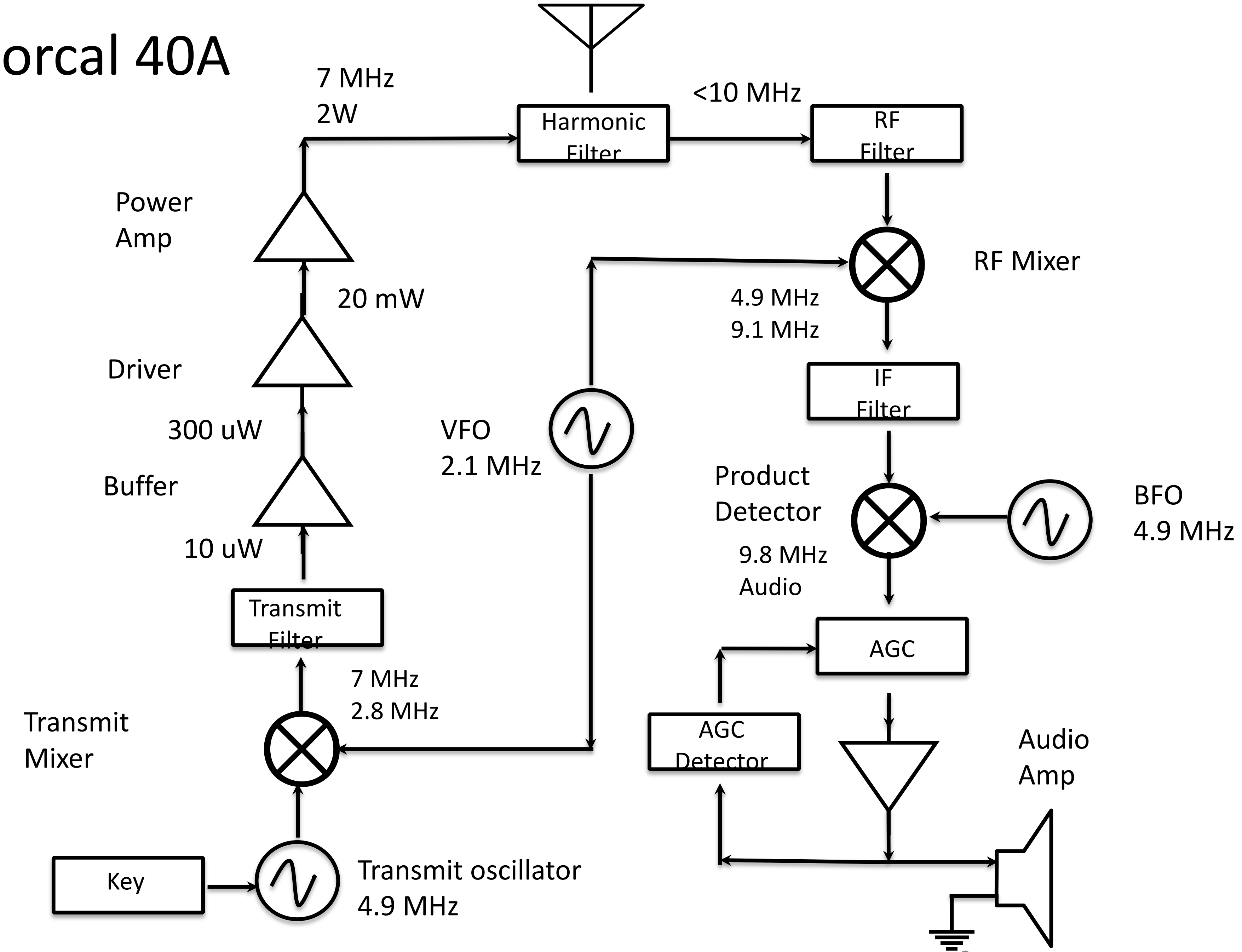
Electronics of Radi

Notes on David Rutledge’s book

John Manferdelli

Norcal 40A


7 MHz
2W
Harmonic Filter
<10 MHz
RF Filter
Power Amp
RF Mixer
20 mW
4.9 MHz
9.1 MHz
Driver
IF Filter
300 uW
VFO
2.1 MHz
Buffer
Product Detector
BFO
4.9 MHz
10 uW
9.8 MHz
Audio
Transmit Filter
AGC
7 MHz
2.8 MHz
Transmit Mixer
AGC Detector
Audio Amp
Key
Transmit oscillator
4.9 MHz

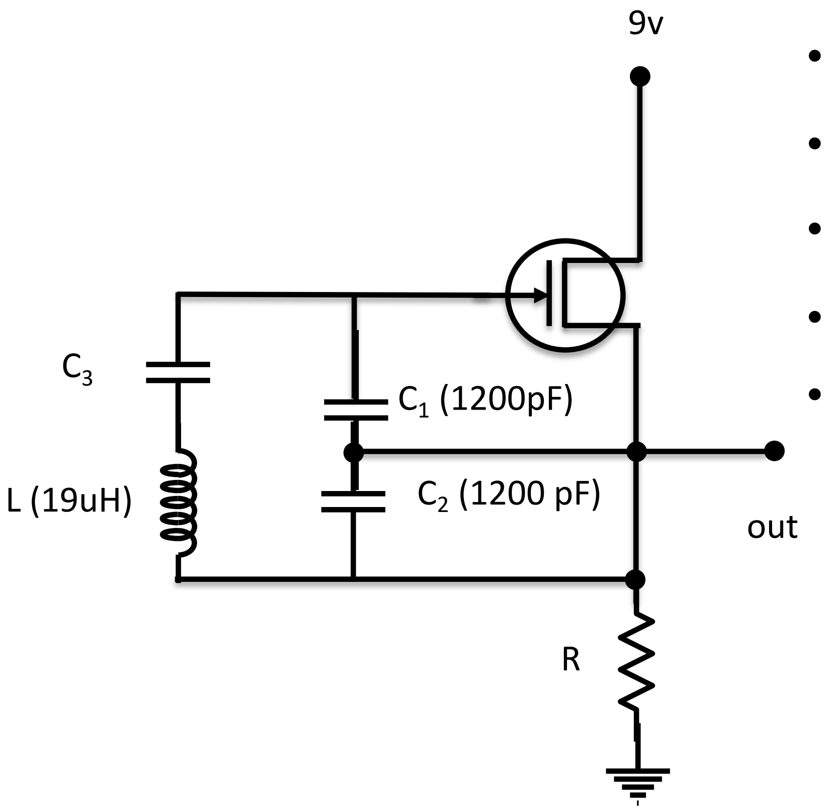
Basic concepts

- E, V
- Phasors
- Energy
- Impedance

Basic concepts

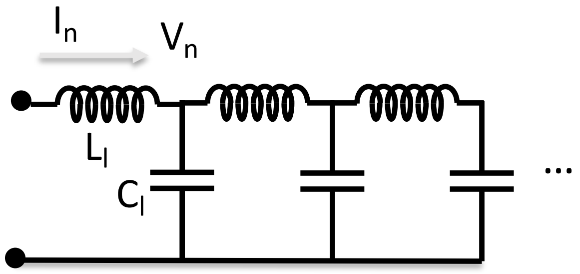
- Decibels
- Resonance
- Modulation

Norcal Clapp



- $i_d = g_m v_{gs}$
- Resonance: $-\frac{1}{j\omega_0 C_2} = j\omega_0 L + \frac{1}{j\omega_0 C_3} + \frac{1}{j\omega_0 C_1}$
- $\omega_0 = \frac{1}{\sqrt{LC}}, C = C_1||C_2||C_3$
- At resonance, $v_{gs} = Ri_d \frac{C_1}{C_2}, L = \frac{C_1}{RC_2}$
- Oscillation continues if $g_m > \frac{C_1}{RC_2}$
- $v_{gs} = 2v_s$

Transmission Lines



Power

$\tau = \frac{V}{V_+} = 1 + \rho = \frac{2Z}{Z+Z_0}, V = 2V_+$

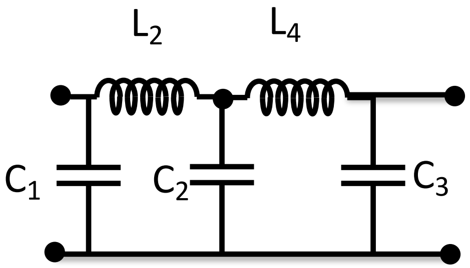
Lookback resistance is $R_s = Z_0$

$P_+ = \frac{{V_+}^2}{2Z_0} = \frac{{V_0}^2}{8Z_0}$, This is the total available power

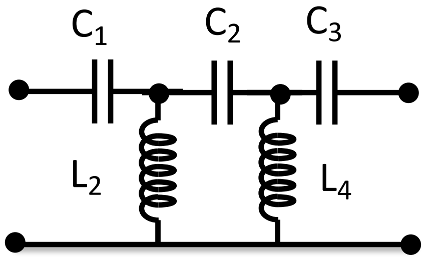
- $V_{n+1} - V_n = -L_l \frac{\partial I_{n+1}}{\partial t},\ L = \frac{L_l}{l}$
- $I_{n+1} - I_n = -C_l \frac{\partial V_n}{\partial t},\ C = \frac{C_l}{l}$
- $\frac{\partial^2 V}{\partial z^2} = LC \frac{\partial^2 V}{\partial t^2}$ and $\frac{\partial^2 I}{\partial z^2} = LC \frac{\partial^2 I}{\partial t^2}$
- Solution is $V(z - vt), v = \frac{1}{\sqrt{LC}}$, for forward wave
- $V' = vLI',\ \frac{V}{I} = \sqrt{\frac{L}{C}},\ Z_0 = \sqrt{\frac{L}{C}}$
- Another solution is $V(z + vt), v = \frac{1}{\sqrt{LC}}$, for r everse wave
- $Z_0 = \frac{V_+}{I_+}, -Z_0 = \frac{V_-}{I_-}, V = V_+ + V_-$
- $P_+(t) = \frac{{V_+}^2}{Z_0},\ P_-(t) = -\frac{{V_-}^2}{Z_0}$
- $\rho = \frac{V_-}{V_+},\ \mathrm{Z} = \frac{V}{I} = \frac{V_+ + V_-}{I_+ + I_-} = \frac{V_+}{I_+} \frac{1+\frac{V_-}{V_+}}{1+\frac{I_-}{I_+}} = Z_0 \frac{1+\rho}{1-\rho}$
- $\rho = \frac{Z-Z_0}{Z+Z_0}$
- $\rho_i = \frac{i_-}{i_+} = -\rho$

Filters

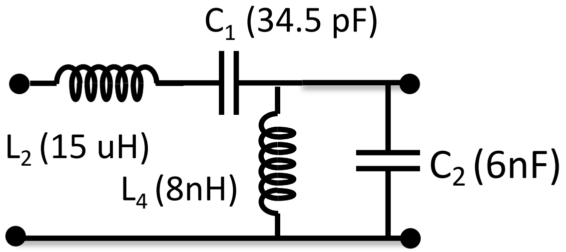
Low pass



High pass



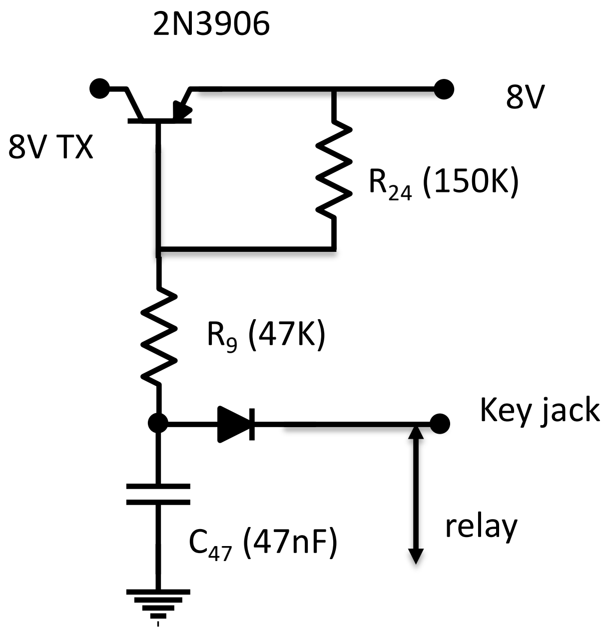
7 MHz bandpass



Acoustics

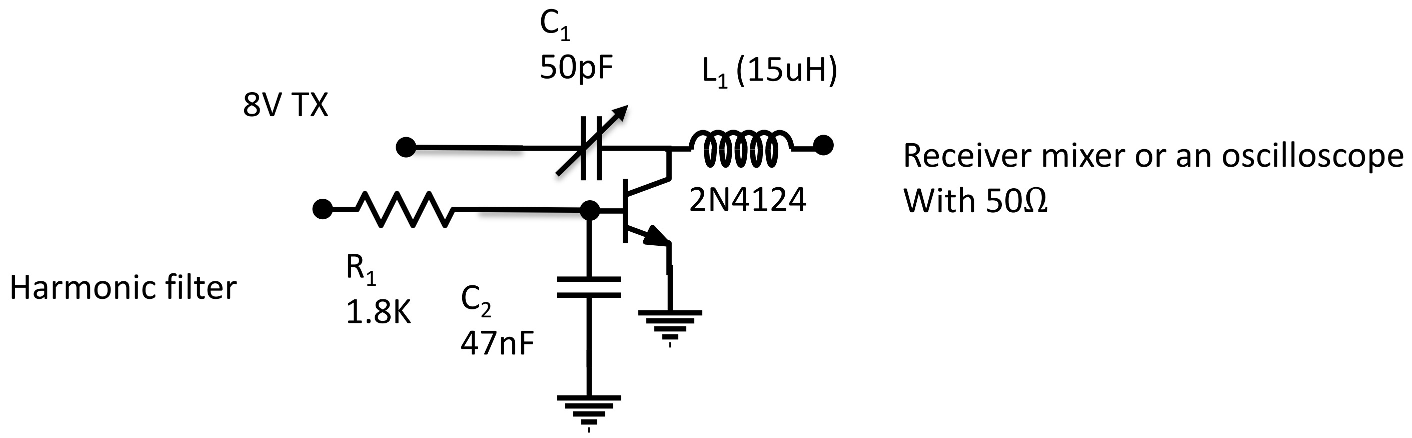
- $\frac{\partial^2 P}{\partial t^2} = \frac{\gamma P}{\rho}\frac{\partial^2 P}{\partial x^2}, v = \sqrt{\frac{\gamma P}{\rho}} = = 332\,\frac{m}{s}$
- $SWR = \frac{\lambda^2}{2\pi A},$ A is the area of the tube

Transmitter switch



- When key is down, transistor conducts

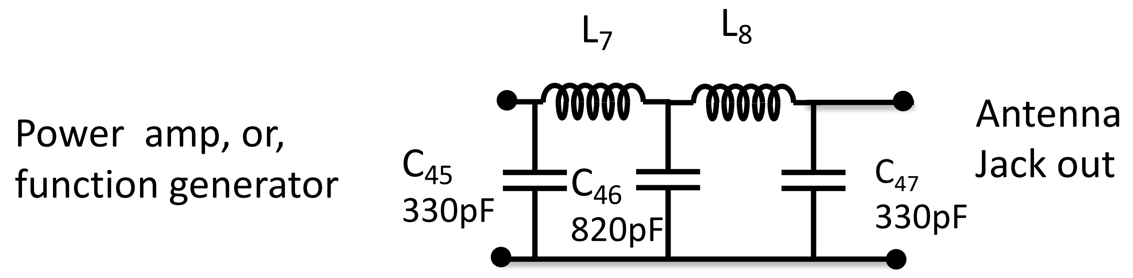
Receiver switch



If using function generator
use a 1.8K resistor

- When transistor conducts the receiver filter shorts

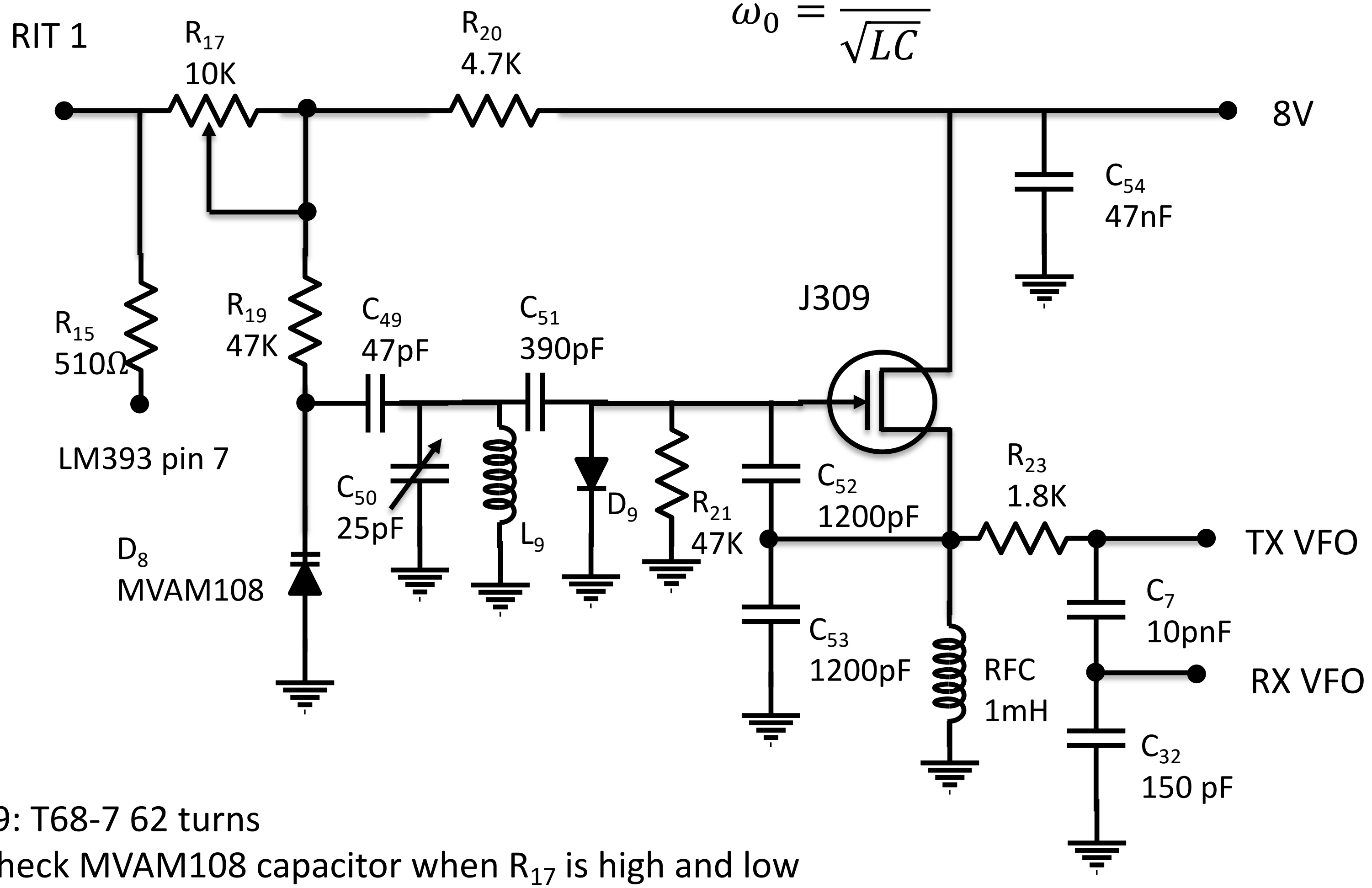
Norcal Harmonic Filter



- L_7, L_8 use T37-2 core, 18 turns, 1.3uH
- Compare loss at 7MHz and 14MHz

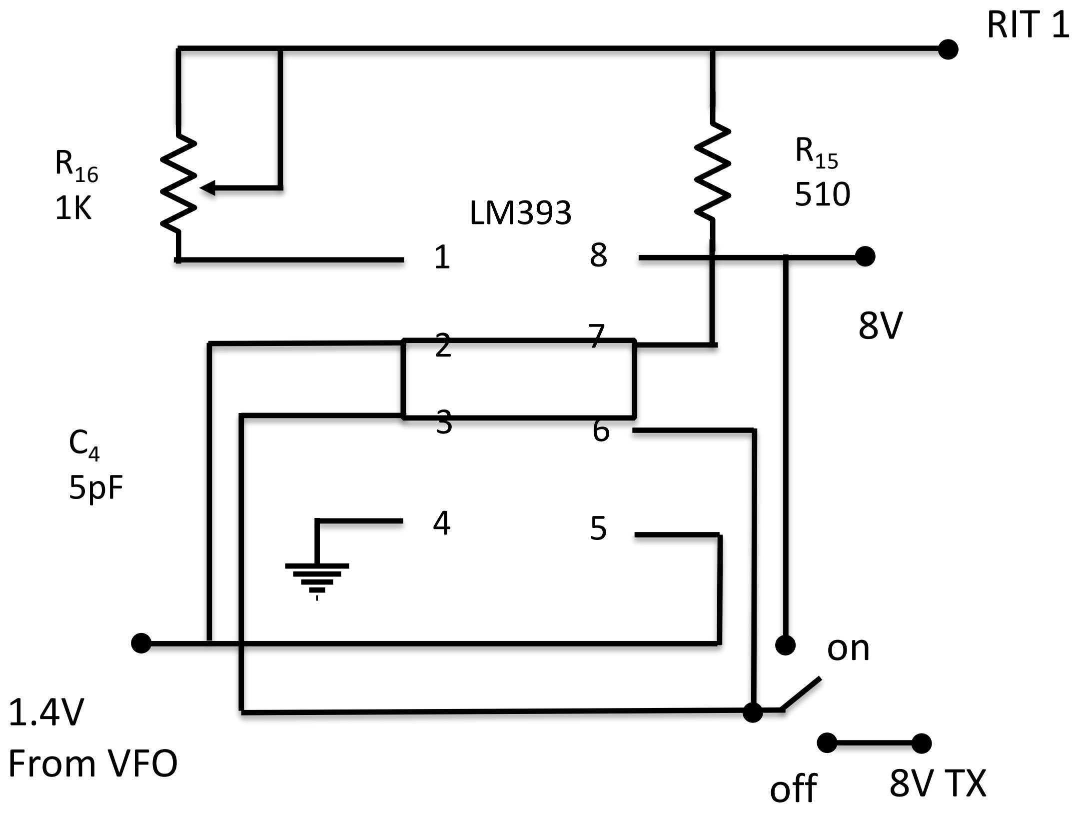
Norcal VCO

$$\omega_0 = \frac{1}{\sqrt{LC}}$$



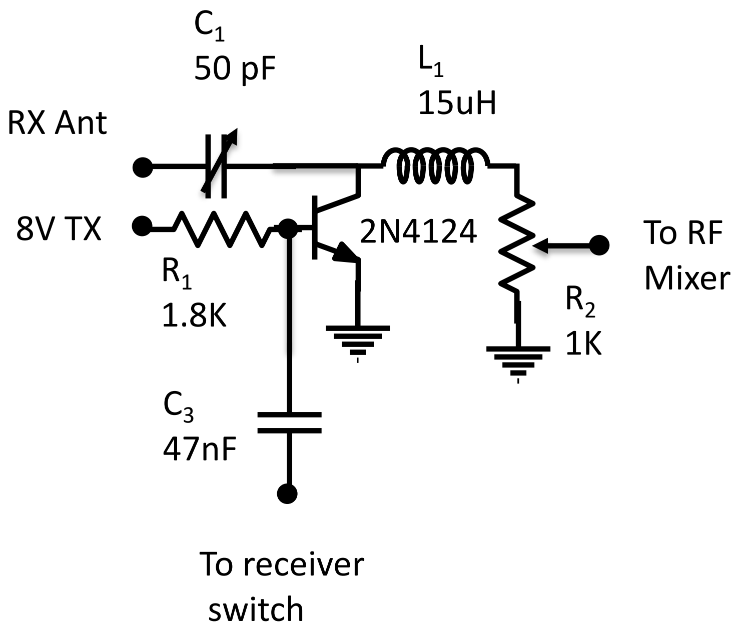
- L9: T68-7 62 turns
- Check MVAM108 capacitor when R_{17} is high and low
- Start resistor (R_{21}) pulls gat to ground at start
- When gain limiting diode (D9) conducts, it pulls gate negative
- Oscillator keeps growing as long as g_m>1/R

Norcal Receiver Incremental Tuning (RIT)

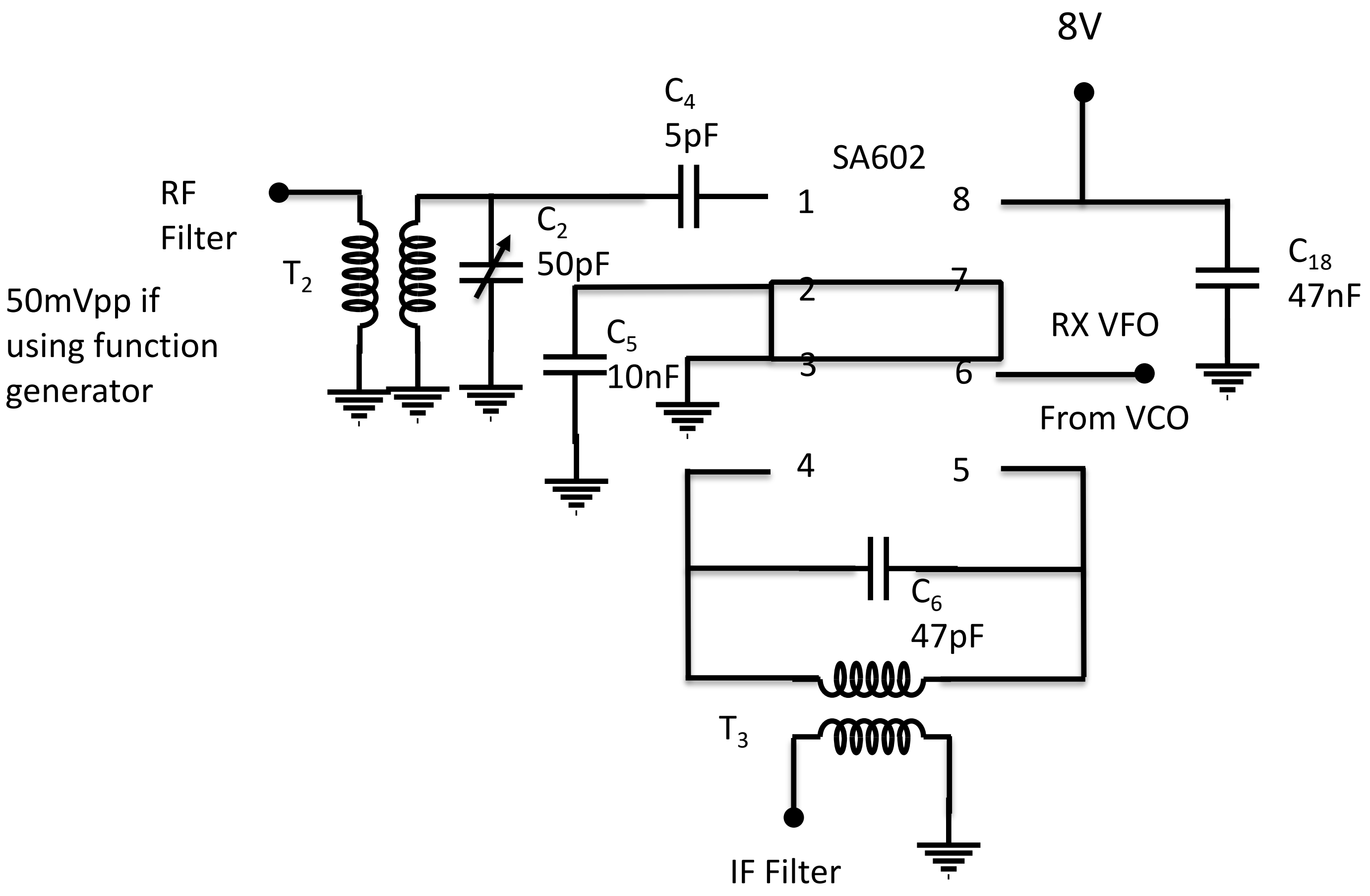


- LM393 is a comparator
- For function generator connect through 1.5K

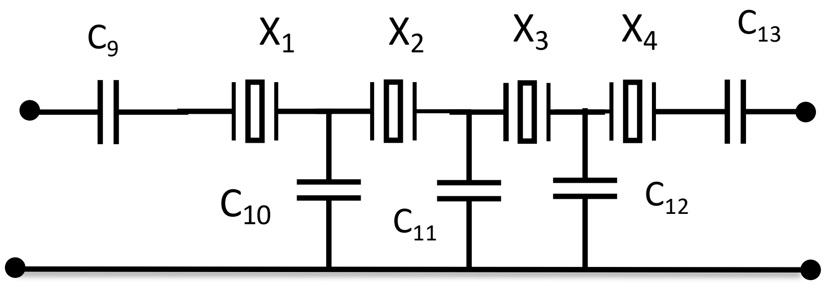
Norcal RF Filter



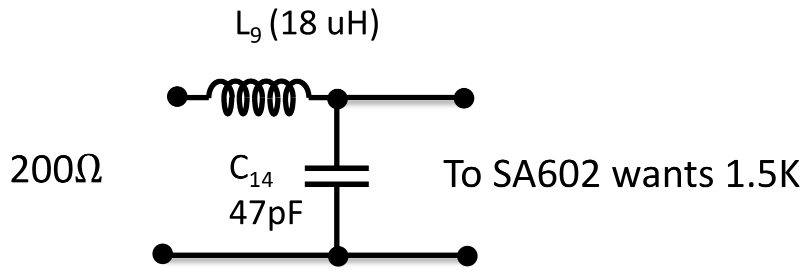
Norcal RF Mixer



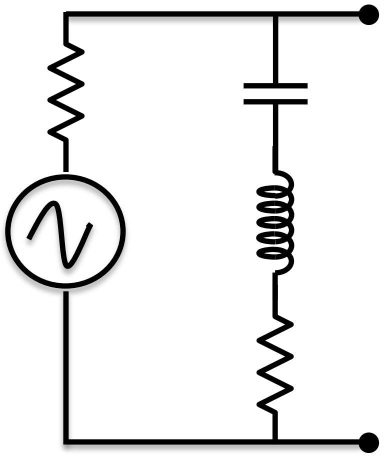
Norcal IF Cohn Filter



- X_1 through X_4 are 4.91 MHz
- C_{10}, C_{11}, C_{12} are 270 pF
- Set function generator to 50mV$_{pp}$ from function generator
- Calculate R and X for filter

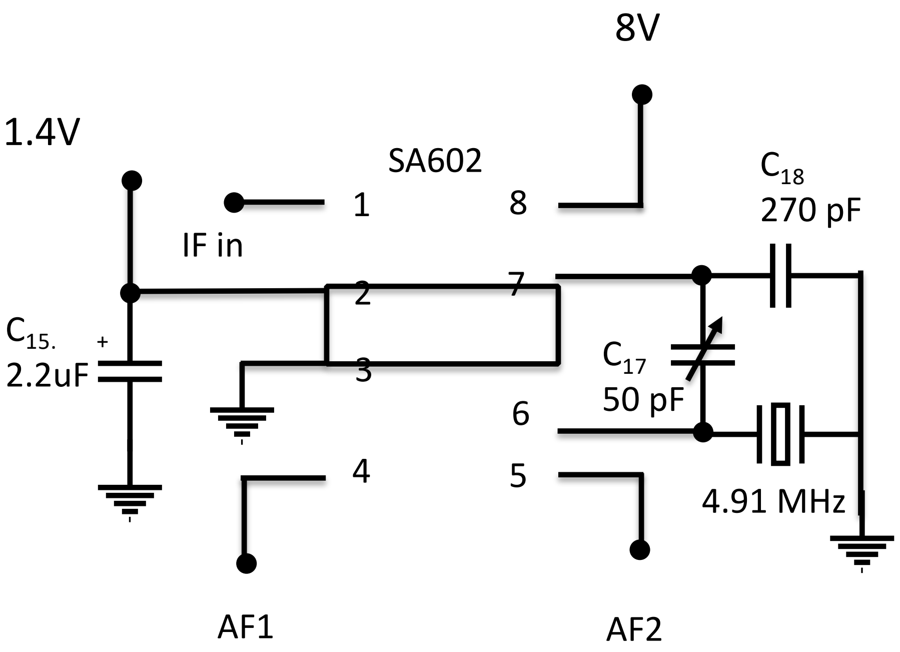


Matching network



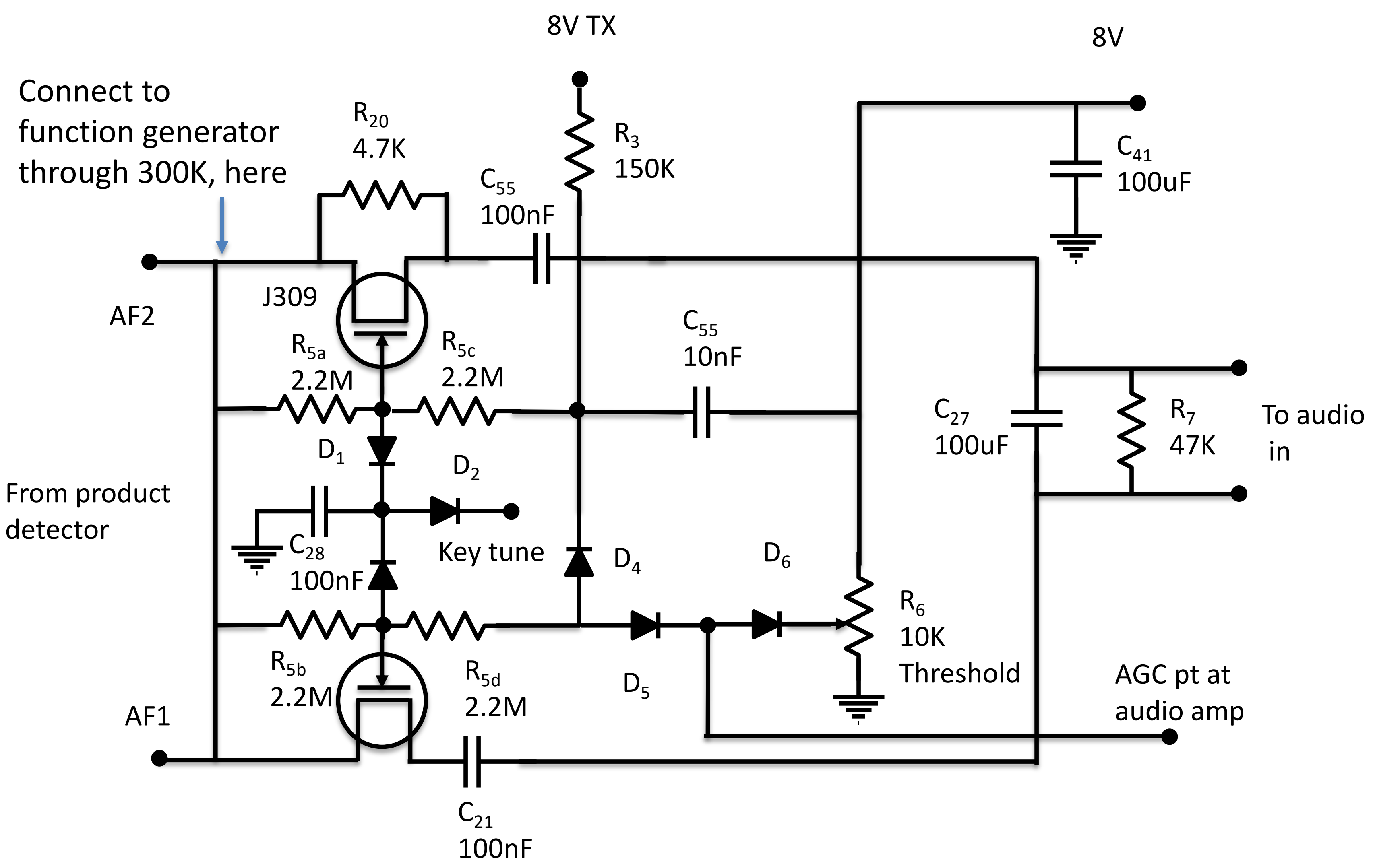
Equivalent circuit for crystal and generator

Norcal Product Detector



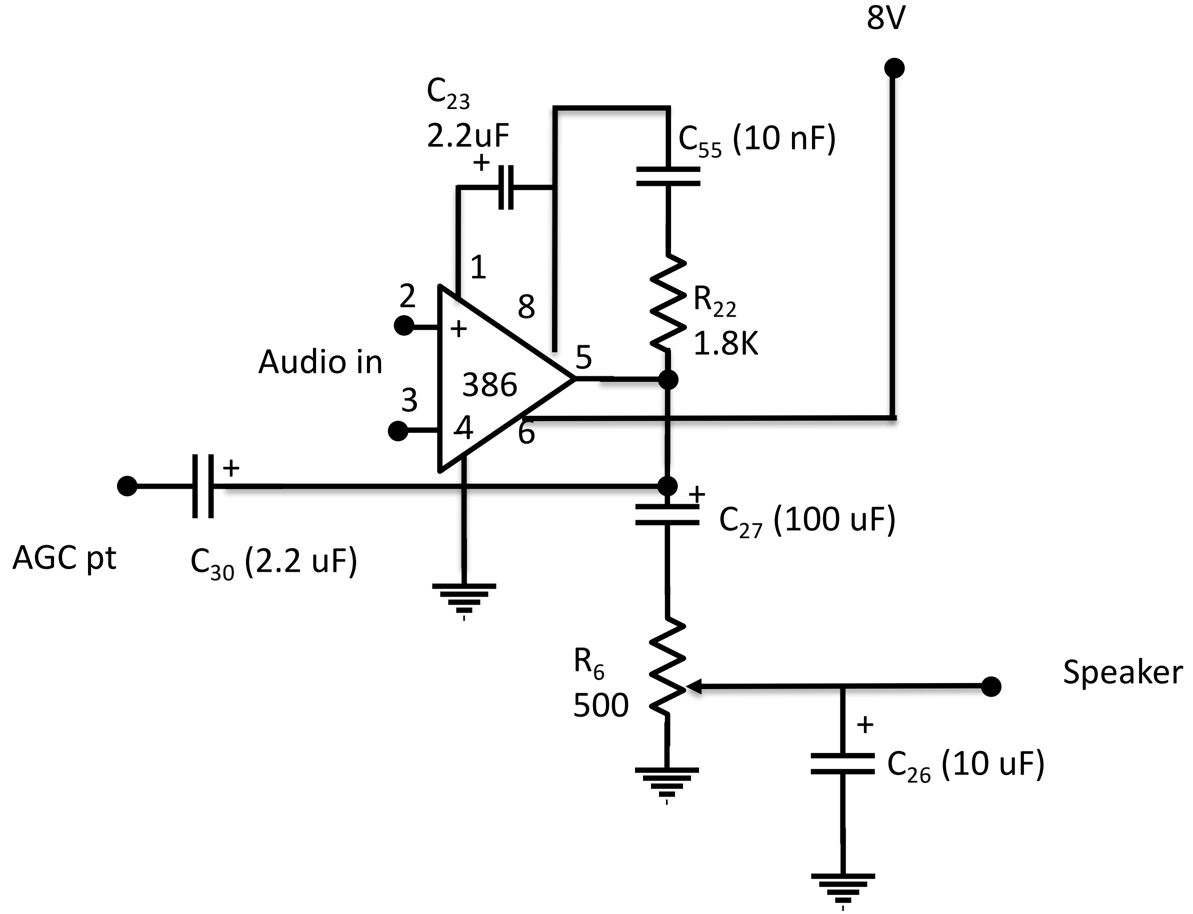
- 620 Hz output through AF1 and AF2

Norcal AGC



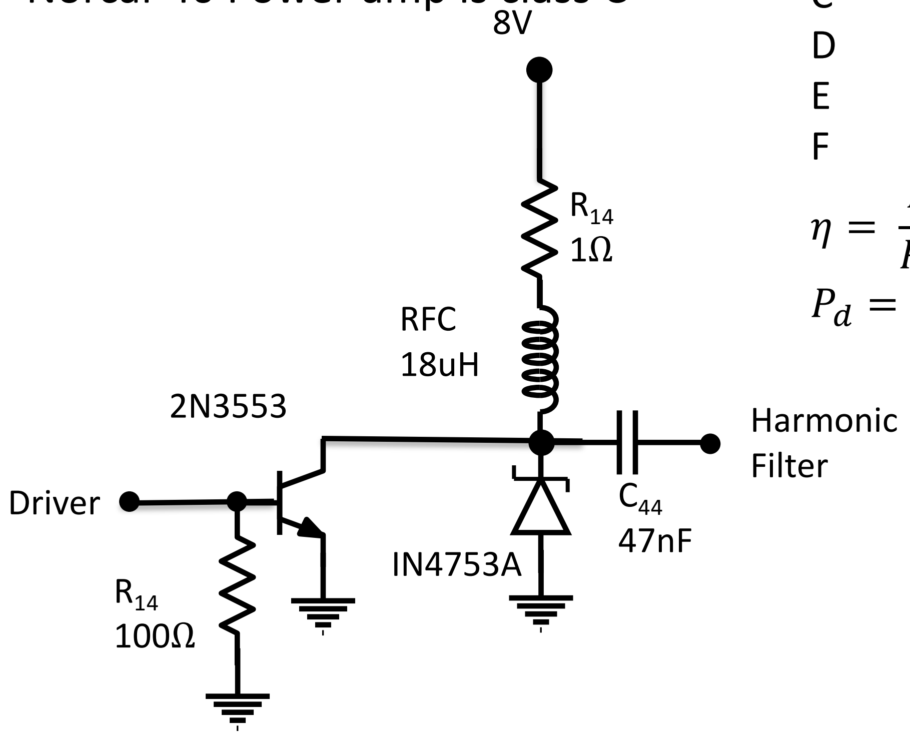
8V TX
8V
Connect to
function generator
through 300K, here
R20
4.7K
R3
150K
C55
100nF
C41
100uF
AF2
J309
R5a
2.2M
R5c
2.2M
C55
10nF
C27
100uF
R7
47K
To audio
in
D1
D2
From product
detector
C28
100nF
Key tune
D4
D6
R6
10K
Threshold
R5b
2.2M
R5d
2.2M
D5
AGC pt at
audio amp
AF1
C21
100nF

Norcal Audio Amp



Norcal Power Amp

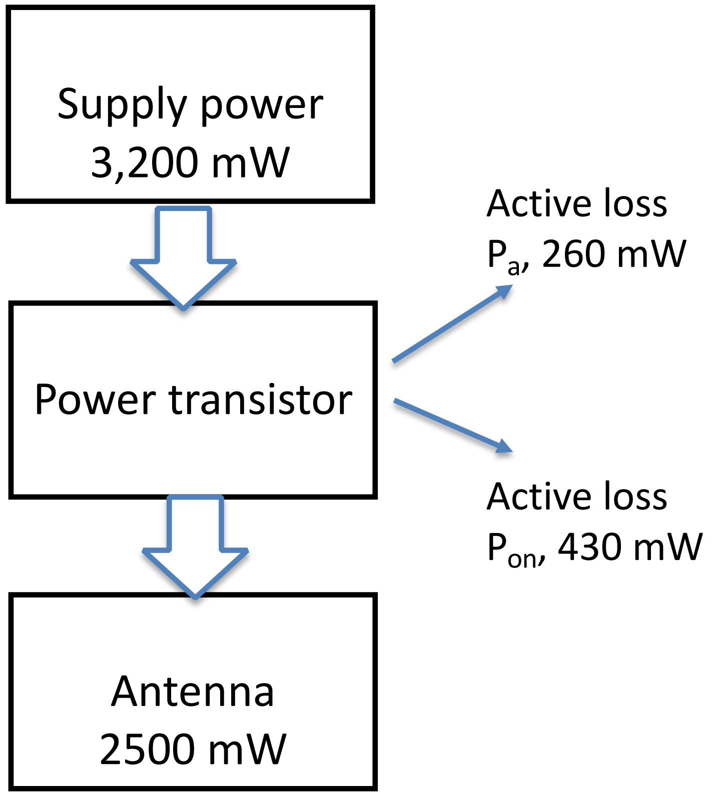
Norcal-40 Power amp is class C



Class	Efficiency	Characteristics
A	35%	Full bias
B	60%	Low bias
C	75%	Saturating
D	75%	Switch in pass-band
E	90%	Voltage switch
F	80%	Harmonic resonators

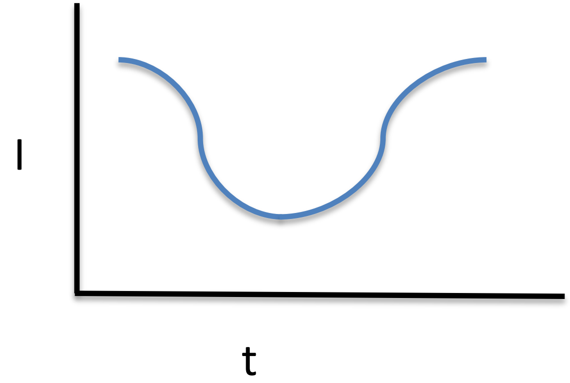
$$\eta = \frac{P}{P_0}, P_d = P_0 - P_i$$

$$P_d = P_a + P_{on}$$

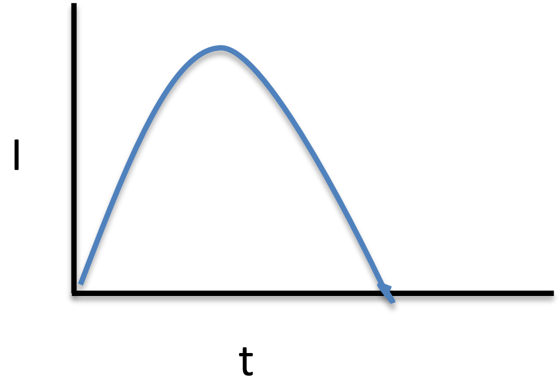


- $R_t = \frac{T - T_0}{P_d}$
- T_0 is ambient temperature, T is heat sink temperature

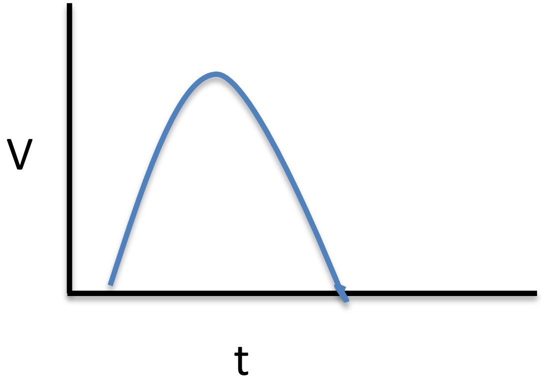
Amplifier classes



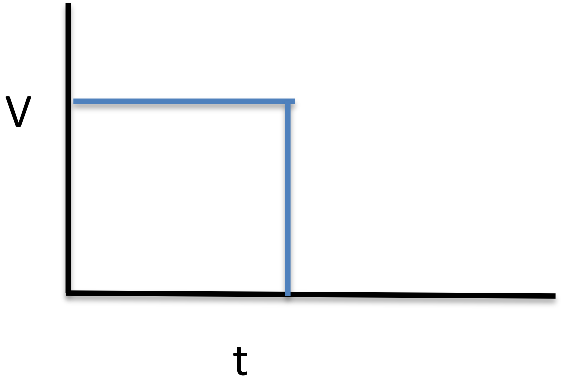
Class A



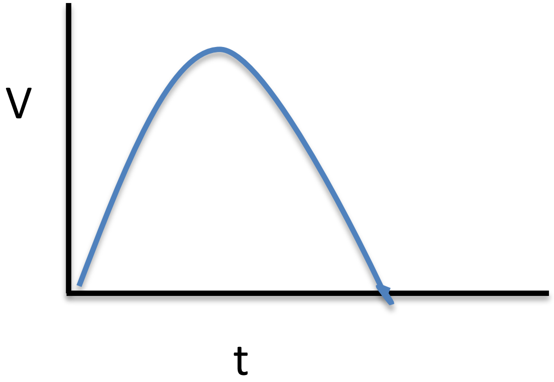
Class B



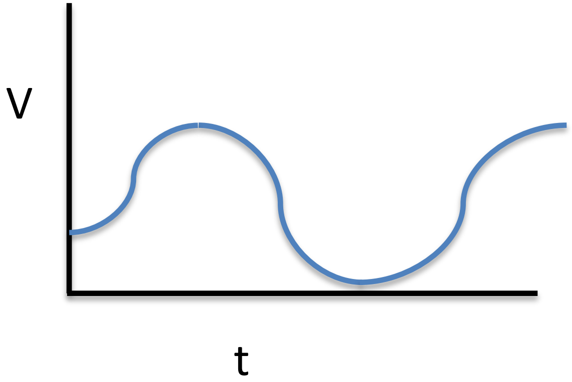
Class C



Class D



Class E

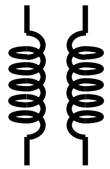


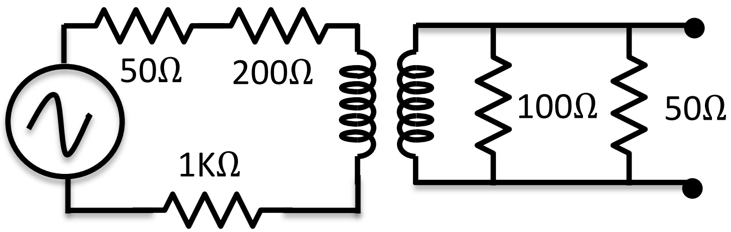
Class F

Norcal matching transformers

- T_1 is driver matcher uses FT 37-43
- Measurement circuit below

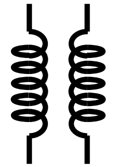
T_1, 14:4

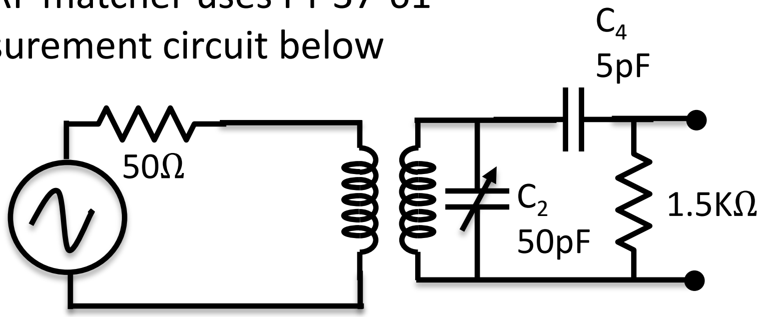




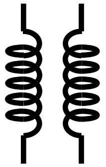
- T_2 is RF matcher uses FT 37-61
- Measurement circuit below

T_2, 1:20

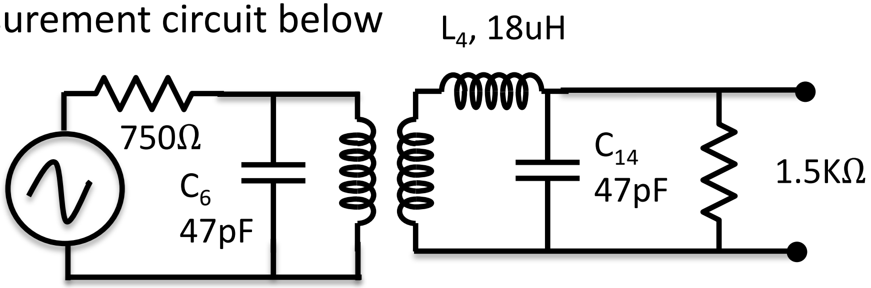




T_3, 23:6

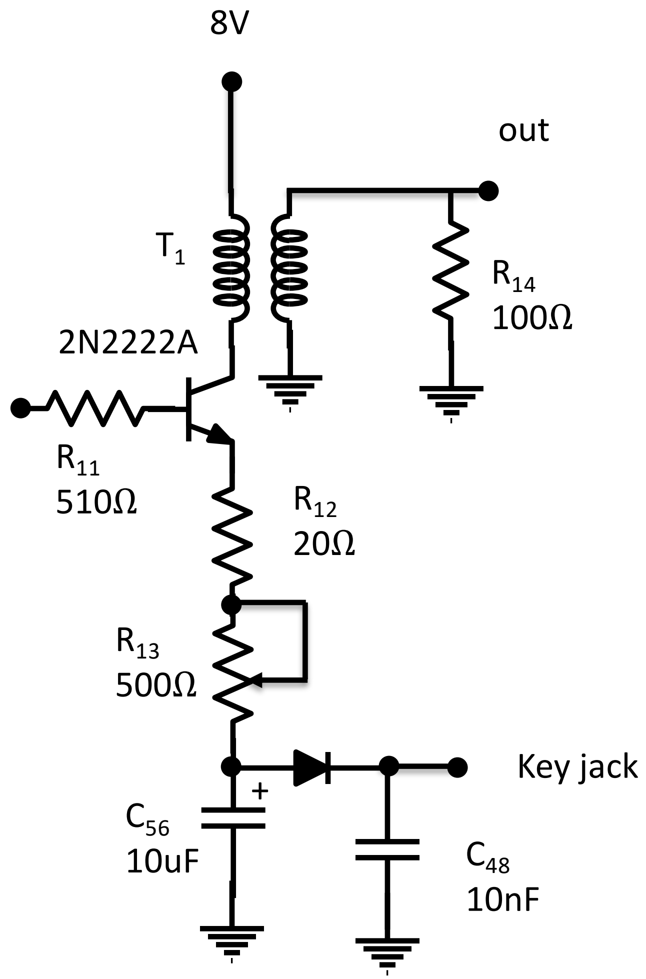


- T_3 is IF matcher uses FT 37-61
- Measurement circuit below

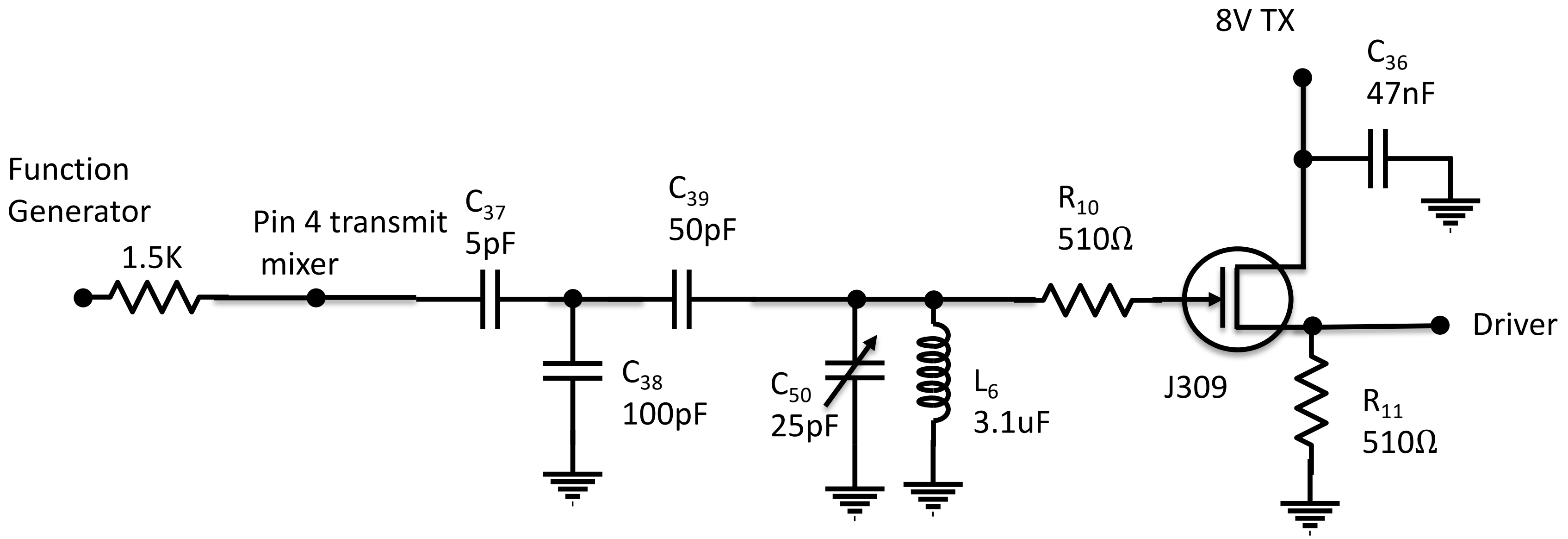


Norcal Driver

- Use 50Ω scope probe

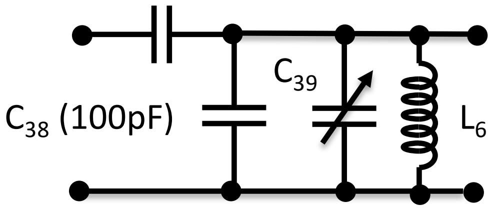


Norcal Buffer



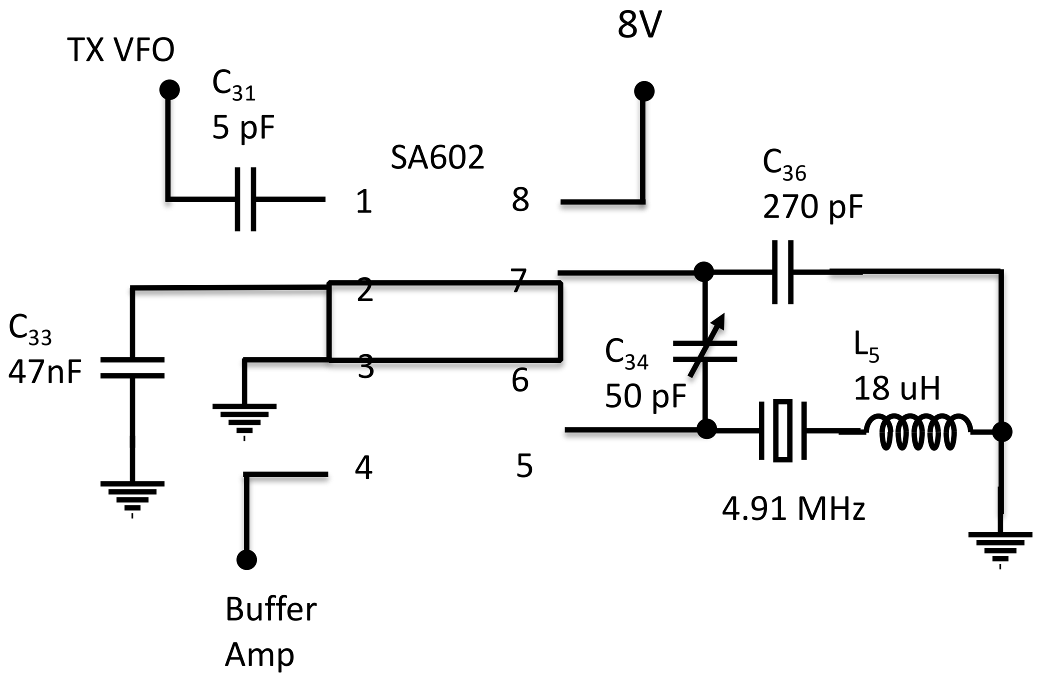
$$G_V = \frac{V}{V_i}$$

Norcal transmit bandpass filter



- $C_{39} = 50pF,$
- L_6 is 36 turns #28 on T37-2 which has $A_l = 4\frac{nH}{turn^2}$
- $L_6 = A_l \cdot 36^2 = 3.1\mu H$
- $Z_2 = -\frac{j}{(C_{38}+C_{39})\omega_o},\ Z_3 = jL_6\omega_o, Z_1 = \frac{j}{C_{37}\omega_o}$
- $Z_{2,3-eq} = \frac{jL_6\omega_0}{L_6(C_{38}+C_{39})\omega_0{}^2-1}$
- Resonance is when $Z_{2,3-eq} \to \infty, \omega_o{}^2 = \frac{1}{(C_{38}+C_{30})L_6} \approx \frac{10^{18}}{465}$, when almost all the voltage drop is across $Z_{2,3-eq}$
  $\omega_o = \frac{10^9}{\sqrt{465}} \approx 50.8\times10^6, f_0 = \frac{\omega_o}{2\pi} \approx 7.1\ MHz$
- Q of filter is: $Q_s = \frac{X_s}{R_s}$. R_s comes from the other compon ents and must be measured
- Note that $Z_{2,3-eq}$ is small for the other modulation prod uct

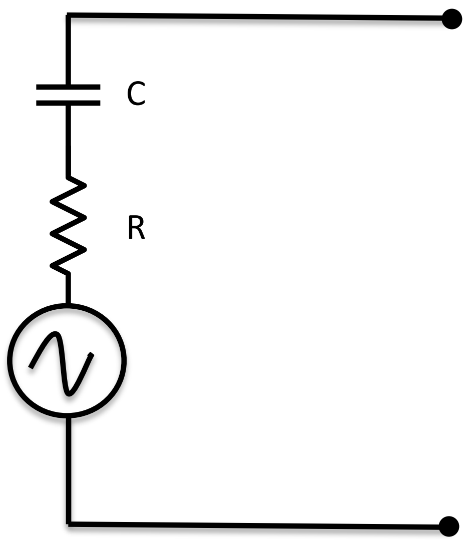
Norcal transmit mixer and oscillator



Antennas and propagation

- From Maxwell, for a plane wave (E in x direction, H in y direction), wave is of form $\exp(j\omega t - j\beta z)$
- $\nabla \times E = -j\mu_0 \omega H$
- $\nabla \times B = j\epsilon_0 \omega E$
- $\beta \hat{z} \times E = \mu_0 \omega H, \beta E_x \hat{y} = \mu_0 \omega H$
- Substituting and taking the restricted cross products, we get: $\beta E_x = \omega \mu_0 \frac{\omega \epsilon_0}{\beta}$, so $\beta = \omega \sqrt{\mu_0 \epsilon_0}$
- Power density: $S = Re\left(\frac{E_x \overline{H_y}}{2}\right) = \frac{(|E_x|)^2}{2\eta_0}$
- $\eta_0 = \frac{E_x}{H_y} = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega$
- Impedance: $P_t = \frac{R|I|^2}{2}$, R is real part of Z, $R = R_r + R_l, \eta = \frac{R_r}{R}$
- Power density for isotropic antenna: $S_i = \frac{P_t}{4\pi r^2}$
- Define $G(\theta, \phi) = \frac{S(\theta,\phi)}{S_r}$. $S(\theta, \phi)$ is just the Poynting vector
- For isotropic reference, $G = \frac{4\pi r^2 S}{P_t}$

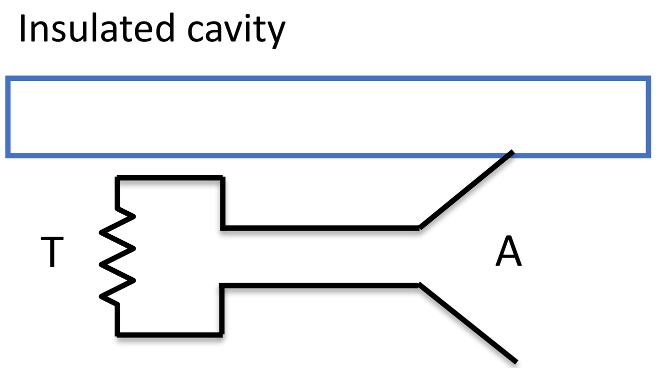
Receiving antenna Thevenin



Antennas and propagation

- Receiving antenna:
- $V_0 = hE$, h is effective antenna length ($h = \frac{l}{2}$ for short antenna)
- For dipole: $V_0 = \frac{l}{2}\, E \sin(\theta)$
- $A(\theta,\phi) = \frac{P_r}{S(\theta,\phi)}$. This is the definition of the effective area, A.
- By reciprocity, $A(\theta,\phi) = \frac{\lambda^2}{4\pi} G(\theta,\phi)$
- $P_r = \frac{|V_0|^2}{8R_a} = \frac{|hE|^2}{8R_a}$, so
- $P_r = \frac{h^2 S \eta_0}{4R}$
- $A = \frac{h^2 \eta_0}{4R}$

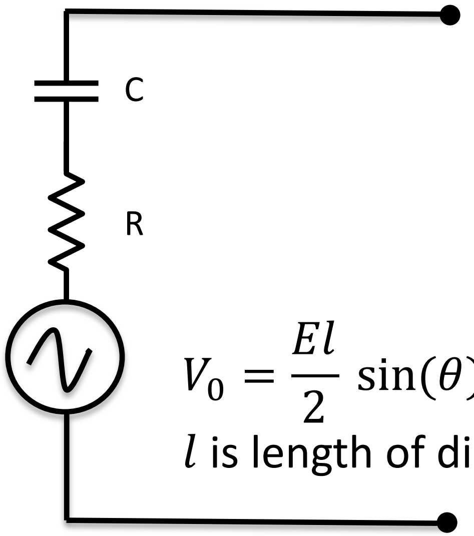
Antennas and propagation



- Antenna theorem: $\oint A \, d\Omega = \lambda^2$
- For cavity on right, T is constant at thermodynamic equilibrium and the same power is transmitted and emitted, the Johnson noise is kT. The energy received is $E = \frac{4\pi kT}{c\lambda^2}$. Set $B = \frac{kT}{\lambda^2}$. $kT = \oint BA \, d\Omega = \oint A \frac{kT}{\lambda^2} \, d\Omega$, which gives the antenna theorem
- For transmitting/receiving antenna pairs: $G_1 A_2 = \frac{|V|^2 \pi r^2}{|I|^2 R_1 R_2} = G_2 A_1$. So $\frac{G_1}{A_1} = \frac{G_2}{A_2} = \frac{4\pi}{\lambda^2}$
- Friis formulas
- $S = \frac{P_t G}{4\pi r^2}, P_r = SA = \frac{P_t G A}{4\pi r^2}$

Reciprocity and dipole

Dipole Thevenin equivalent circuit



$V_0 = \frac{El}{2}\sin(\theta)$

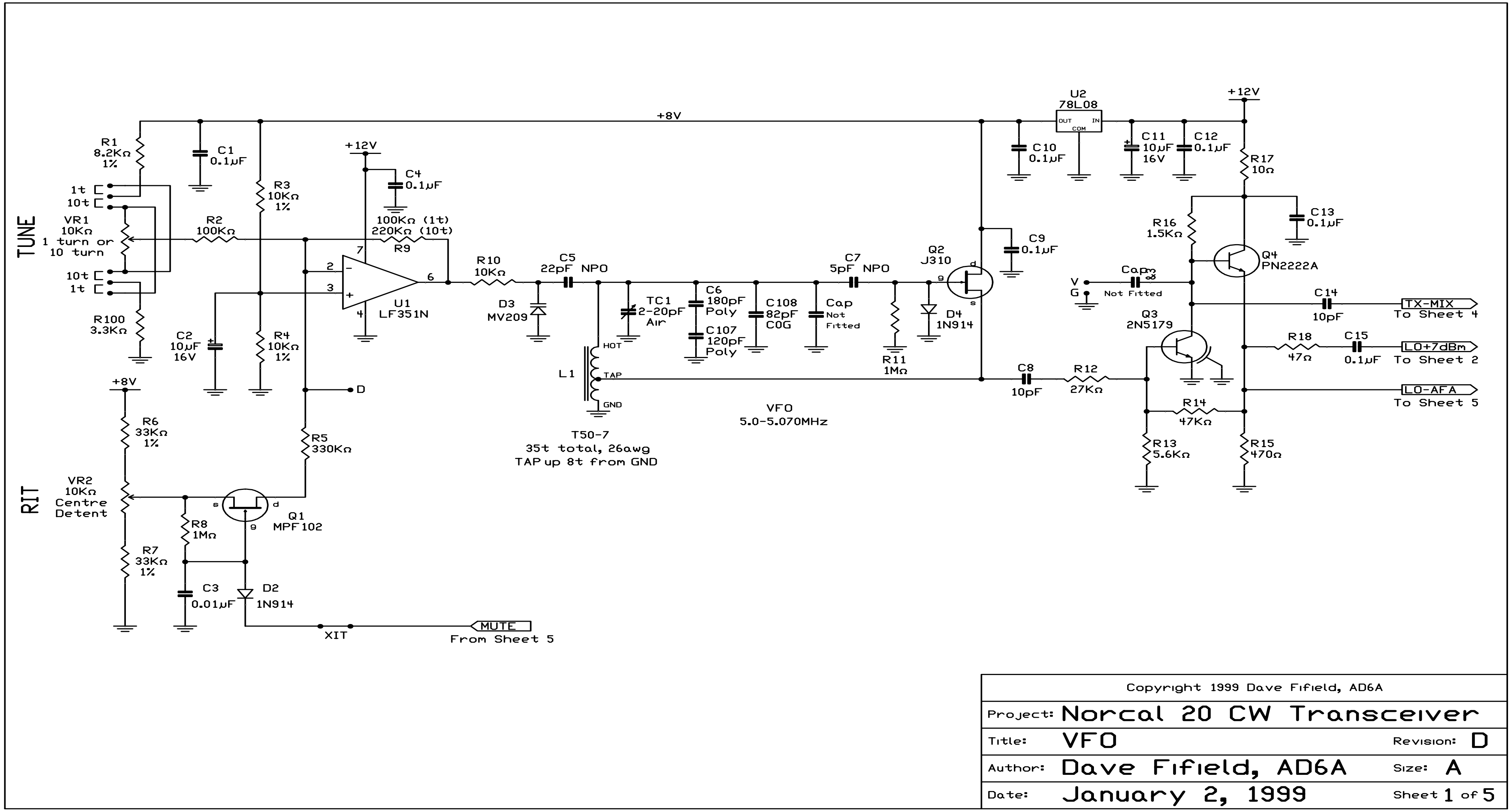
l is length of dipole

- For dipole (Length: $l = \frac{\lambda}{2}$)
- $\lambda^2 = \int A \, d\Omega = \int \frac{h^2 \eta_0}{4R_r} \, d\Omega$, so
- $R_r = \frac{l^2 \eta_0}{16\lambda^2} \int sin^2(\theta) d\Omega = \eta_0 \frac{\pi}{6} \left(\frac{l}{\lambda}\right)^2$
- $A = \frac{3\lambda^2}{8\pi} sin^2(\theta)$ and $G = 1.5 \, sin^2(\theta)$. . Note we used $h = \frac{l}{2}\sin(\theta)$
- For Norcal, $G = 1$, $A = 150m^2$, for $r = 2000 \, m, P_r = 6pW$

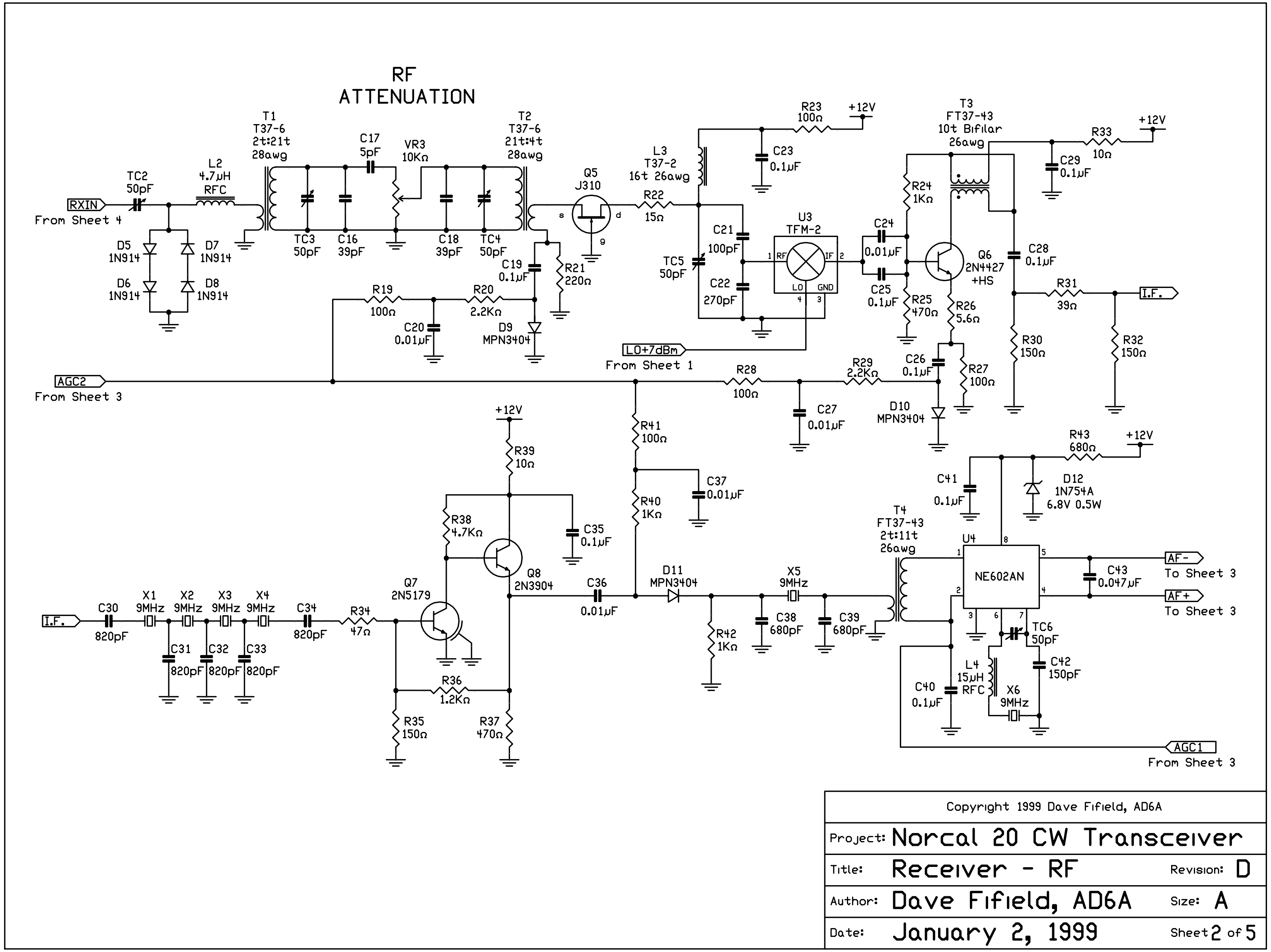
Noise

- $V_{n(rms)} = \sqrt{\frac{1}{\tau}\int_0^{\tau} V(t)^2 \ dt}$
- $P_n = \frac{{V_{n(rms)}}^2}{R}$, R is load resistance
- $SNR = \frac{P}{P_n}$
- $MDS = \frac{P_n}{G}$
- Nyquist
- $V_C = \frac{1}{j\omega C} \frac{V_n}{R + j\omega L + \frac{1}{j\omega C}}$
- $\overline{|V_c|^2} = \frac{\overline{|V_n|^2}}{|1 - \omega^2 LC + j\omega RC|^2}$
- Expected energy at resonance is $kT = \frac{C}{2}\int_0^{\infty} |V_c|^2 df$
- $\int_0^{\infty} \frac{1}{|1 - \omega^2 LC + j\omega RC|^2} df = \frac{1}{4RC}$
- So, $\overline{|V_c|^2} = 8\mathrm{kTR}$

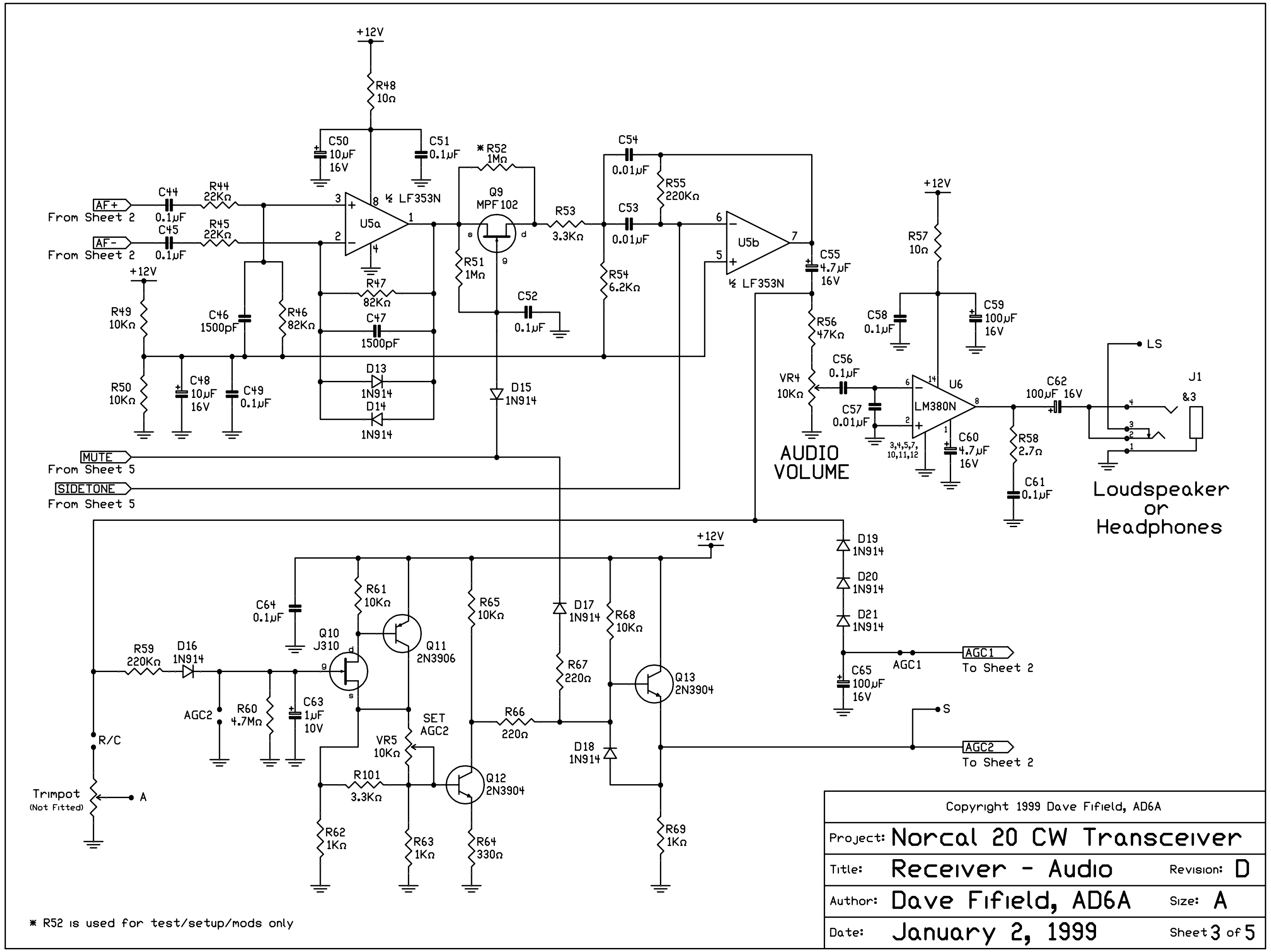
Norcal circuit diagram, 1



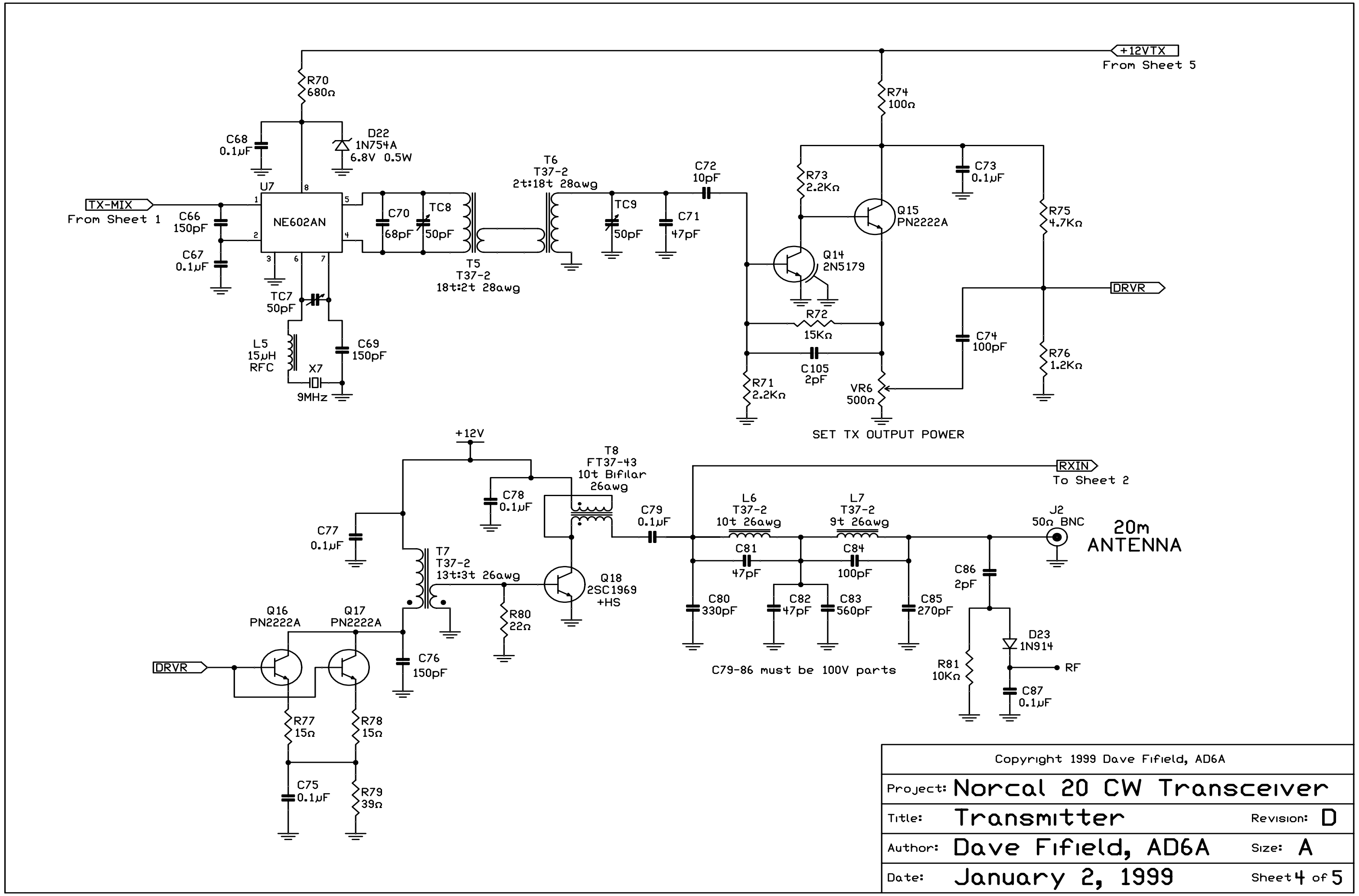
Norcal circuit diagram, 2



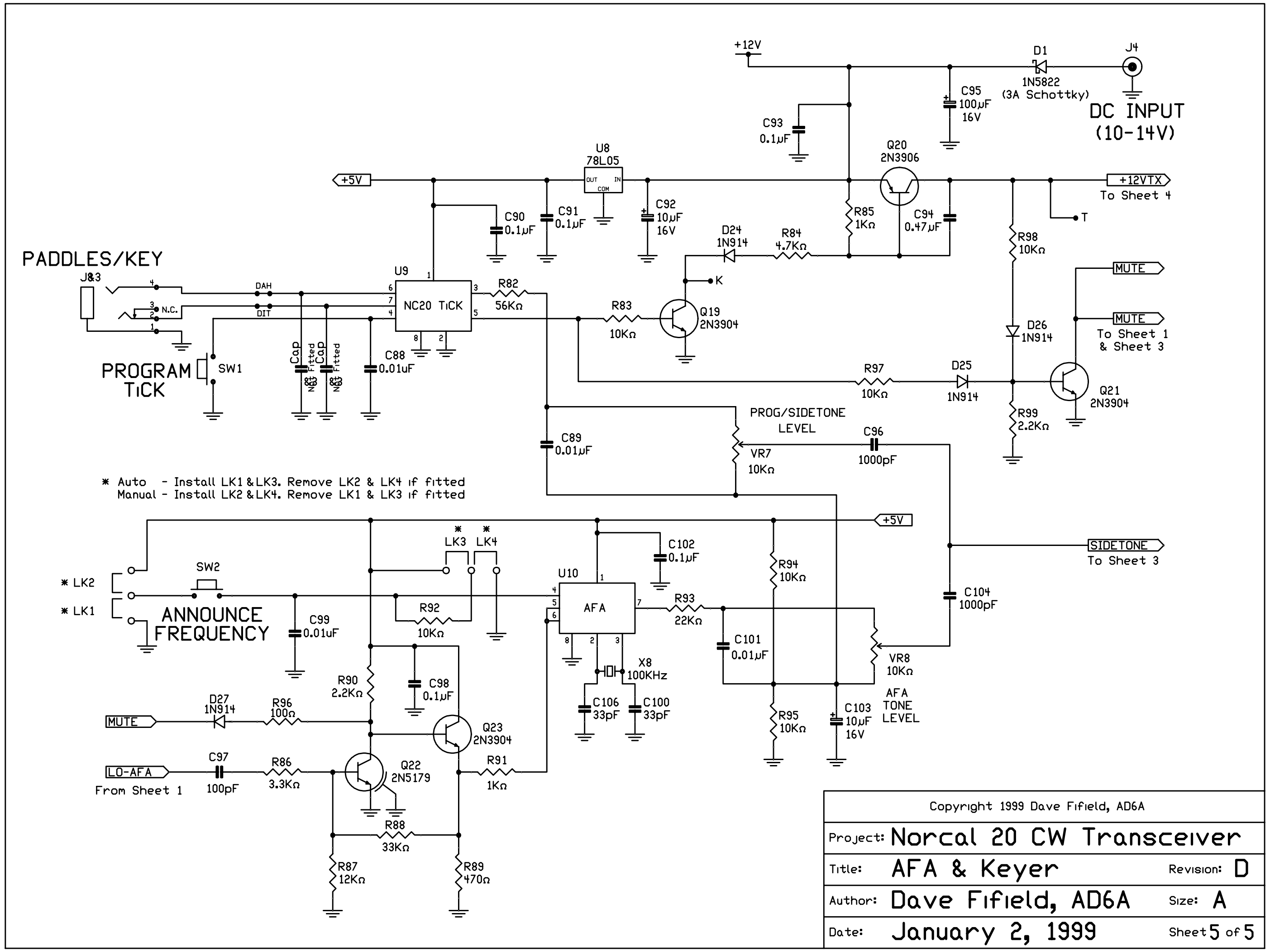
Norcal circuit diagram, 3



Norcal circuit diagram, 4



Norcal circuit diagram, 5



Block Diagram

Block Diagram