Repeater 102
(Perhaps actually Repeater 201?)

Connecting cool stuff to your repeater …
and hopefully it works!

Doug Sharp, K2AD

RMHAM University
Original Session: January 25, 2019
Revised Tech Talk: December 28, 2022

What are we going to cover today?

Repeater Basics	Interfaces	The Digital Transition	Callsigns that begin with the letter “K”	System Applications	Potpourri Q&A
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Repeater Basics for $400

- What is mic gain and deviation?
- Audio – Flat versus Emphasized
- Bandwidth and Emissions Mode
- Repeater Performance
- Test Equipment

Deviation

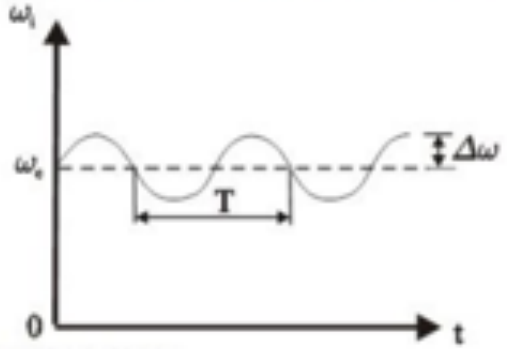
Angle Modulation

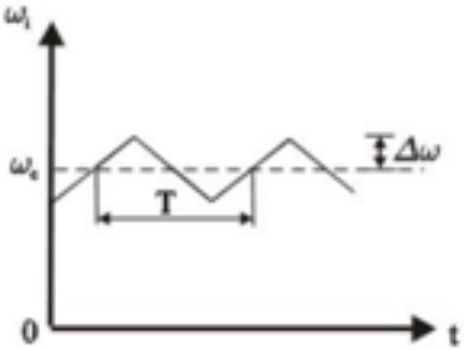
Frequency deviation

The instantaneous frequency of FM signal, $\omega_{FM}(t) = \omega_c + k_{FM}m(t)$, varies with time.

Frequency deviation is the maximum frequency change from the average ω_c, i.e. $\Delta\omega = k_{FM}|m(t)|_{max}$

The frequency deviation is a useful parameter for determining the bandwidth of the FM signals.





Deviation versus Mic Gain

Excerpt from www.k0bg.com/audioxmit.html

"Every single type of modulation, AM, FM (both phase and true FM), SSB (Single Side-Band), etc., all have a specific set of operating parameters. Some of those parameters are set in stone, and some are dynamic.

Transceivers which transmit SSB, have easily-adjustable microphone gain controls, and often speech processing settings as well. It is the misuse of these controls, and the misuse of measuring techniques we're going to discuss.

On the other hand, FM transceivers usually don't have (external) microphone gains, and never have speech compression in the usual sense. They do have pre-emphasis, but that's a whole new subject, and we're not going there!"

Good article … and this is where we are going!

Deviation versus Mic Gain

Deviation

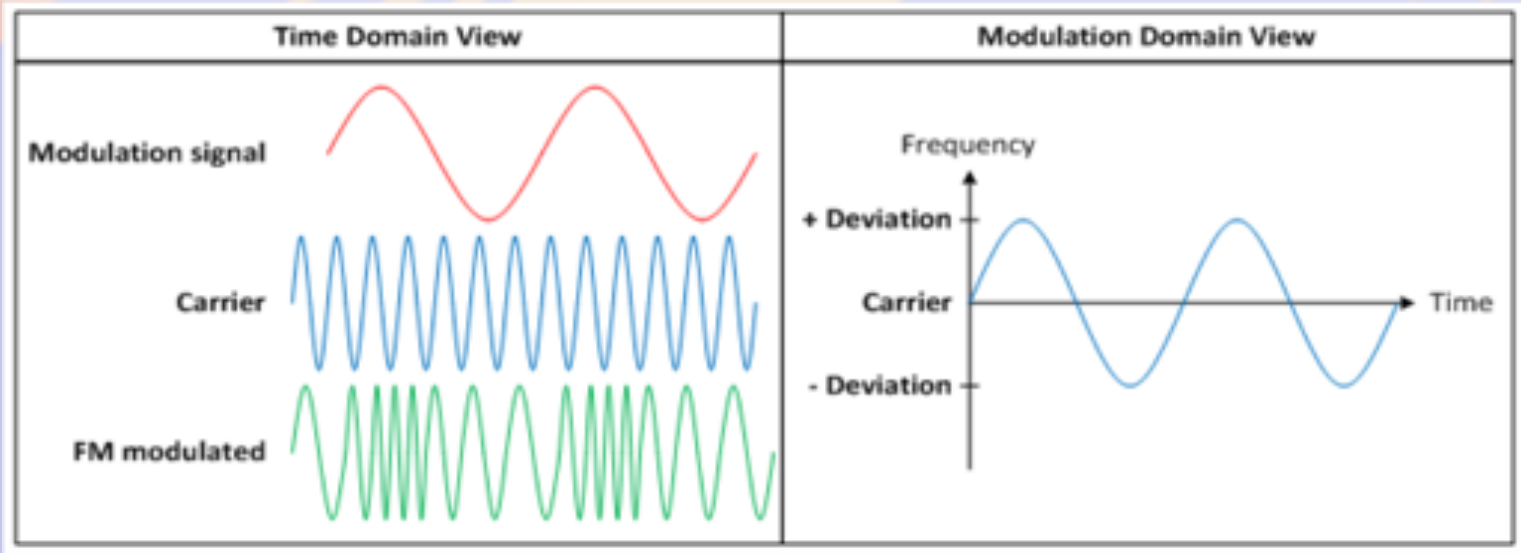
- Frequency deviation is used in FM radio to describe the maximum difference between an FM modulated frequency and the nominal carrier frequency
- We have all heard radios with very low deviation on the local repeater
  - Why? What is wrong?

Analog Problem

Mic Gain

- How much audio you apply to the radio modulation circuit
  - Is this also a problem with digital?

Analog and Digital Problem



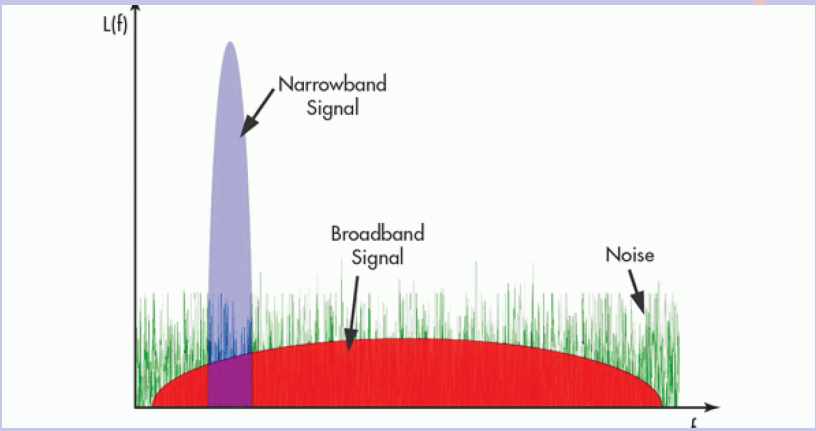
Bandwidth and Emission Mode

Emission Mode *from Wikipedia*

The International Telecommunications Union uses an internationally agreed system for classifying radio frequency signals. Each type of radio emission is classified according to its bandwidth, method of modulation, nature of the modulating signal, and type of information transmitted on the carrier signal. It is based on characteristics of the ***signal****, not on the transmitter used.*

Modulation	Emission Designator
Analog FM (wideband)	16K0F3E
Analog FM (narrowband)	11K2F3E
DMR (TRBO)	7K60FXE
D-STAR (Digital Voice)	6K25F7W
P25 Phase 1	8K10F1E
P25 Phase 2	9K80D7W
NXDN	8K30F1D
System Fusion	???

Bandwidth



Repeater Performance

Audio quality

- Flat versus Emphasized
- Speaker versus Discriminator
- The infamous 1000Hz tone at 3 kHz deviation
- It’s not rocket science … set your audio levels so everything is flat
- Use test equipment (covered in the next few slides)

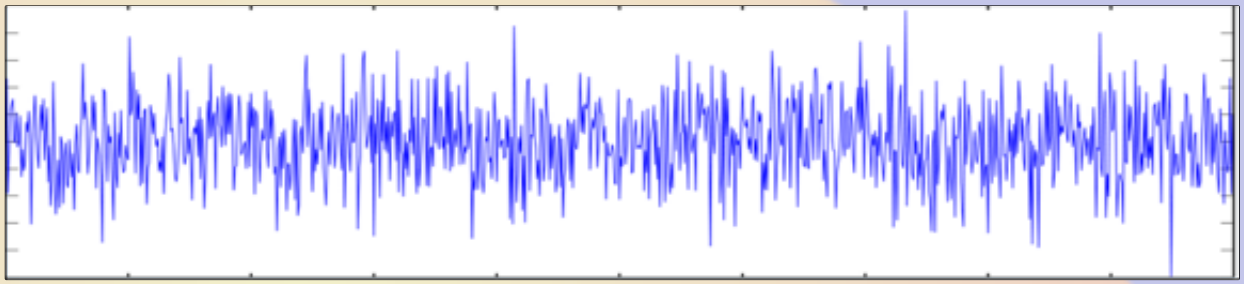
I can’t stand crappy audio!

Receiver Audio

3000-5000 Hz

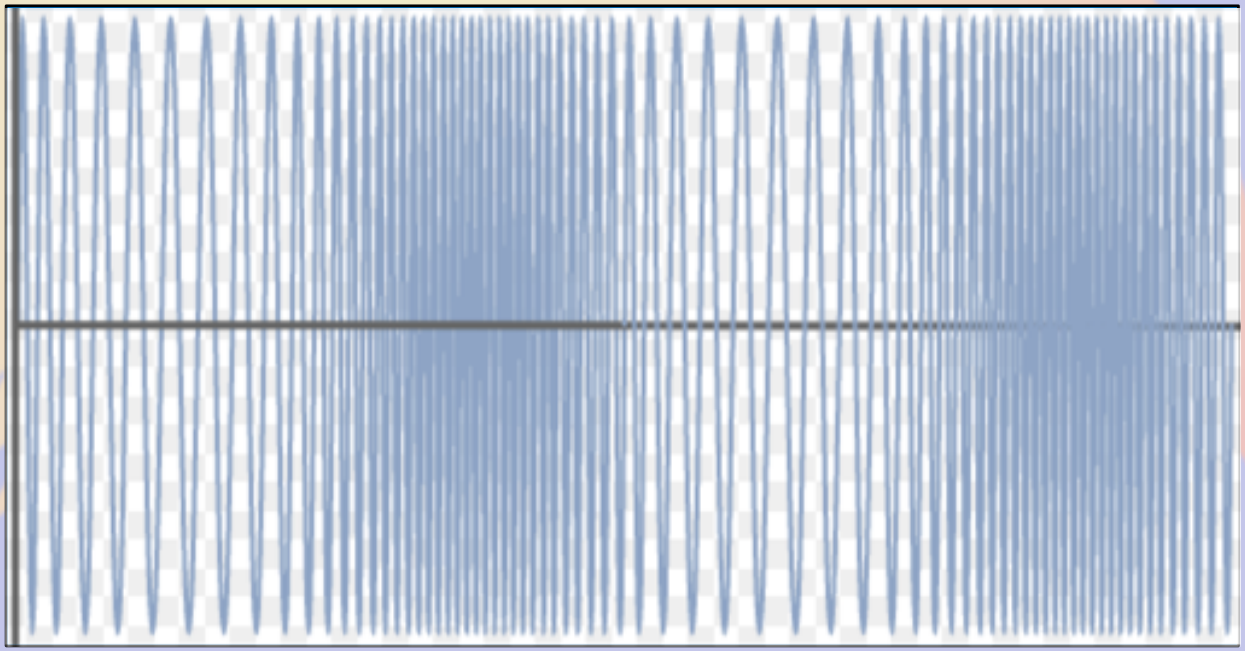
Squelch and

Signal to Noise



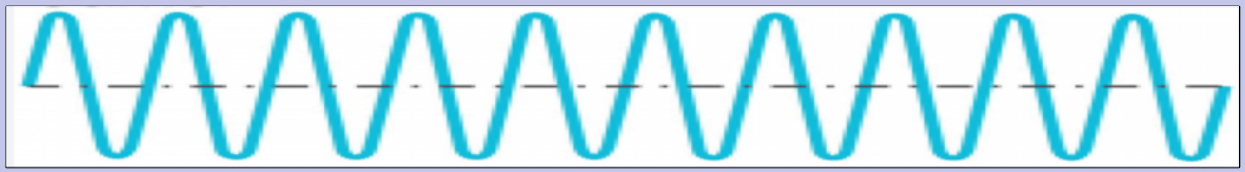
Voice

300 – 3000 Hz



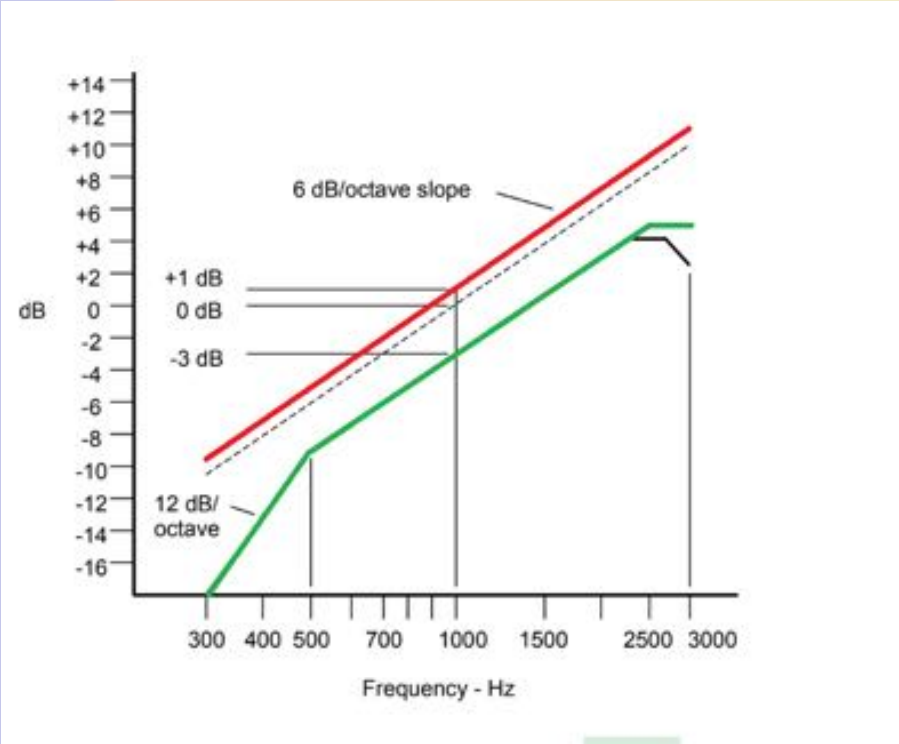
CTCSS Signaling

67.0 – 250 Hz

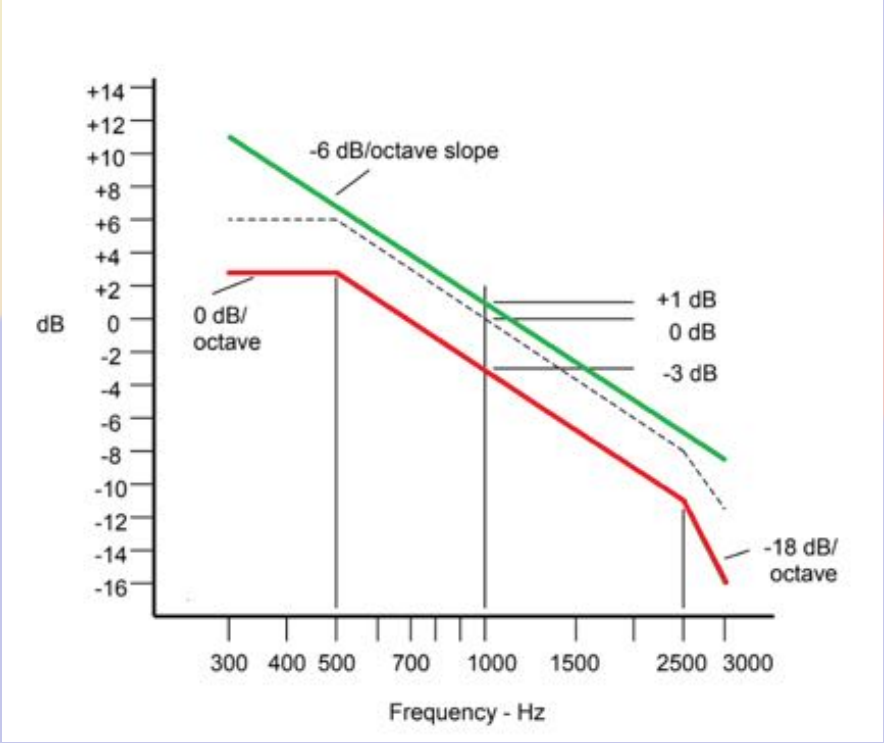


Emphasis and Deemphasis

- Analog FM Transmitters send audio as Emphasized audio
- The Analog FM Receiver de-emphasizes the audio for the user
- Why not send “flat audio” over the radio?



A graph of Emphasized Audio by DJ0WH



A graph of De-emphasized Audio by DJ0WH

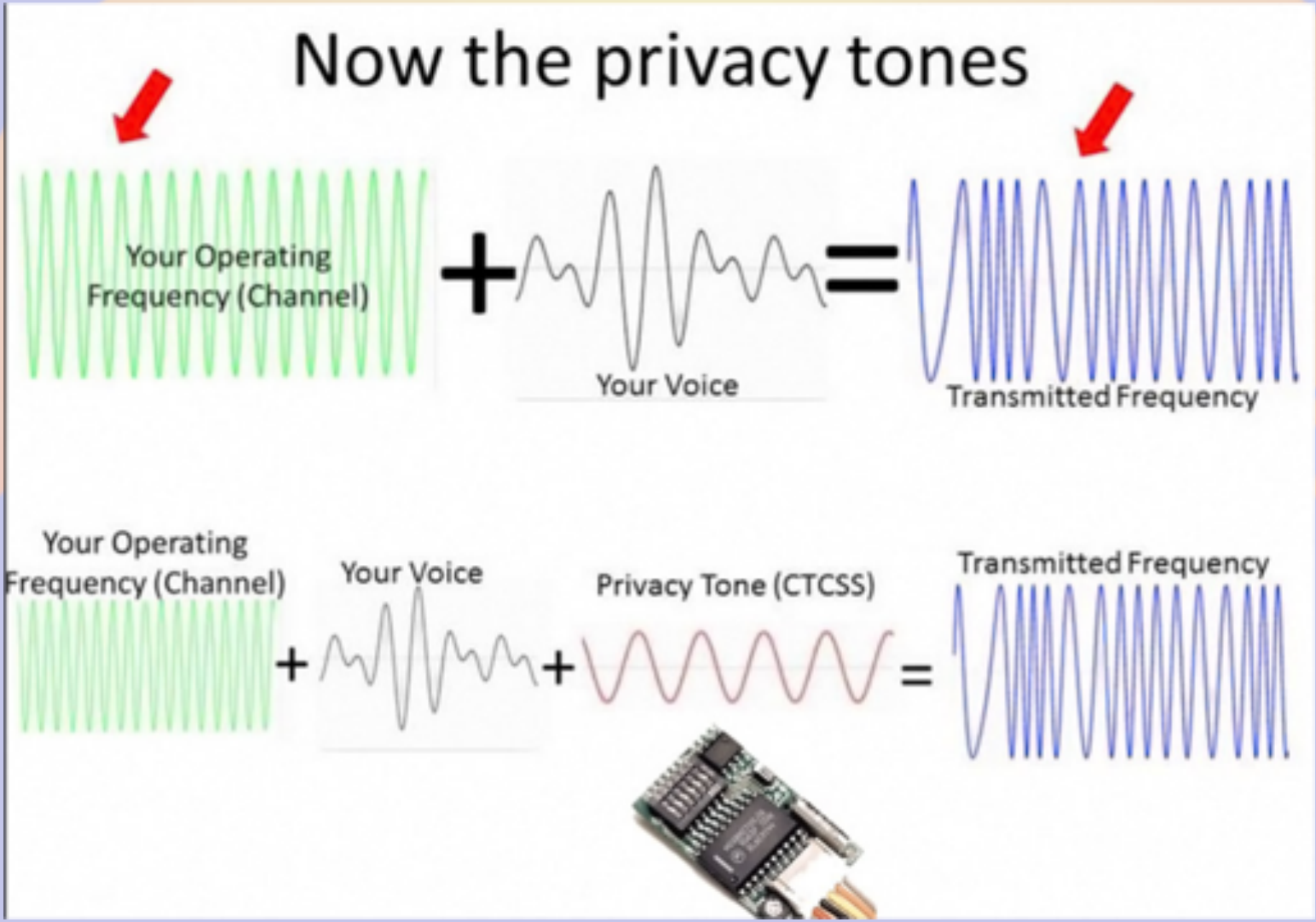
Repeater Performance

Signaling (Carrier, CTCSS, DTCSS, Digital Code)

- Carrier Squelch repeaters are for rookies
- CTCSS is a minimum (Decode and Encode)
  - PL
  - Channel Guard
  - Quiet Channel
- DTCSS is also becoming commonplace
  - DPL
  - Digital Channel Guard

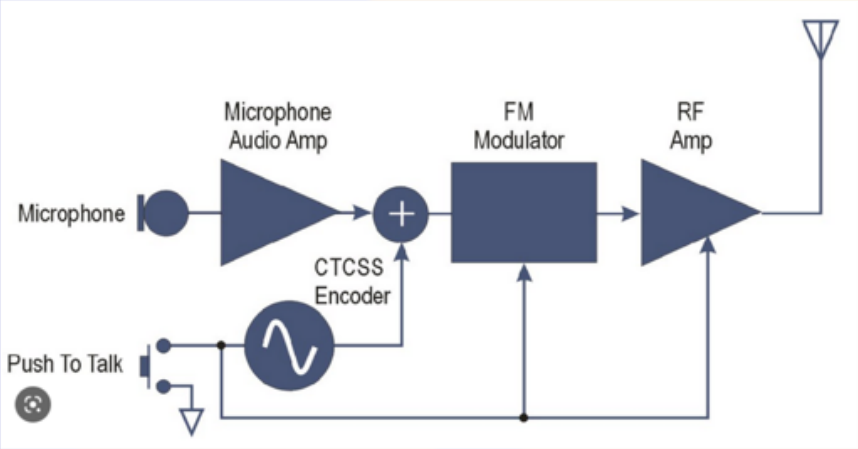
CTCSS Encode

A nifty graphic borrowed from Com-Spec.com

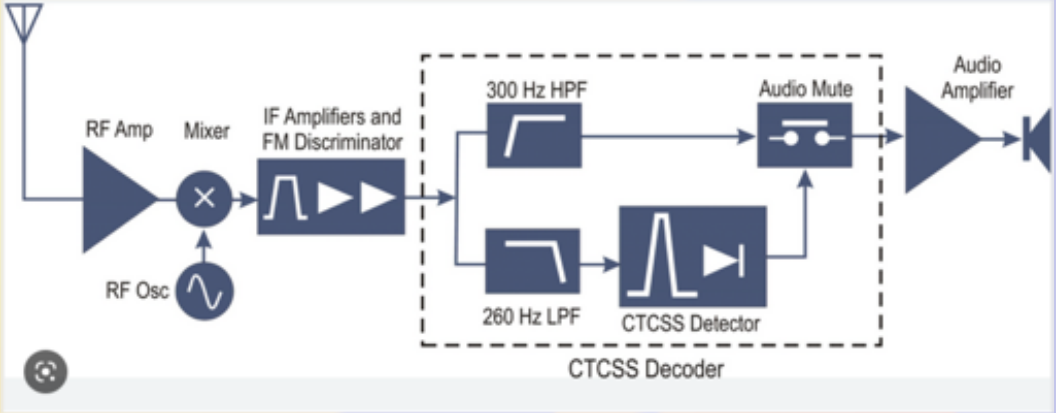


Some Nice CTCSS Diagrams

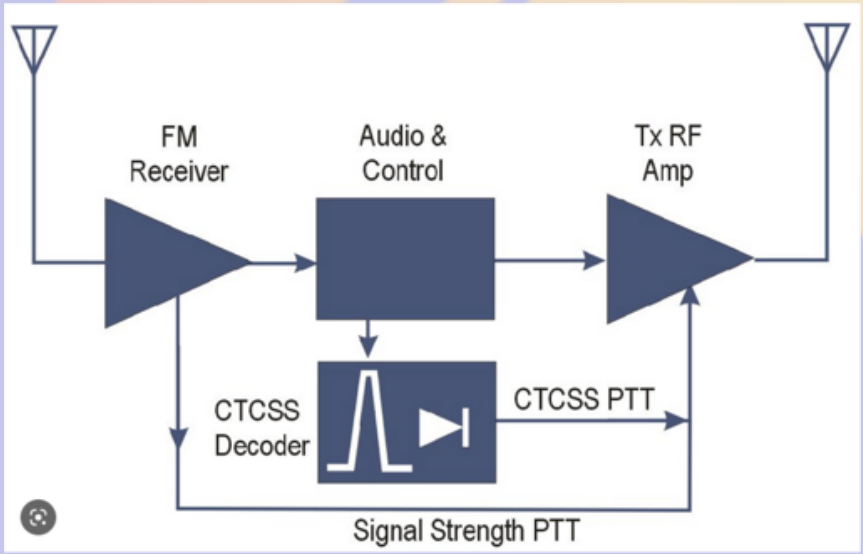
Credit to ZL2PD



Mic Audio and CTCSS transmitting using a single input



An example of a CTCSS Decoder



Mic Audio and CTCSS transmitting using dual inputs

Some things to think about

- Will your CTCSS Decode tone be passed from your receiver to your transmitter?
- Does the CTCSS tone “pass-thru” as a clean tone at the proper level or deviation?
- Maybe I should encode my own CTCSS tone on my transmitter?
- What if I use a “split tone” like Colorado Connection?

Repeater Performance

What important to consider?

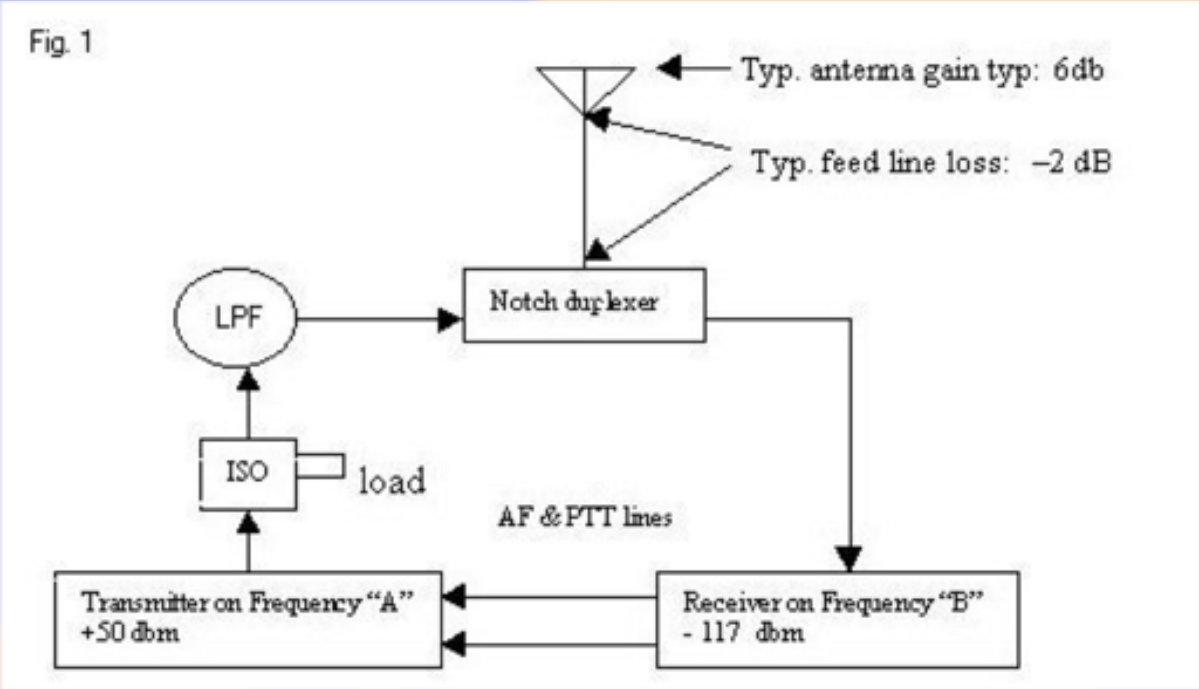
- Transmitter power
- Receiver sensitivity
- Repeater De-sense
- Noise Floor
- Audio quality
- Signaling (Carrier, CTCSS, DTCSS, Digital Code)

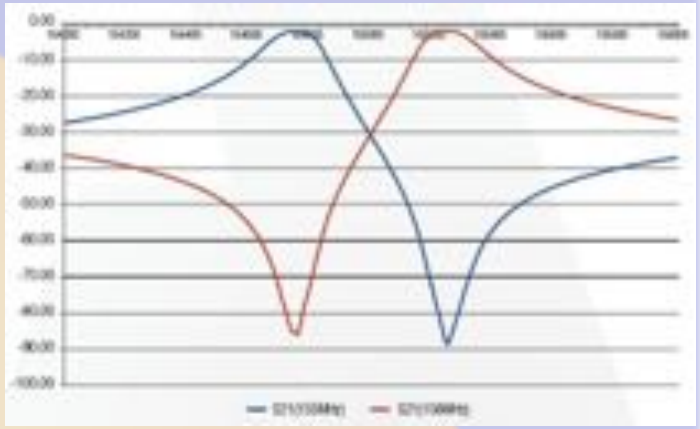
Repeater Performance

What important to consider?

- Transmitter power
  - More is not always better
  - You can do a lot with only 10-25 watts
  - Don’t cook people with high power and low antennas
- Receiver sensitivity
  - Receiver performance is king!
  - No one likes an “alligator repeater” that is deaf
  - Please build elephants

System Isolation



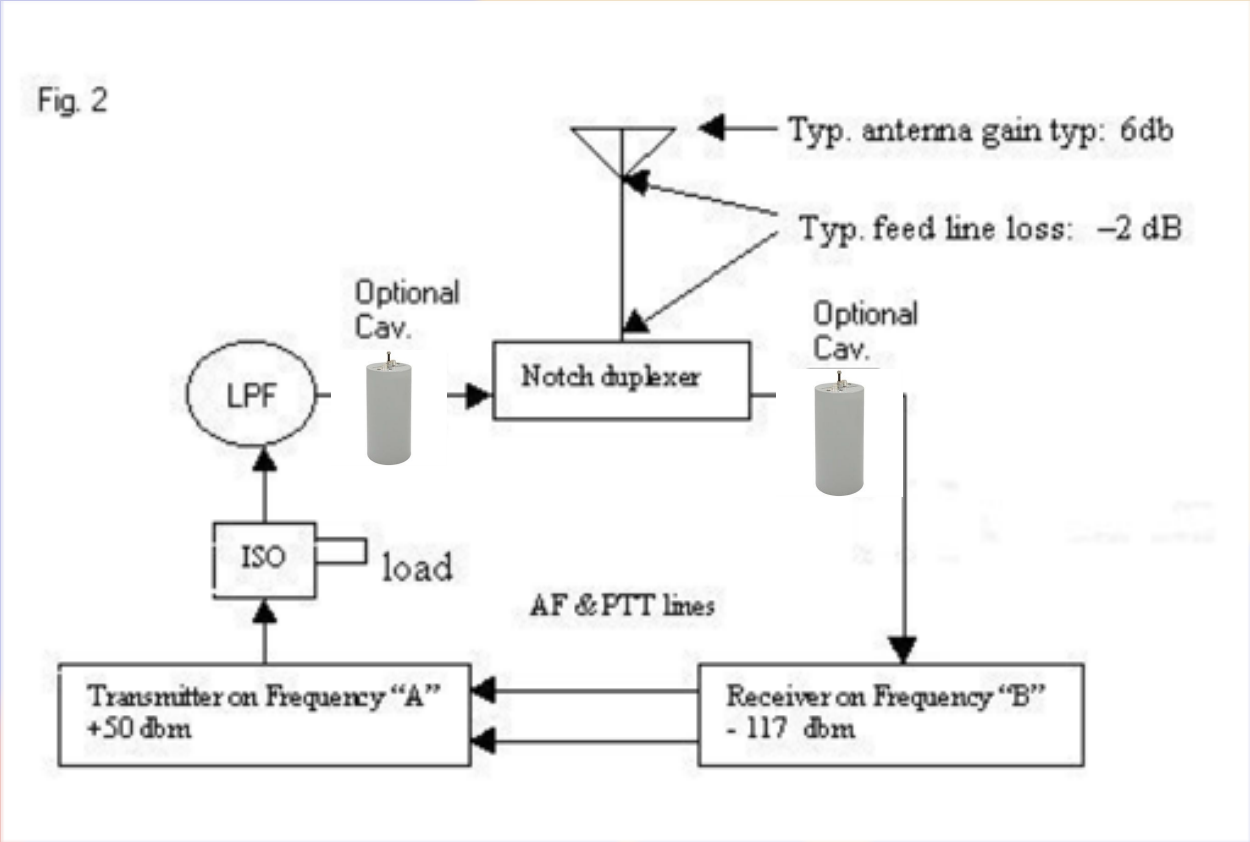


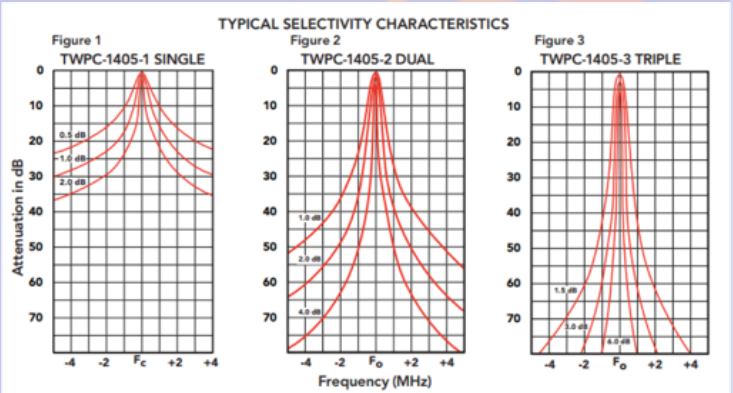
- You need a duplexer with sufficient performance to isolate your transmitter from your receiver

- Sometimes a "Mobile Duplexer" is sufficient
- In most cases you will need a traditional full-size Duplexer

Graphic from: Repeater Builder article "**Receiver desense testing by Karl Shoemaker, AK2O"**

More System Isolation

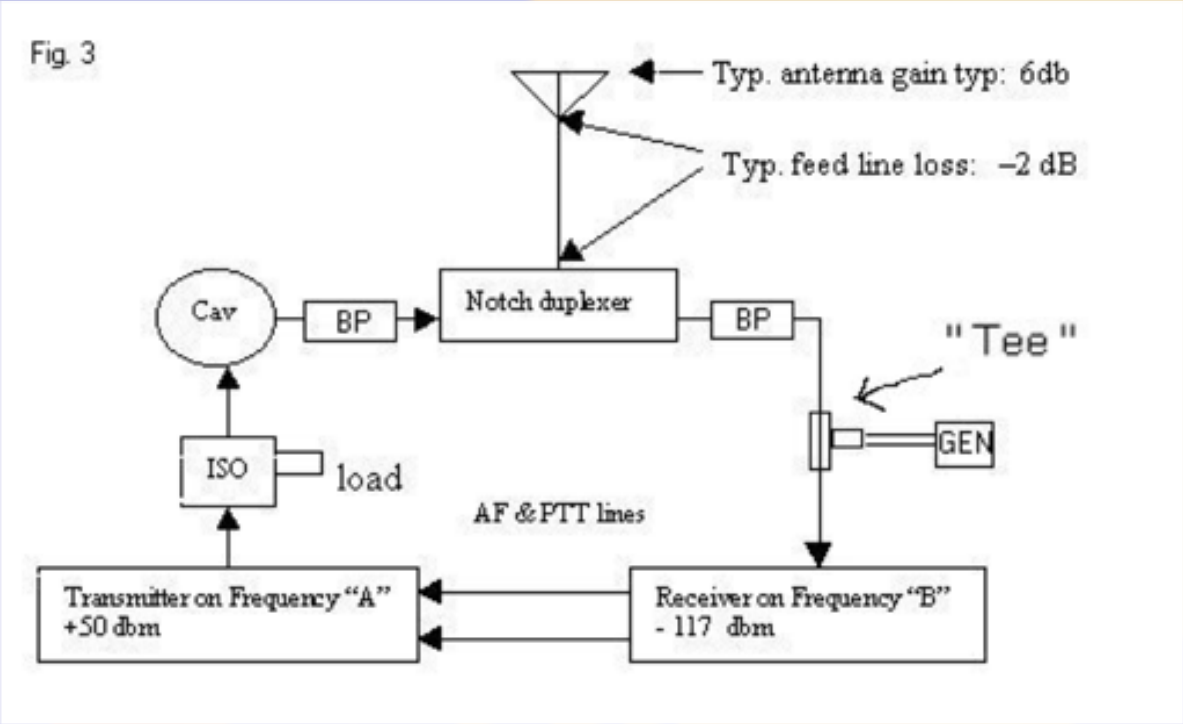


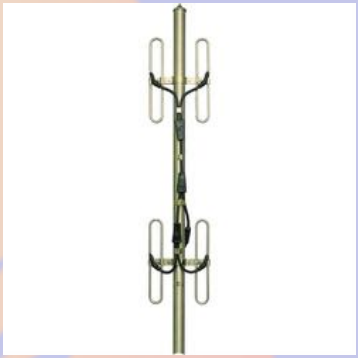


- Sometimes you need just a little more isolation
- So add a bandpass cavity

Graphic from: Repeater Builder article "**Receiver desense testing by Karl Shoemaker, AK2O"**

System Performance





- First - Disable your transmitter, connect a dummy load in place of the antenna, and measure receiver sensitivity
- Second - With the transmitter disabled, connect the antenna, repeat sensitivity measurement
- Last, Enable your transmitter, and measure receiver sensitivity

- Did you record the same sensitivity measurement each time? If not, you have a problem!

Graphic from: Repeater Builder article "**Receiver desense testing by Karl Shoemaker, AK2O**"

Repeater Performance

Noise Floor

- Not all repeater sites are created equal
- You want a low noise floor site
- When testing at my house I can measure a 20 dB difference in noise floor between 10’ AGL and 50’ AGL on VHF
- BAD - Thorodin Mountain has an approx 15 dB noise floor from the tower mounted antennas
- GOOD – Squaw Mountain has an approximate 1-2 dB noise floor on VHF

Test and Measurement Equipment

From a past RMHAM University by Bob Witte, K0NR

Why do we need electronic measurements?

- Bob's First Law of Electronic Measurement

  With electricity, most of the time we cannot observe what is going on without measuring instruments.

- Bob's Second Law of Electronic Measurement

  When we can observe electricity directly, it is often a bad thing.

Test Equipment

Analog and Digital versions

- Signal Generator
- Spectrum Analyzer
- Service Monitor
- Oscilloscope
- Volt Meter

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Repeater Interfaces for $800

- Analog Controllers
- Analog Controllers that speak IP
- Digital Controllers
- Mixed Mode Controllers

Repeater Interfaces for $800

- Analog Controllers

Just add programming and you are on the air

Inputs
- Receiver Audio
- Carrier Sense
- CTCSS / DTCSS Decode
- Logic Inputs
- + 12VDC

Outputs
- Transmitter Audio
- Push to Talk
- CTCSS / DTCSS Encode
- Logic Outputs

Repeater Interfaces for $800

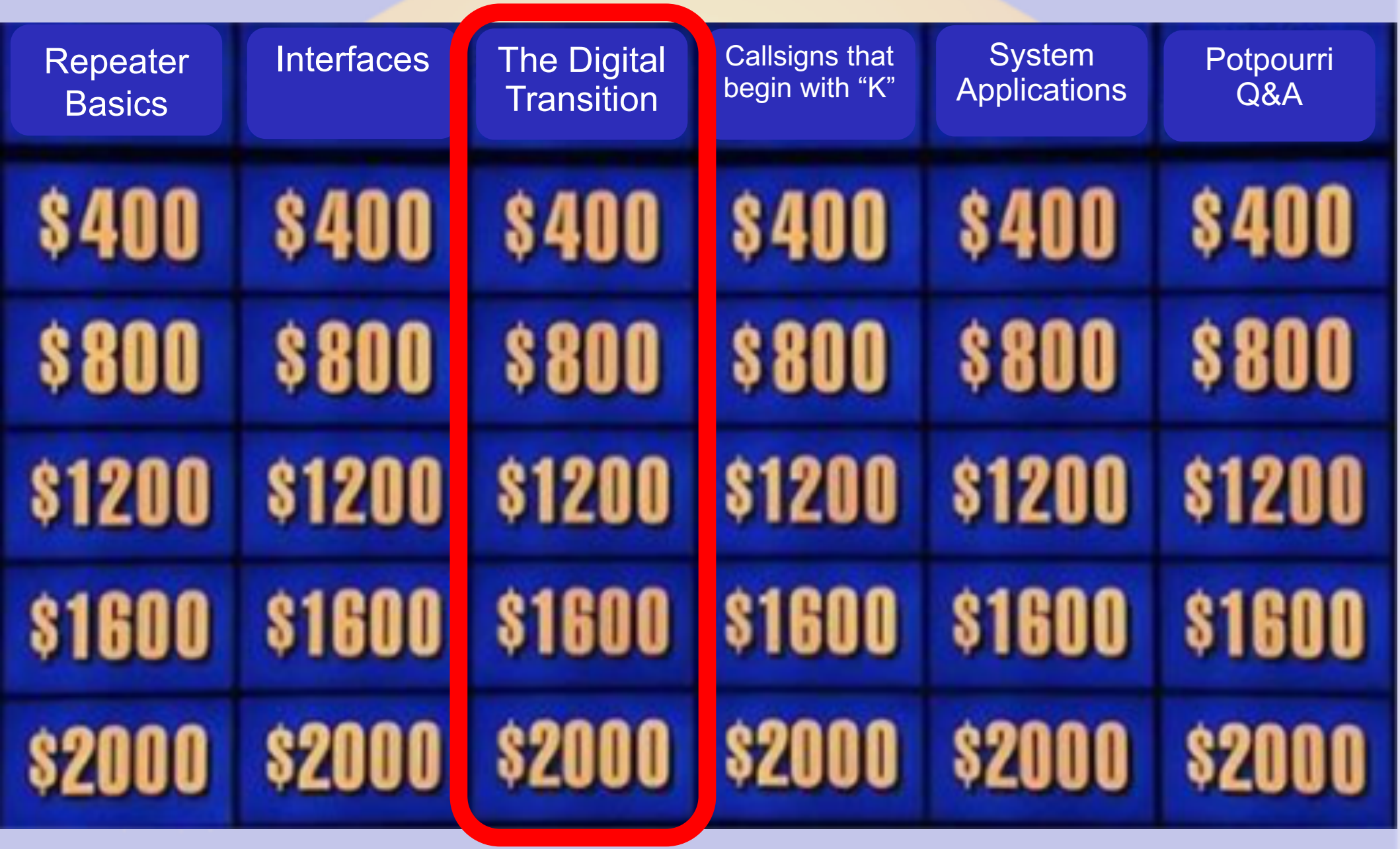
Analog Controllers that speak IP

- Simple to interface
- Somewhat complicated to program
- Requires additional server/controller components
- RTCM supports receiver voting

Inputs
- Receiver Audio
- Squelch (RTCM internal SQ)
- CTCSS / DTCSS Decode
- + 12VDC

Outputs
- Transmitter Audio
- Push to Talk
- CTCSS Encode

What are we going to cover today?



The Digital Transition for $1200

Why Digital?

- Modern technology
- Less Noise
- Easier to extend range with linking
- Why not?

Why are you talking about digital repeaters when tonight we are discussing Analog repeaters?

The Digital Transition for $1200

FDMA vs TDMA vs CDMA

- Frequency Division Multiple Access
  - Analog FM
  - D-STAR, Fusion, NXDN, P25 Phase 1
- Time Division Multiple Access
  - DMR (TRBO), P25 Phase 2
- Code Division Multiple Access
  - Not many ham systems … but Broadband data, cellphones

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Callsigns that begin with the letter K

Who is K2AD?

A quick break to acknowledge everyone participating tonight

What clubs, groups and individuals are participating tonight?

- Approximately 45 individual participants

Representing

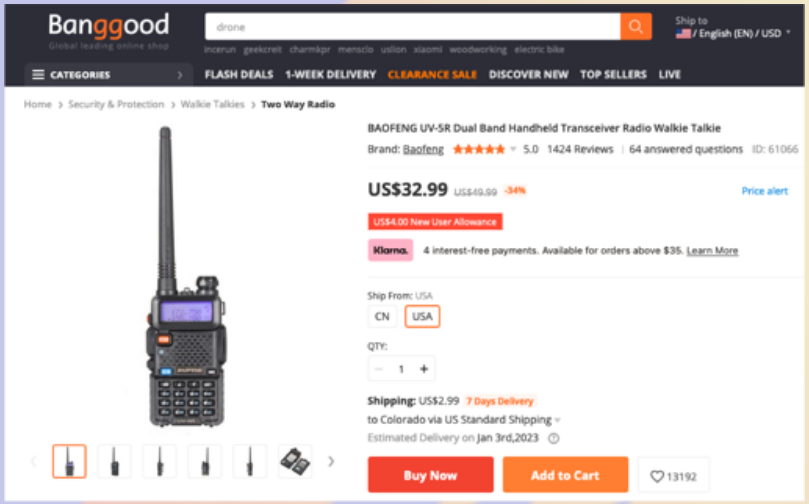
- Aurora Repeater Association – N0ARA
- Colorado Connection – KB0VJJ
- Colorado Repeater Association – W0CRA
- Fun Machine Repeater System – WE0FUN
- Longmont ARC – W0ENO
- Northern Colorado ARC – W0UPS
- Rocky Mountain Ham Radio – N0SZ

and of course, your host Doug, K2AD

along with Technical Directors Mark, N7CTM and Dave, WA1JHK !

Crap Radios ?!?

Weak signals and poor audio is common when a majority of your users are running around the state with a piece of crap in their hand!



- You get what you pay for
- Spectral purity is lacking
- Transmit audio is usually low

- I’m not sure this bang was very good?

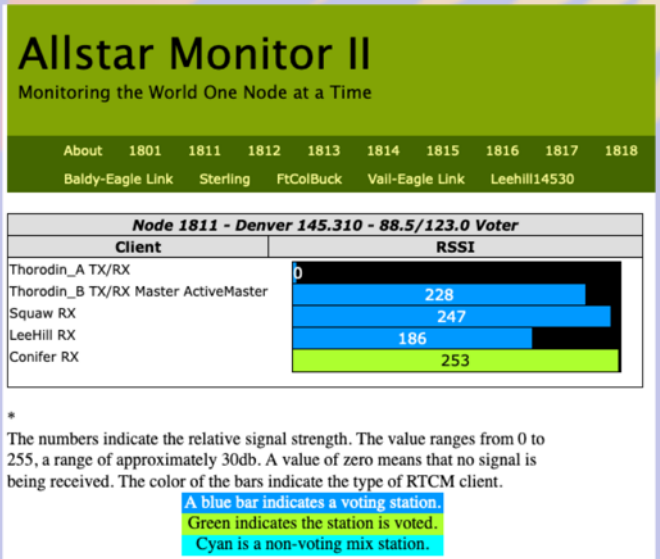
Let me see if I can improve my signal

No wonder you sound like dog squeeze

Receiver Voting

- Receiver Voting can improve in-bound repeater coverage
- Deploy multiple receivers across your coverage area
- The strongest receiver is automatically selected every 20 milliseconds, and sent to the transmitter

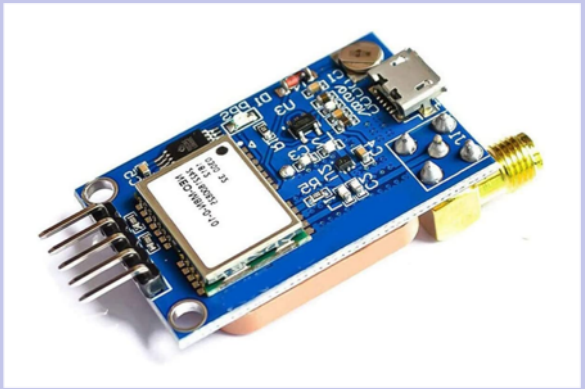
- Voting is good
- But it requires an accurate GPS reference
- And also requires a low latency IP backhaul link

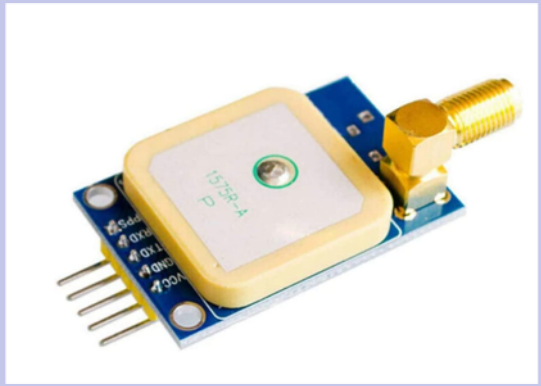


GPS Receivers

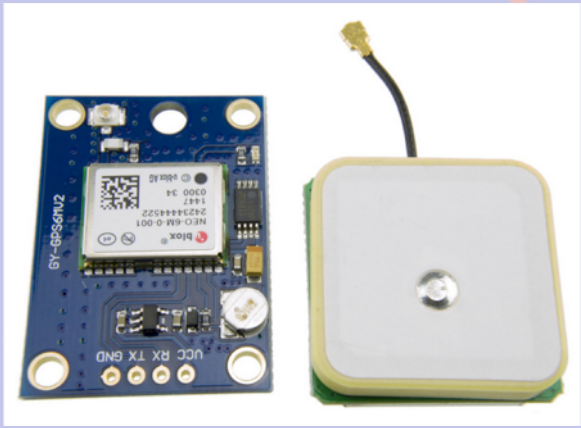
- Voting requires an accurate GPS reference
- Why?
  - Incoming receiver signals are digitized and sent over the IP link to the Voting Comparitor
  - We need to align all these packets to select the receiver with the highest Signal to Noise Ratio
- We are still trying to find the best GPS reference for our ColCon sites
- The GPS reference must have both Serial Data and 1PPS signals

This is the GPS we are trying to package and deploy
… but we are having some issues





This one not so good.
Does anyone know why?



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System Applications for $2000

Use Case examples

Repeater Equipment

- GE MASTR II & III
- Kenwood TKR
- Motorola MTR2000
- A couple of mobiles

Controllers

- RTCM
- URI-X
- SCOM 7330
- MMDVM

I should be able to connect anything to anything. Right?

Maybe … but anyone can build just one.

System Applications for $2000 Repeater Interfaces

Receiver

- +DC Voltage
- Ground
- Receiver Audio
  - Emphasized vs Deemphasized
  - Squenched vs un-squelched
- Carrier Activity
  - COR
- Tone signaling
  - CTCSS Decode

Transmitter

- +DC Voltage
- Ground
- Transmit Audio
  - Flat audio
- Push to Talk
  - Logic signal, often active low
- Tone signaling
  - CTCSS Encode

SCOM 7330 to almost anything

- It just works
- Connect your radio
- Program
- You are on the air!

Inputs
- Receiver Audio
- Carrier Sense
- CTCSS / DTCSS Decode
- Logic Inputs
- + 12VDC

Outputs
- Transmitter Audio
- Push to Talk
- CTCSS / DTCSS Encode
- Logic Outputs

Kenwood TKR750/850 to RTCM

Interfacing the Kenwood TKR750/850 to the RTCM

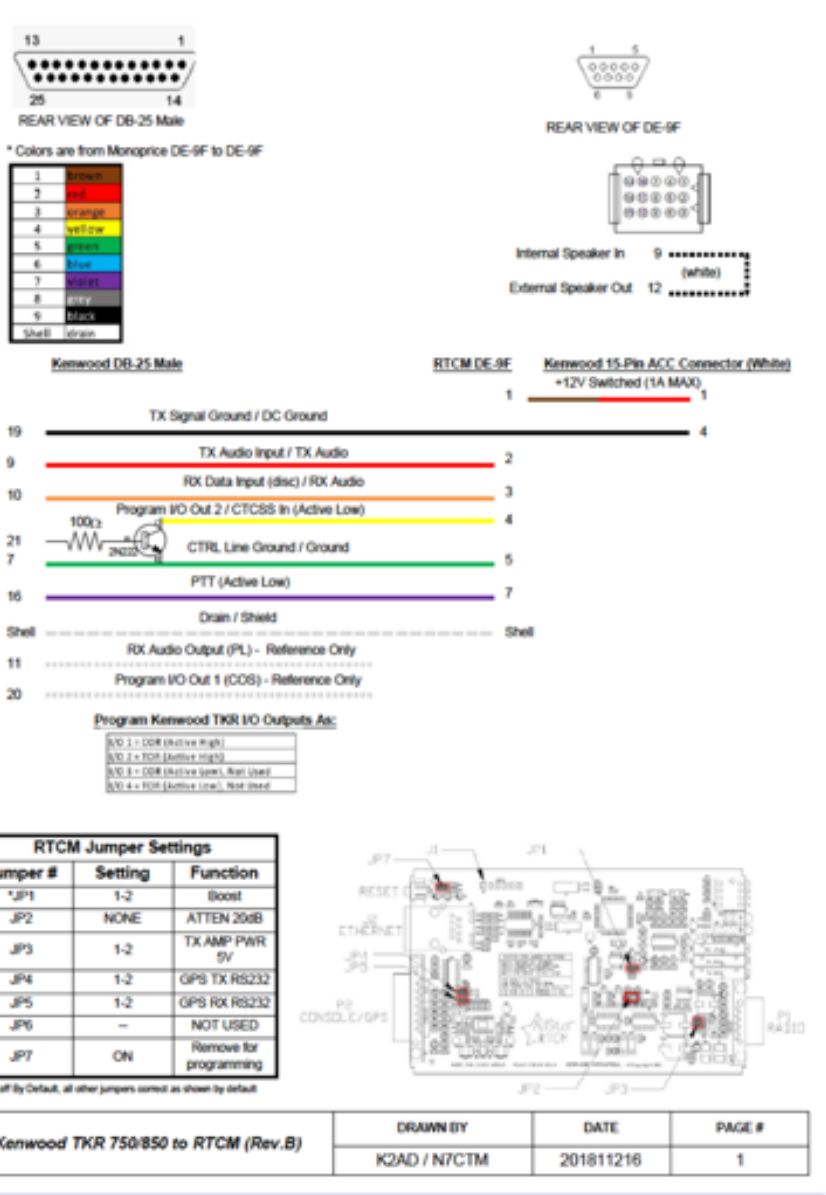
- This should be easy!
- Just connect
  - Receiver Audio
  - PL
  - Transmit Audio
  - PTT
- It should just work. NOPE!!!

What went wrong?

- The Carrier and CTCSS lines were not properly signaling the RTCM
- Found after the equipment was deployed

Solution:

- Add a buffer transistor to the CTCSS line
- Re-program repeater and RTCM
- Don’t make this mistake again



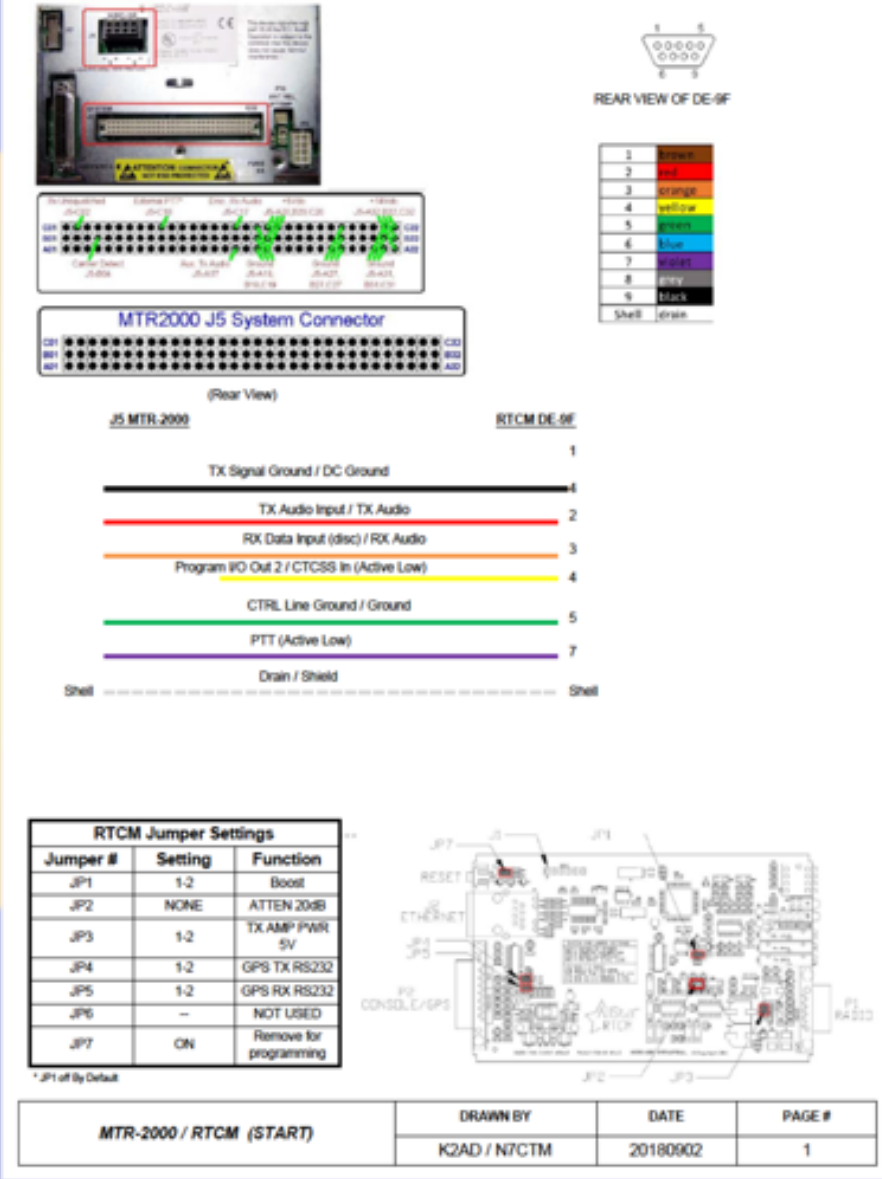
Motorola MTR2000 to RTCM

Interfacing the Motorola MTR2000 to the RTCM
- This should be easy! Have I said this before?
- Just connect
  - Receiver Audio
  - PL
  - Transmit Audio
  - PTT
- It should just work. NOPE!!!

What went wrong?
- Issue with TX audio “crackle”
- Issue with Encode CTCSS

Solution:
- Route TX Audio through line card input.
- Do not use Mic Input

- Decide how to generate CTCSS
  - CTCSS Encode from MTR2000?
  - CTCSS Encode from RTCM?



RTCM Jumper Settings		
Jumper #	Setting	Function
JP1	1-2	Boost
JP2	NONE	ATTEN 20dB
JP3	1-2	TX AMP PWR 5V
JP4	1-2	GPS TX RS232
JP5	1-2	GPS RX RS232
JP6	--	NOT USED
JP7	ON	Remove for programming

* JP1 off By Default

MTR-2000 / RTCM (START)	DRAWN BY	DATE	PAGE #
	K2AD / N7CTM	20180902	1

Motorola SLR5700 and MTR3000 to RTCM

Interfacing the Motorola MTR2000 to the RTCM
•Again, this should be easy!
•This is a new design repeater with DB25 option connector
•It should just work? NOPE!!!
•I'm glad I tested this before heading to the mountain

What went wrong?
- All seemed OK … until we looked using test equipment
- Issue 1: Encode CTCSS not following PTT
  - Encode CTCSS would change with RX audio
  - We could not find a way to have CTCSS Encode follow the Mic In and PTT
- Issue 2: Discriminator Audio dropped lick a rock at 3000Hz

Solution:
- Issue 1: Has a workaround
  - Inject the CTCSS Encode signal from the RTCM
  - Be sure to filter the RX CTCSS tone before passing it to the transmitter
- Issue 2: This is a showstopper
  - Without audio between 3000-5000Hz, the squelch circuit in the RTCM will not operate
  - Also the noise detector that is required for voting will not operate

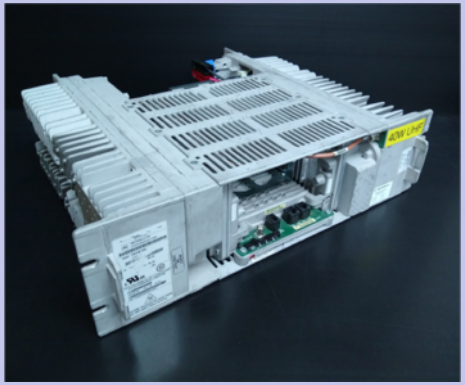
What will be “ColCon Repeater 2023?”

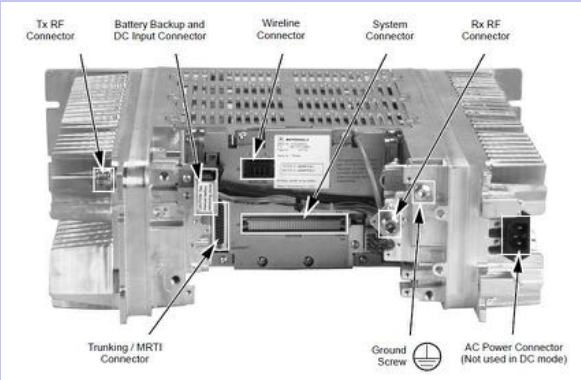
- ColCon has selected the Motorola MTR2000 for our future deployments

- Isn’t this repeater platform 20 years old? Yes.
    - It is a solid repeater
    - Available in quantity
    - And will interface with our current (and future) controllers
- Why not deploy the Motorola MTR3000 as did RMHAM?
    - MTR3000 was designed to be a digital repeater
    - It has issues with the Receiver Discriminator Audio above 3000Hz
    - Digital processing precludes Simulcast operation in the future
    - They are more expensive than MTR2000

- Our current GE MASTR III repeaters require 9 Rack Units (15.75”) rack space
- The Motorola MTR2000 deploys in 3 Rack Units (5.25”) rack space

- Built in to the MTR2000 is
    - Power supply with battery backup connection
    - Transmitter at 40 or 100 watts
    - Receiver
    - Basic repeater control cards including expansion card space





What is the Voter2 or Voter2K?

Voter2 (also called Voter2K) is Hardware and Software to evolve the RTCM while maintaining the current RTCM features

Hardware

- Our goal is to improve the RTCM hardware
  - Buffered Input and Output lines
  - External precision 10 MHz reference input
  - On-card filter for RX CTCSS tone
  - Newer and available microprocessor

Form Factor Goal

- One or two PWB cards that fit inside the MTR2000 card cage

Additional Features

- Interface to MTR2000 alarm logic signals
  - PA failure
  - High VSWR
  - AC power fail
- Possible serial interface for programming and debugging?

What are we going to cover today?

Repeater Basics	Interfaces	The Digital Transition	Callsigns that begin with “K”	System Applications	Potpourri Q&A
$400	$400	$400	$400	$400	$400
$800	$800	$800	$800	$800	$800
$1200	$1200	$1200	$1200	$1200	$1200
$1600	$1600	$1600	$1600	$1600	$1600
$2000	$2000	$2000	$2000	$2000	$2000

And the final Jeopardy! question

- What is “are we there yet?”
- Q&A
- Discussion

Thanks for attending de K2AD

Backup Material

Backup Material

Interfaces

Repeater Interfaces for $400

Mixed Mode Controllers

- Supports Analog XOR Digital operation
- Some commercial repeaters built-in as standard or optional equipment
- Possible to build from scratch?
  - Yes, likely but you have some system interface work to do

Backup Material

Digital Transition

The Digital Transition for $600

- Why Digital?
- FDMA vs TDMA vs CDMA
- Digital Modes
- Digital Test Equipment

The Digital Transition for $600

Digital Modes – Which is better?

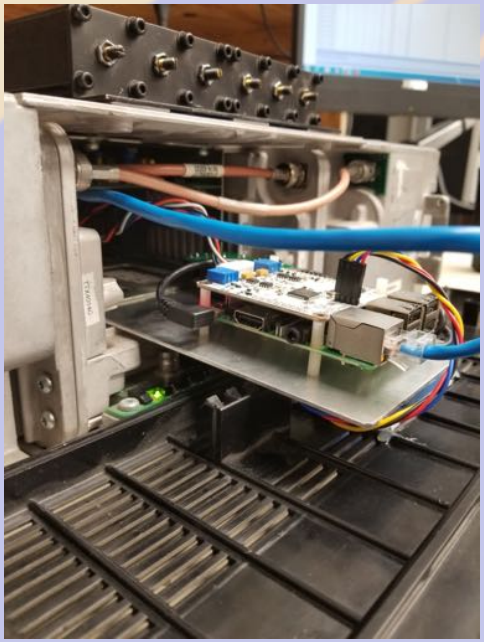
- They are just different
- Let's talk about this one

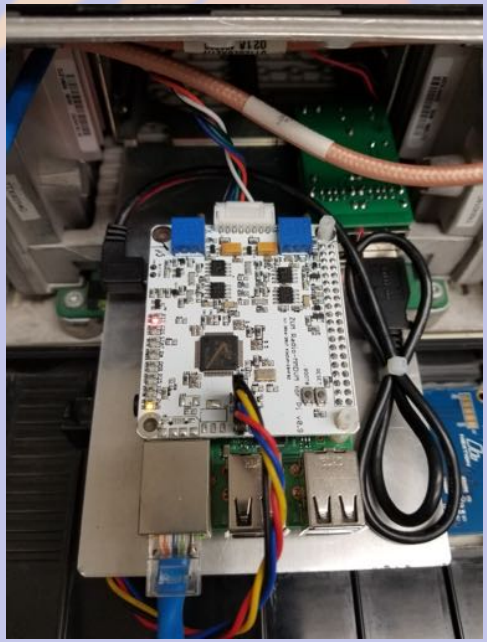
- And maybe build a bridge?
  - What if we had a bridge that allows DMR / D-STAR / NXDN / P25 and Analog to interoperate?
  - RMHAM has started building that bridge thanks to efforts by N0PKT, K0JSC and K0GUR. We need to continue this effort.

Repeater Interfaces for $400

Digital Controllers – MMDVM

- Inexpensive
- Piggy Back on Raspberry Pi
- Multiple Protocols
  - DMR
  - D-STAR
  - P25
  - NXDN
  - Fusion





MTR2000 to MMDVM (multi-mode)

Interfacing the MTR2000 to the MMDVM
•Information courtesy of K0GUR
•Connect MMDVM and rPi to the MTR2000
•Use rear backplane connector

What went wrong?
•Perhaps nothing
•Is it perfect interface? (levels and proper digital modulation)
•Not sure … but it works well

Future:
•Put this repeater on a digital service monitor
•Look at occupied bandwidth, eye pattern, and BER/FER
•Perform range testing
•Compare with an “indigenous repeater”
•Run analog desense test

The Digital Transition for $600

Digital Test Equipment

- There are a few pieces of digital test equipment out ther
- But they are expensive
- You can “get close” using analog equipment … but does close only win in the game of horseshoes?