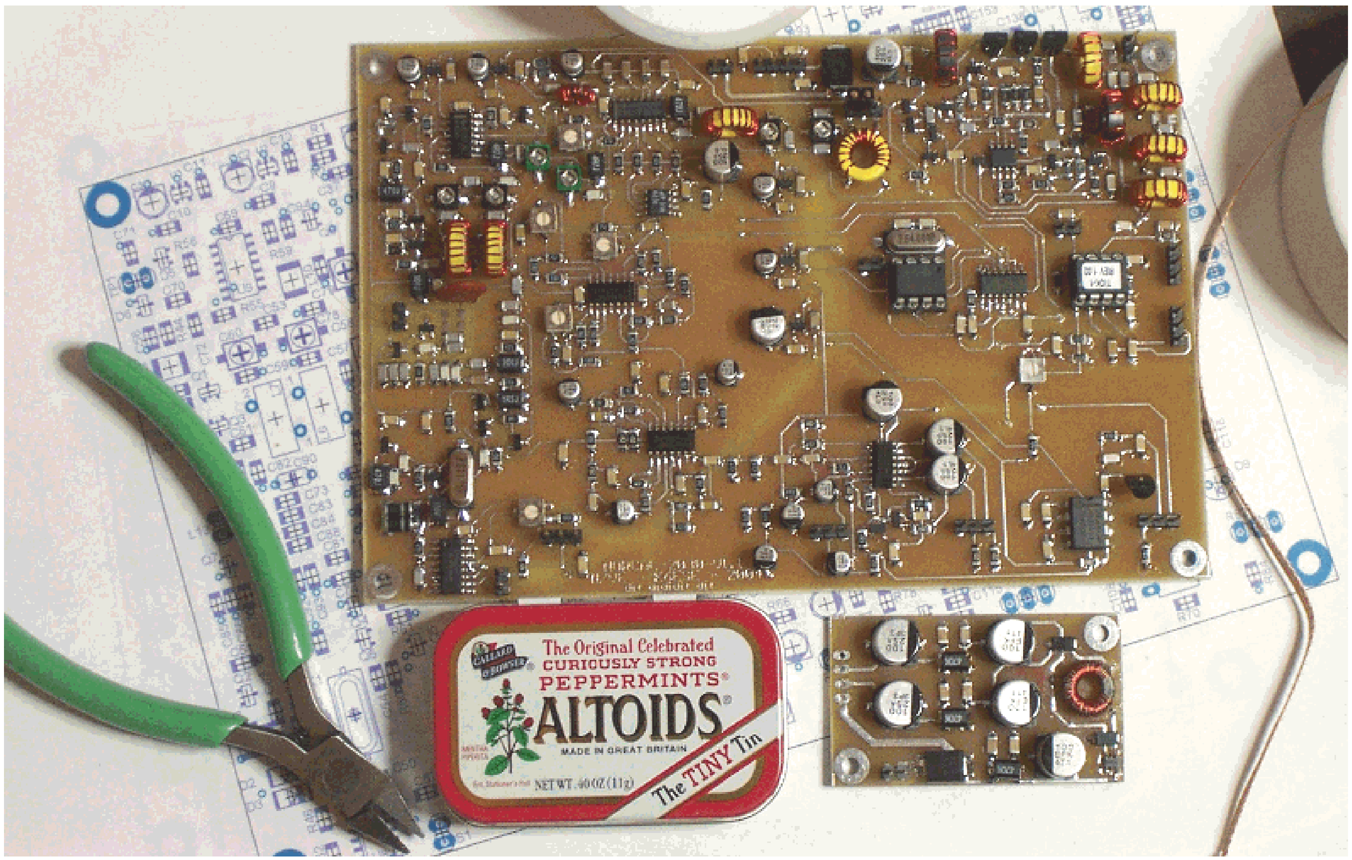
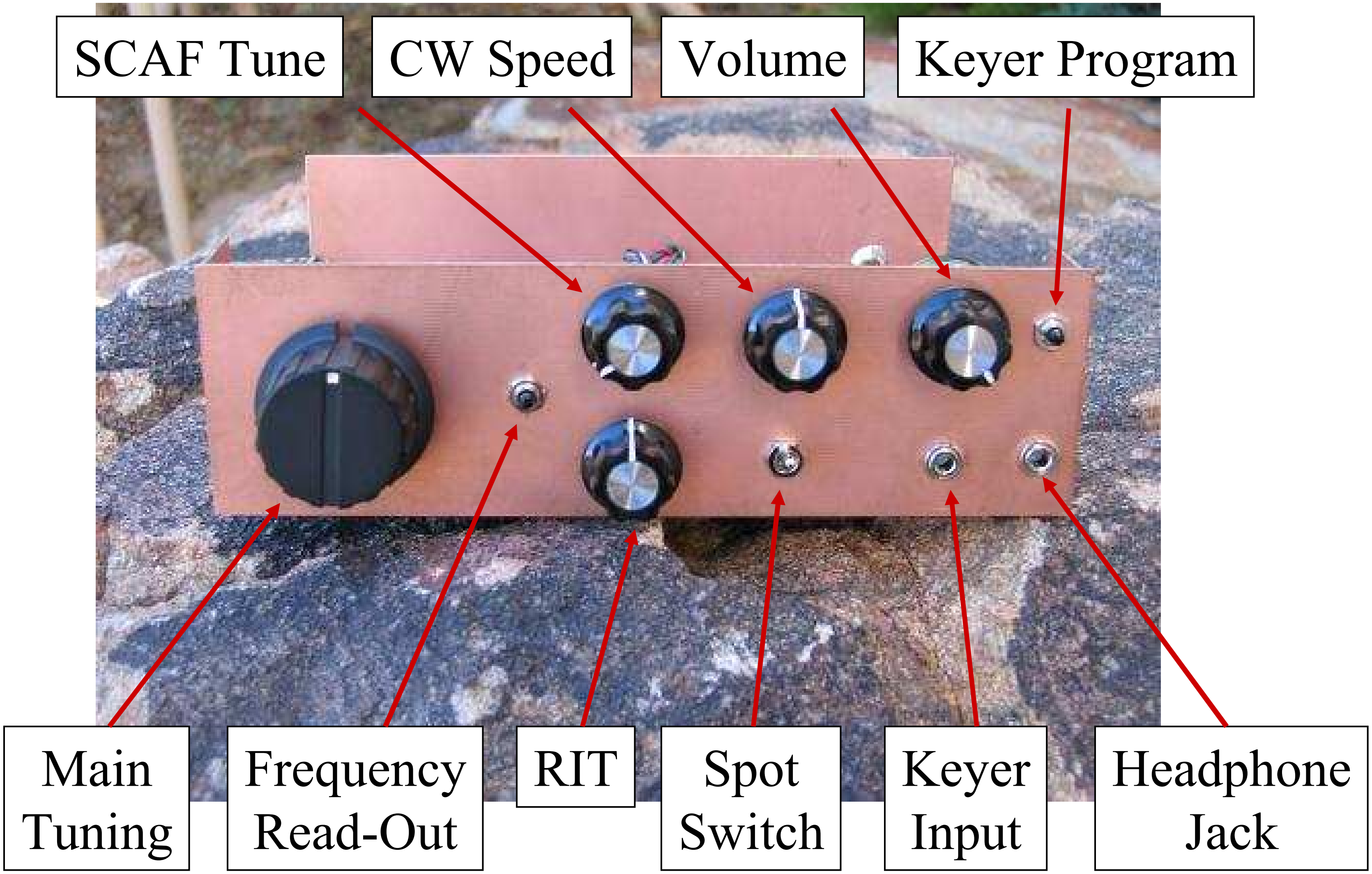
Very High Performance Image Rejecting Direct Conversion Receivers

Or how can an 11 ma receiver out perform the world's best ham transceivers?



Dan Tayloe, N7VE

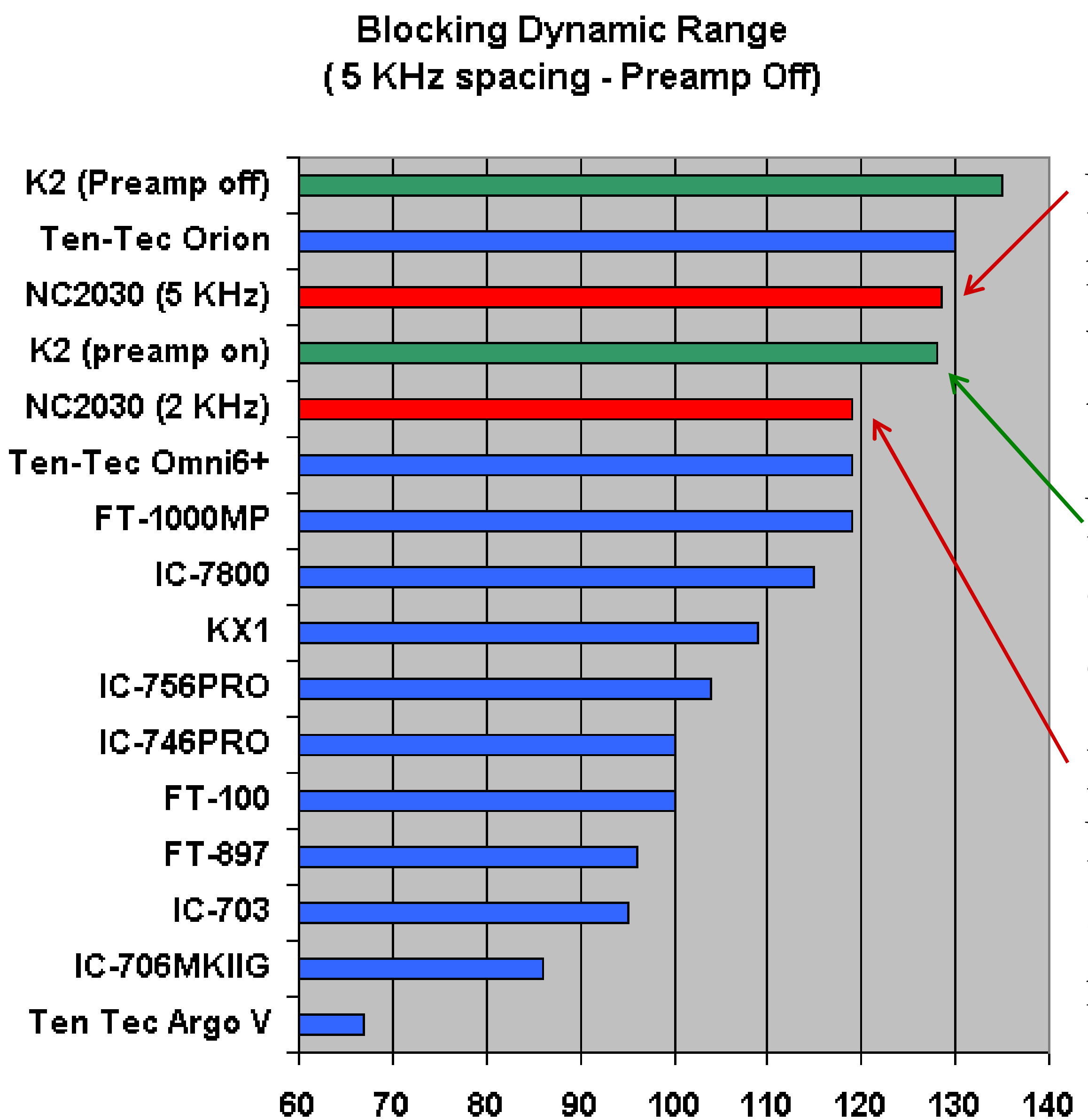
NC2030 20m Prototype



NC2030 Receiver Specs

- MDS (3db S+N/N): ***-135 dbm*** (0.1 uV)
- Receiver Bandwidth (-6db): ***350-800 Hz***
- IP3 DR: ***93db*** (2KHz), ***105 db*** (5 KHz), ***109 db*** (10 KHz)
- BDR: ***119db*** (2 KHz), ***128.5db*** (5 KHz), ***139db*** (10 KHz), ***142db*** (20 KHz)
- Image rejection: ~ ***>45 db over the band***
- Receiver current drain: ~***11 ma at 12v***

BDR: A Comparison – 5 KHz

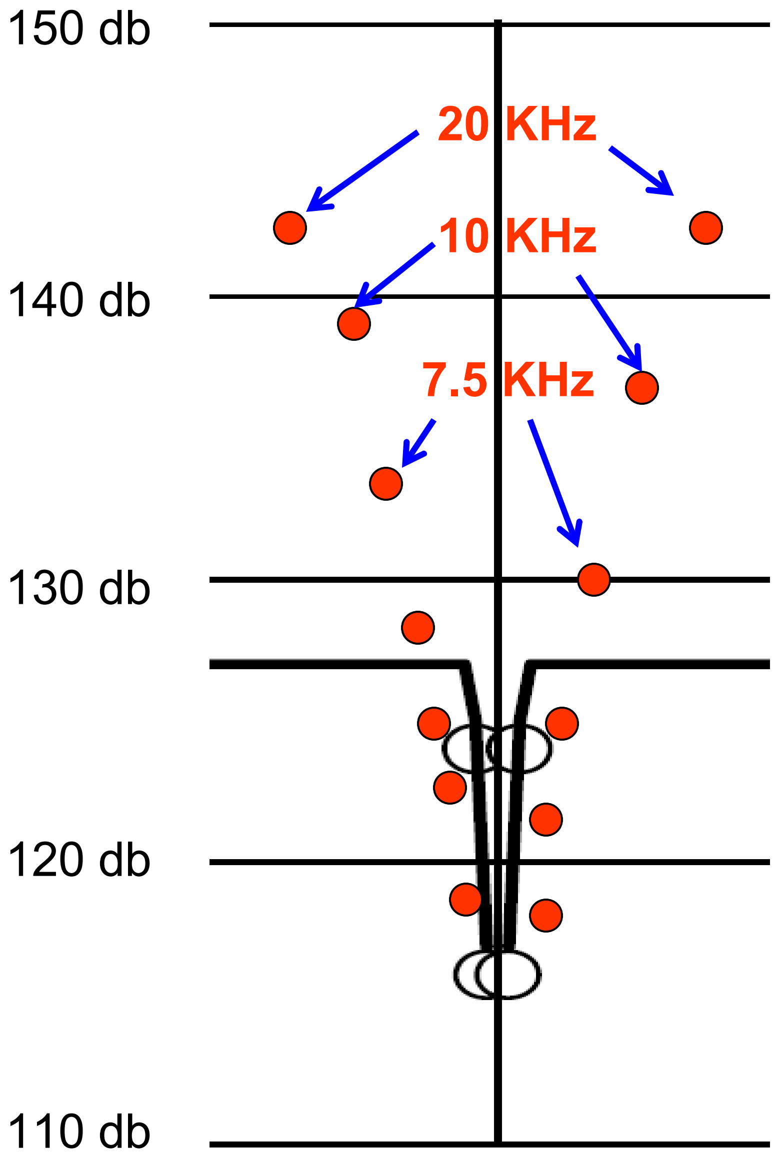


NC2030 ***at full sensitivity***, ranks among the best rigs which were measured with their RF pre-amps *off.*

Note: With the RF pre-amp on, the K2 suffers a 7 db degradation in blocking

Even at only ***2 KHz***, the NC2030 performs at least as well as all but two rigs measured at ***5 KHz***.

Blocking DR: A comparison (vs. K2)



***Extracted from QST K2 expanded report**

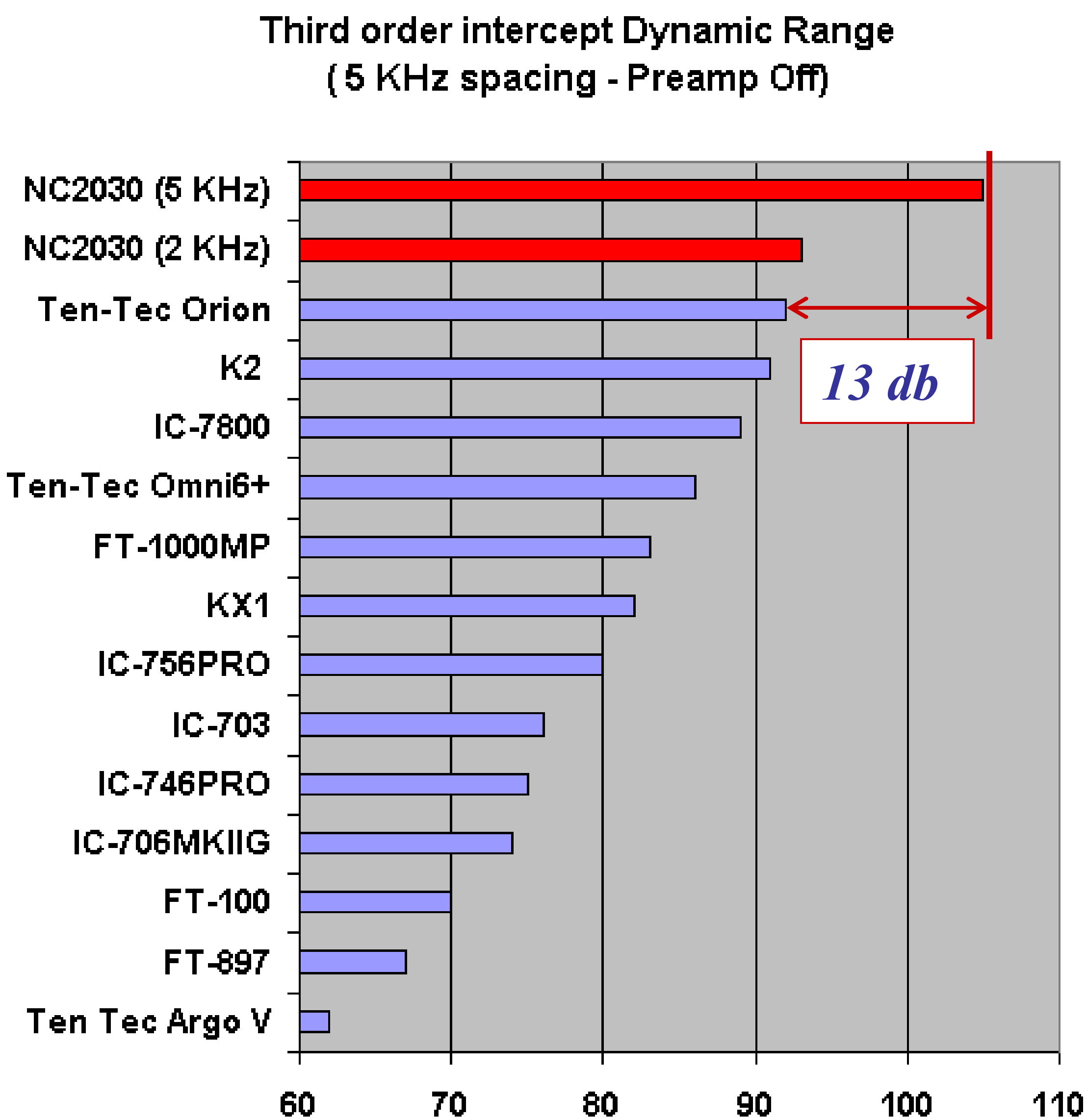
KHz	Low Side	High Side
2	119	
3	122	118
4	125.5	122
5	128.5	125
6	-	-
7	133	130
10	139	137
20	142	142

NC2030 Blocking DR does not plateau
- Rejection keeps improving

K2 plateau shows IF amp saturation
- Signals on the other side of the band (300+ KHz away) can still cause blocking

=> NC2030 blocking is a bit worse close in, much better further out

IP3DR: A comparison – 5 KHz

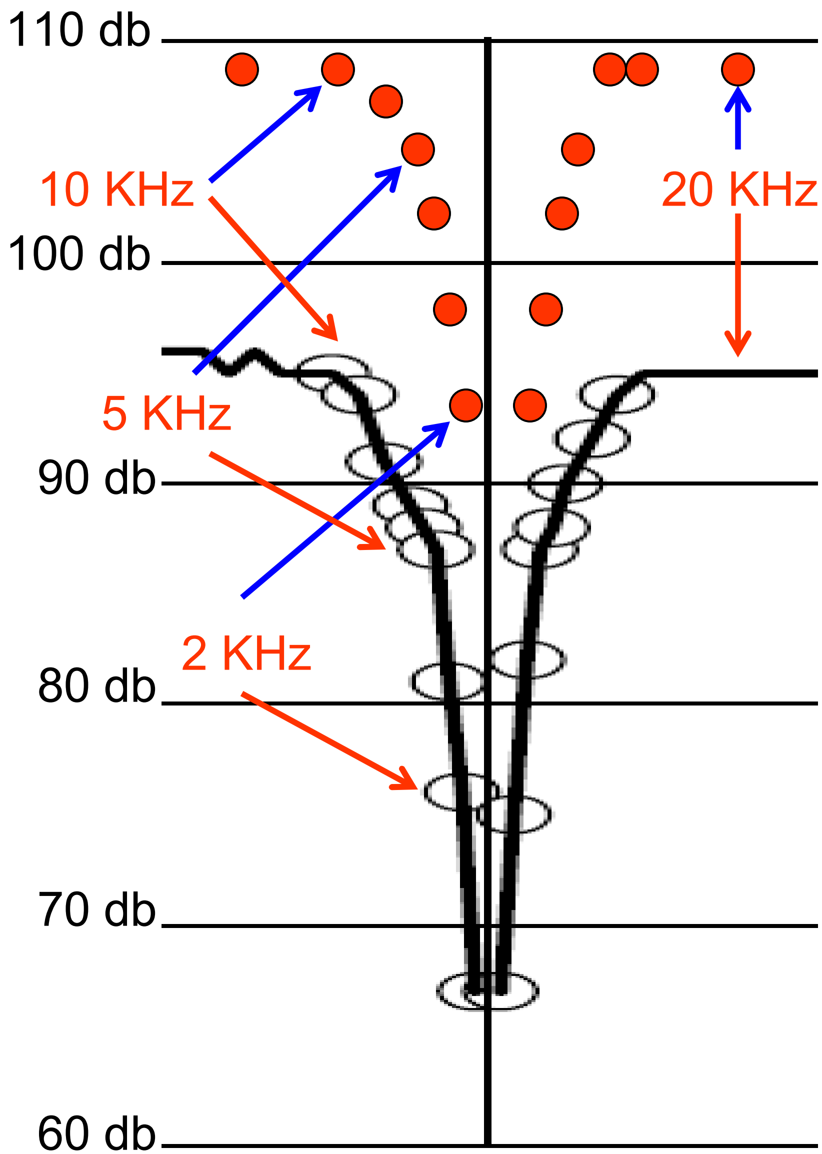


NC2030 at ***5 KHz*** is ***13 db*** better than the best.

NC2030 at ***2 KHz*** is still better than all the rest at ***5 KHz***.

Not a true apple-to-apples comparison since NC2030 is at ***full sensitivity*** while other rigs have ***pre-amps off***

IP3 DR: A comparison (vs. K2)



***Extracted from QST K2 expanded report**

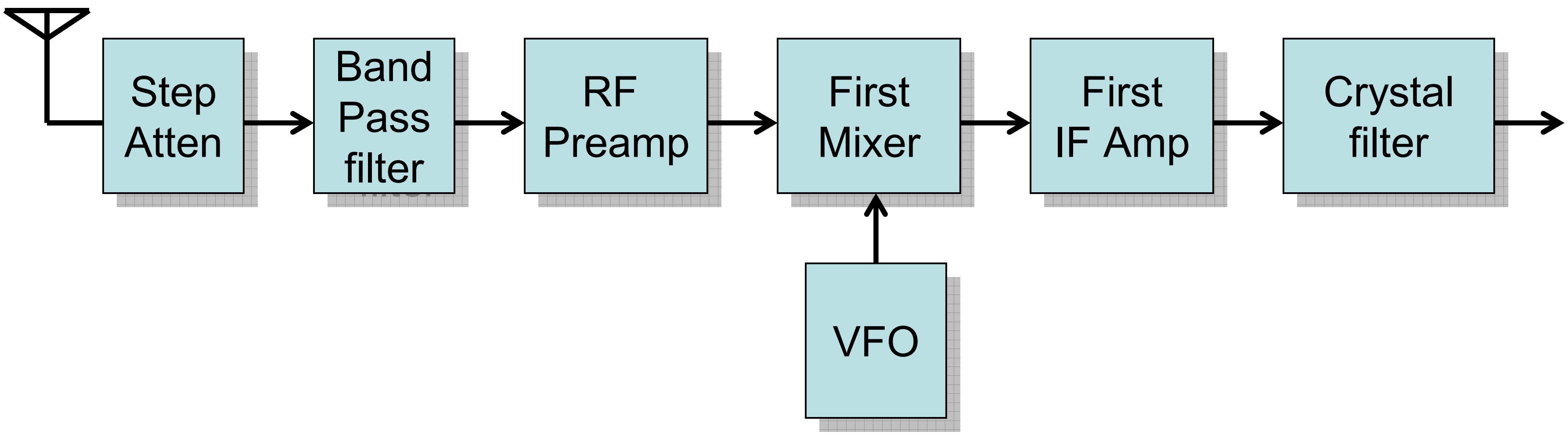
KHz	Low Side	High Side
2	**93**	**-**
3	98.5	93.5
4	102	98.5
5	**105**	**102**
6	**-**	106
7	**107.5**	**109**
10	109	109
20	109	109

IP3DR is *noticeably better* than the best radios available (K2/Orion)

NC2030 appears *17 db* better 2 KHz away (93 db vs. 76 db)

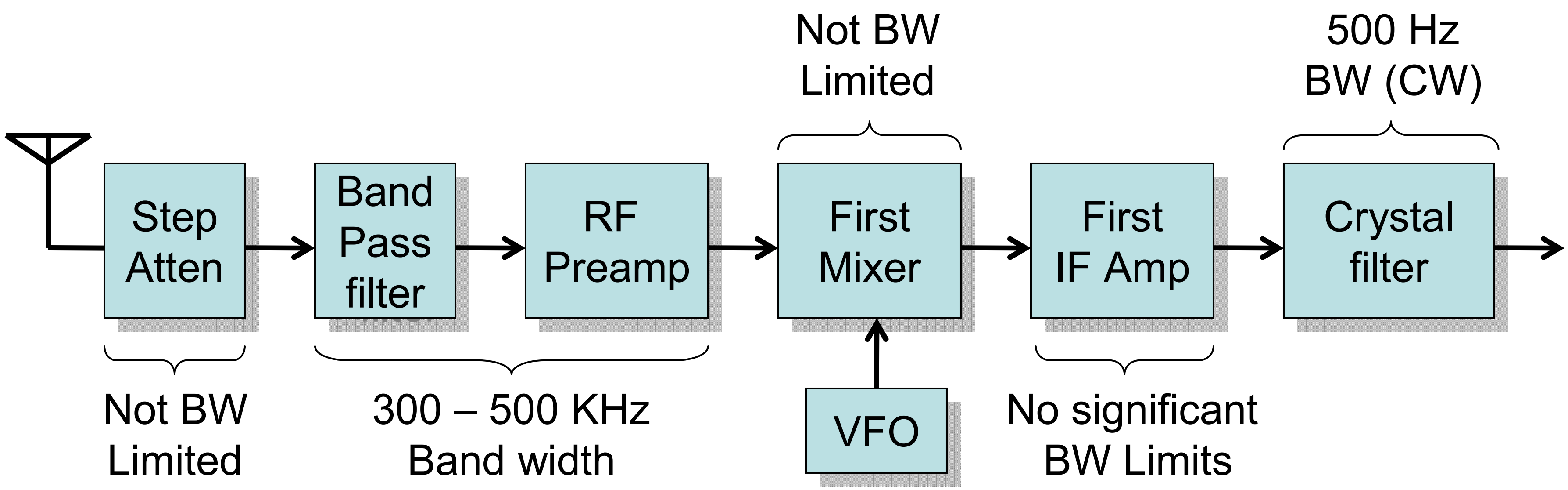
NC2030 appears *18 db* better 5 KHz away (105 db vs. 87 db)

Typical Superhet Front End



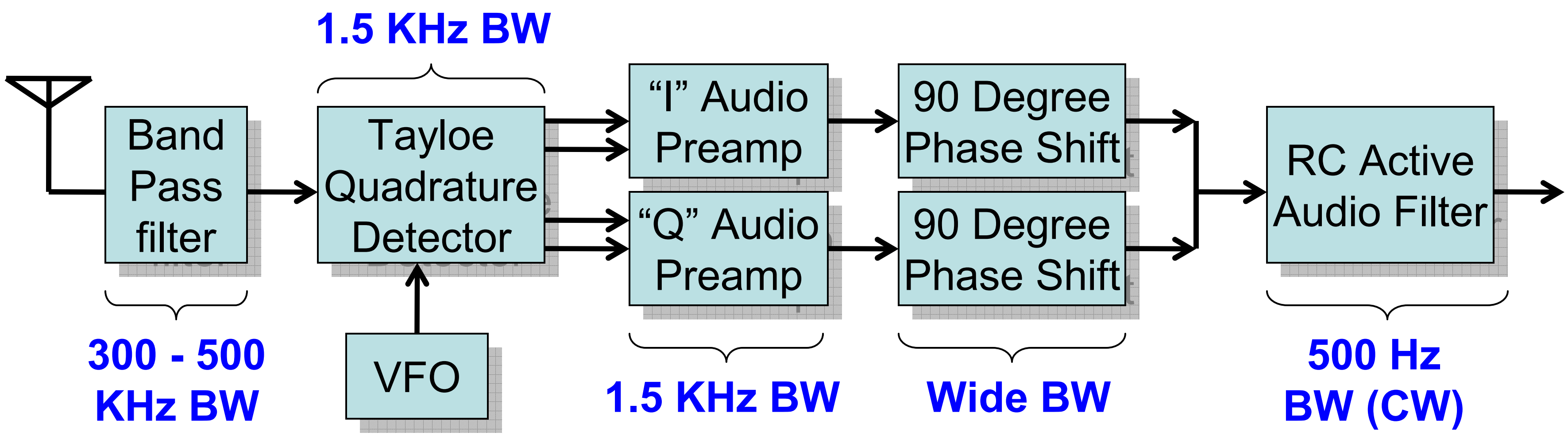
- This is a simplified view, but represents many superhet receiver front ends
- The ***large signal performance*** is set in the sections ***before*** the radio “brick wall” filtering (Xtal filter)

Superhet Front End Bandwidth



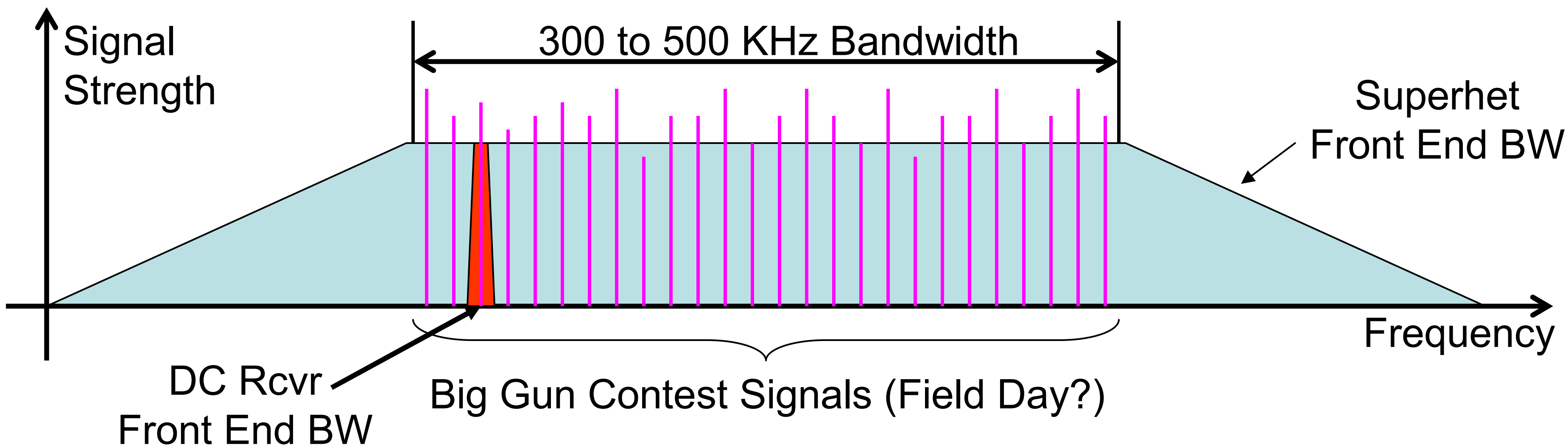
- RF preamp, first mixer, and first IF amp sees ***all signals*** in the ***entire band*** all at the same time.
- Wide front end bandwidth is the main reason ***preamps are turned off*** and ***attenuators are kicked*** in during a contest.

Phasing DC Front End



- The narrow bandwidth direct conversion detector allows ***few signals*** to get to the audio preamps.
- The audio preamps also has a narrow bandwidth, thus off frequency signals are ***attenuated even further*** prior to the receiver "brick wall" audio filter

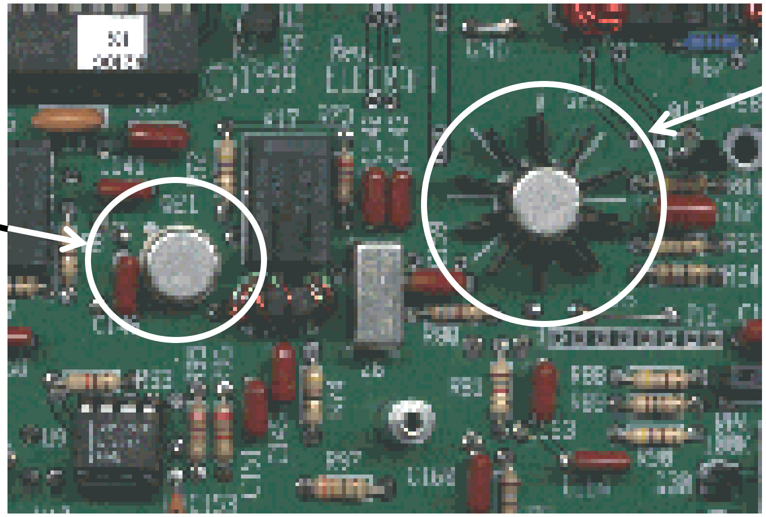
Band View: Superhet Vs. DC RCVR



- Superhet RF preamp/Mixer/IF Amp ***sees all signals at full strength***
  - Must remain linear with the ***sum of all the signals on the band***
  - ***This is hard!*** RF pre-amp on/off, Attenuators, Variable IF amp gain
  - Requires a lot of power to stay linear; IF amp often uses ***50 to 100 ma***
- DC receiver sees only a fraction of the band
  - Must remain linear over ***just a few*** of the many signals on the band
  - Only the close in signals are problems; ***-16 db, 5 KHz*** away, ***-40 db*** at ***20 KHz***
  - ***A much easier problem!***

Superhet RF/IF Preamps

RF pre-amp,
No heat sink

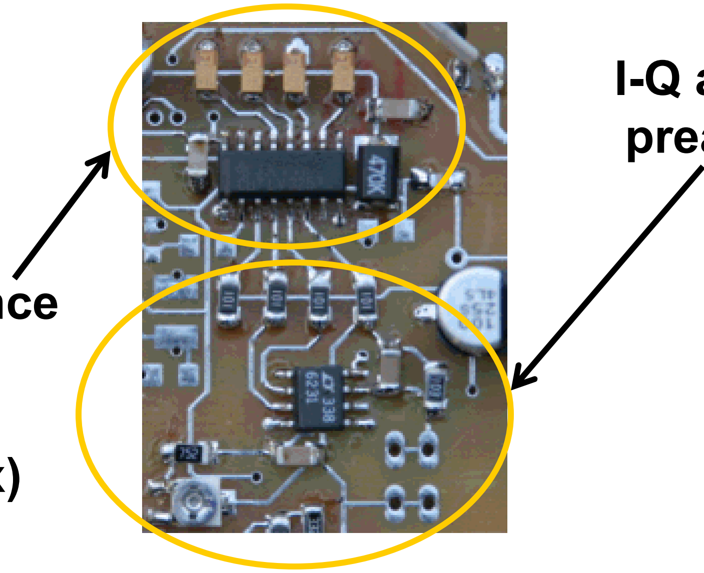


IF amp w/
heat sink

IF amps are normally built to handle more power than RF Amps

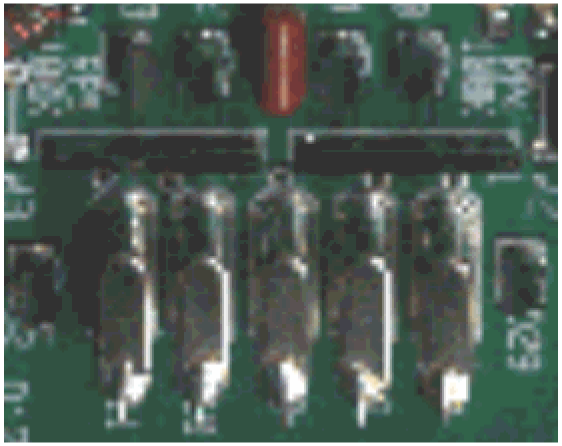
- RF and IF amps are typically 50 ohm in, and low Z out
  - These are both ***power*** amplifiers
- Wide band, high signal linearity amps require ***lots of power***
- RF pre-amps are not normally designed to survive large in band signals
  - Which is why they are ***useless*** and ***get turned off*** in a contest
  - First mixer can only handle so much power out of RF preamp anyway
  - Superhet performance measured with ***RF Preamp off*** for a reason

DC Receiver Detector/AF Preamps



- Detector has ***~0.9 db*** of conversion loss rather than the typical high performance superhet ***6 to 8 db*** mixer loss
  - Thus, RF preamp ***not needed*** to overcome first mixer loss
  - Allows receiver to have both ***high sensitivity*** & ***large signal*** performance
- AF Pre-amp is low Z in, high Z out, ***voltage amplifier***
  - ***Voltage amplification*** takes less power than ***power amplification***
- Detector/AF preamp rolls off relatively quickly
  - ***16 db down at 5 KHz, 27 db at 10 KHz, 39 db at 20 KHz***

Superhet “Brick Wall” Filters

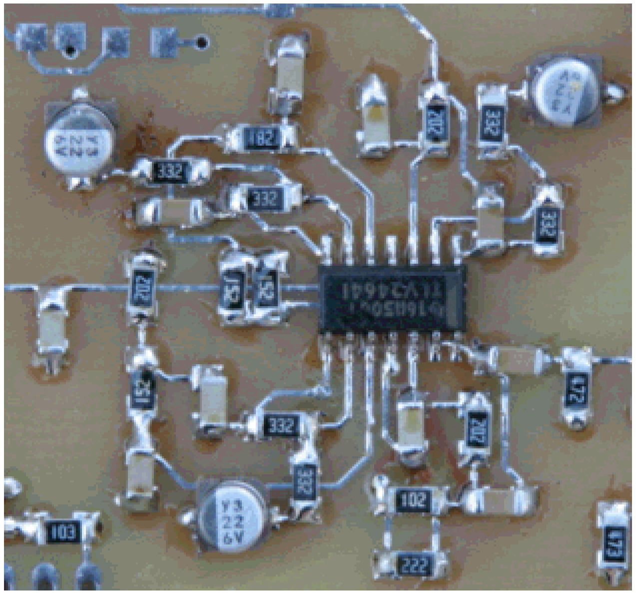


Typical crystal filter, 5 crystals

- RF preamps and IF amps must have power limits because of ***crystal filter limitations***

- Crystals used in xtal filters typically ***10 mW***
  - ***~1.4v RF limit, blocking limit of ~140 db BDR***
- Crystal power limitations may contribute to ***close in IP3 problems***
- ***FT243 crystals might make superior filters***
  - ***Old FT243 crystals handle much higher power levels***

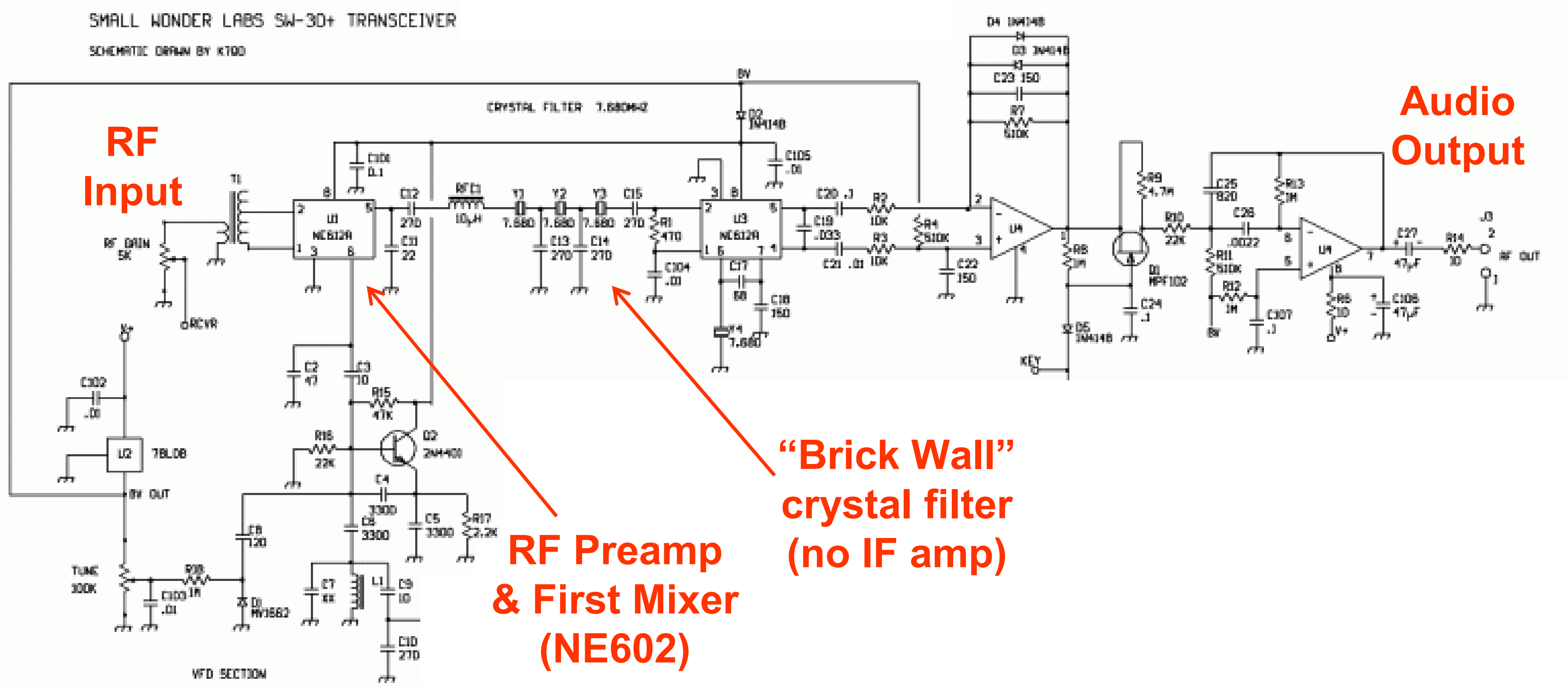
DC Receiver “Brick Wall” Filters



8 pole low pass filter

- NC2030 8 pole low pass filter
- High voltage, ***very high dynamic range*** “brick wall” RC filters are easily constructed
  - Caps typically ***50v***
  - ***1/2w*** resistors common
  - Op amps typically ***+/- 18v (36v)***
- R/C filters: ***Lots of Rs and Cs!***
- With a ***3v*** receiver chain, NC2030 has ***~13 db better IP3DR*** and ***similar BDR*** to the best available rigs
  - And this is at ***full sensitivity***, not “RF Pre-amp off”!

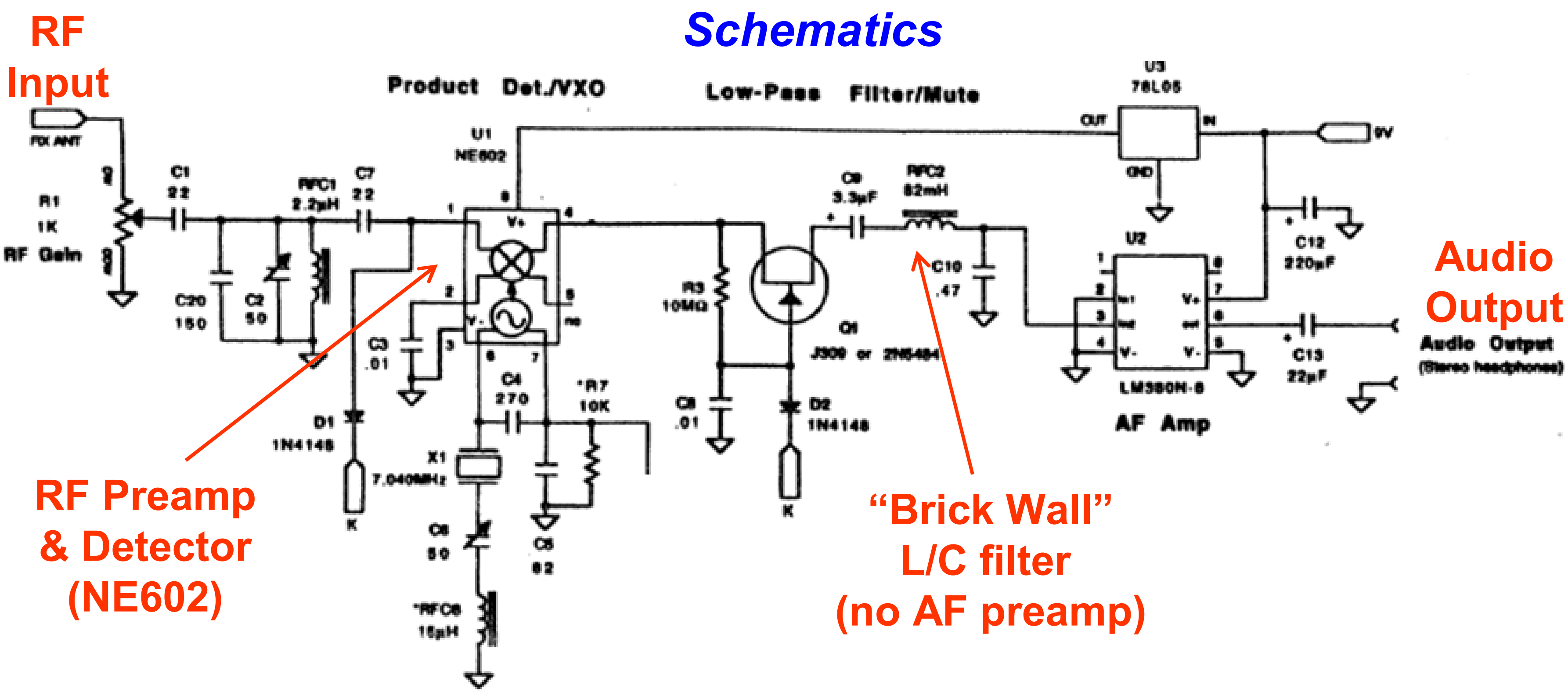
Superhets can be simple



However, this is not a high performance superhet

DC Receivers can be simple also

"49er" Receiver Schematics



However, this is not a high performance DC Rcvr

A High Performance Phasing DC Receiver (NC2030) has a Price

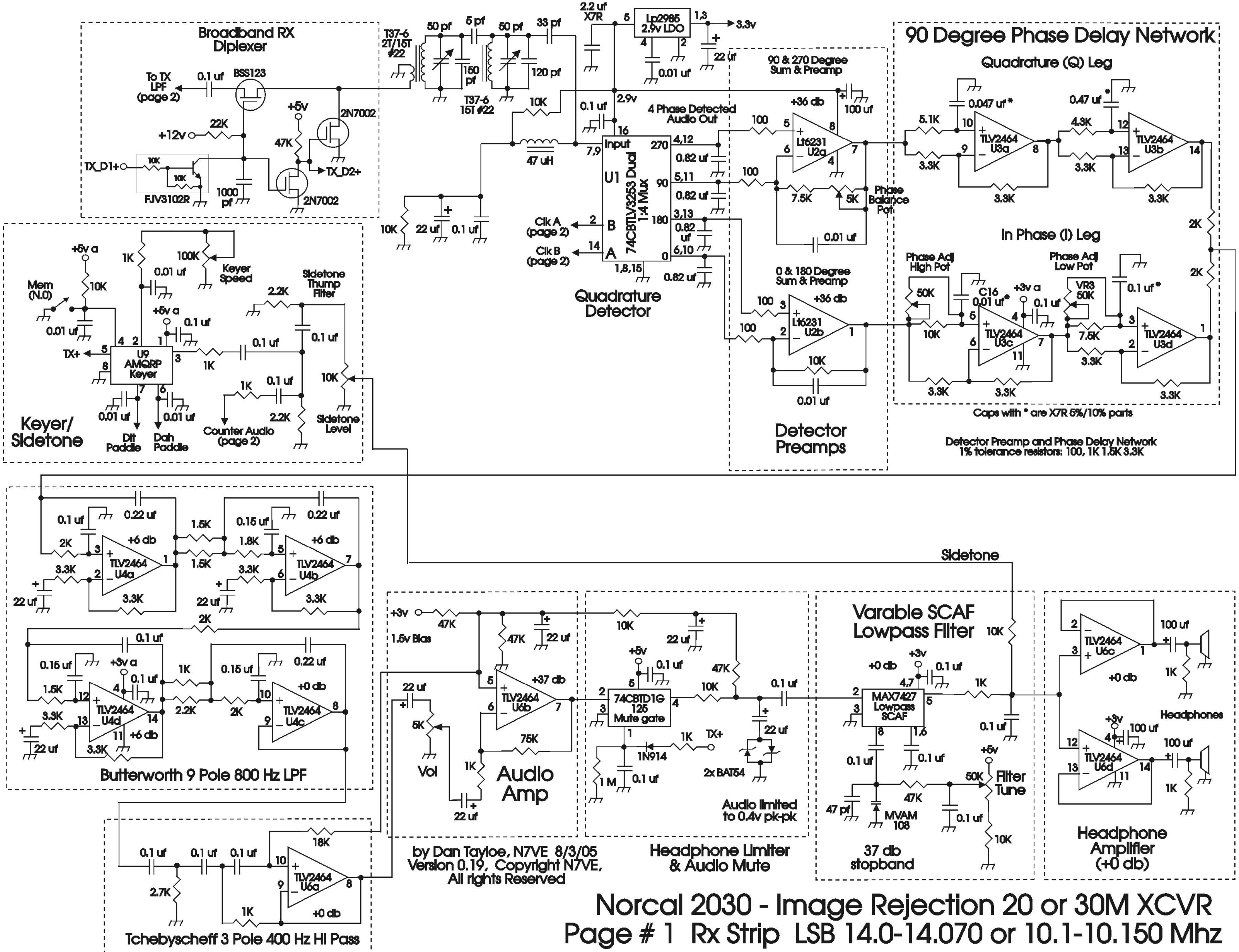
Lots of parts, with many Rs and Cs!

- ~280 out of 360 total parts are Rs and Cs

- ***175 Capacitors***
- ***108 Resistors***
- 25 Inductors
- 19 ICs
  - 5 op amps, 5 LDO voltage regulators, 5 digital ICs, 2 uPs, 1 SCAF, and 1 switching regulator
- 17 Transistors
- 17 diodes
- 2 crystals

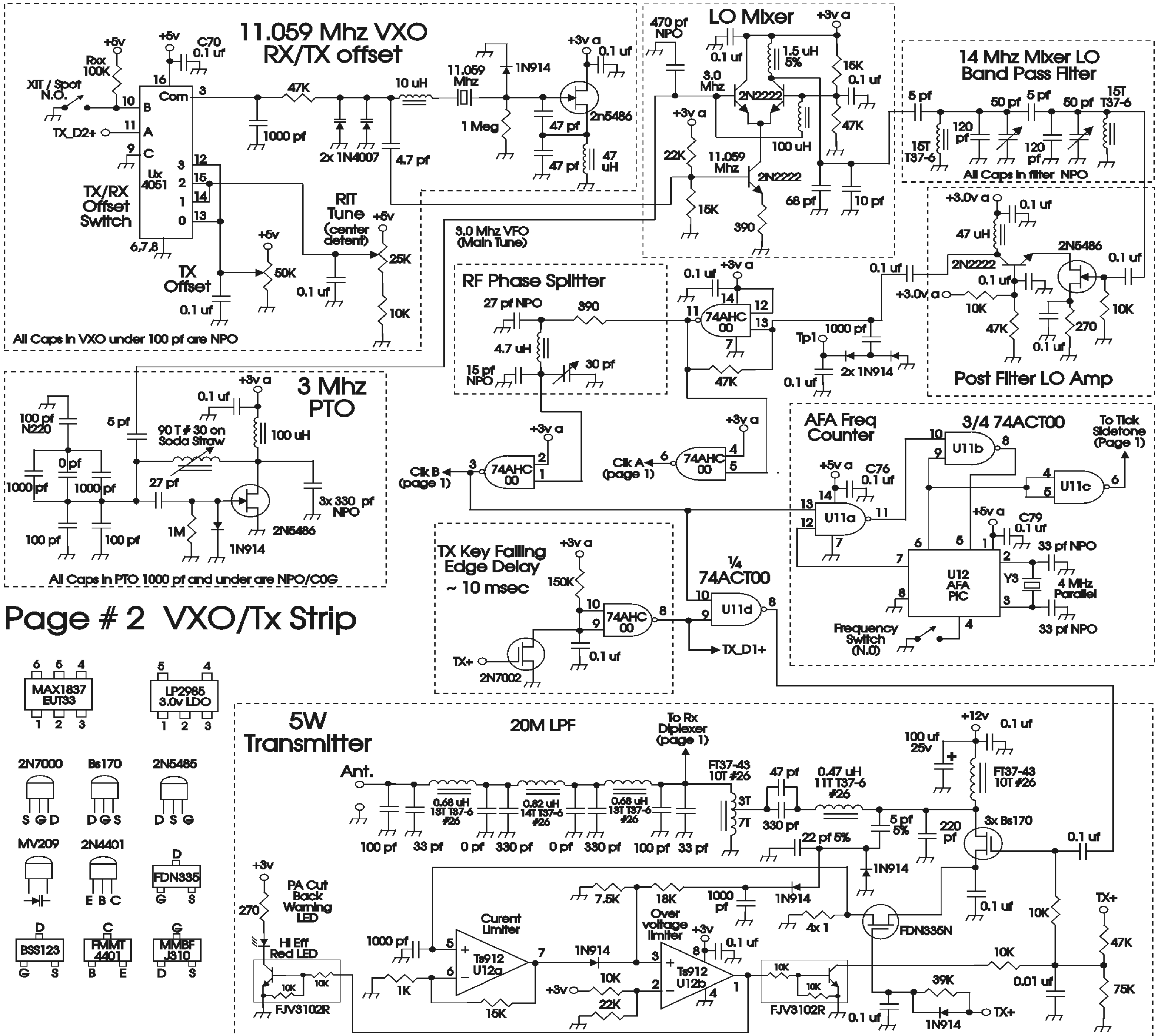
$\Rightarrow$ ***High performance DC Receiver (NC2030) is more complex than a typical superhet***

- But higher performance <u>and</u> less power!

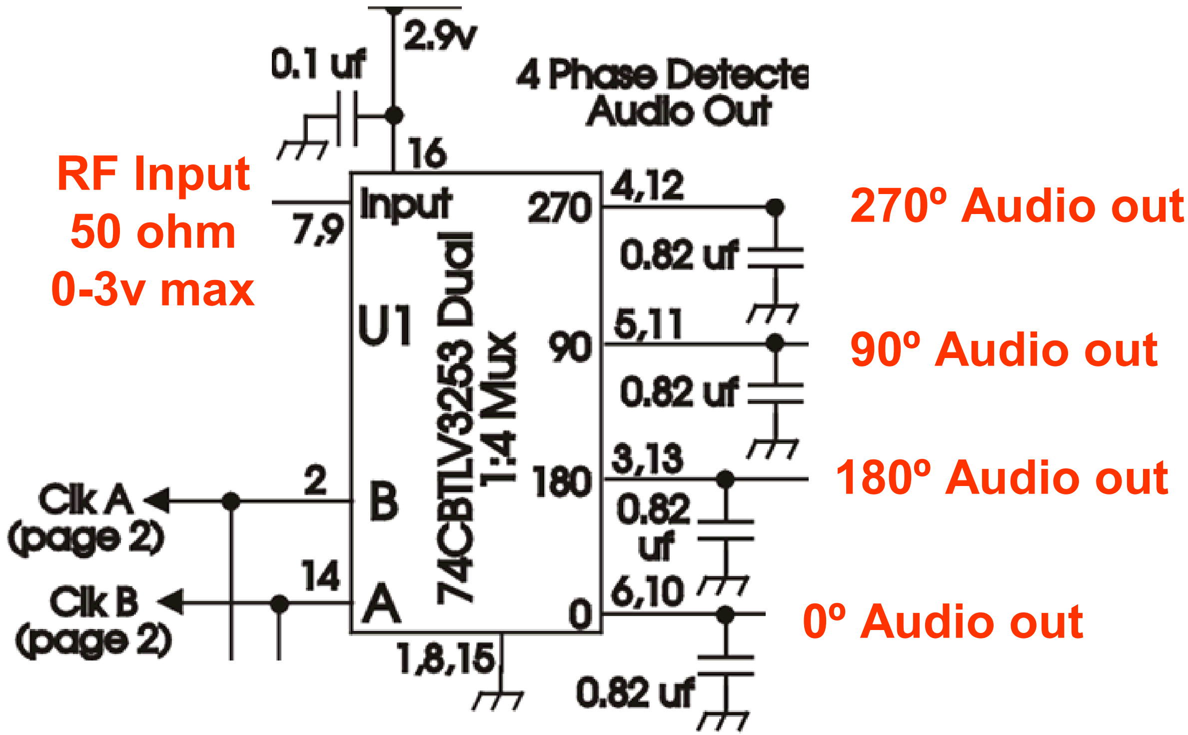


Broadband RX Diplexer
To TX LPF (page 2)
BSS123
2N7002
FJV3102R
TX_D1+
TX_D2+
T37-6 2T/15T #22
T37-6 15T #22
Lp2985 2.9v LDO
3.3v
Quadrature Detector
74CBTLV3253 Dual 1:4 Mux
4 Phase Detected Audio Out
Clk A (page 2)
Clk B (page 2)
Detector Preamps
90 & 270 Degree Sum & Preamp
0 & 180 Degree Sum & Preamp
Phase Balance Pot
90 Degree Phase Delay Network
Quadrature (Q) Leg
In Phase (I) Leg
Phase Adj High Pot
Phase Adj Low Pot
Caps with * are X7R 5%/10% parts
Detector Preamp and Phase Delay Network 1% tolerance resistors: 100, 1K 1.5K 3.3K
Keyer/ Sidetone
U9 AMQRP Keyer
Keyer Speed
Sidetone Thump Filter
Sidetone Level
Counter Audio (page 2)
Dit Paddle
Dah Paddle
Mem (N.O)
Sidetone
Butterworth 9 Pole 800 Hz LPF
Tchebyscheff 3 Pole 400 Hz Hi Pass
Audio Amp
1.5v Bias
Vol
Headphone Limiter & Audio Mute
74CBTD1G125 Mute gate
Audio limited to 0.4v pk-pk
2x BAT54
Varable SCAF Lowpass Filter
MAX7427 Lowpass SCAF
MVAM 108
Filter Tune
37 db stopband
Headphone Amplifier (+0 db)
Headphones
by Dan Tayloe, N7VE 8/3/05
Version 0.19, Copyright N7VE, All rights Reserved
Norcal 2030 - Image Rejection 20 or 30M XCVR
Page # 1 Rx Strip LSB 14.0-14.070 or 10.1-10.150 Mhz

Page # 2 VXO/Tx Strip



Quadrature Detector



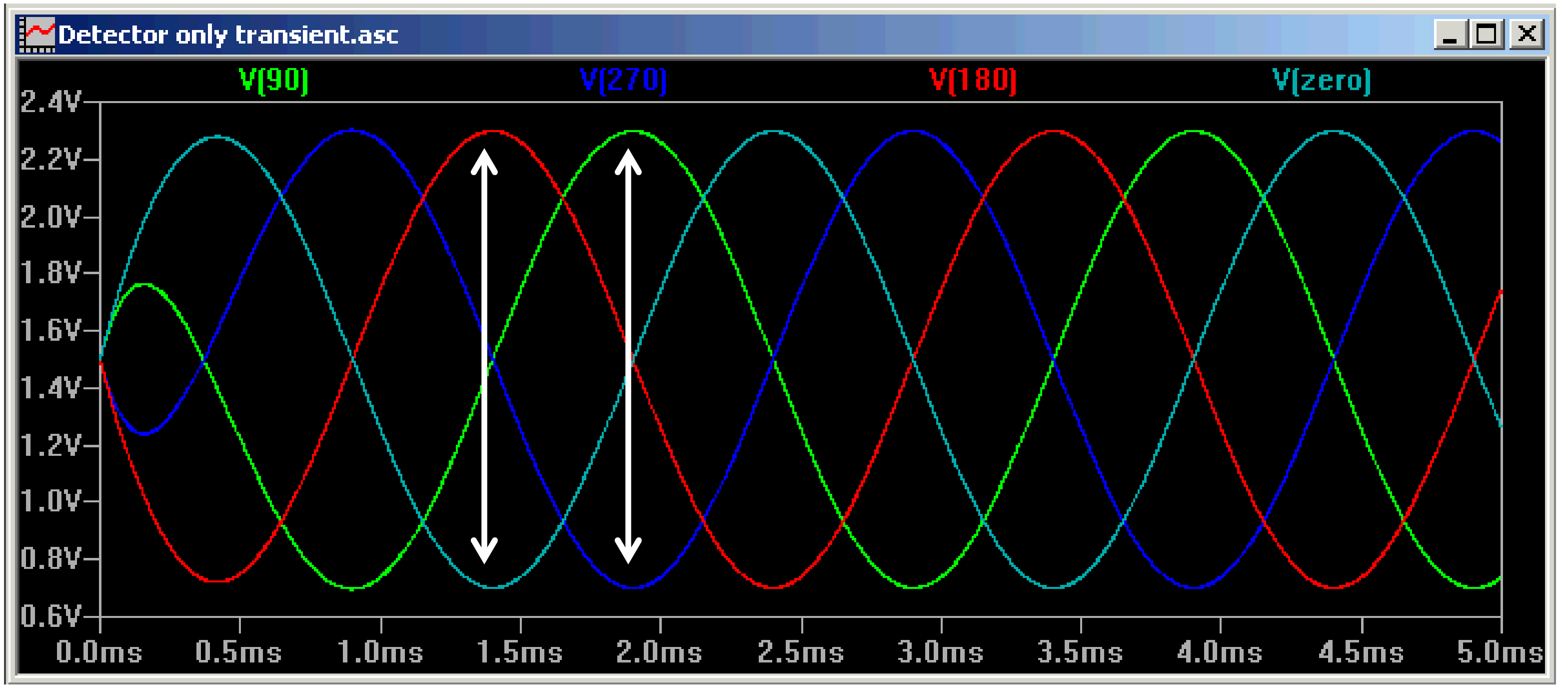
One 50 ohm input,
Four 200 ohm outputs
No power gain

Output ~0.9x Input
due to integration
on detector caps
~0.9 db loss

Diode mixer : *6 db* of
conversion loss typical

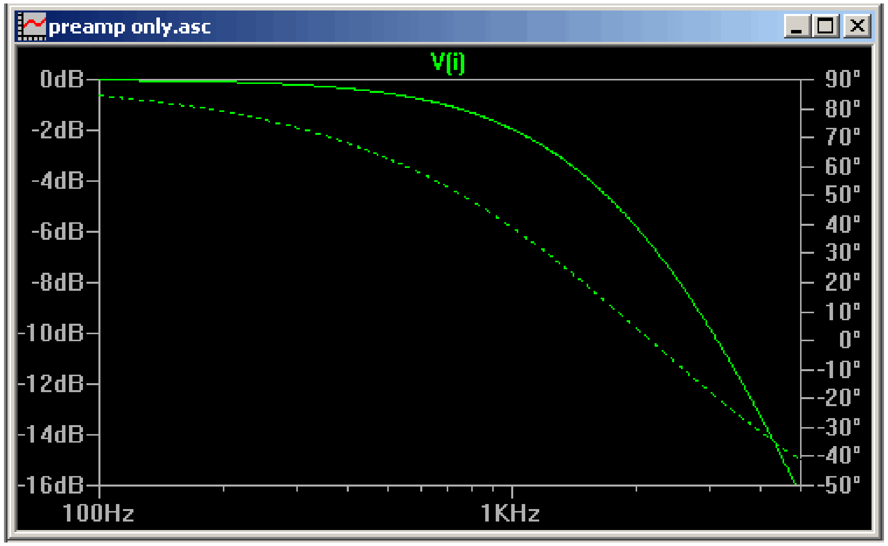
- Clocks route RF input to 1 of four Detector Caps at a 4x rate
- Each det. cap. averages ¼ cycle of RF – *Audio!*
- Four blade ceiling fan w/ strobe light analogy

Quadrature Detector Outputs



- Note that 0º & 180º and 90º & 270º outputs are *mirror images* of each other.
- These pairs (such as 0º & 180º) are summed *differentially* via + & - inputs of op-amps

NC2030 5 KHz Blocking Calculations



- *The simple RC roll off of the Detector and AF preamp is somewhat gradual, but* ***16 db of attenuation*** *greatly helps BDR (and IP3DR also)*

- AF Preamp has 66x of voltage gain (*36 db*)

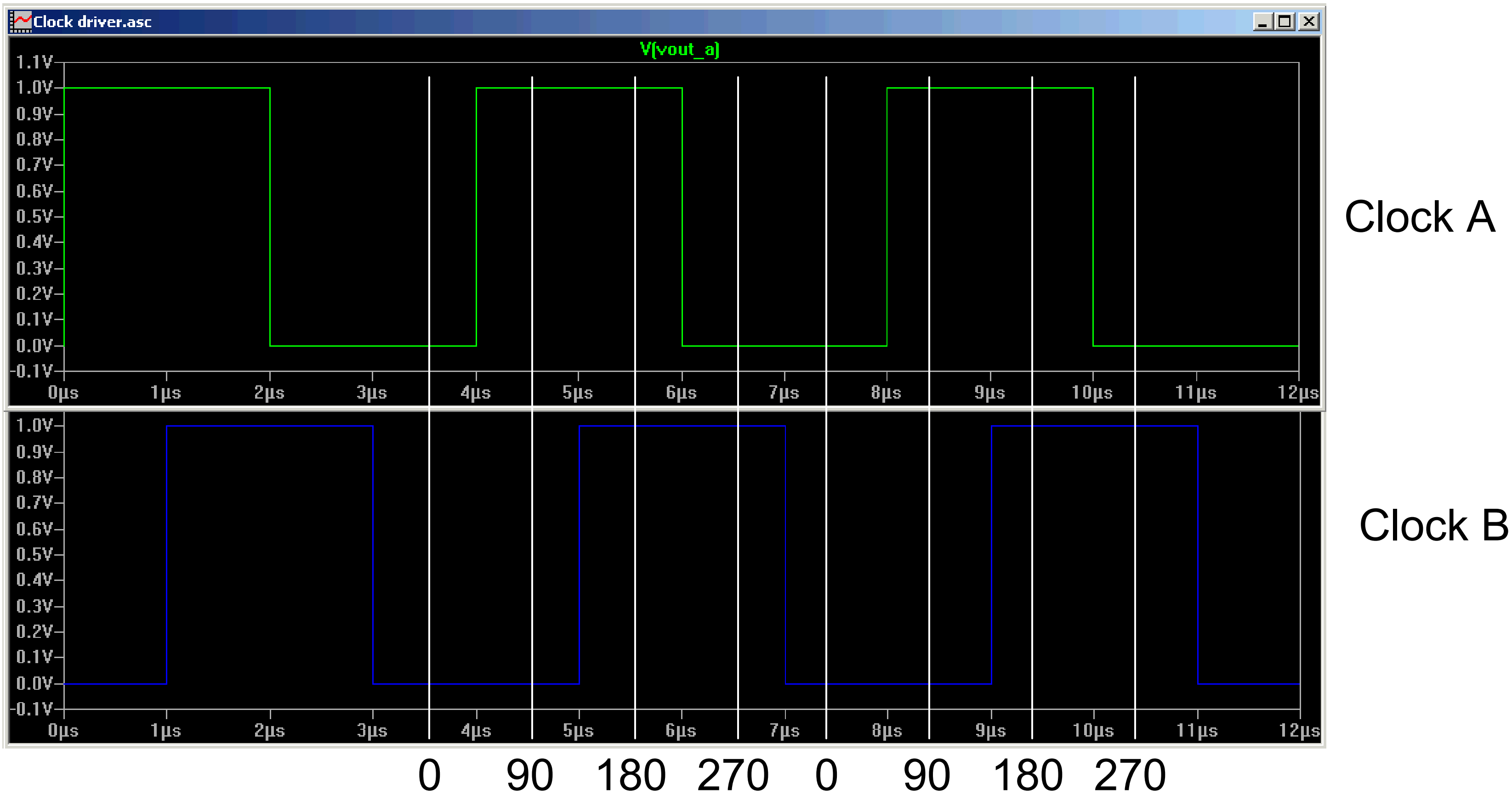
- *16 db* roll off at 5 KHz leaves 20 db of gain (*10x*)

- With 3v pk-pk max audio output, RF input blocks at *0.3v* (*-6 dbm)* 5 KHz away

- Using -135 dbm sensitivity, BDR = 135 – 6 = 129 db

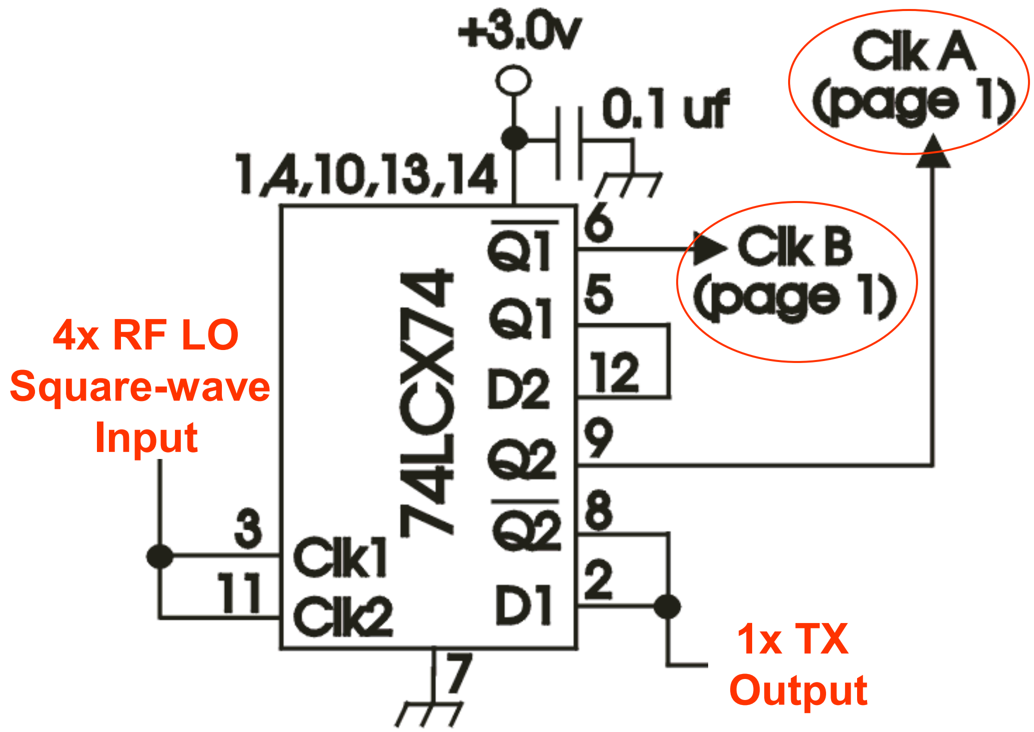
- Actual measured result 128.5 db BDR at 5 KHz

Detector Clock Drive



- Need to switch to ***each of four*** **outputs every RF cycle, ¼ cycle dwell time on each detector output**
- **Two phase clock used to get** ***four output states***

Detector Clock Drive Circuit A



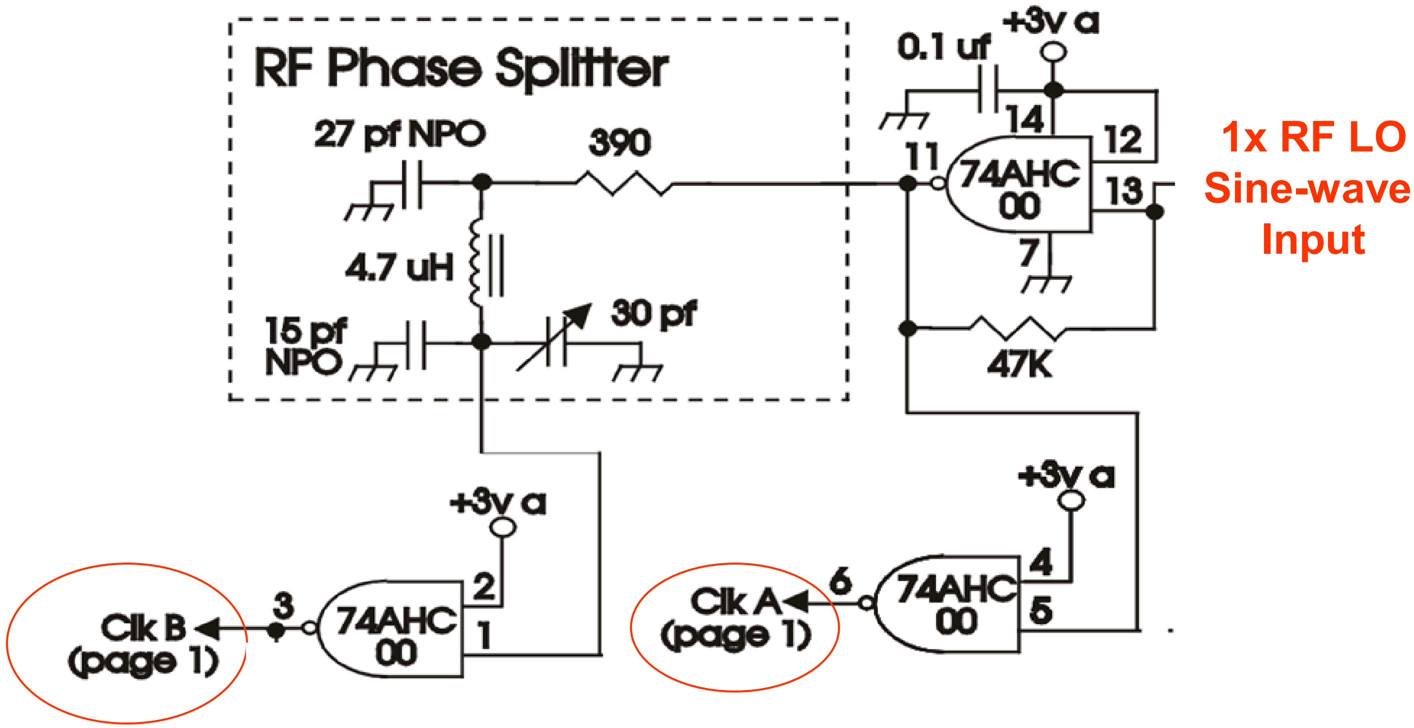
Four states

0 0
0 1
1 1
1 0

Not a straight binary counter

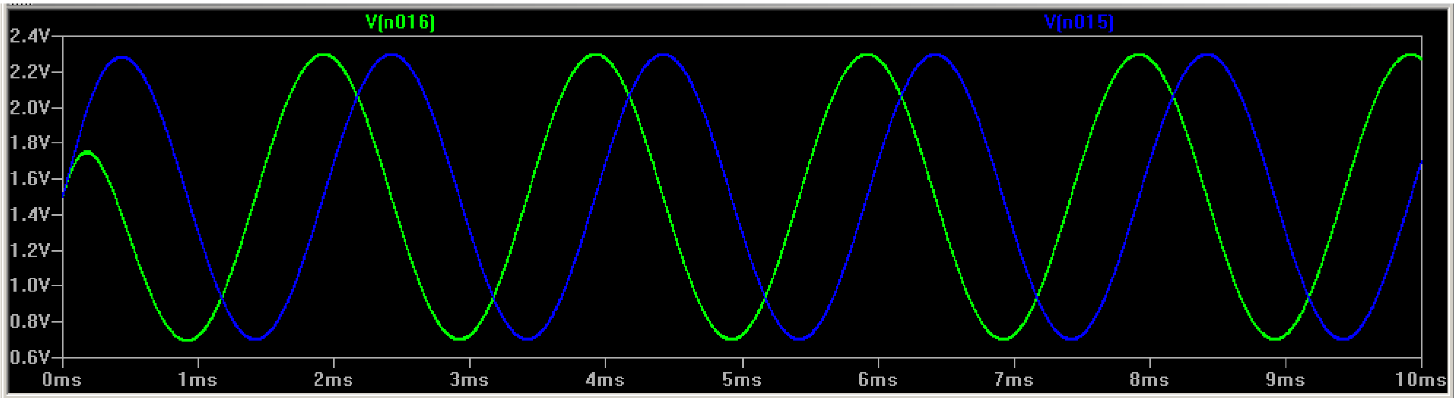
- ***4x frequency source*** **used with digital dividers**
- **Advantage: Accurate clocks, *excellent opposite sideband rejection over a very wide range***
- **Disadvantage: Dividers are a bit *power hungry***

Clock Drive Circuit B (NC2030)

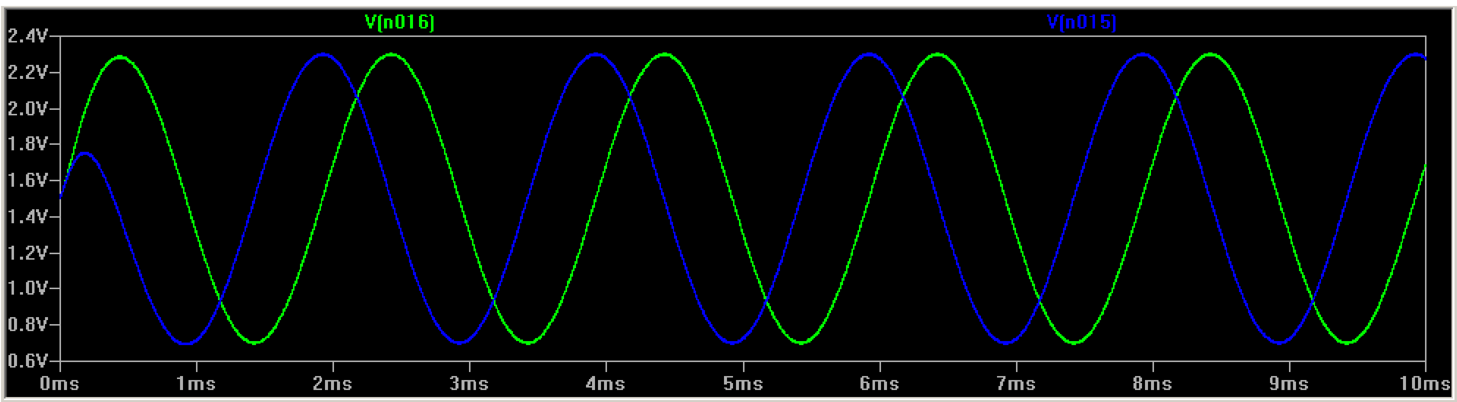


- *1x frequency source* **used with L/C delay section**
- **Advantage:** ***Uses much less power*** **than dividers**
- **Disadvantage: Bandwidth limited,** ***USB rejection good over a limited range*** **(i.e., CW portion of band)**

I – Q USB and LSB Outputs



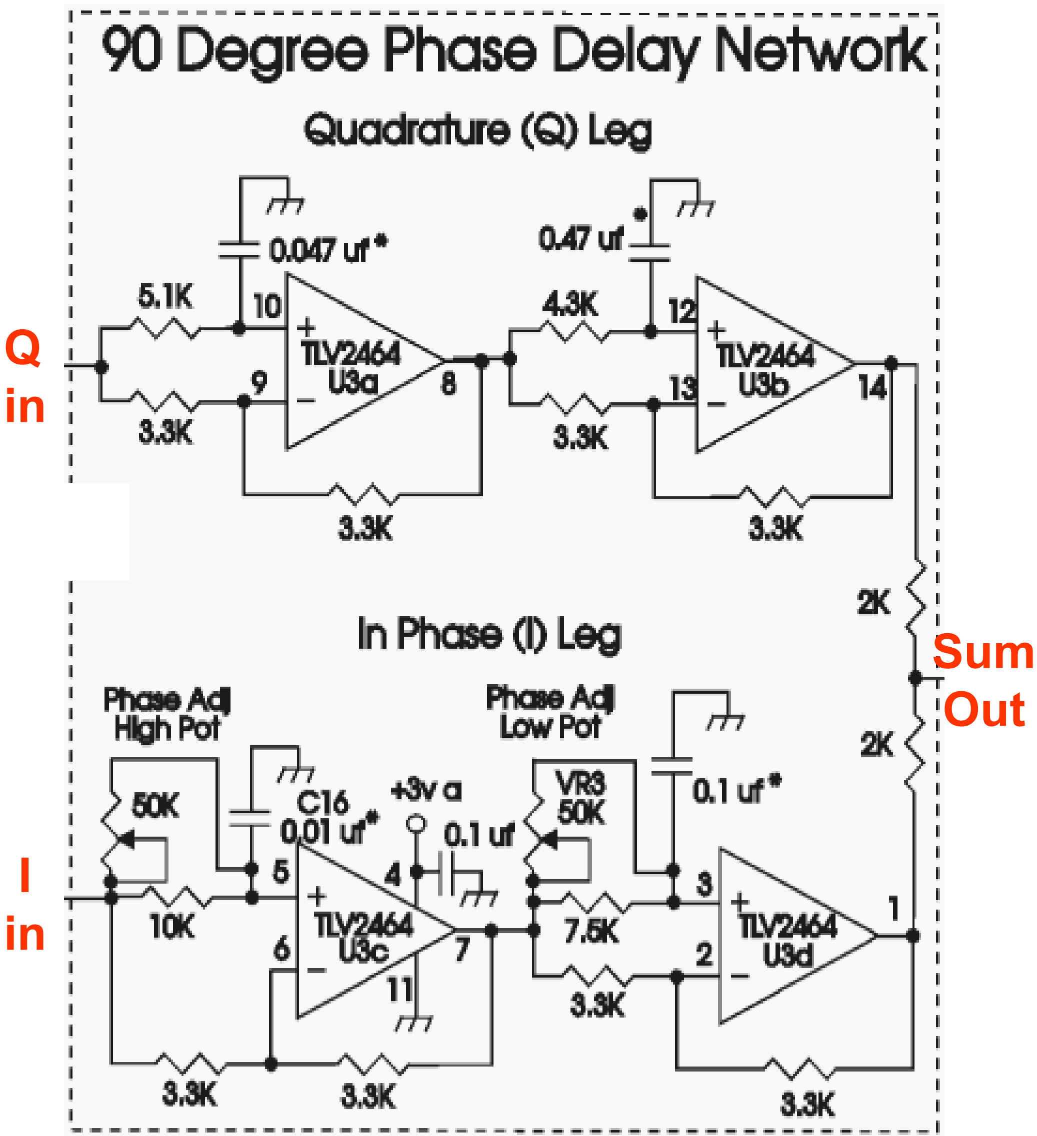
USB I,Q



LSB I,Q

- I (0º, 180º) and Q (90º, 270º) are *90 degrees* apart
- USB/LSB depends on which *leads the other*

90º Shift Phasing Network



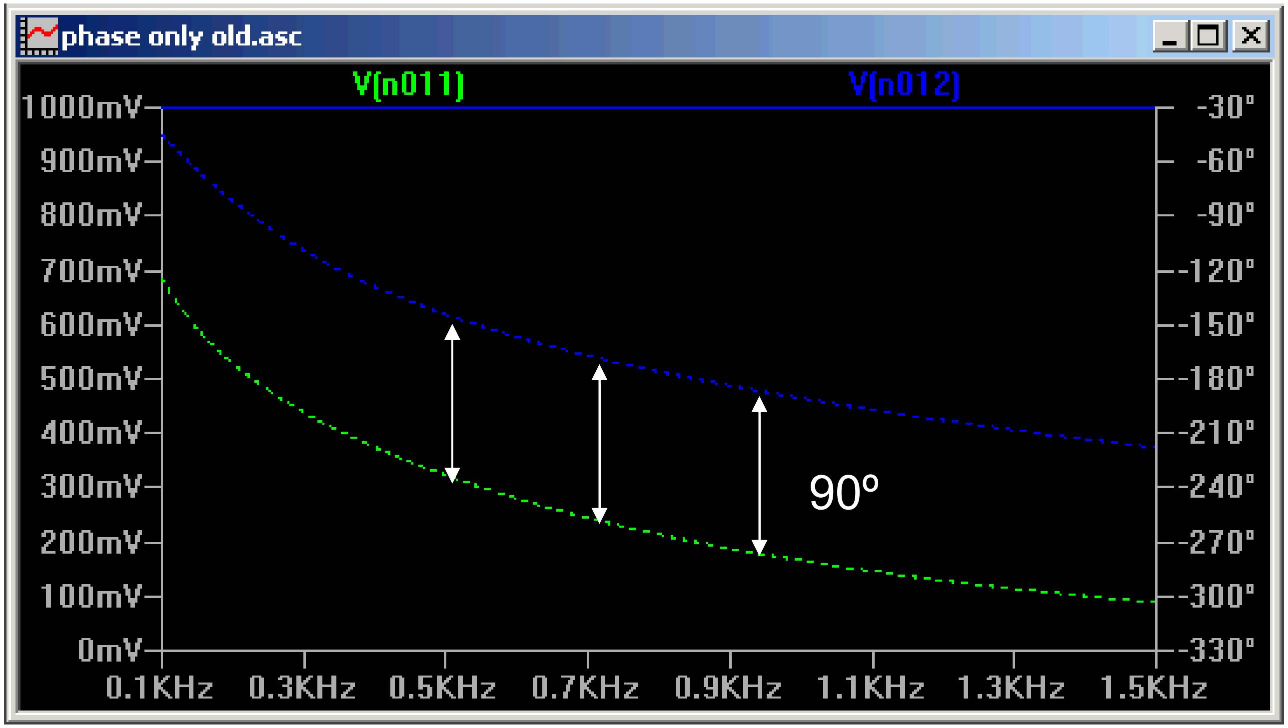
- Two stage R/C phase shift network

- ***Both sides cause phase shift***
  - One side starts first
  - 2^{nd} trails 1^{st} by 90º

- Limited sideband rejection range

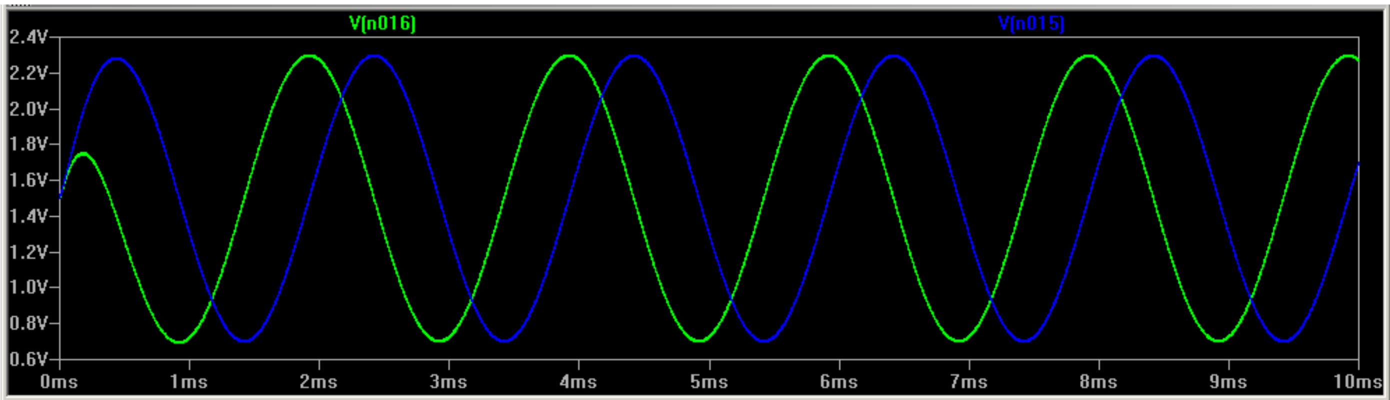
- ***Rejection range optimized for CW bandwidth (500 Hz)***

Phasing – How to Get 90º Shift

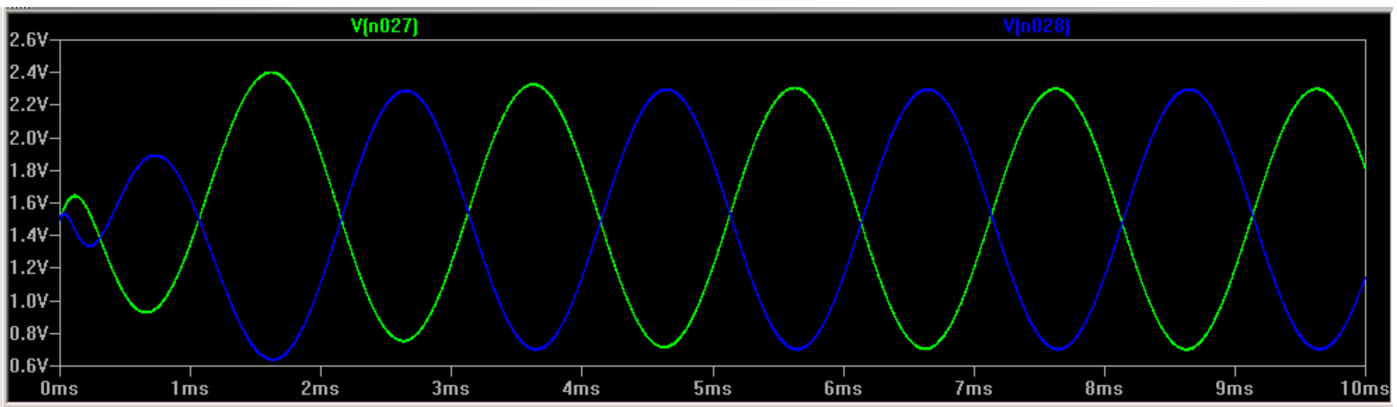


- **One side starts falling in phase after the other**
- ***The late side is adjusted to be exactly 90º late***
- **The 90º difference is good for a *limited range***

USB After 90º Phase Shift



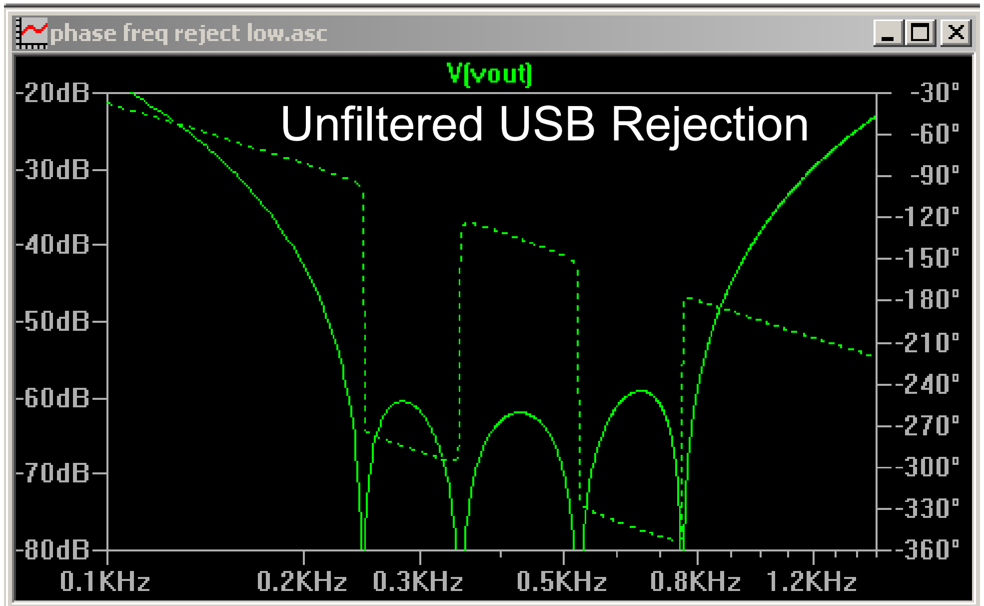
USB I,Q before phasing

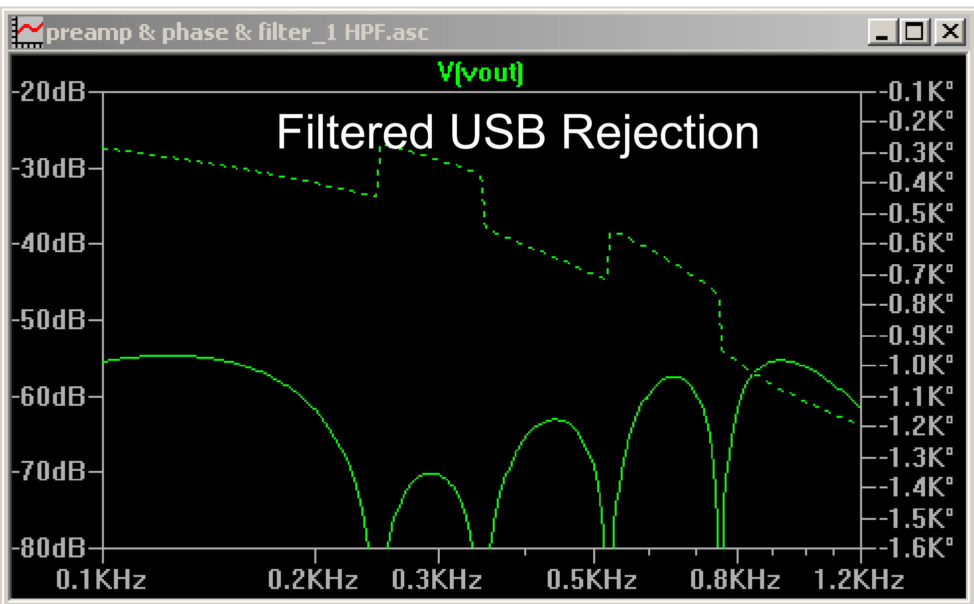


USB I,Q after phasing

- ***After phase shifting, I & Q opposites of each other***
- **Phasing outputs sum to zero – *USB suppressed***

USB Rejection Plot





- **USB rejection *varies* across audio bandpass**

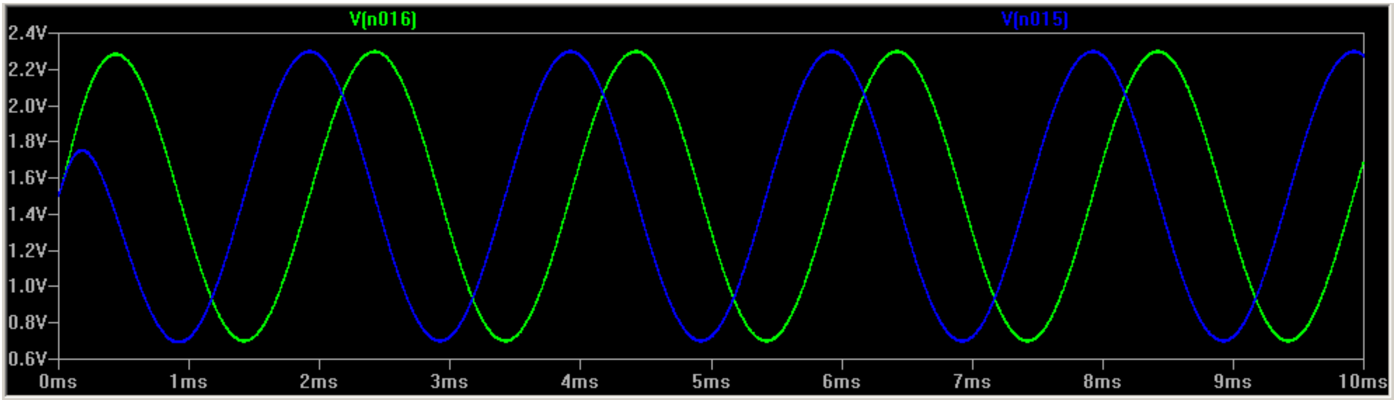
- **Smallest USB rejection at 150 &650 Hz, *~ 55 db* down**

- **Filtering improves high & low frequency rejection**

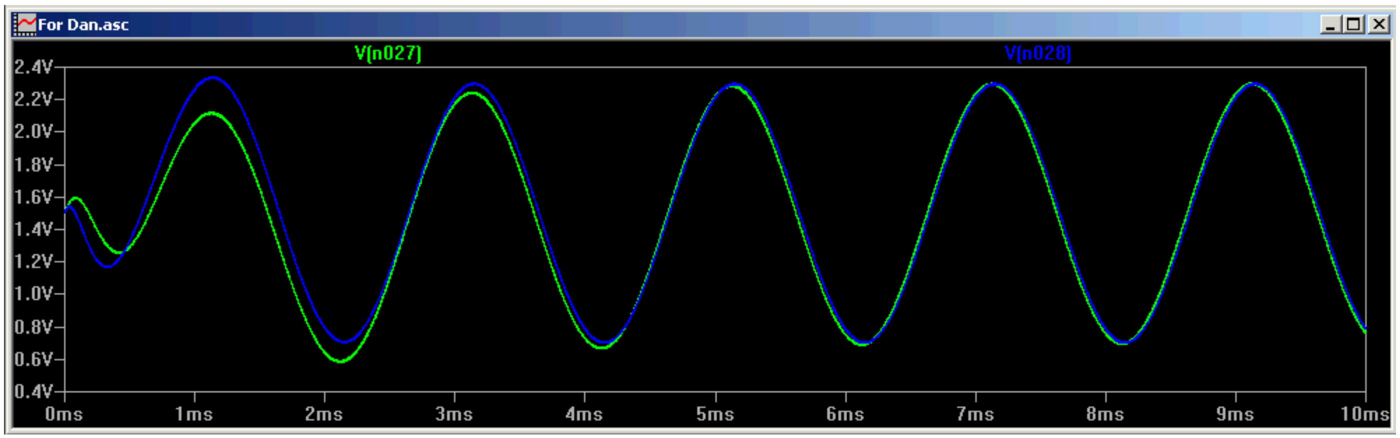
- **Rejection shown is best case**
    - **LO clock uses L/C phasing**
    - ***Causes USB rejection to vary across band***

    > 45 db across the band typical

LSB After 90º Phase Shift



LSB I,Q before phasing

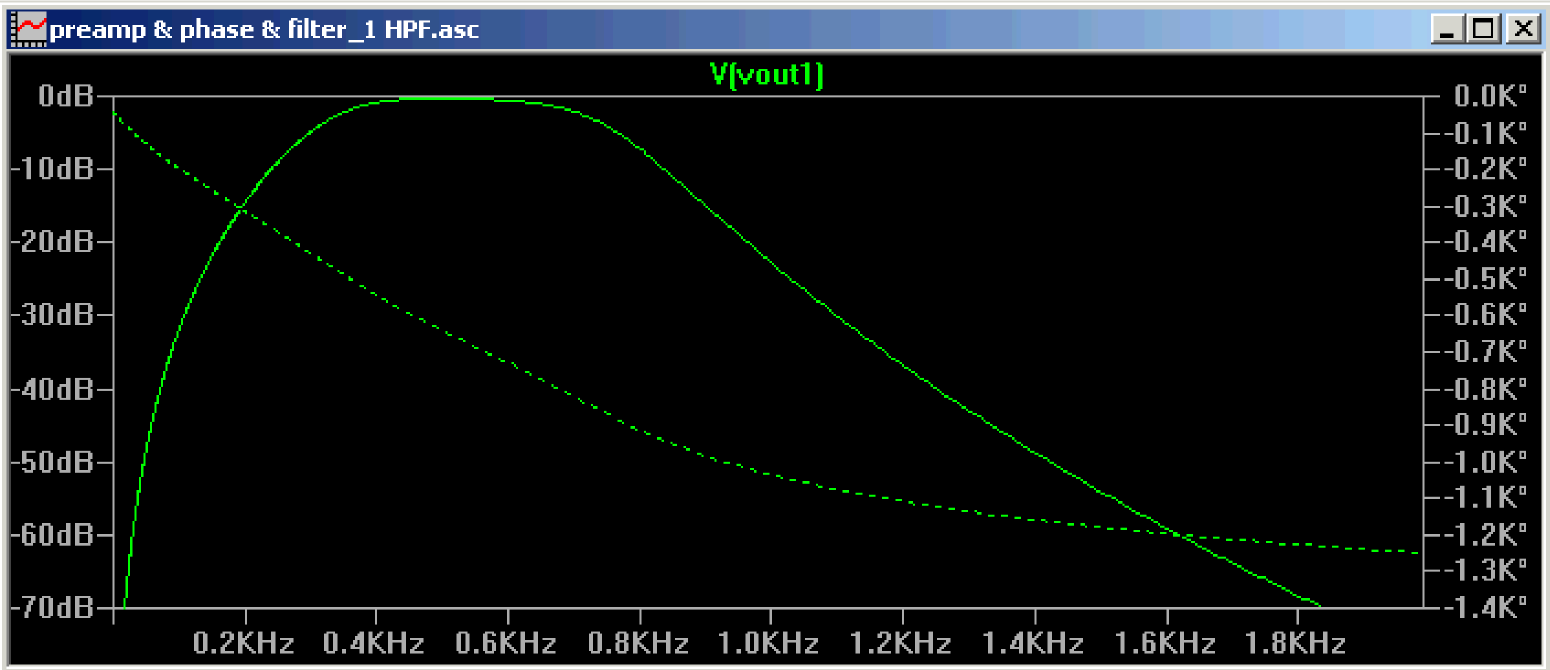


LSB I,Q after phasing

- ***After phase shifting, I & Q are in phase***
- **Phasing outputs sum to 2x –** ***LSB enhanced***

LSB Audio Response Plot

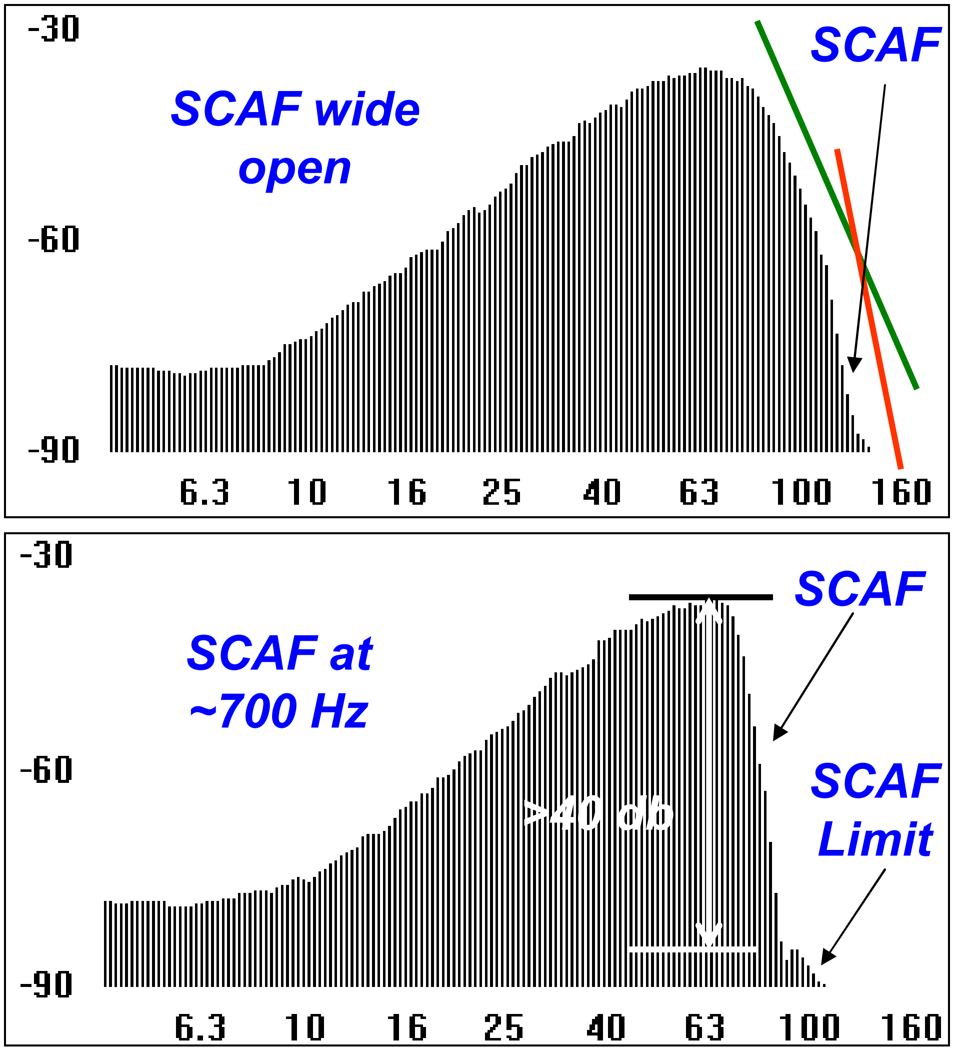
SCAF LPF not included



- **6db at 350 & 800 Hz; 60 db at 50 Hz & 1.6 KHz**
- **Does not include the additional 40 db of variable SCAF LPF attenuation**
- ***Main RC filter designed for low audio ringing***

LSB Audio Response Plot

Actual Band Noise – 30m



- **High side audio roll off is very step**
- **SCAF cleans up high frequency roll off even when "wide open"**
- **SCAF very good at removing a high side interferer when needed**
- ***Noise below 100 Hz is a sound card issue***

DC Receiver Pwr Consumption

- Quadrature detector ***voltage*** driven not ***power*** driven as required by diode mixers.
  - 74CBTLV3253 is a dual 4:1 analog bus switch
- First low noise audio preamplifier outputs are ***voltage*** outputs, not ***power***, as needed by superhets
- ***3v*** receiver powered by a 3v & 5v switching supply, giving a ***3x power savings*** over simple linear regulation from 12v

DC Receiver Pwr Consumption

- VFO and VXO; 3 ma
- LO mixer; 1.6 ma
- LO filter amp; 9.5 ma
- LO squaring & detector driver (74AHC00); 0.8 ma
- Quadrature detector (“Tayloe Mixer”); 4.4 ma
- First audio LNA & phase shift network; 7.8 ma
- High and low pass RC filters and headphone drivers; 2 ma
- SCAF variable audio low pass filter; 1 ma

=> Roughly ***30 ma*** total receiver drain at ***3v*** supply

- ***14 ma*** for the ***LO subsystem***, ***16 ma*** for the ***receiver line up***

=> ***11 ma at 12v*** into the 3v & 5v switching supply

Conclusions

DC receivers have a performance advantage over superhets because:

1. ***DC quadrature det has lower loss (1 vs. 6 db)***
   - DC does not need an RF amp for high sensitivity
2. ***DC detector has a limited ~1.5 KHz bandwidth***
   - The superhet mixer can be 100's of MHz wide
3. ***DC AF amp also has ~1.5 KHz bandwidth***
   - The superhet has a wide bandwidth IF amp (>1 MHz?)
4. ***DC receiver uses R/C active filters, not crystals***
   - Superhet good to ~2v pk-pk because of its crystal filter
   - DC filter is good to 36v pk-pk signal
   - DC can have superior large signal capabilities (20+ db higher than current 3v NC2030)