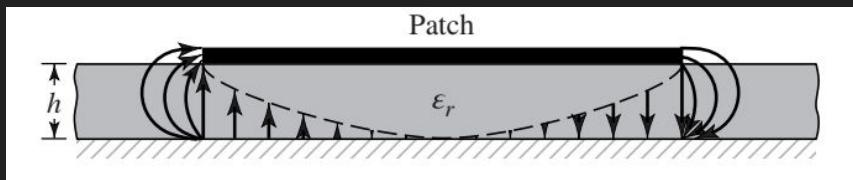
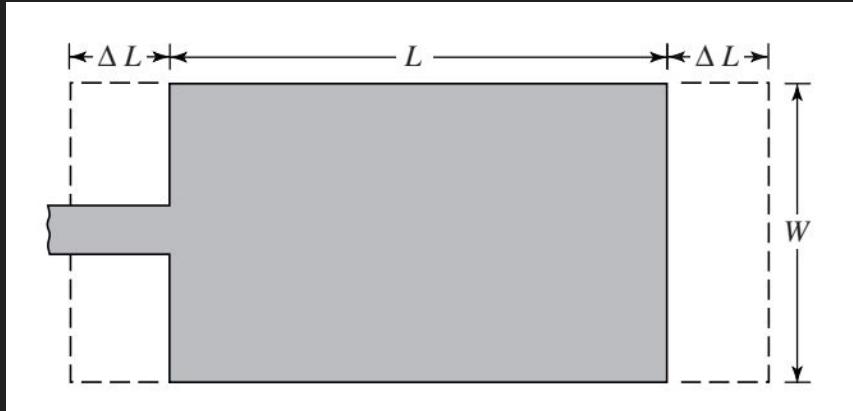


Actual microstrip line

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-1/2}$$

Patch Antenna Math

Due to fringing effects, electrically the patch looks greater than physical dimensions



$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{W}{h} + 0.8 \right)}$$

$$L = \frac{1}{2f_r \sqrt{\epsilon_{\text{reff}}} \sqrt{\mu_0 \epsilon_0}} - 2\Delta L$$

Patch Antenna Math

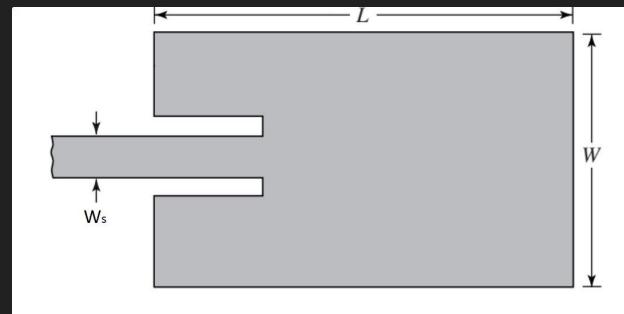
Stripline calculation

If following is satisfied then use that strip width

$$A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left(0.23 + \frac{0.11}{\epsilon_r} \right) \quad \frac{W_s}{d} = \frac{8e^A}{e^{2A} - 2} \text{ if } \frac{W_s}{d} < 2$$

Else use following

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}} \quad \frac{W_s}{d} = \frac{2}{\pi} \left[B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left\{ \ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r} \right\} \right] \text{ if } \frac{W_s}{d} > 2$$



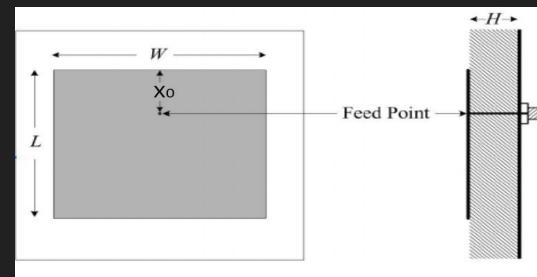
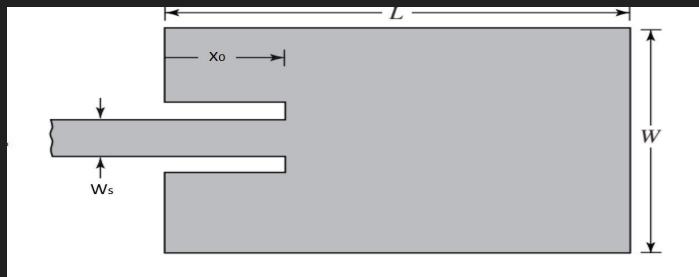
Patch Antenna Math

Inset calculation for both microstrip and probe fed patch antennas

$$Z_{in}(x = 0) = 90 \frac{\epsilon_r^2}{\epsilon_r - 1} \left(\frac{L}{W} \right)^2$$

$$Z_{in}(x = x_0) = Z_{in}(x = 0) \cos^2 \left(\frac{\pi}{L} x_0 \right)$$

$$y_0 = \frac{1}{2}W$$



Automating Patch Antenna Math

```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --help
usage: antenna_calculator.py rectangular_patch [--help] [--verbose] [--type {microstrip,probe}] -f FREQUENCY -er RELATIVE_PERMITTIVITY -h HEIGHT
                                                [-u {meter,centimeter,millimeter,inch}] [-du {meter,centimeter,millimeter,inch}] [--dxfoutput DXFOUTPUT]
                                                [--pngoutput PNGOUTPUT]

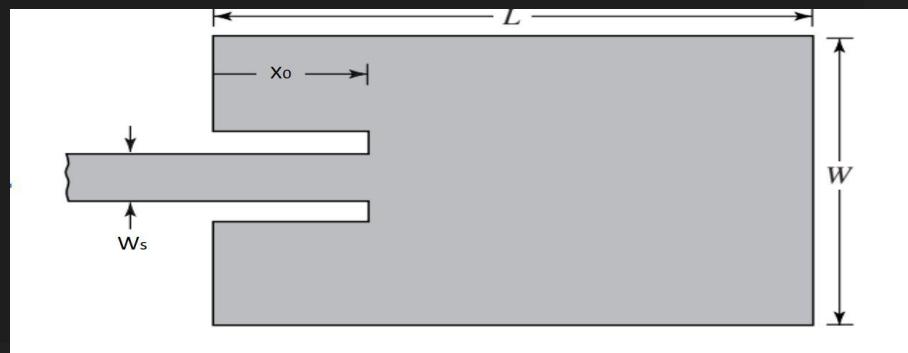
optional arguments:
  --help            Show this help message and exit
  --verbose
  --type {microstrip,probe}
                    Type of patch
  -f FREQUENCY, --frequency FREQUENCY
                    Frequency in Hz
  -er RELATIVE_PERMITTIVITY, --relative_permittivity RELATIVE_PERMITTIVITY
                    Relative permittivity
  -h HEIGHT, --height HEIGHT
                    Substrate height in meters
  -u {meter,centimeter,millimeter,inch}, --unit {meter,centimeter,millimeter,inch}
                    Unit of measurement
  -du {meter,centimeter,millimeter,inch}, --dxfunit {meter,centimeter,millimeter,inch}
                    DXF Unit of measurement
  --dxfoutput DXFOUTPUT
                    Name of DXF file
  --pngoutput PNGOUTPUT
                    Name of PNG image for printing
```

Automating Patch Antenna Math

Example 2.4 GHz antenna with FR4

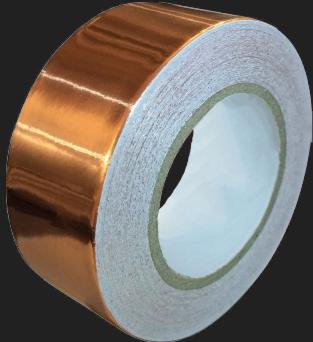
```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type microstrip -f 2.4e9 -er 4.4 -h 1.6e-3
[*] W = 38.04 millimeter
[*] L = 29.44 millimeter
[*] Ws = 3.06 millimeter
[*] y0 = 19.02 millimeter
[*] x0 = 11.32 millimeter
```

```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type microstrip -f 2.4e9 -er 4.4 -h 1.6e-3 --verbose
{'subparser_name': 'rectangular_patch', 'verbose': True, 'type': 'microstrip', 'frequency': 2400000000.0, 'relative_permittivity': 4.4, 'height': 0.0016, 'unit': None, 'dxffunit': None, 'dxfoutput': 'patch.dxf', 'pngoutput': 'patch.png'}
[*] W = 38.04 millimeter
[*] Ereff = 4.09
[*] dL = 738.82 micrometer
[*] Leff = 30.92 millimeter
[*] L = 29.44 millimeter
[*] A = 1.529861949318471
[*] A Ws/d = 1.9118593643297774
[*] A is valid
[*] Ws = 3.06 millimeter
[*] y0 = 0.01901814435781827
[*] y0 = 19.02 millimeter
[*] Zin_0 = 396.6828700137873
[*] Zin_x0 = 50
[*] x0 = 0.01131973828663886
[*] x0 = 11.32 millimeter
```



Manufacturing Patch Antennas

- Copper tape
- Chemical etching
- PCB milling
- Computer numerical control (CNC) method
- Professional fabrication



Copper Tape

Materials needed:

- Copper Tape
- Single Sided FR-4
- SMA Connector

[« Back to results](#)



Roll over image to zoom in

 **Copper Tape Conductive Adhesive [1 Inch x 66ft] Copper Foil Tape for EMI Shielding Barrier, Guitar Cavity, Electrical Conductive for Soldering, Stained Glass, and More**

Visit the Kraftex Store

★★★★★ 3,436 ratings

Price: **\$12.99** Get Fast, Free Shipping with Amazon Prime & FREE Returns

Get \$50 off instantly: Pay \$0.00 \$42.99 upon approval for the Amazon Rewards Visa Card. No annual fee.

| Brand | Kraftex |
|---------------------|---------------|
| Material | Vinyl, Copper |
| Number of Items | 1 |
| Compatible Material | Glass, Paper |

About this item

• Strong Adhesive - Here is our copper conductive tape [1inch, 66ft], with super sticky adhesive, and protective backing for long-lasting use. The best copper shielding tape on the market; handy for many





Roll over image to zoom in

 **wlaniot 10pcs SMA Female PCB Panel Edge Mount Connector Straight Solder RF Coaxial Adapter Vertical Thru Hole Goldplated**

Visit the wlaniot Store

★★★★★ 79 ratings

\$9.99

Get Fast, Free Shipping with Amazon Prime & FREE Returns

Get \$50 off instantly: Pay \$0.00 \$9.99 upon approval for the Amazon Rewards Visa Card. No annual fee.

Color: SMA Edge Mount

| Color | Price |
|-------|--------|
| Gold | \$9.99 |
| Black | \$7.99 |

Type: SMA Connector PCB sma female mount connector, End Launch PCB Mount .062" (1.57mm) [Pin-to-Skin] **Impedance:** 50 Ohm **Body Material:** Brass **Attachment Method:** PCB Mount Solder, Frequency Range: 3GHz **The interface dimensions and technical characteristics are in accord with the specifications of MIL-C-39012, IEC 169-15 and CECC 22.210.** **The sma pcb connector edge mount worked for Nano VNA board, PCB antenna base stations antennas PC/LAN, wireless modules, wireless devices, equipments and ground transmission system in vibratory and harsh environment etc.** **Never worry about quality security problems. We are confident in the quality of our sma pcb connector and willing to provide 1MONTHS Replacement Warranty and 100% Satisfaction Guarantee. If you unfortunately get a defective one, please contact our customer support.**

[« Back to results](#)



Roll over image to zoom in

 **MCIGICM FR-4 Copper Clad PCB Laminate Circuit Board, Single Side, 4 x 2.7 inch (10Pcs)**

Visit the MCIGICM Store

★★★★★ 401 ratings | 7 answered questions

\$6.99

Get Fast, Free Shipping with Amazon Prime & FREE Returns

| Material | Copper/Glass |
|-----------------|---------------------------|
| Brand | MCIGICM |
| Item Weight | 0.14 Kilograms |
| Item Dimensions | 3.94 x 0.39 x 4.72 inches |
| LxWxH | |

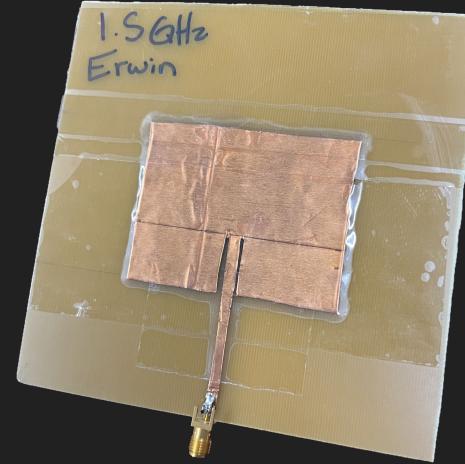
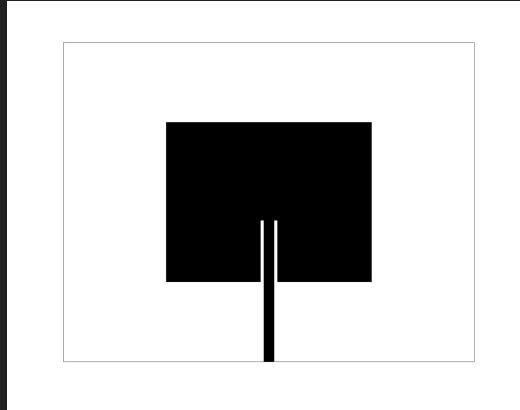
About this item

• This Copper Clad Plated Printed Board is designed for Etch Etching Project. Single Sided (SS) Blank Copper on the Front, FR4 Bakelite on the Back.10 cm x 10 cm - 2.7" x 4" (WxL), 1.6mm - 0.062" Thickness, Weight 1.4g - 0.5oz. Each 10 pieces epoxy Resin 4 x 2.7 inch **Packed with Moisture Protecting Bag to Prevent Copper Rust. 10pcs Bare Boards Kit Delivered in their Best Condition.** **Single-Sided Cuttable Fiber Glass and FR-4 Flame Resistant Good for Etch, Electrical, Power DIY IoT prototyping proto Projects.**

Copper Tape

Use the printout as a template to help cut the tape

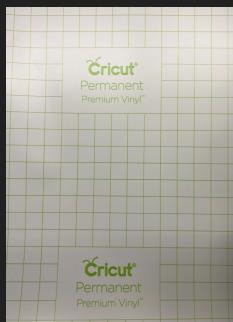
```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type microstrip -f 1.5e9 -er 4.4 -h 1.6e-3 --pngoutput 1_5_FR4_
microstrip.png
[*] W = 60.86 millimeter
[*] L = 47.41 millimeter
[*] Ws = 3.06 millimeter
[*] y0 = 30.43 millimeter
[*] x0 = 18.25 millimeter
```



Chemical Etching

Materials needed:

- Muriatic Acid (HCl)
- Hydrogen Peroxide (H_2O_2)
- Double Sided FR-4
- SMA Connector
- Iron
- Laser Printer
- Vinyl Backing
- Nail Polish (optional)
- Thermometer/FLIR camera (optional)



wlaniot 10pcs SMA Female PCB Panel Edge Mount Connector Straight Solder RF Coaxial Adapter Vertical Thru Hole Goldplated

Visit the wlaniot Store

4.5 stars - 79 ratings

\$1.99

Get Fast, Free Shipping with Amazon Prime & FREE Returns

Get \$50 off instantly: Pay \$0.00 ~~\$9.99~~ upon approval for the Amazon Rewards Visa Card. No annual fee.

Color: SMA Edge Mount

\$1.99 \$1.99

Type: SMA Connector PCB sma female mount connector, End Launch PCB Mount .062" (1.57mm) IPackage: 10pcs SMA female connectors

- Impedance:50, Body Material: Brass, Attachment Method: PCB Mount Solder, Frequency Range:3GHz
- The interface dimensions and technical characteristics are in accord with the specifications of MIL-C-39012, IEC 169-15 and ECEC 22110.
- This product has been widely worked for Nano VNA board, PCB antenna, base stations antennas PC/LAN, wireless modules, wireless devices, equipments and ground transmission system in vibratory and harsh conditions etc.
- Never worry about any security problems. We are confident in the quality of our sma pcb connector and willing to provide 1 MONTHS Replacement Warranty and 100% Satisfaction Guarantee. If you unfortunately get a defective one, please contact our customer support.



Heyarbeit Double-Sided Copper Clad Laminate PCB Circuit Board, FR4 300x200mm 11.81x7.87 inch, 1.6mm Thickness DIY Prototyping PCB Board, Name Board, 1pcs

\$16.99

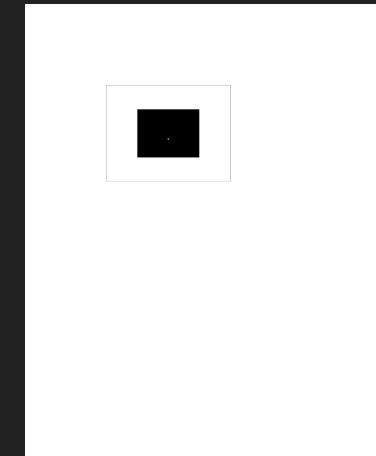
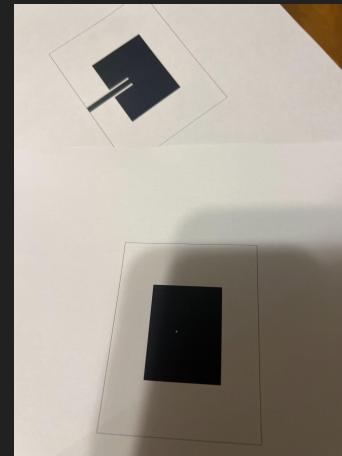
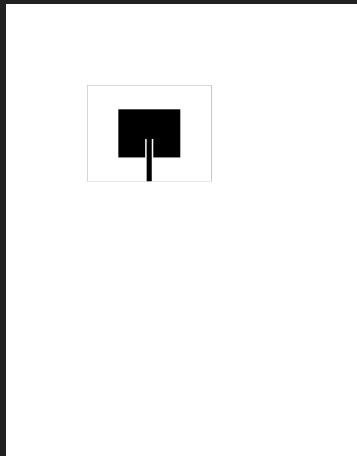
Size: 300x200x1.6mm 1pcs

| | | |
|--------------------|--------------------|--------------------|
| 150x100x1.5mm 1pcs | 150x150x1.5mm 1pcs | 180x120x1.5mm 1pcs |
| 200x150x1.5mm 1pcs | 200x200x1.5mm 1pcs | 230x150x1.5mm 2pcs |
| 250x130x1.5mm 1pc | 250x130x1.5mm 3pcs | 300x200x1.6mm 1pc |
| 400x300x1.6mm 1pc | | |

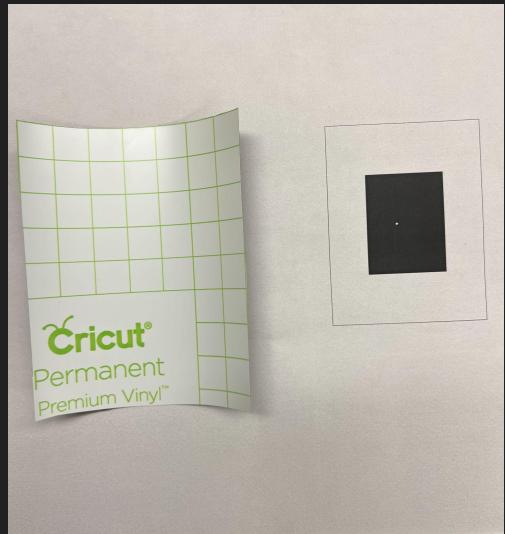
- [Dimension] - Size 300 x 200mm / 11.81" x 7.87 "L*W"; Thickness(approx.) : 1.6mm / 0.06"
- [Material] - PCB circuit board is made of glass fiber FR4 material, which has the characteristics of high strength, good plasticity, not easy to bend, good conductivity, smooth surface and durable
- [Feature] - PCB circuit board has good mechanical and dielectric properties, good heat resistance and moisture resistance, low loss, good conductivity and excellent processing performance, high strength and excellent high-temperature bending strength
- [Application] - PCB circuit boards are very suitable for making PCB circuit boards and models; Widely used in DIY solder, product development, DIY experiments, maintenance, production, etc
- [Note1] - The oxide layer on the surface of the copper-clad laminate needs to be polished clean with fine sandpaper to ensure that the carbon powder can be firmly printed on the copper-clad laminate during transfer; The surface of the board should be polished bright without obvious stains
- [See more product details](#)

Chemical Etching

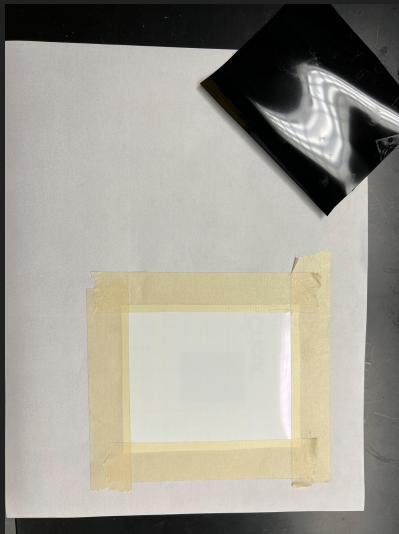
```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type microstrip -f 2.4e9 -er 4.4 -h 1.6e-3 --pngoutput 2_4_FR4_
microstrip.png
[*] W = 38.04 millimeter
[*] L = 29.44 millimeter
[*] Ws = 3.06 millimeter
[*] y0 = 19.02 millimeter
[*] x0 = 11.32 millimeter
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type probe -f 2.4e9 -er 4.4 -h 1.6e-3 --pngoutput 2_4_FR4_probe
.png
[*] W = 38.04 millimeter
[*] L = 29.44 millimeter
[*] y0 = 19.02 millimeter
[*] x0 = 11.32 millimeter
```



Chemical Etching



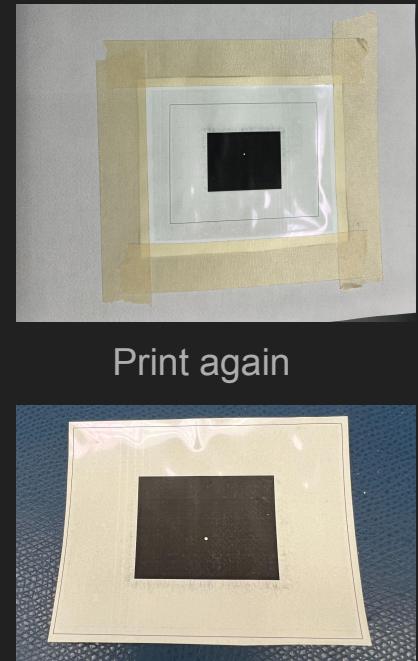
Print on regular paper



Attach vinyl backing
glossy side up



Place paper back in
the printer's input tray



Trim excess backing

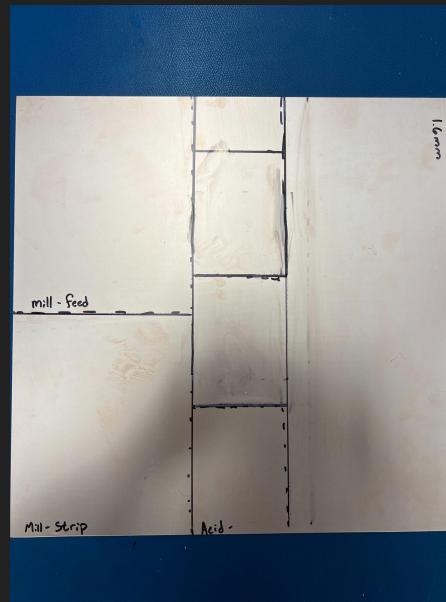
Chemical Etching



Double-sided FR-4



Measure the thickness



Measure cuts



Cut

Chemical Etching

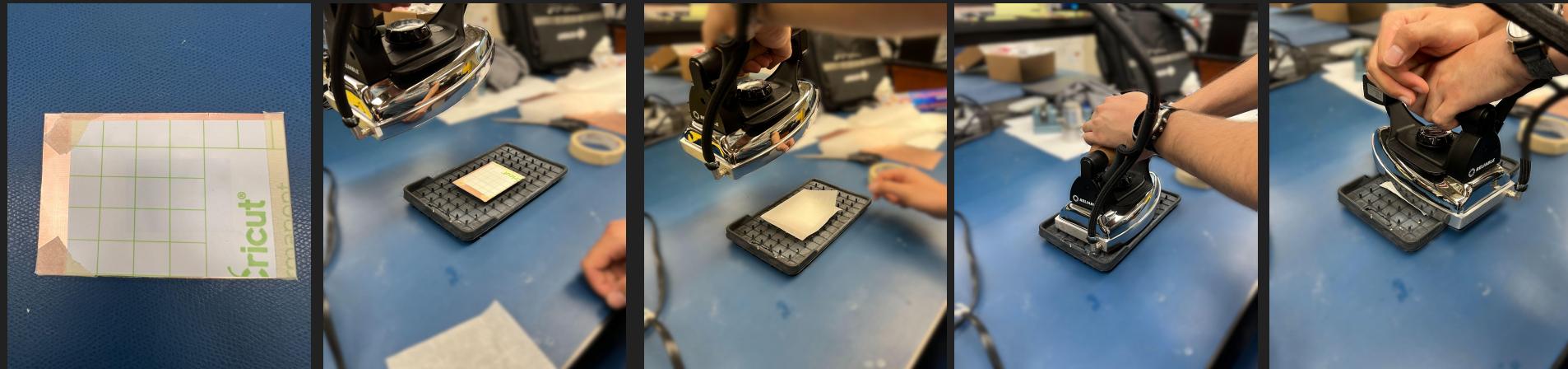


Turn on the iron



It should be between 140-158 °C

Chemical Etching



Tape the printed
patch to FR-4

Place it under the
iron

Place parchment
(baking) paper on top

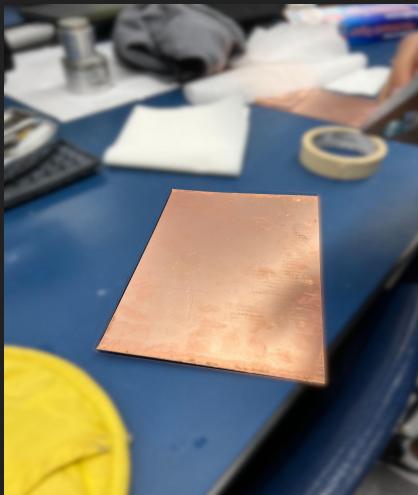
Iron for about 2-3
min

Move the iron
around

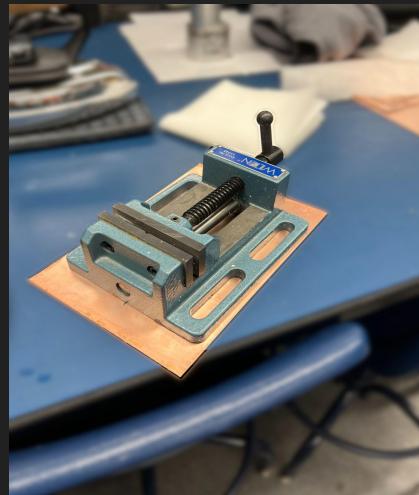
Chemical Etching



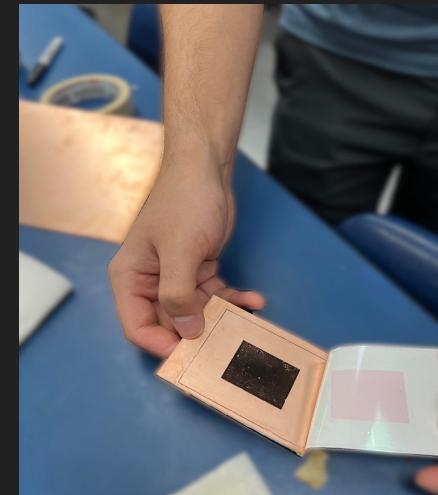
Remove the iron



Add a flat surface

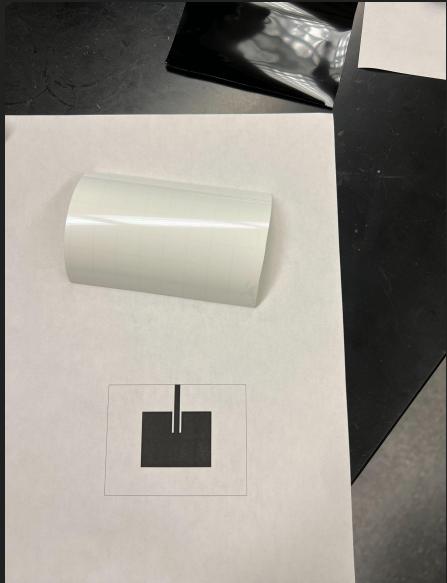


Place a heavy weight

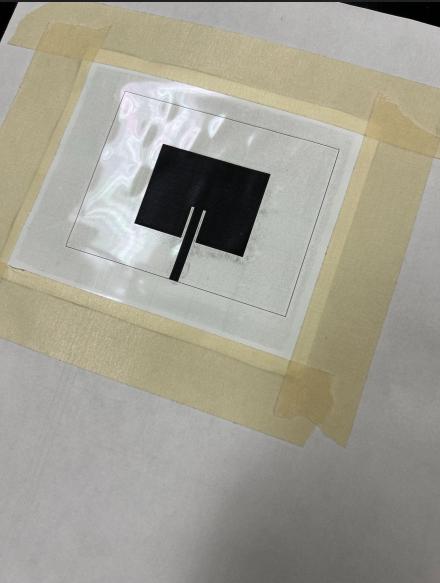


Peel the vinyl

Chemical Etching



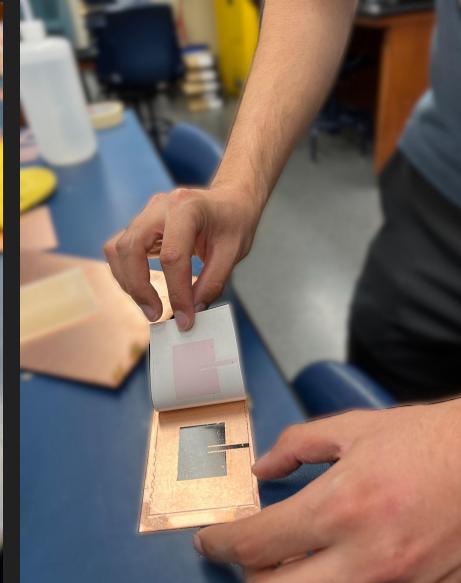
Attach vinyl backing



Print

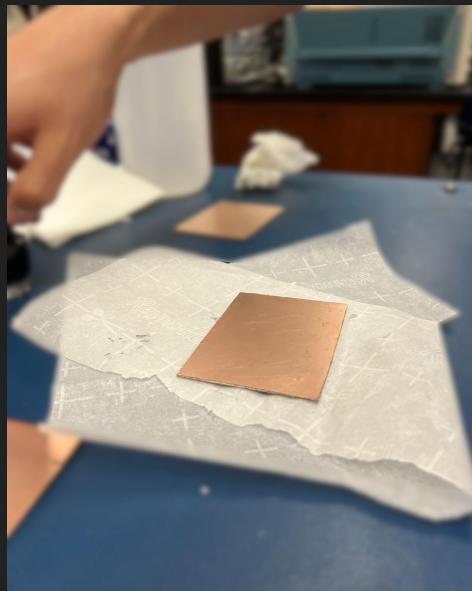


Iron



Done

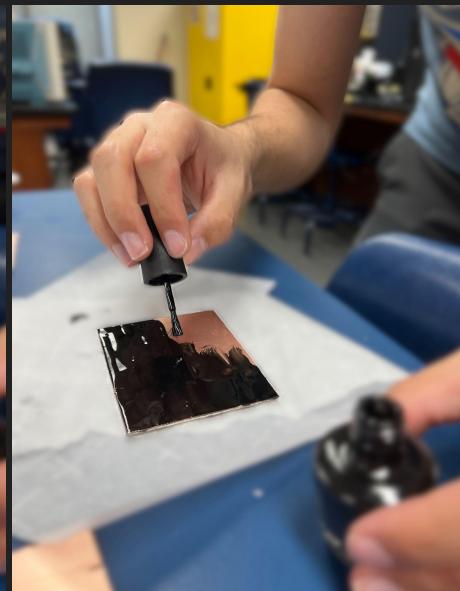
Chemical Etching



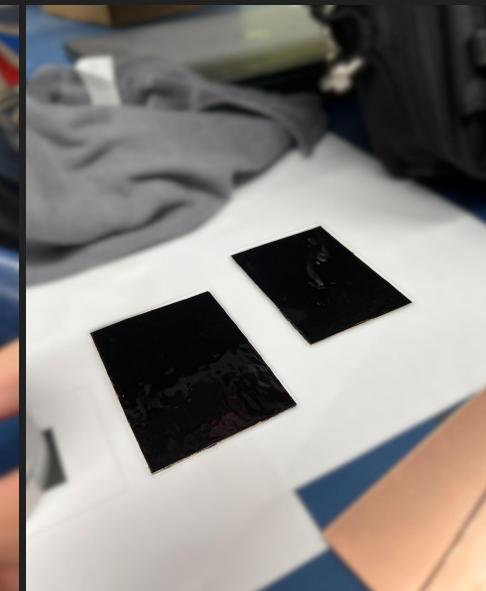
Turn the patch to the
other side



Apply a coating



Apply a coating



Let it dry

Chemical Etching

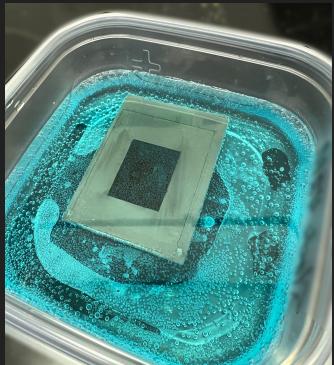
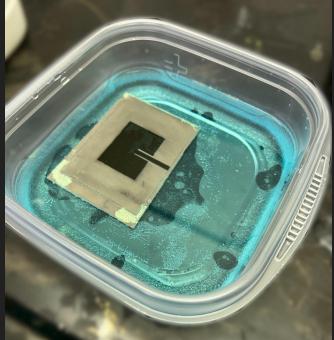


1x Muriatic Acid (HCl)



2x Hydrogen Peroxide (H₂O₂)

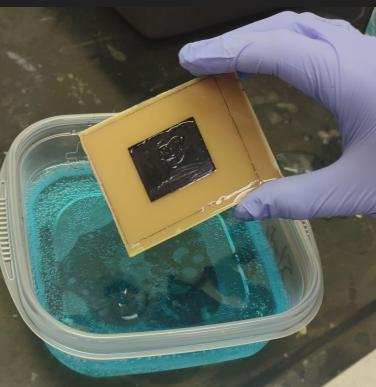
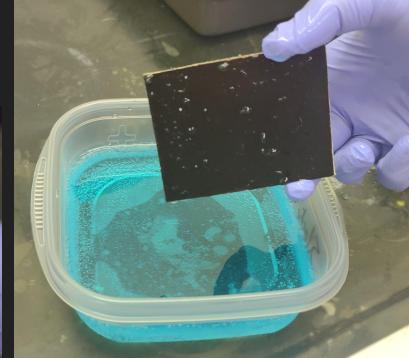
Chemical Etching



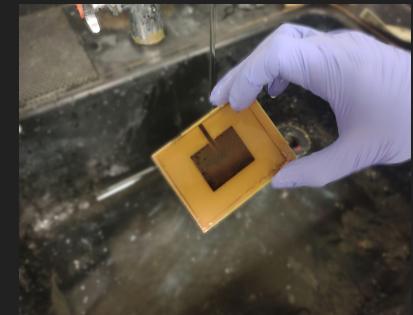
Start the process



Acid removing the
copper

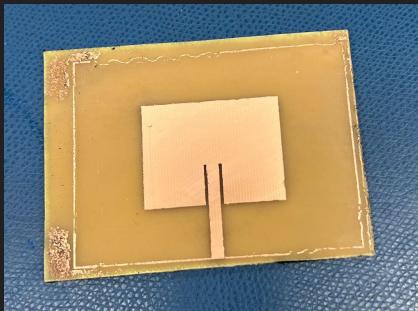


Copper removed



Rinse with water

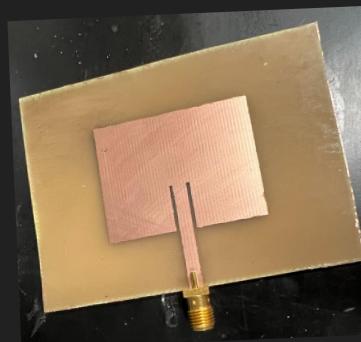
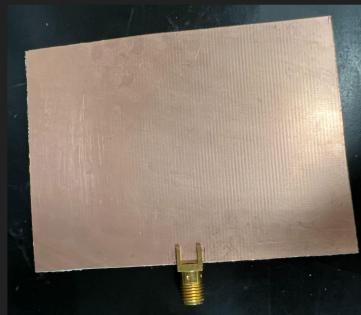
Chemical Etching



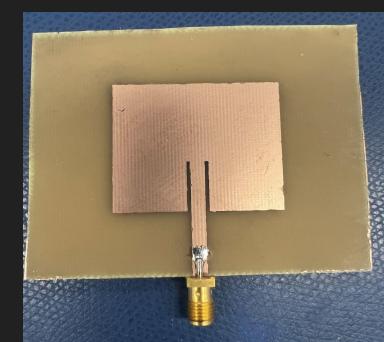
Clean using acetone



Cut SMA connector legs

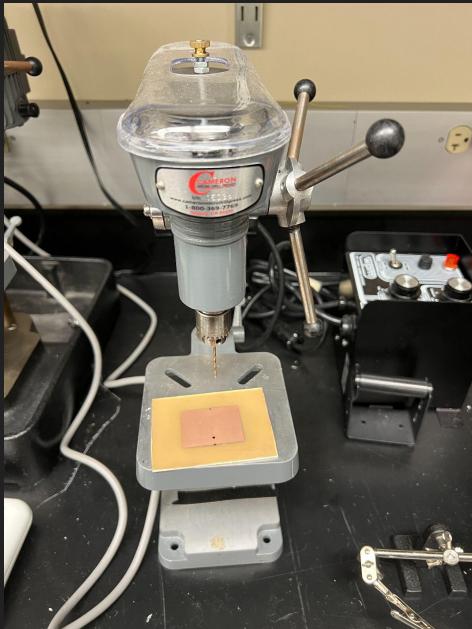


Attach SMA connector

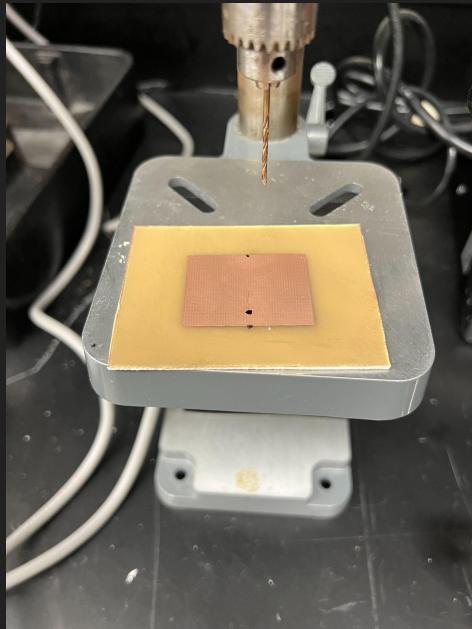


Solder the pin

Chemical Etching



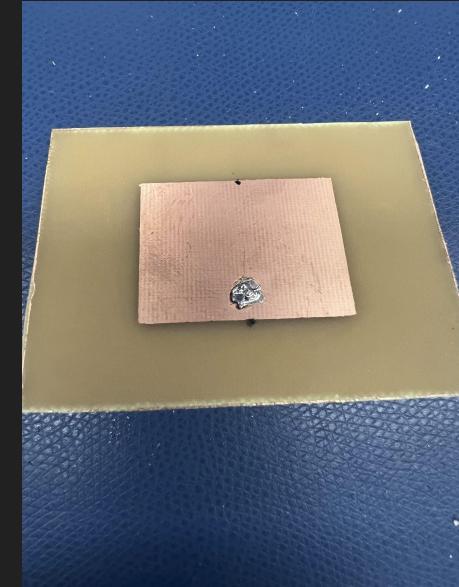
Position thin drill bit carefully



Drill the hole



Solder on both sides

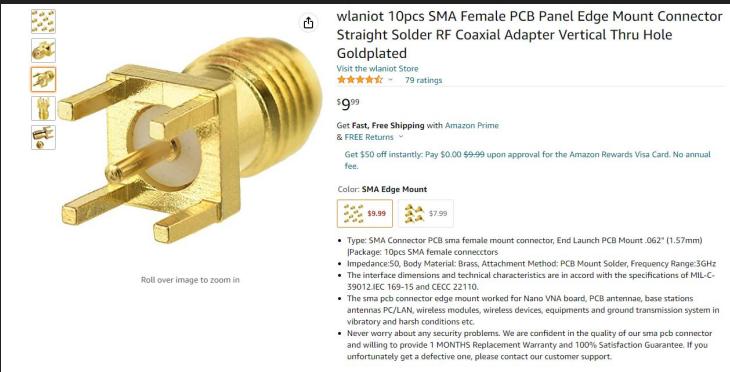


Cut the top of the pin

PCB milling

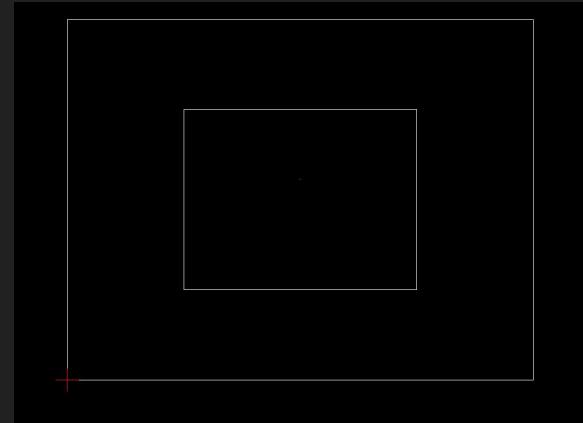
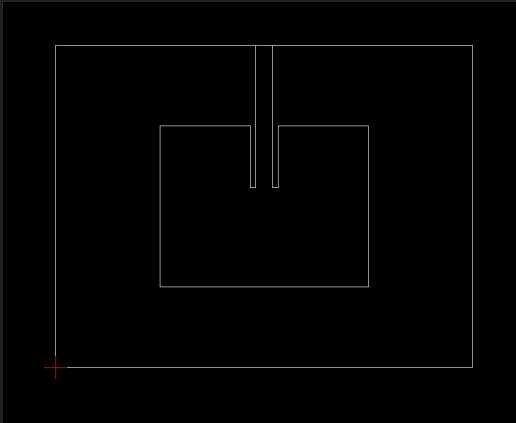
Materials needed:

- PCB Prototyping Machine
- Double Sided FR-4
- SMA Connector

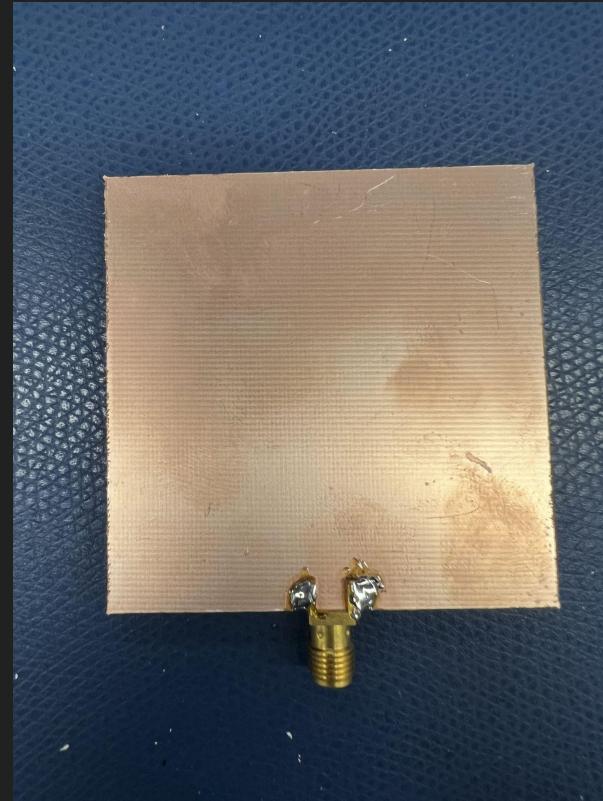
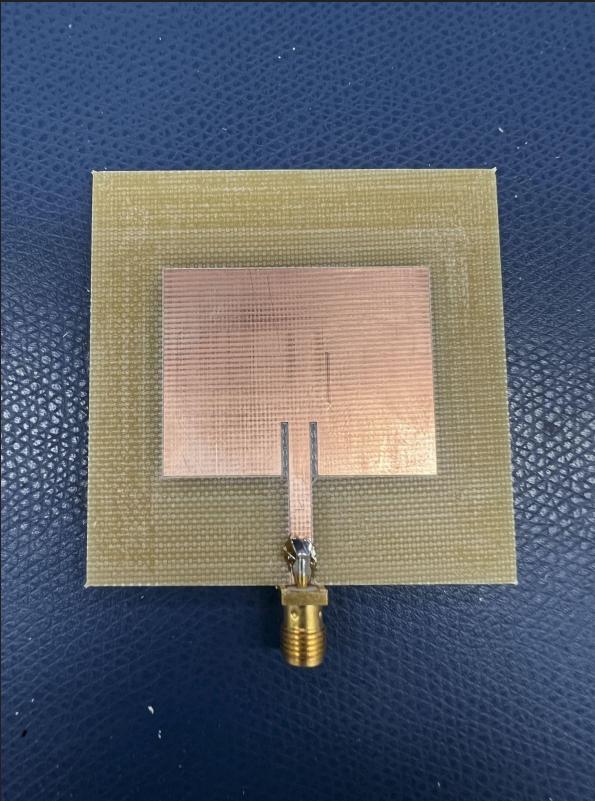


PCB milling

```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type microstrip -f 2.4e9 -er 4.4 -h 1.6e-3 --dxunit millimeter  
--dxfoutput 2_4_FR4_microstrip_mm.dxf  
[*] W = 38.04 millimeter  
[*] L = 29.44 millimeter  
[*] Ws = 3.06 millimeter  
[*] y0 = 19.02 millimeter  
[*] x0 = 11.32 millimeter  
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type probe -f 2.4e9 -er 4.4 -h 1.6e-3 --dxunit millimeter --dx  
foutput 2_4_FR4_probe_mm.dxf  
[*] W = 38.04 millimeter  
[*] L = 29.44 millimeter  
[*] y0 = 19.02 millimeter  
[*] x0 = 11.32 millimeter
```



PCB milling



CNC Method

Materials needed:

- CNC Machine
- Double Sided FR-4
- SMA Connector

Inventables X-Carve 1000mm CNC Machine

[Home](#) / [Store](#) / [CNC Machines](#) / [Inventables X-Carve 3D Carvers](#)



The X Carve 1000mm from Inventables is a desktop CNC Machine powered by the Makita Variable Speed Compact Router (RT0701C). Capable of cutting your designs from wood, plastic, and soft metals. Compatible with 1/8" and 1/4" router bits, the X-Carve 1000mm is ready to tackle your next project.

Top Inventables X-Carve 1000mm features:

- 3x Faster carving than the Previous Generation X-Carve
- Makita Compact Router delivers powerful performance and precision
- More clamping options than ever before
- Nearly double the carvable volume of the previous X-Carve model

Tagged: CNC Machines, inventables CNC Machines and Inventables CNC Machines

Product No. M-MY5-K70W

Available Add-ons (4)

- Inventables X-Carve Makita Spindle Mount
(Out of stock) Price: \$35.00 [View Addon >](#)
- Makita Precision Collet - 1/8"
Price: \$25.00 [View Addon >](#)
- CLEARANCE - Project Wood - Finished Walnut Board - 6" x 11" x 1/2"
Price: \$27.75 [View Addon >](#)

[SHOW MORE ADD-ONS](#)

Price: \$2,599.00

Availability: In Stock

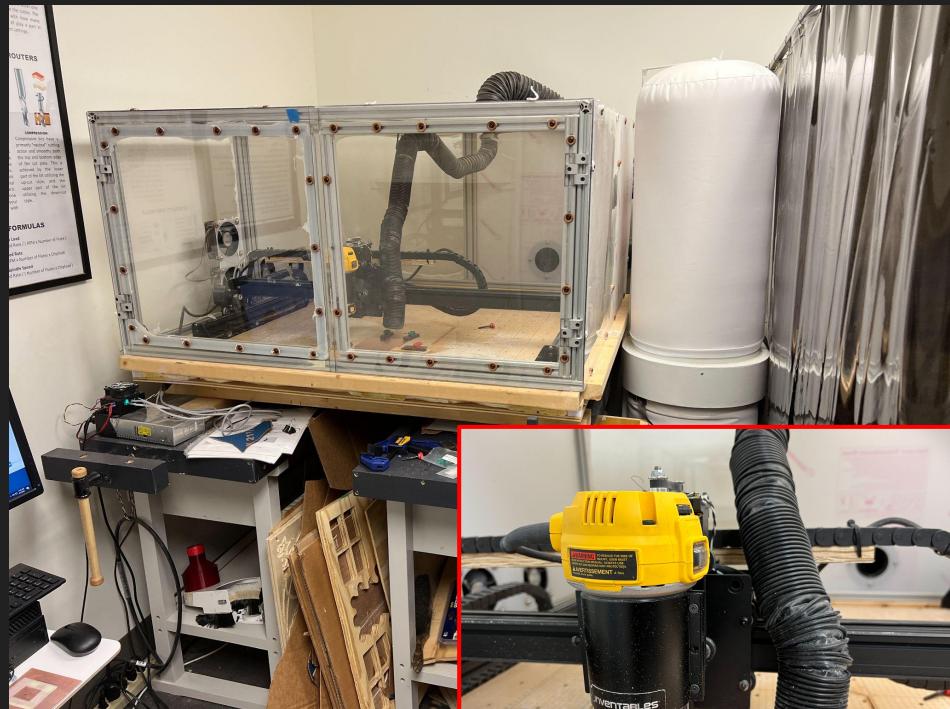
Order Now: Ships Tomorrow  Free U.S. Shipping

Qty: 1 [ADD TO CART](#)

INVENTABLES X-CARVE 1000MM

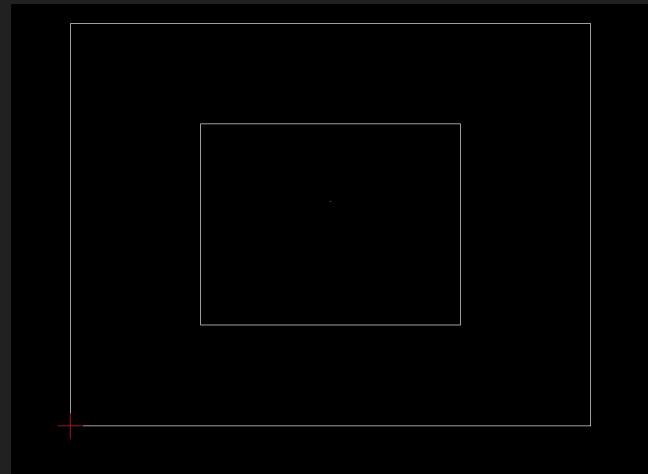
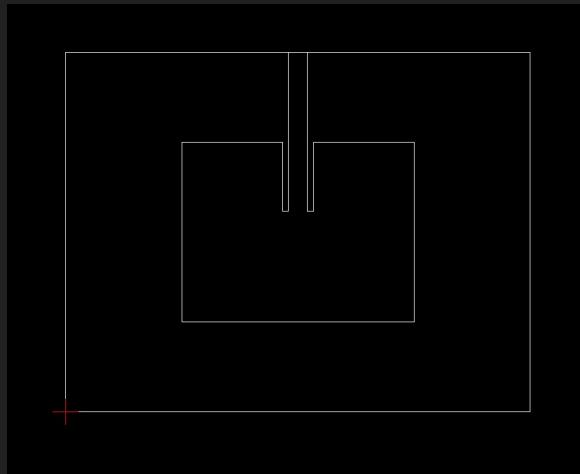
FASTER, MORE RIGID, AND MORE ACCURATE THAN EVER

The Inventables X-Carve is a reliable, customizable, and expandable CNC machine that is ideal for entrepreneurs and small businesses alike. Its new and improved model is 3X Faster, More Rigid, and more accurate than the original X-Carve. Powered by the Makita Variable Speed Compact Router (RT0701C) and Supported by Inventables Easel Pro Design Software, X-Carve is capable of cutting your designs from



CNC Method

```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type microstrip -f 2.4e9 -er 4.4 -h 1.6e-3 --dxfout unit inch --dxf
output 2_4_FR4_microstrip_inch.dxf
[*] W = 38.04 millimeter
[*] L = 29.44 millimeter
[*] Ws = 3.06 millimeter
[*] y0 = 19.02 millimeter
[*] x0 = 11.32 millimeter
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type probe -f 2.4e9 -er 4.4 -h 1.6e-3 --dxfout unit inch --dxfoutpu
t 2_4_FR4_probe_inch.dxf
[*] W = 38.04 millimeter
[*] L = 29.44 millimeter
[*] y0 = 19.02 millimeter
[*] x0 = 11.32 millimeter
```



Professional Fabrication

Common file formats:

- KiCAD
- EagleCAD
- Gerber

Let's get started!

Drag and drop your KiCAD, EagleCAD, or zipped Gerber files

The image shows a screenshot of the OSH PARK website. At the top, there is a navigation bar with links for "OSHPARK", "ABOUT US", "SERVICES", "SUPPORT", "SHARING", and "LOG IN". Below the navigation bar, a purple header banner reads "All fabrication services". A large red rectangular box highlights the text "3 copies for \$5/square inch". The main content area displays four service options: "Prototype", "After Dark", "Super Swift", and "4 Layer". Each service has a corresponding icon and a brief description. A dashed red arrow points from the highlighted text in the purple banner down to the "3 copies for \$5/square inch" text in the "Prototype" service description.

OSHPARK ABOUT US SERVICES SUPPORT SHARING LOG IN

All fabrication services

We produce high quality boards in production. All our services come with Gold (ENIG) finish. These are

3 copies for \$5/square inch

Prototype
Our classic 1.6mm PCB service
3 copies for \$5/square inch
ships in 9-12 days

After Dark
Black substrate and clear mask
3 copies for \$5/square inch
ships in 12-21 days

Super Swift
Our prototype boards, but faster
3 copies for \$10/square inch
ships in 4-5 business days

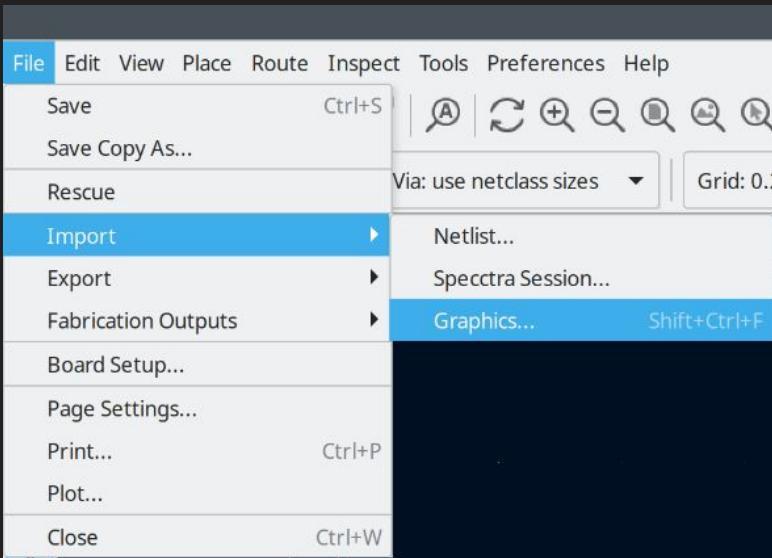
4 Layer
More layers and improved RF
3 copies for \$10/square inch
ships in 9-14 days

Professional Fabrication

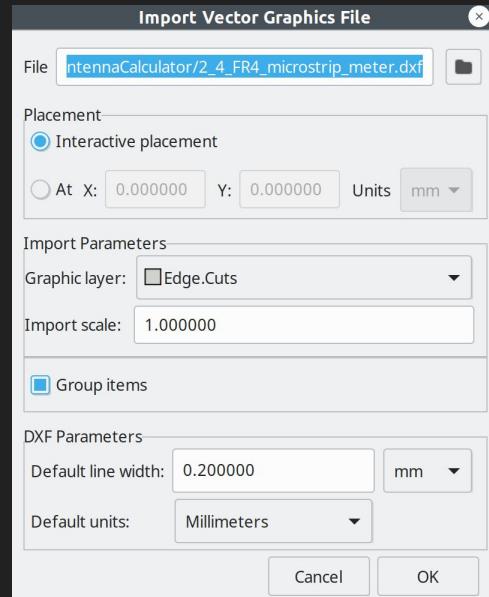
- Currently not supported direct export
- Planned in future releases
- Workaround: DXF file can be converted
 - KiCAD 6 PCB Editor allows DXF import
 - It can be exported as KiCAD file or Gerber

```
dollarhyde@ops:~/VCU/AntennaCalculator$ python3 antenna_calculator.py rectangular_patch --type microstrip -f 2.4e9 -er 4.4 -h 1.6e-3 --dxfout unit meter --dx
foutput 2_4_FR4_microstrip_meter.dxf
[*] W = 38.04 millimeter
[*] L = 29.44 millimeter
[*] Ws = 3.06 millimeter
[*] y0 = 19.02 millimeter
[*] x0 = 11.32 millimeter
```

Professional Fabrication



Import Graphics

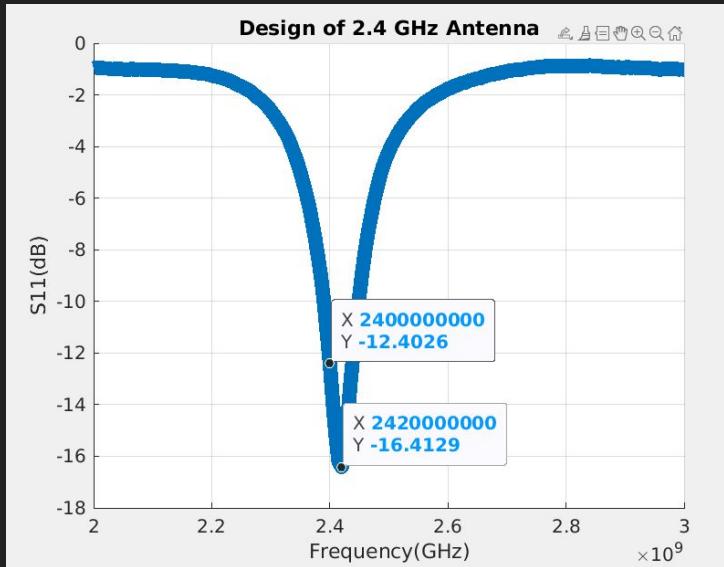


Import dxf with mm settings



Confirm the size is accurate

Measurements



S11 measured



Gain measured - 5.12 dBi

Measurements

Calculate the Power Received by the Receiver

Transmit Power (P_t)

 dBm

Transmit Antenna Gain (G_t)

 dBi

Receive Antenna Gain (G_r)

 dBi

Wavelength

 meter

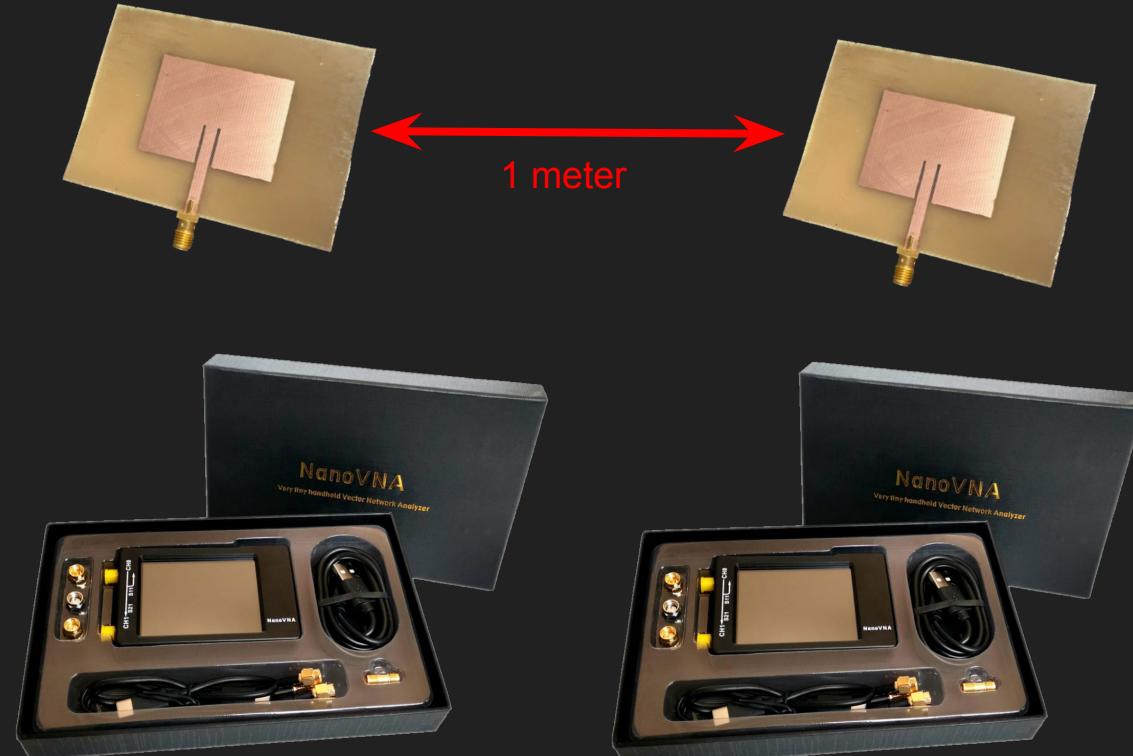
Antenna Separation (R)

 meter

Result

Power Received (dBm):

Power Received (W):



Check Local Laws

| ISM Frequency Range | | ISM Band Type |
|---------------------|------------|---------------|
| 6.765 MHz | 6.795 MHz | Regional |
| 13.553 MHz | 13.567 MHz | Worldwide |
| 26.957 MHz | 27.283 MHz | Worldwide |
| 40.66 MHz | 40.7 MHz | Worldwide |
| 433.05 MHz | 434.79 MHz | Regional |
| 902 MHz | 928 MHz | Regional |
| 2.4 GHz | 2.5 GHz | Worldwide |
| 5.725 GHz | 5.875 GHz | Worldwide |
| 24 GHz | 24.25 GHz | Worldwide |
| 61 GHz | 61.5 GHz | Regional |
| 122 GHz | 123 GHz | Regional |
| 244 GHz | 246 GHz | Regional |



Conclusion

Rectangular patch antennas are simple and inexpensive to manufacture

This presentation showcased a tool to help with antenna calculations:

- <https://github.com/dollarhyde/AntennaCalculator>

Make your own antenna and share it with the community

References

- [1] C. A. Balanis, Antenna theory: Analysis and design. Hoboken, NJ: Wiley, 2016.
- [2] J. D. Kraus and R. J. Marhefka, Antennas for all applications. Boston, Mass: McGraw-Hill, 2008.
- [3] W. L. Stutzman and G. A. Thiele, Antenna Theory and design. Hoboken, NJ: Wiley, 2013.

