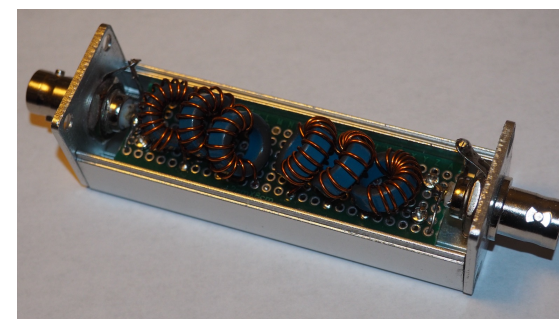


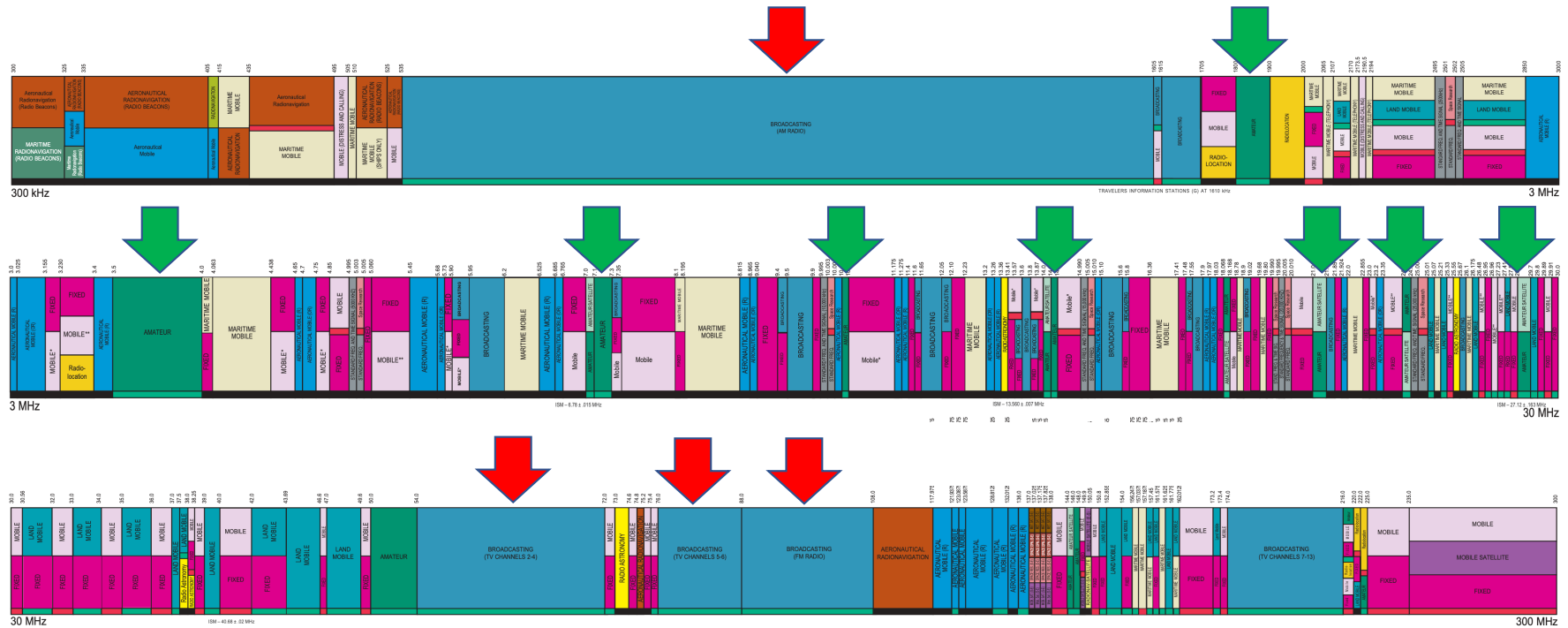
## External Filters for Ham Radio



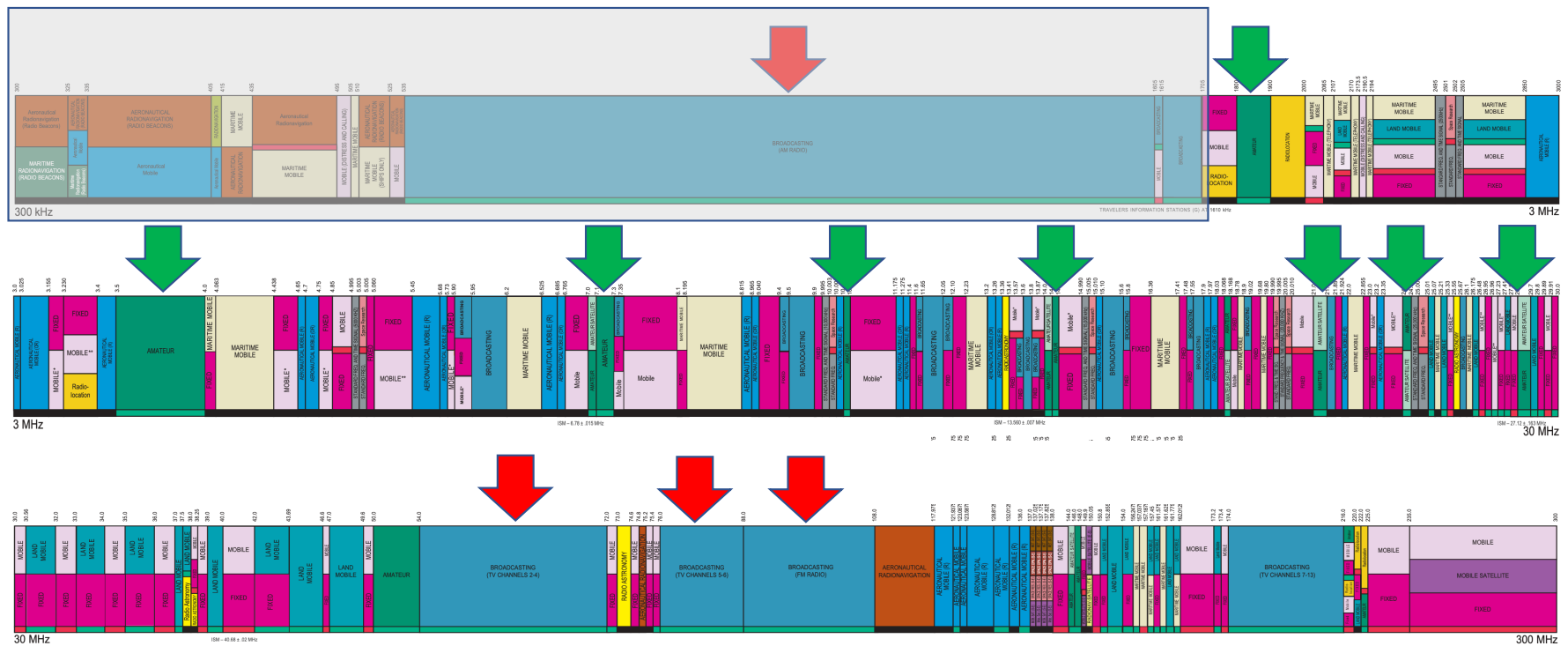
Dick Knight  
N1OR



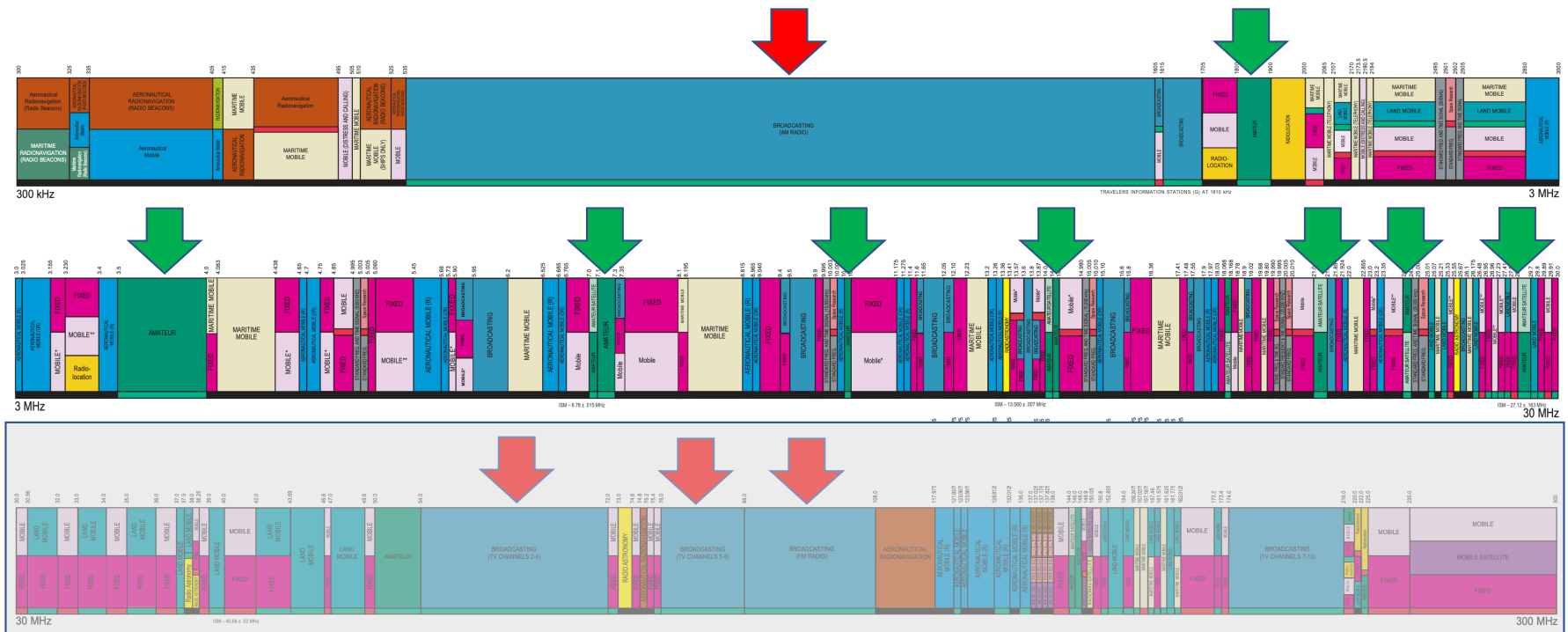
# Filters for HF Ham Radio RF Interference



# “High Pass” Filter for AM Radio Interference



# “Low Pass” Filter for FM Radio and TV Interference





# “Band Pass” Filter for Nearby Ham Radio Interference



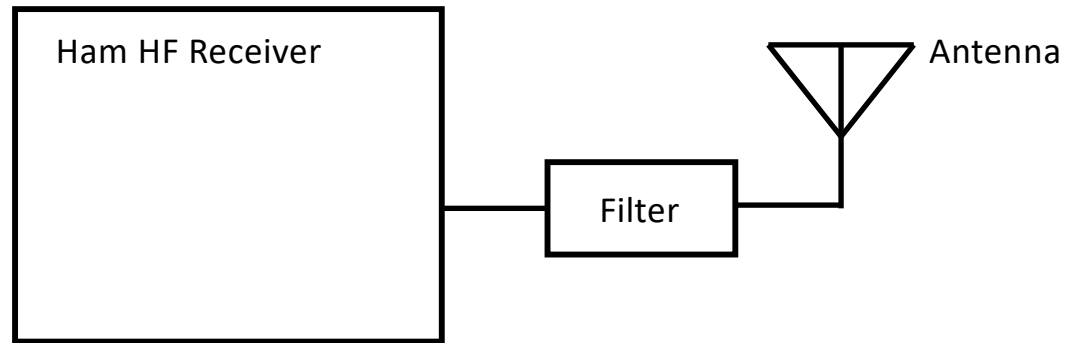
# A Filter might be useful if ...

- A powerful AM radio transmitter is near your location ...
- A TV station or FM radio transmitter is near your location ...
- Ham's are operating near each other (ex: Field Day)
- You have a Software Defined Radio

EXAMPLE: KD7DTS and KN6PHZ enjoy both operating highly portable QRP SDR rigs from local parks and peaks that are often also home to commercial AM or FM radio, TV or other transmitters. And they often operate at the same time on adjacent bands.

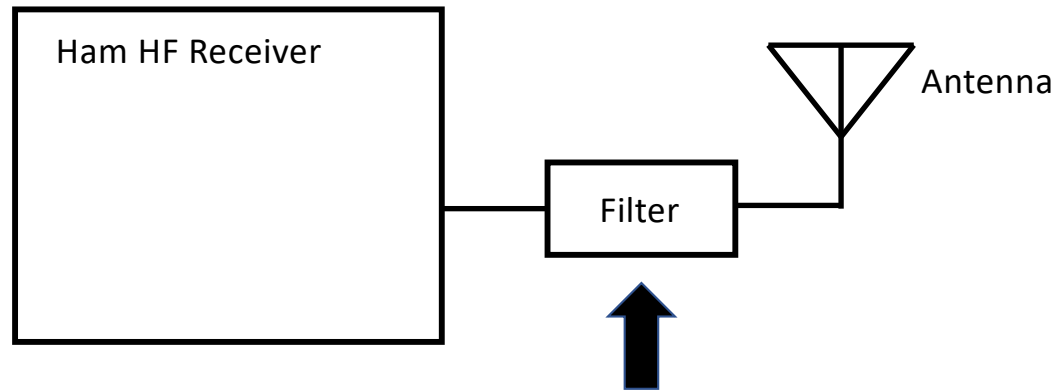


# Adding an external filter to a radio ...



seems easy, ...

# Adding an external filter to a radio



Channel Master CM-3250 High Pass Filter Removes Noise and RF Interference

★★★★☆ 18

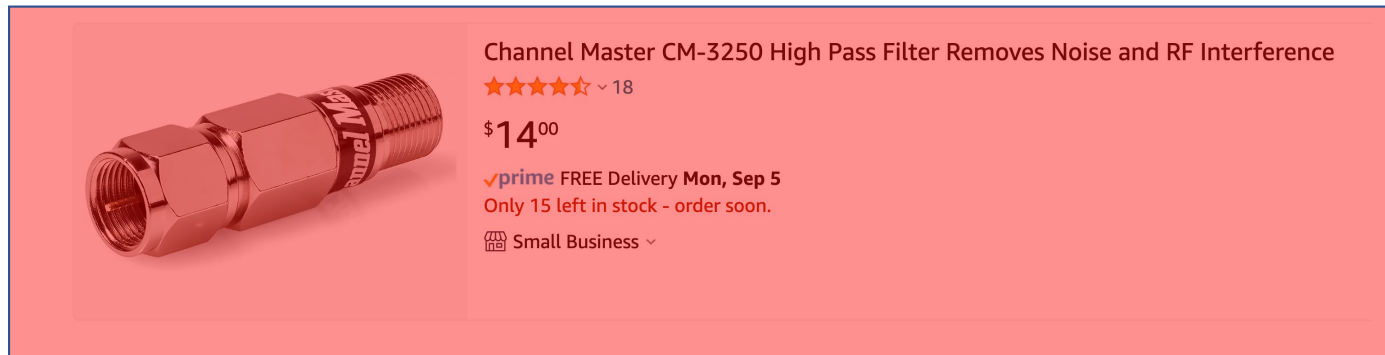
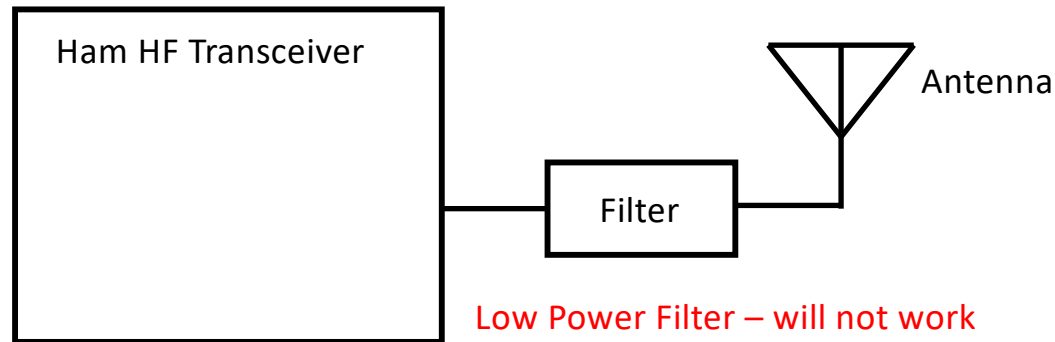
\$14<sup>00</sup>

✓prime FREE Delivery **Mon, Sep 5**

Only 15 left in stock - order soon.

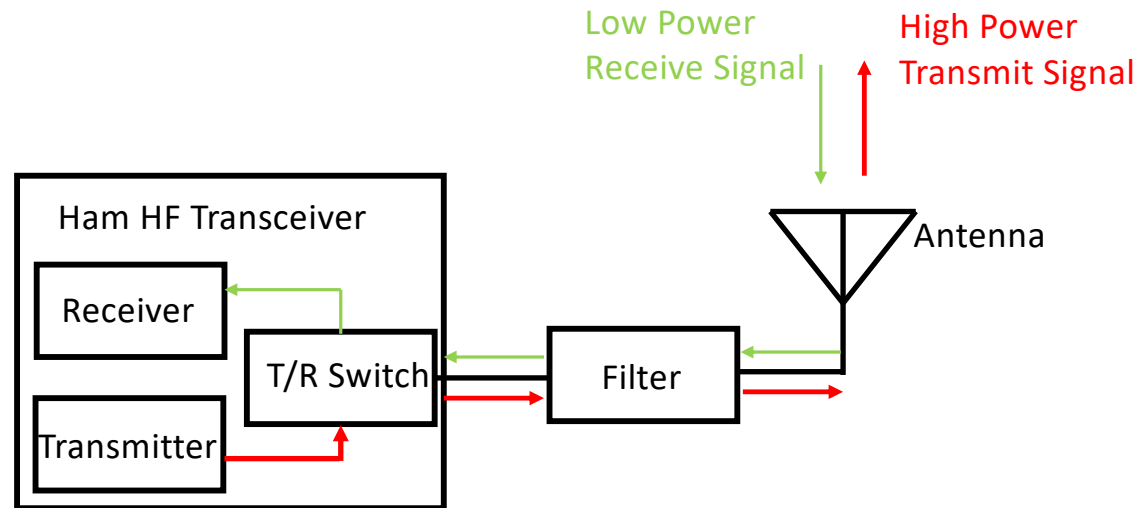
Small Business ▼

# Adding an external filter to a ham transceiver



These inexpensive filters are designed  
for use with low power receivers!

# Adding an external filter to a ham transceiver

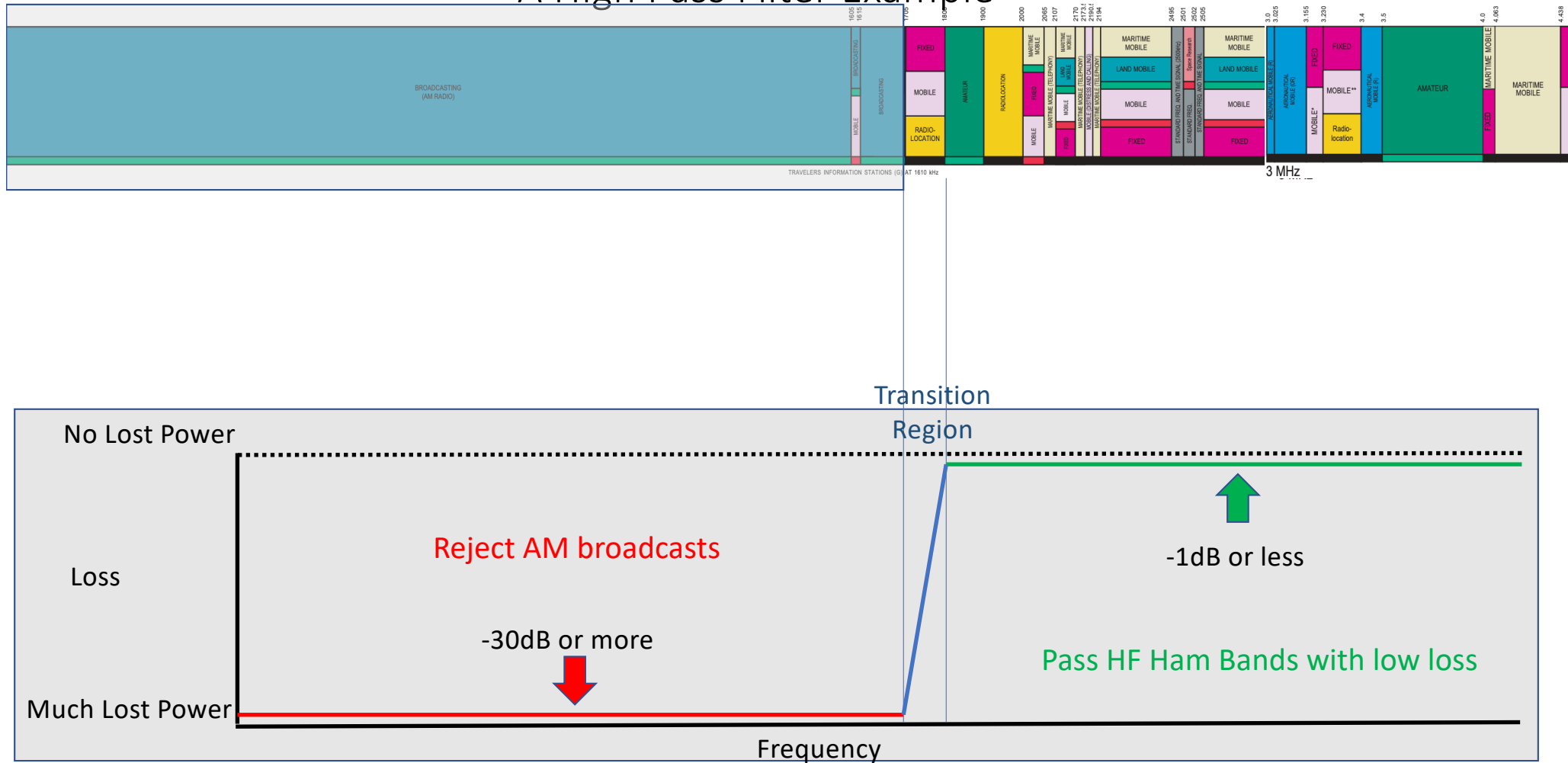


The filter must handle the full output power with minimal loss!



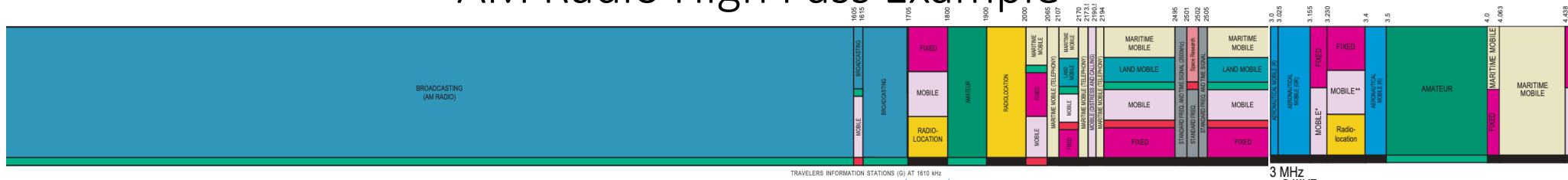
# Specifying the right filter:

## A High Pass Filter Example



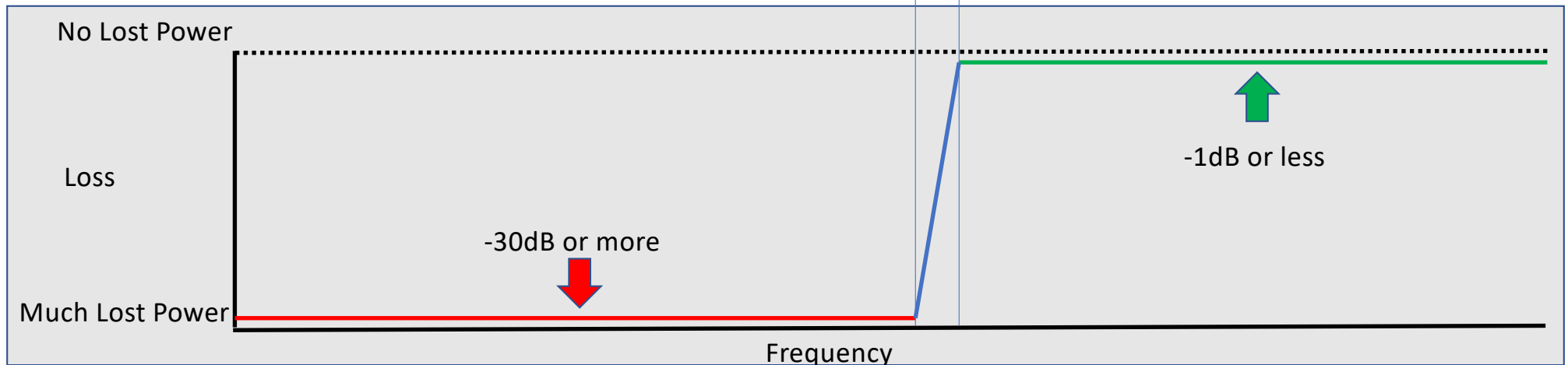
# Specifying the right filter:

## AM Radio High Pass Example



Power Handling:  
Loss in Reject Band:  
Loss in Pass Band:  
Transition Region:  
50 ohm I/O Match

Greater than Transceiver Output Power  
As High as Possible (-30db or better)  
As Low as Possible (<1db)  
As Narrow as Possible  
Close to 50 Ohms (<1.5:1 VSWR)



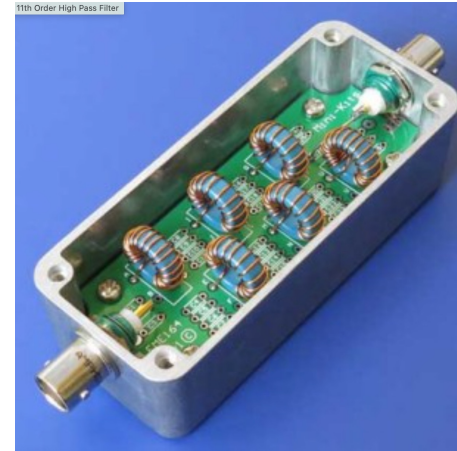
# Finding the Right Filter

Things to consider:

- A. How many filters (of various types) are desired
- B. Cost of each filter, cost for total of all filters desired
- C. Electrical specifications: see previous slide
- D. User needs: Size, Weight, Cost, Ruggedness, Connectors, Style
- E. Personal preference:
  - . Prefer to purchase a quality product
  - . Would like an accessible DIY kit project yielding a quality filter
  - . Enjoy DIY design and construction (and perhaps learning new technologies)

# Example Filters

DLW High Pass

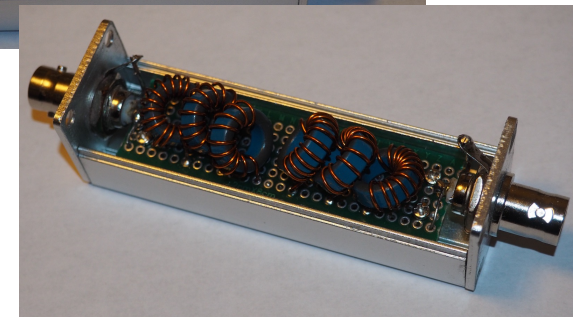
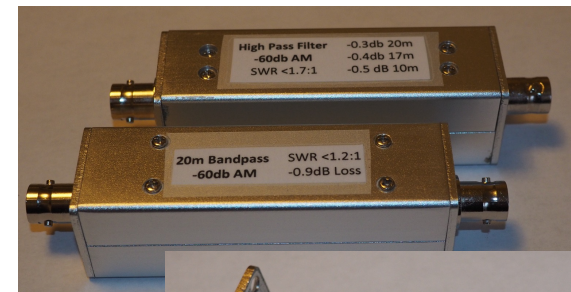


MiniKits High Pass

MFJ Low Pass



SOTabeams 2m  
(note connectors)

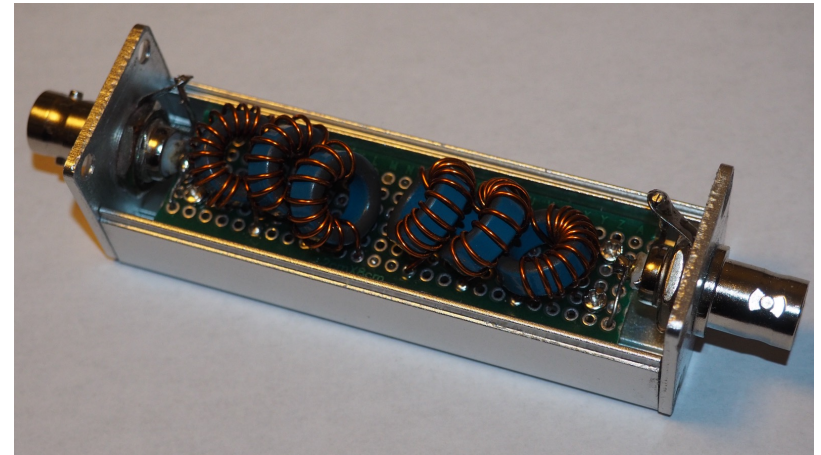


# Snapshot of Filter Sources

		High Pass	Low Pass	Band Pass	2 Meters	Power	~ Cost
<b>Commercial Products</b>							
DLW Associates		x				200W	\$195
MFJ			x			1,500W	\$125
DX Engineering		x	x	x	x	200-1,500W	\$125-700
SOTabeams					x		\$125
E-bay		Various offerings , mostly from China				~100-200W	~\$60
<b>DIY Kits</b>							
Minkits		x	x	x		10/50/100W	\$60
	Requires:						
	Soldering iron/solder						
	Small hand tools						
	Drill/bits						
	Multimeter						
<b>DIY</b>							
Various on internet, e-bay		x	x	x	x	10W	
	Requires:					(100W with care, 1000W good luck!)	
	Above plus:						
	NanoVNA						
	Toroid cores						
	Capacitors						
	"Magnet" wire						
	Insulated wire						
	Circuit boards						
	Mechanical package						
	Connectors						

# Designing and Building a Filter - DIY

- Design and Simulation
  - Design for Performance
  - Design for “buildability”
    - Tools for Filter Design and Simulation
    - Tools for Circuit Analysis and Optimization
- Component Selection and Assembly
  - Mechanical Assembly Technology
  - Capacitors and Inductor Selection/Fabrication and Optimization
    - Use of nanoVNA
    - Other tools and techniques
- Evaluation and Optimization
  - Use of nanoVNA and the Smith Chart





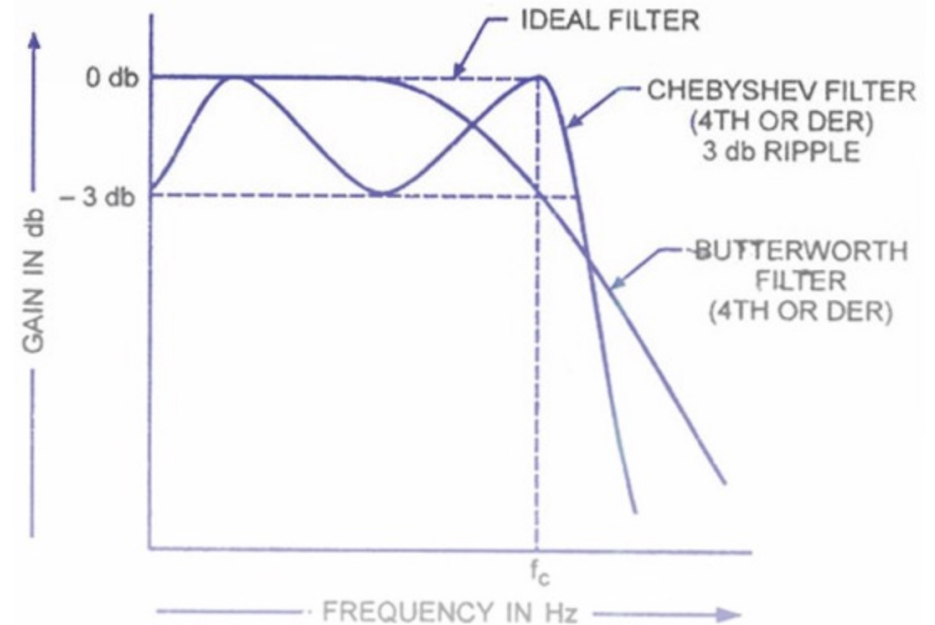
# Select a Filter Type

Chebyshev: “equal ripple”

- . A bit more bandwidth
- . Steeper band edge “roll off”

Butterworth: “maximally flat”

- . Smooth pass band
- . **I find these easier to build with adequate isolation**



Chebyshev and Butterworth Filter

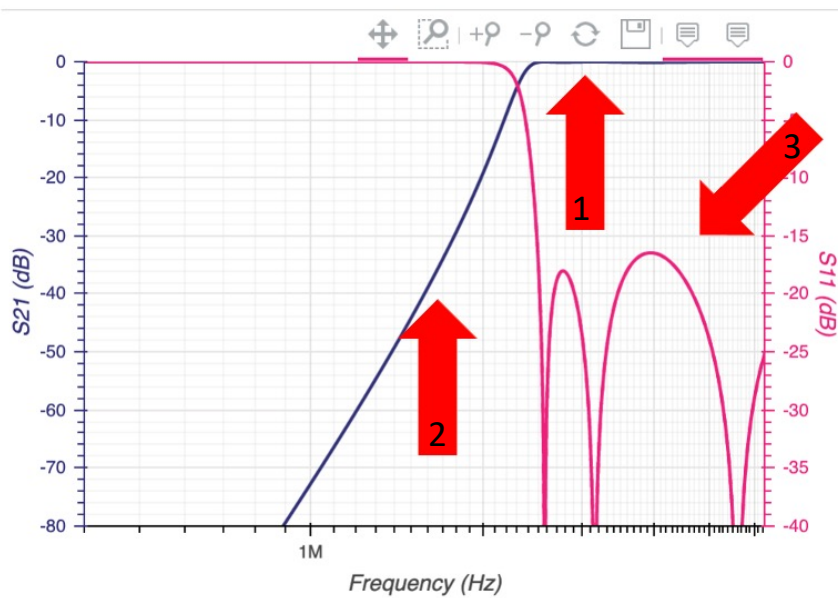
Source:

[https://www.quora.com/](https://www.quora.com/Which-of-these-is-better-Chebyshev-filters-or-Butterworth-filters)

Which-of-these-is-better-Chebyshev-filters-or-Butterworth-filters

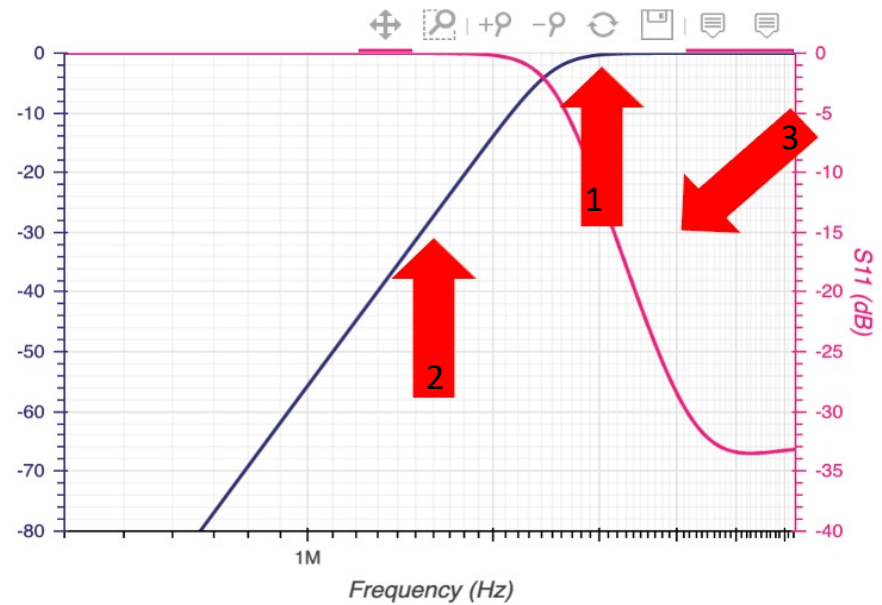
# Chebyshev vs. Butterworth HP Filters

Chebyshev



markimicrowave.com | Sep 05, 2022

Butterworth



markimicrowave.com | Sep 05, 2022

# Example 1 Find an Existing Filter Design to Build

- Use an Existing Design

- Example:

<http://www.arrl.org/files/file/Technology/tis/info/pdf/8809017.pdf>

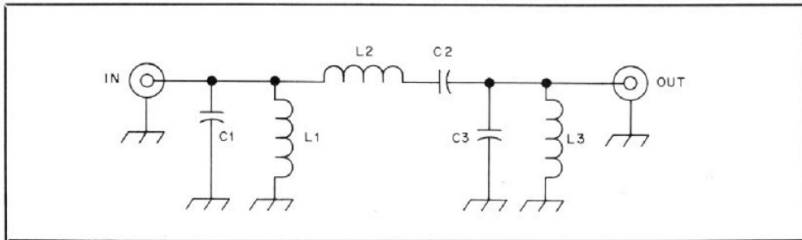


Fig 1—Schematic diagram of the three-pole Butterworth band-pass filters.

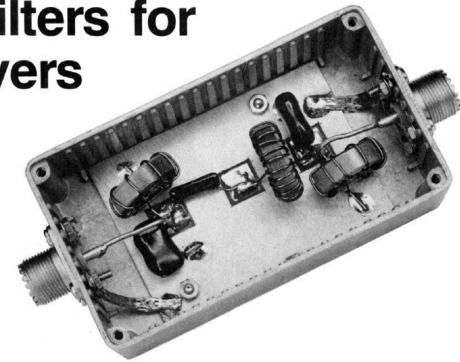
**Table 1**  
**HF Band-Pass Filter Specifications**

Band (MHz)	C1/C3 (pF)	C2 (pF)	L1/L3 ( $\mu$ H)	L2 ( $\mu$ H)	T-68-6 core		T-80-6 core		$F_r$ (MHz)
					L1/L3 (no. turns)	L2	L1/L3 (no. turns)	L2	
1.8	4000	400	2.2	22	22	69	23	70	1.75
3.5	2000	200	1.1	11	16	48	16	50	3.38
7	1000	100	0.55	5.5	11	35	11	35	6.78
14	500	50	0.28	2.8	8	25	8	25	13.56
21	330	33	0.18	1.8	7	20	7	20	20.65
28	250	25	0.14	1.4	6	17	6	18	27.39

## Band-Pass Filters for HF Transceivers

Do your multiple-transmitter Field Day or contest efforts suffer from intrastation interference? These handy and inexpensive filters can help!

By Lew Gordon, K4VX  
PO Box 105  
Hannibal, MO 63401



**This filter will be modeled in the next section to demonstrate use of modeling tools.**

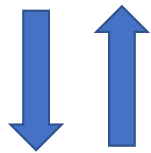
Many filter “prescriptions” for HP, LP and BP filters are available on-line or as kits.

The tools described in the next section support analysis of existing designs or new designs “from scratch”.

# Example 2 Unique Filter Design and Analysis

- A Way to Design with Professional-Level Tools – Free, On-line:

Filter Design Analysis



Filter Modeling

RF TOOLS | Marki  
Design Tools ▾ Calculators ▾ Converters ▾ Contact

Bare Die, Surface Mount, Connectorized | DC-125GHz

Adapters Amplifiers Attenuators Baluns Bias Tees Couplers DC Blocks Equalizers Filters Hybrids Limiters IQ Mixers Mixers Multipliers Power Dividers

Shattering Performance Barriers Since 1991

**LC Filter Design Tool** Calculate LC filters circuit values with low-pass, high-pass, band-pass, or band-stop response. Select Chebyshev, Elliptic, Butterworth or Bessel filter type, with filter order up to 20, and arbitrary input and output impedances. [More info](#)

<https://rf-tools.com/lc-filter>

<https://rf-tools.com/lc-filter/description.html>

ANALOG DEVICES  
AHEAD OF WHAT'S POSSIBLE™

Search

COMPANY | MYANALOG | PRODUCTS | APPLICATIONS | DESIGN CENTER | EDUCATION | SUPPORT

Design Center > Circuit Design Tools & Calculators > LTspice

Search

Simulation Models

Reference Designs

Evaluation Hardware & Software

**LTspice**

Fast • Free • Unlimited

LTspice® is high performance SPICE simulator software, including a graphical schematic capture interface. Schematics can be probed to produce simulation results—easily explored through LTspice's built-in waveform viewer. LTspice's enhancements and models improve the simulation of analog circuits when compared to other SPICE solutions.

<https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html>

# DIY Design: Demo Tools with the 3.5MHz Filter from Example 2

**RF TOOLS** | Marki microwave | Design Tools | Calculators | Converters | Contact

Bare Die, Surface Mount, Connectorized | DC-125GHz

Adapters | Amplifiers | Attenuators | Baluns | Bias Tees | Couplers | DC Blocks | Equalizers | Filters | Hybrids | Limiters | IQ Mixers | Mixers | Multipliers | Power Dividers

Shattering Performance Barriers Since 1991

### LC Filter Design Tool

Calculate LC filters circuit values with low-pass, high-pass, band-pass, or band-stop response. Select Chebyshev, Elliptic, Butterworth or Bessel filter type, with filter order up to 20, and arbitrary input and output impedances.

[More info](#)

**Filter Properties**

Response: **Bandpass** | Type: **Butterworth**

Topology: **Conventional, Shunt First** | Order: **3**

Lower Cutoff Frequency: **2.95** MHz | Upper Cutoff Frequency: **4.55** MHz

Input Impedance ( $\Omega$ ): **50** | Output Impedance ( $\Omega$ ): **50**

Additional Settings  
Component Values: **Exact**

**Step 1**

[Compute](#) [Reset](#)

**3rd Order Butterworth Bandpass**  
Lower Cutoff Freq. = 2.950 MHz; Upper Cutoff Freq. = 4.550 MHz

**Step 2**

markimicrowave.com | Sep 05, 2022

**Insertion Loss and Return Loss** | **Phase and Group Delay**

**S-Parameters** | **Export**

**Step 3**

markimicrowave.com | Sep 05, 2022

# DIY Design: 3.5MHz Bandpass Example

## Step 4: Add “real world tolerances”

**Filter Properties**

Response: Bandpass Type: Butterworth

Topology: Conventional, Shunt First Order: 3

Lower Cutoff Frequency: 2.95 MHz Upper Cutoff Frequency: 4.55 MHz

Input Impedance (Ω): 50 Output Impedance (Ω): 50

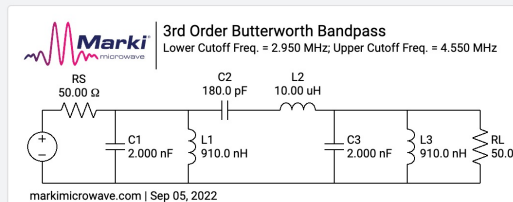
**Additional Settings**

Component Values: Standard

Capacitor Values: E24 (5% tolerance) Min. Capacitor Value: 1.00 pF

Inductor Values: E24 (5% tolerance) Min. Inductor Value: 1.00 nH

Compute Reset



**RF TOOLS** | **Marki** | Design Tools | Calculators | Converters | Contact

**Bare Die, Surface Mount, Connectorized | DC-125GHz**

Adapters | Amplifiers | Attenuators | Baluns | Bias Tees | Couplers | DC Blocks | Equalizers | Filters | Hybrids | Limiters | IQ Mixers | Mixers | Multipliers | Power Dividers

**Shattering Performance Barriers Since 1991**

### LC Filter Design Tool

Calculate LC filters circuit values with low-pass, high-pass, band-pass, or band-stop response. Select Chebyshev, Elliptic, Butterworth or Bessel filter type, with filter order up to 20, and arbitrary input and output impedances. [More info](#)

**Filter Properties**

Response: Bandpass Type: Butterworth

Topology: Conventional, Shunt First Order: 3

Lower Cutoff Frequency: 2.95 MHz Upper Cutoff Frequency: 4.55 MHz

Input Impedance (Ω): 50 Output Impedance (Ω): 50

**Additional Settings**

Component Values: Exact

Compute Reset

**Step 1**

**3rd Order Butterworth Bandpass**  
Lower Cutoff Freq. = 2.950 MHz; Upper Cutoff Freq. = 4.550 MHz

markimicrowave.com | Sep 05, 2022

**Step 2**

**Insertion Loss and Return Loss** **Phase and Group Delay**

**S-Parameters** **Export**

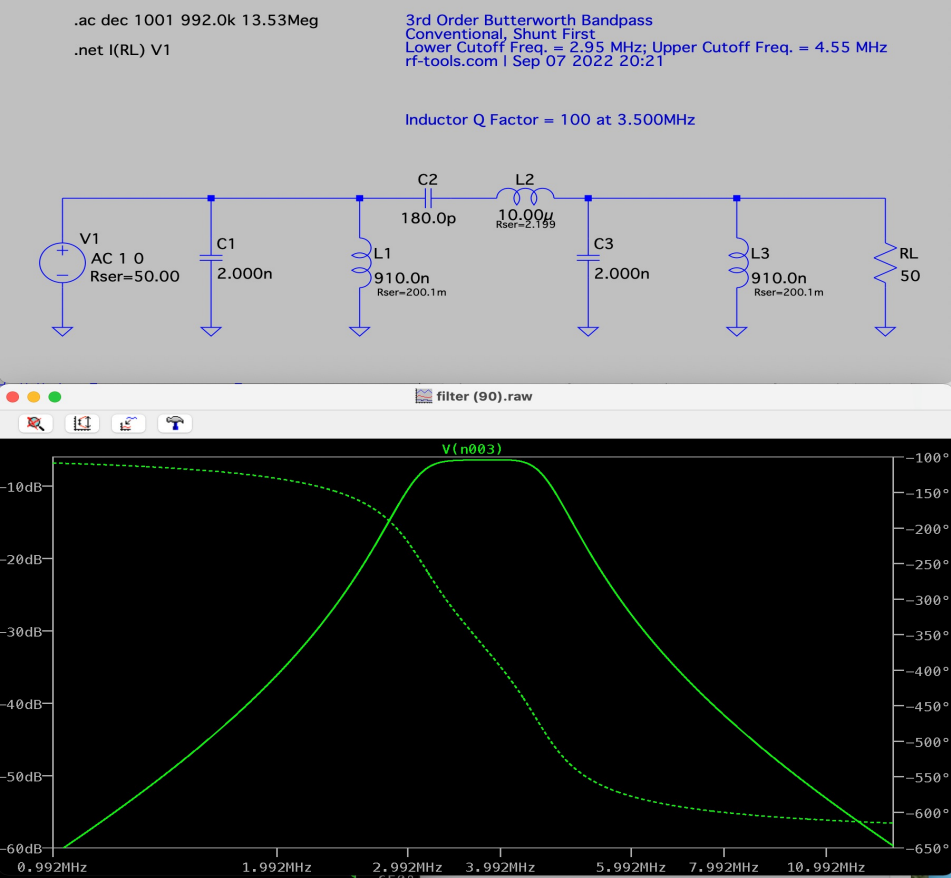
markimicrowave.com | Sep 05, 2022

**Step 3**



# DIY Design: 3.5MHz Bandpass Example

## Step 5: Export to Spice



Filter Properties

Response: Bandpass Type: Butterworth

Topology: Conventional, Shunt First Order: 3

Lower Cutoff Frequency: 2.95 MHz Upper Cutoff Frequency: 4.55 MHz

Input Impedance (Ω): 50 Output Impedance (Ω): 50

Additional Settings

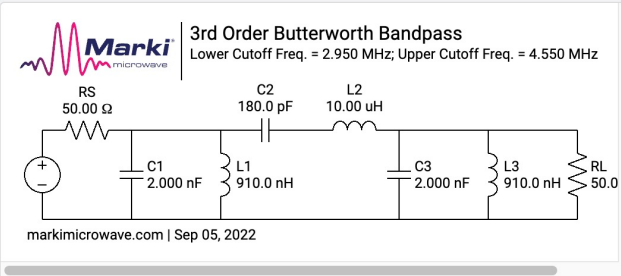
Component Values

Standard

Capacitor Values: E24 (5% tolerance) Min. Capacitor Value: 1.00 pF

Inductor Values: E24 (5% tolerance) Min. Inductor Value: 1.00 nH

Compute Reset



Insertion Loss and Return Loss Phase and Group Delay

S-Parameters Export

Export to LTSpice

LTSpice is a free circuit simulator available for download on [analog.com](https://analog.com).

For more info on how to export and use LTSpice for filter simulation [click here](#).

Simulation Type: S-Parameters

Finite Inductor Q Factor: ☒ Monte Carlo: ☐

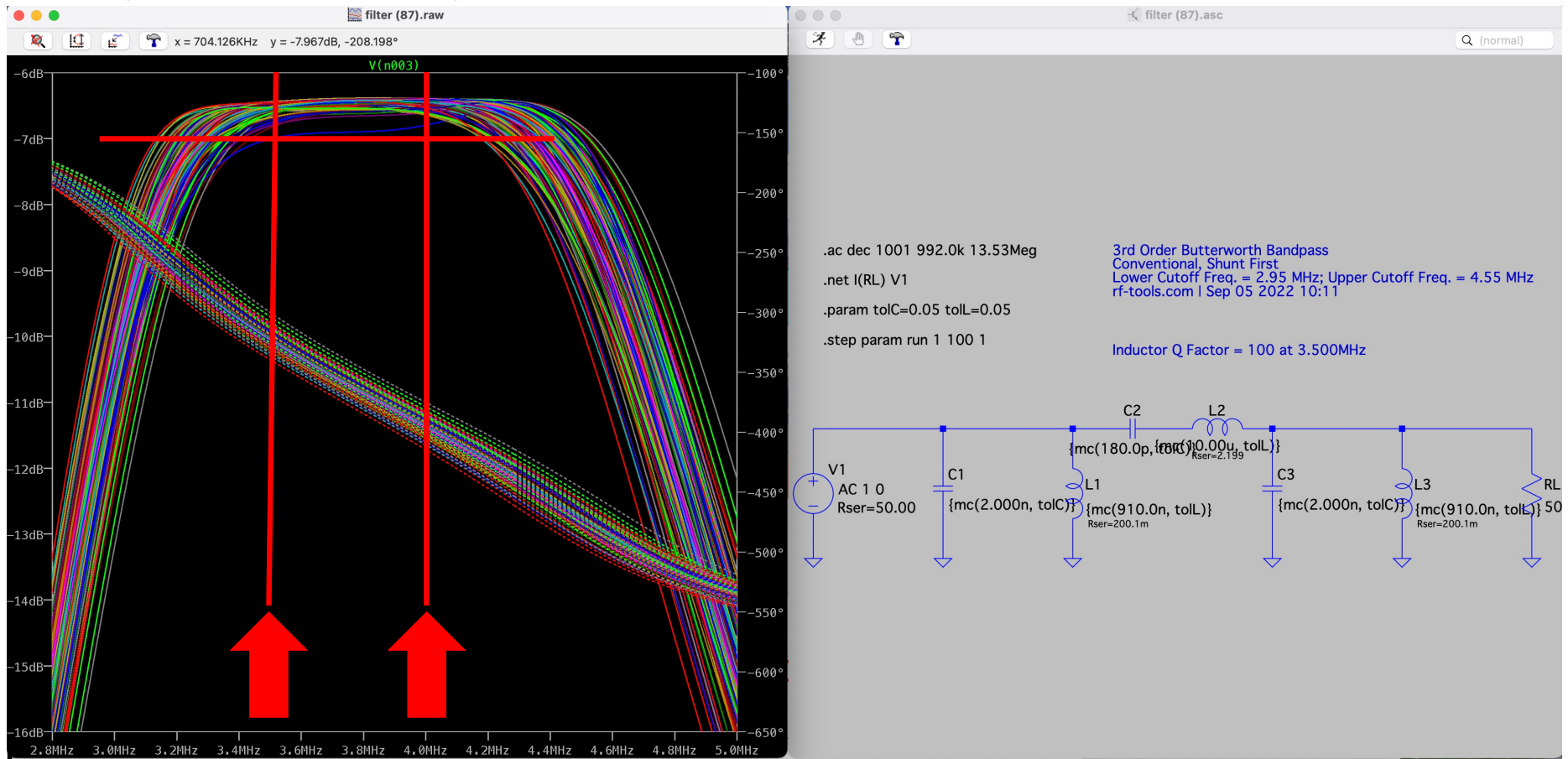
Q Value: 100 Q Specific Frequency: 3.5 MHz

Export LTSpice

Export to Qucs

# DIY Design: 3.5MHz Bandpass Example

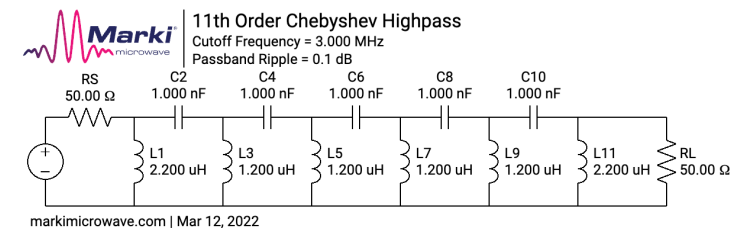
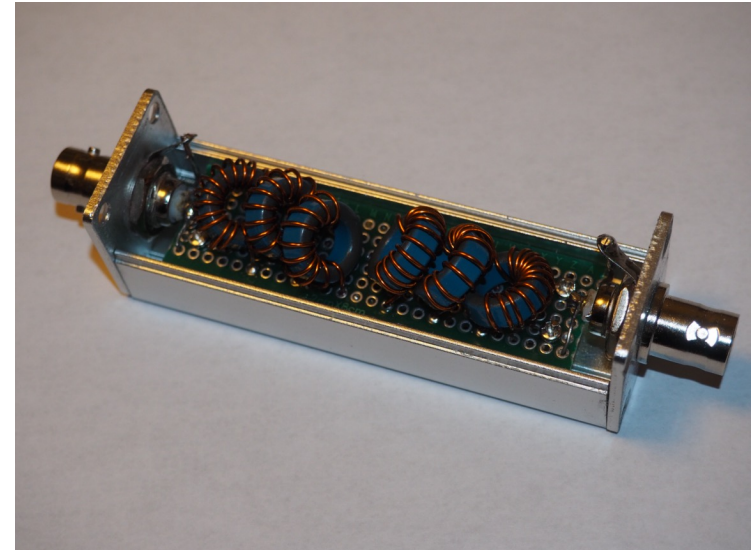
## Step 7: Explore Design Performance



## Example 3 Filter Construction and Test

### N10R High Pass Design as Reference Example

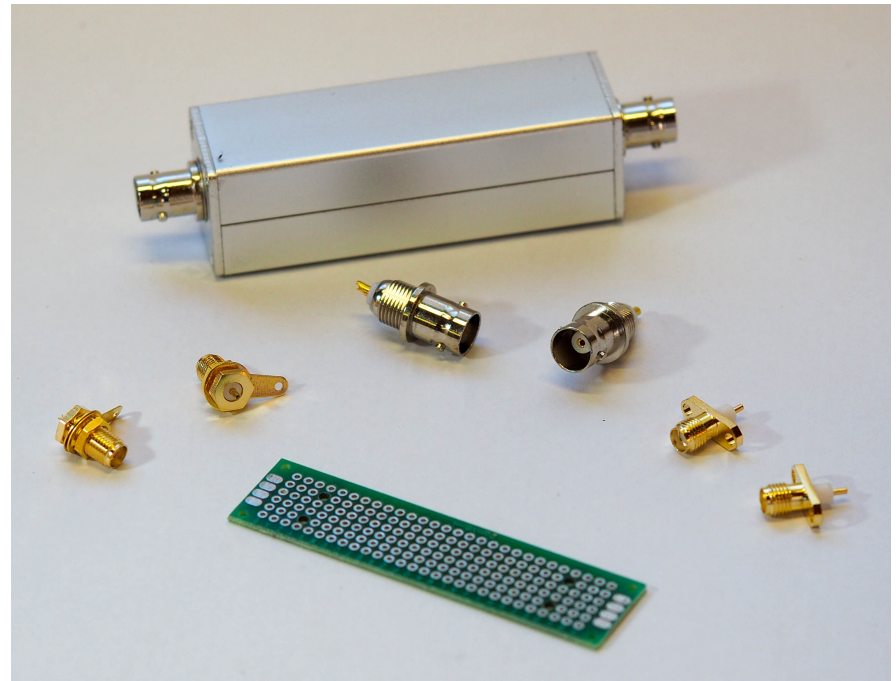
- Mechanical construction
- Selecting components (using nanoVNA)
- Building toroidal inductors
- Testing filter performance (using nanoVNA)
- DIY vs. Commercial Performance



# Mechanical Design Choices

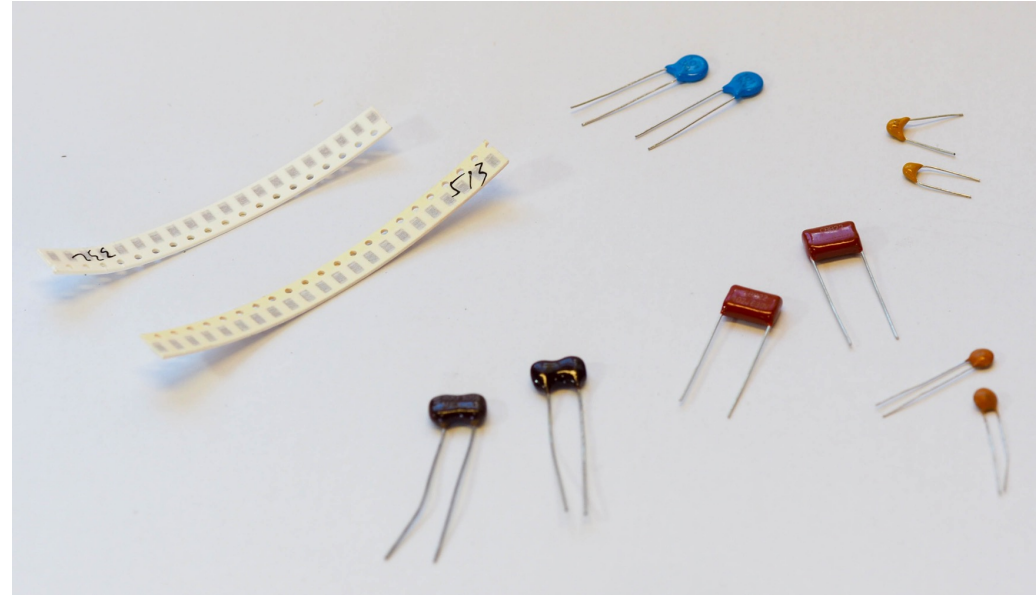
- Case: Size/Style Project Box: Many Choices, **Extruded Aluminum**
- Components: **Leaded** or Surface Mount, Microstrip; Fixed or Variable
- Interconnect: Blank Circuit Board, **Project Board**, Custom
- Connectors: SMA, **BNC**, TNC, N

Choices in Bold for Following Example Project



# Capacitors

Choices in **Bold** for Following Example Project



- Style: **Leaded**, Surface Mount, Through Hole (Air Variable)
- Voltage/Power Rating (10W minimum - tested to >50W)
- Self Resonance Frequency
- Values available to match design?
- Loss (“Q”):
  - Many materials have too much loss for “low loss” filters
  - Low loss types: **Silver Mica**, Polystyrene, Ceramic (some types), Air Variable



# Inductors

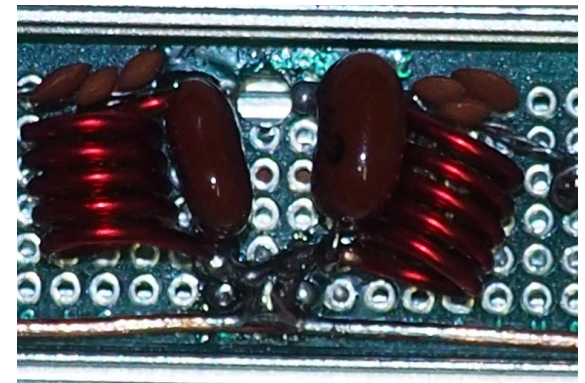


Amidon Winding Calculator  
<https://coil32.net/online-calculators/amidon-iron-powder-cores-calculator.html>

Air Core Calculator  
<https://hamwaves.com/inductance/en/index.html#input>

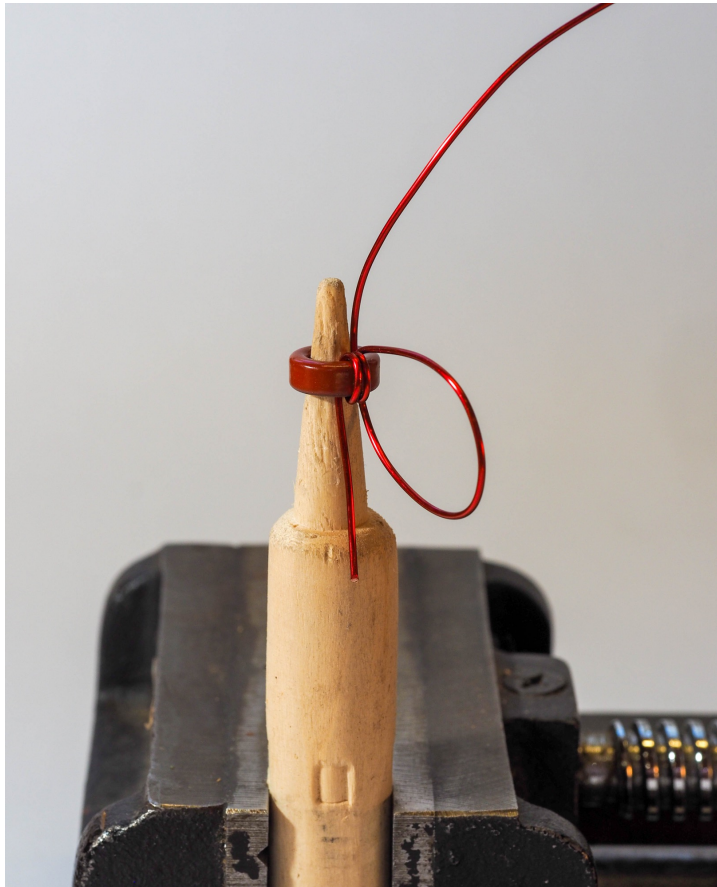
- Usually a **DIY Item** in HF Filters
- Style: AirCore (Helical), **Iron Powder Toroid**, ...
- Voltage/Power Rating
- Self Resonance Frequency
- Practical Value Range
- Loss ("Q"): Very Critical Limitation for Filter Loss

Choices in Bold for Following Example Project





# Simple Tool to Make Toroid Winding Easy



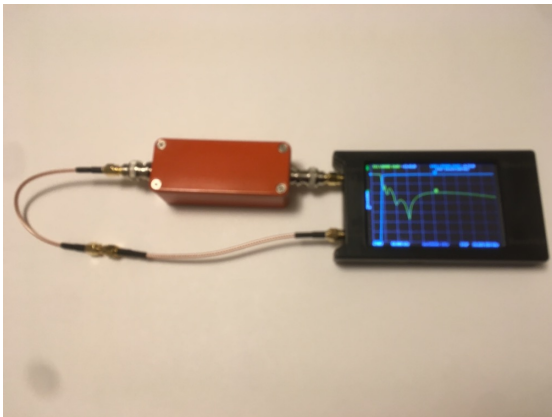


### Vector Network Analyzer

- . nanoVNA's are inexpensive
- . Cover frequencies to >1.5GHz
- . Many functions for evaluating component and filter performance

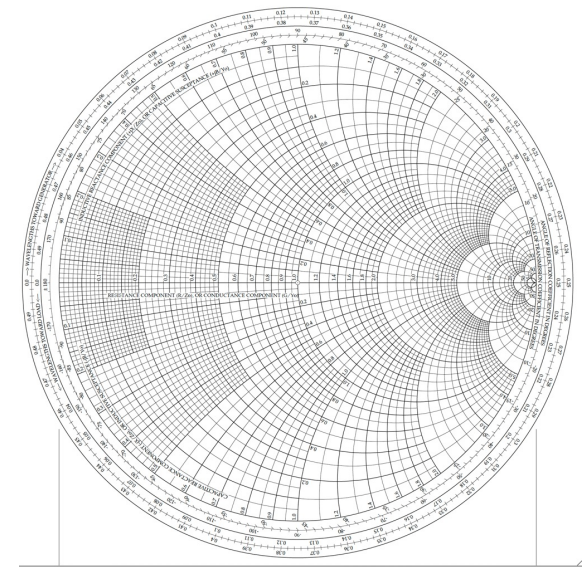


## Test and Optimization: Powerful Tools



### Smith Chart Display

- . Takes some effort to understand/use
- . Often not covered in youtube intros
- . Powerful visualization tool
- . Tremendously useful for optimization





Toroid Inductor



50 Ohm Resistor



Polystyrene Capacitor

## Component Values vs. Frequency

nanoVNA in Smith Chart Mode



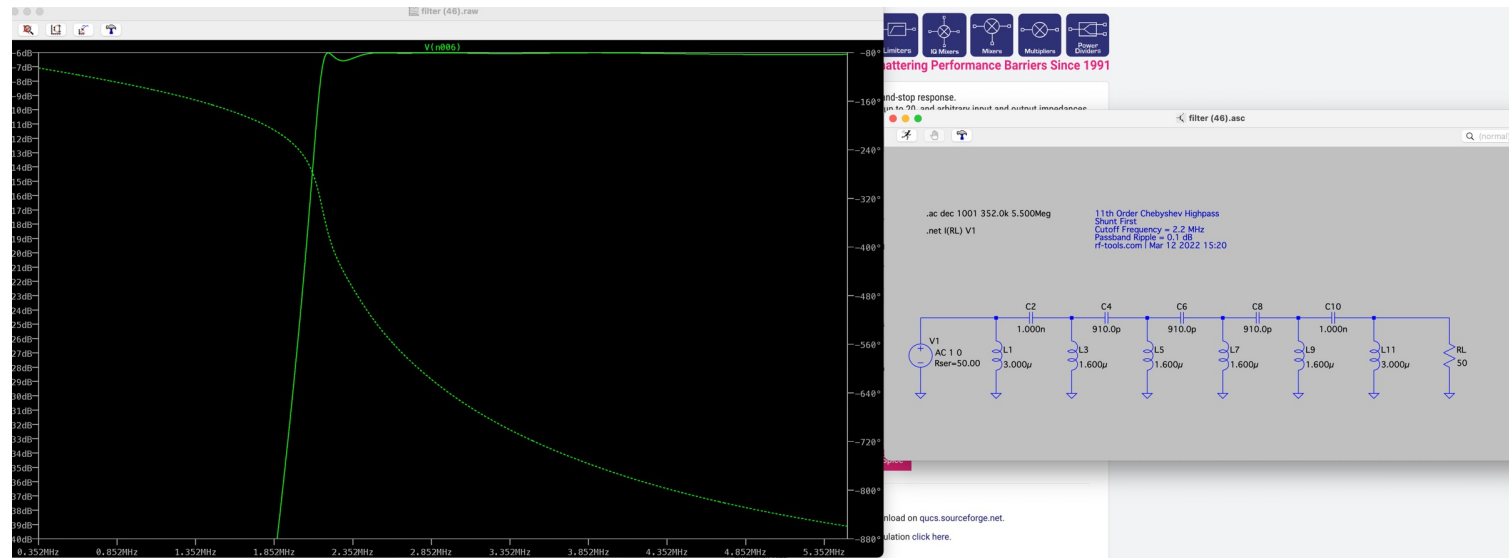
Resonant Frequency

Inductor and Capacitor in Parallel

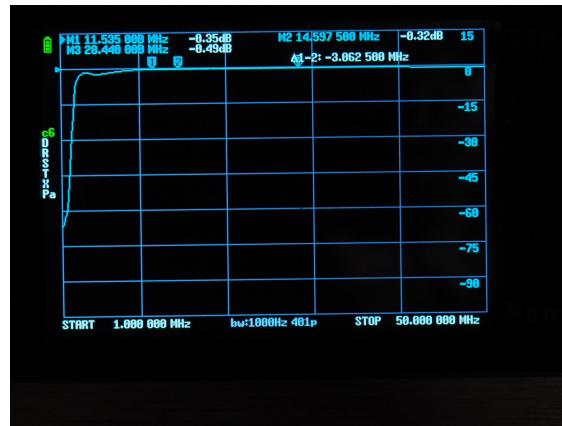
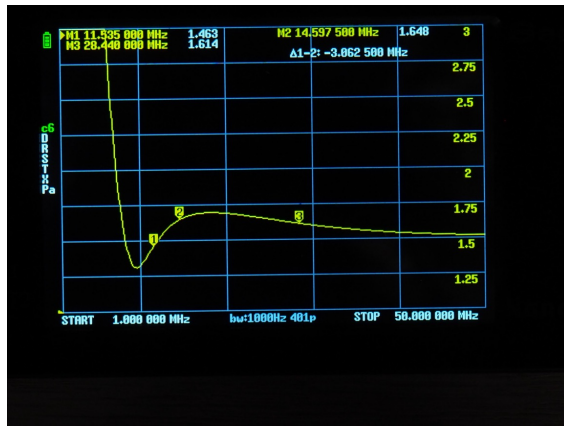
Try it yourself: Explore the Smith Chart at [https://www.will-kelsey.com/smith\\_chart/](https://www.will-kelsey.com/smith_chart/)

# Putting it All Together!

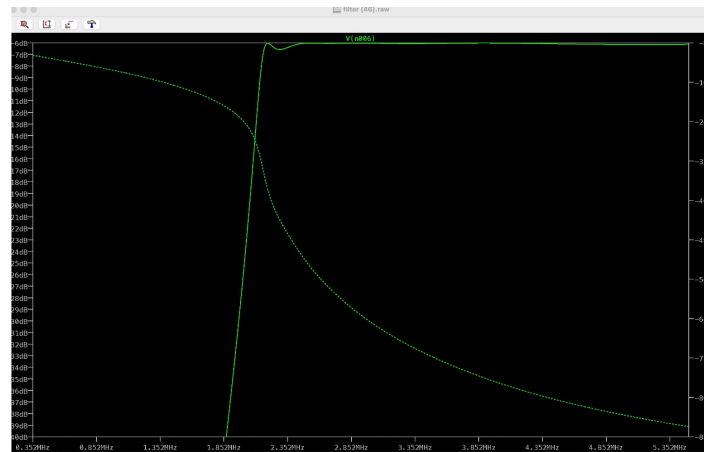
## N1OR DIY High Pass Filter



Design vs. Actual Performance







“Perfect” Simulation Model

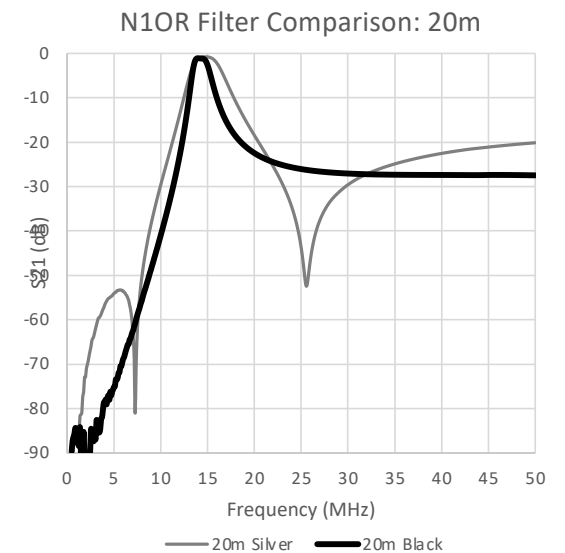
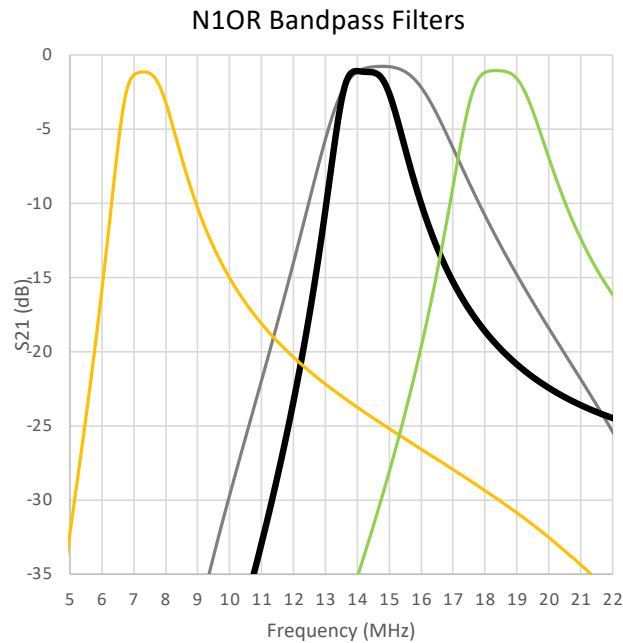
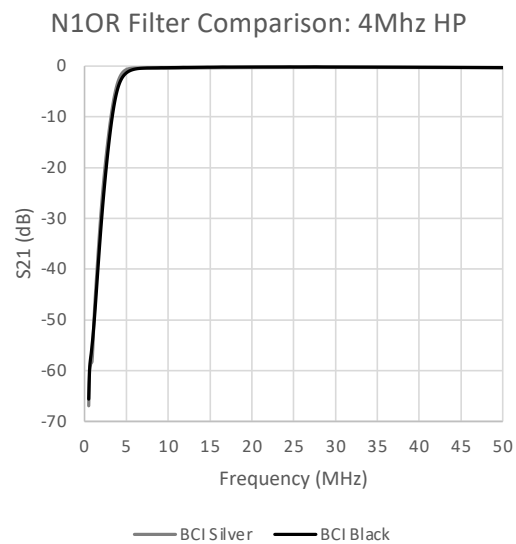
## Beware of Differences from the Model



- Often does not matter if outside frequencies of interest
- Typically created by imperfect models of real components
- Magnetic coupling can often be eliminated by “shielding” within the filter



# How well do DIY filters\* stack up?



\*Silver/Black refer to the N1OR filter case colors: 20m Silver 20m Black 40m Silver 17m Silver

# Thank you for your engagement!

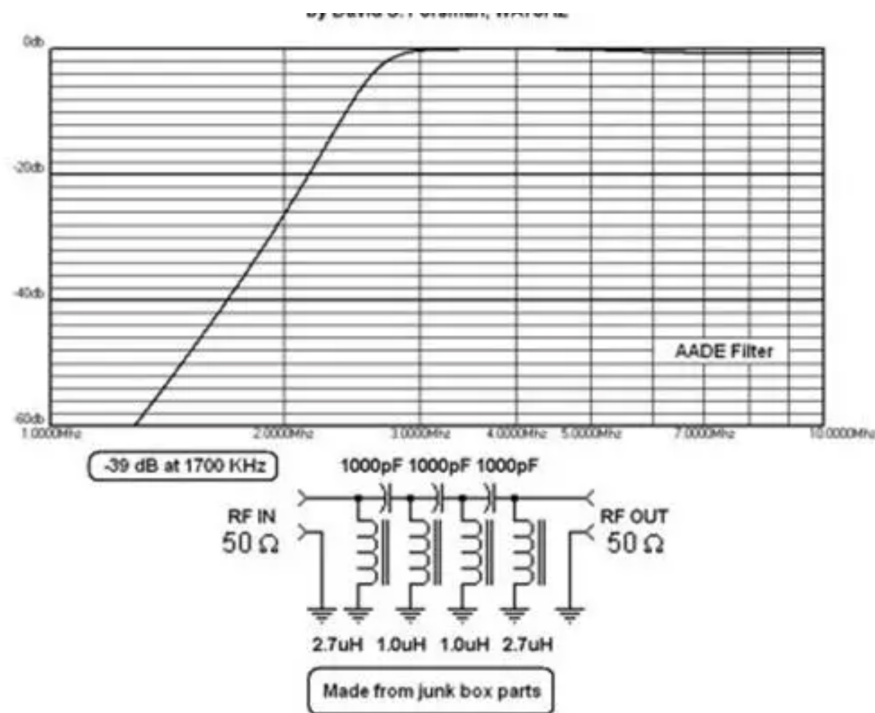
- Thank you to the W6TRW Club for the opportunity to present!
- Special thanks to KD7DTS for inspiring this project, for identifying operator needs, and for filter test and analysis!

# Appendix

- 1. A “Junk Box” high pass filter, with web link
- 2. Smith Chart plotter, with web link



# A Simple “Junk Box” DIY Filter



<https://swling.com/blog/2016/02/a-simple-homebrew-high-pass-filter/>

# Resonant Circuit Example

[https://www.will-kelsey.com/smith\\_chart/](https://www.will-kelsey.com/smith_chart/)

Frequency	10	MHz	Frequency span ±	4	MHz
Characteristic Impedance	50	Ω	Permittivity eff	1	
Impedance	9.12 - 66.9j				
Reflection Coefficient	0.259 - 0.839j				
VSWR	15.4				
Admittance	0.00200 + 0.0147j				
Reflection Coefficient	0.878 ∠ 287°				

Click below to add a component to your system

Series Capacitor	Parallel Capacitor	Series Inductor	Parallel Inductor	Series Resistor	Parallel Resistor
Transmission Line	Open Stub	Shorted Stub	Capacitor w/ ESR	Inductor w/ ESR	RLC
Custom (beta)					

Below is your system, note impedance is looking towards the BLACK BOX

DP1 DP2 DP3

