

Electronics of Radio

Notes on David Rutledge's book

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Basic concepts

- Potential difference (V, ϕ): $\phi = \int_a^r E \cdot ds$, energy per charge, $1V = 1 J/s$
- Kirkoff 1: $\sum_{loop} V_i = 0$ (Conservation of energy)
- Kirkoff node: $\sum_{node} I_i = 0$ (Conservation of charge)
- $V(t) = V_p \cos(\omega t)$, $\omega = 2\pi f$, $I(t) = I_p \cos(\omega t)$, $\omega = 2\pi f$
- Instantaneous power: $P(t) = V(t)I(t) = V_p I_p \cos^2(\omega t)$
- Average power: $P_a = \int_0^{1/f} V(t)I(t)dt = V(t)I(t) = \int_0^{2\pi/\omega} V_p I_p \cos^2(\omega t)dt = \frac{V_p I_p}{2}$
- Band names:

Name	Frequency
VLF	3-30kHz
LW	20-300kHz
MW	300kHz-3MHz
HF	3MHz-30MHz
VHF	30-300MHz

Name	Frequency
UHF	300MHz-1GHz
uW	1-30GHz
milliW	30-300GHz
submilliF	>300GHz

Signals

- Gain (G) expressed in decibels: $G = 10 \log_{10}(P_{out}/P_{in})$
- Mixer:
 - $V(t) = \cos(\omega_1 t) \cos(\omega_2 t) = \frac{1}{2} [\cos(\omega_+ t) + \cos(\omega_- t)]$, $\omega_+ = \omega_1 + \omega_2$, $\omega_- = \omega_1 - \omega_2$
- Modulation

Name	Equation
AM	$V(t) = a(t)\cos(\omega_c t)$
FM	$V(t) = V_c \cos((\omega_c + a(t))t)$
FSK	$V(t) = V_c \cos(\omega_1 t)$, if 1 $V(t) = V_c \cos(\omega_0 t)$, if 0
PSK	$V(t) = +V_p \cos(\omega t)$, if 1 $V(t) = -V_p \cos(\omega t)$, if 0

Resistors, capacitors, inductors, diodes

- Resistor: $IR = v$
- Capacitor: $CV = q, C \frac{dV}{dt} = i$
- Inductor: $V = L \frac{di}{dt}$
- Diodes
- Energy stored

Impedance and phasors

- Impedance and phasors

Phasor Power

- Impedance and phasors

Circuit analysis with Kirchhoff and impedance

- RC circuits
- Parallel and series

Filters

- x

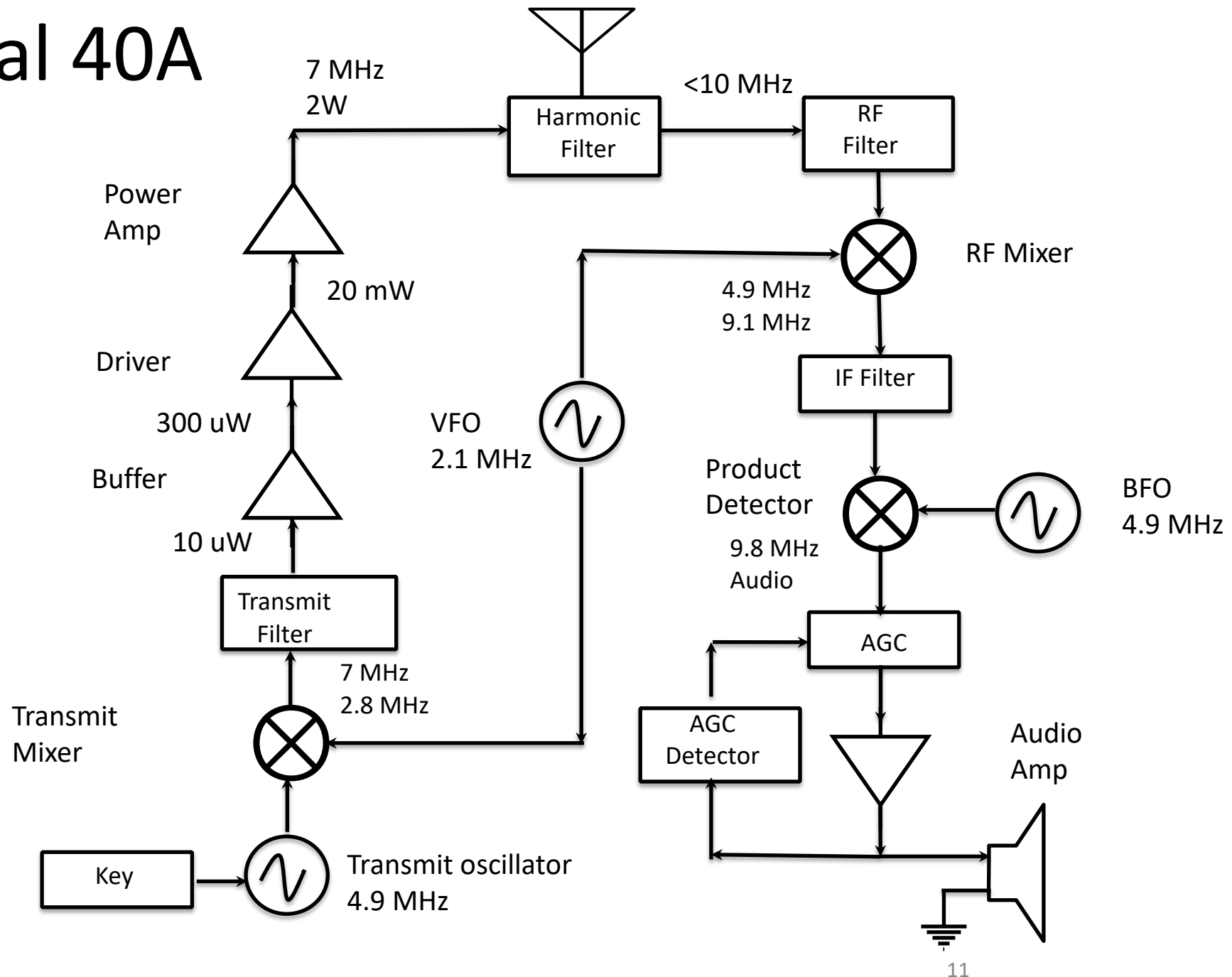
Thevenin and Norton

- Lookback

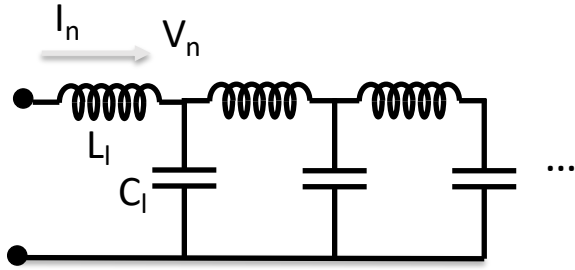
Resonance and Q

- Resonance

Norcal 40A



Transmission Lines



Power

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

Lookback resistance is $R_s = Z_0$

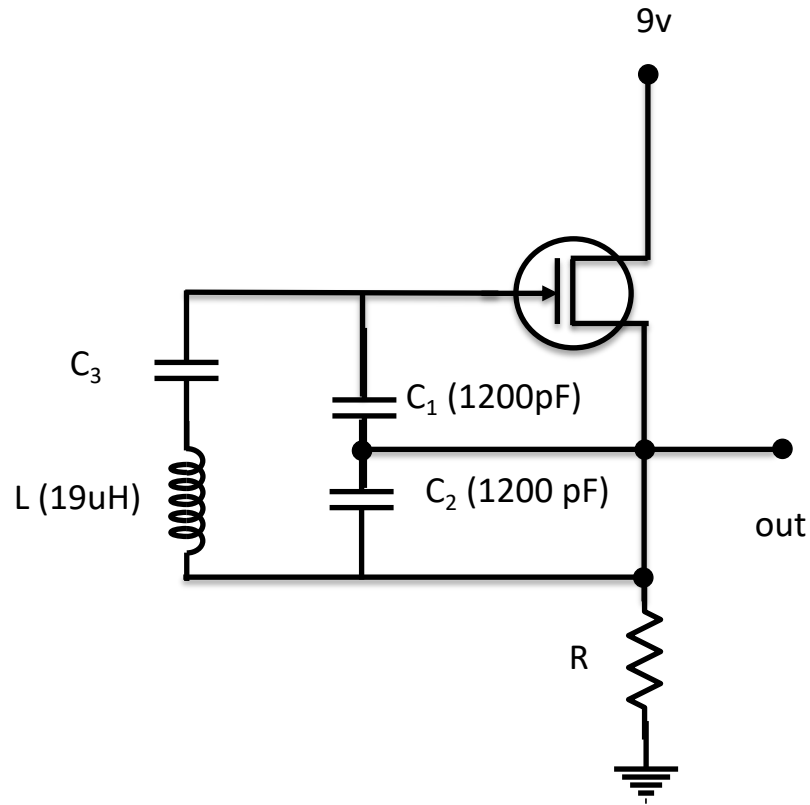
$$P_+ = \frac{V_+^2}{2Z_0} = \frac{V_0^2}{8Z_0}, \text{ This is the total available power}$$

- $V_{n+1} - V_n = -L_l \frac{\partial I_{n+1}}{\partial t}, L = \frac{L_l}{l}$
- $I_{n+1} - I_n = -C_l \frac{\partial V_n}{\partial t}, C = \frac{C_l}{l}$
- $\frac{\partial^2 V}{\partial z^2} = LC \frac{\partial^2 V}{\partial t^2}$ 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 reverse wave
- $Z_0 = \frac{V_+}{I_+}, -Z_0 = \frac{V_-}{I_-}, V = V_+ + V_-$
- $P_+(t) = \frac{V_+^2}{Z_0}, P_-(t) = -\frac{V_-^2}{Z_0}$
- $\rho = \frac{V_-}{V_+}, Z = \frac{V}{I} = \frac{V_+ + V_-}{I_+ + I_-} = \frac{V_+}{I_+} \frac{1 + \frac{V_-}{V_+}}{1 + \frac{I_-}{I_+}} = Z_0 \frac{1 + \rho}{1 - \rho}$
- $\rho = \frac{Z - Z_0}{Z + Z_0}$
- $\rho_i = \frac{i_-}{i_+} = -\rho$

Transmission Lines - continued

x

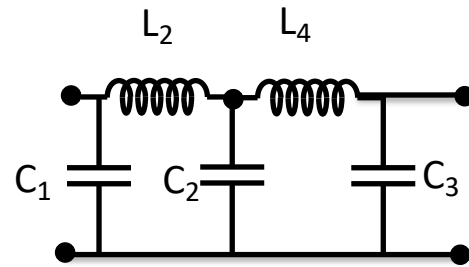
Norcal Clapp oscillator



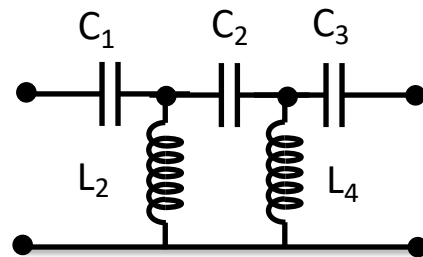
- $i_d = g_m v_{gs}$
- Resonance: $-\frac{1}{j\omega_0 C_2} = j\omega_0 L + \frac{1}{j\omega_0 C_3} + \frac{1}{j\omega_0 C_1}$
- $\omega_0 = \frac{1}{\sqrt{LC}}, C = C_1 || C_2 || C_3$
- At resonance, $v_{gs} = R i_d \frac{C_1}{C_2}, L = \frac{C_1}{RC_2}$
- Oscillation continues if $g_m > \frac{C_1}{RC_2}$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

Filters

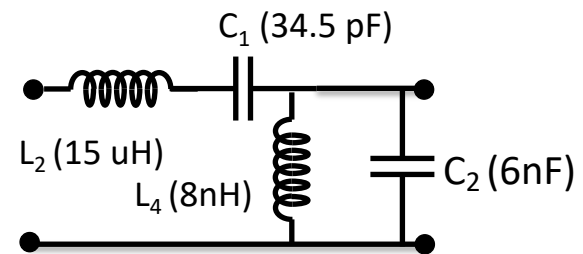
Low pass



High pass



7 MHz bandpass



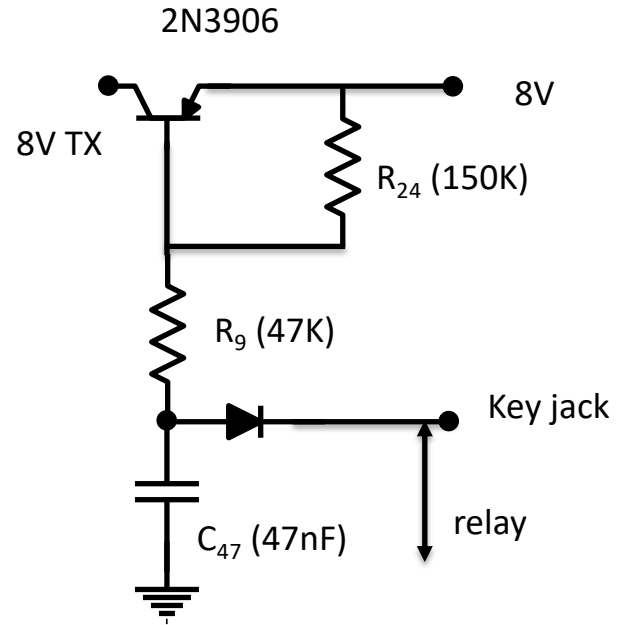
Acoustics

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

Transistors

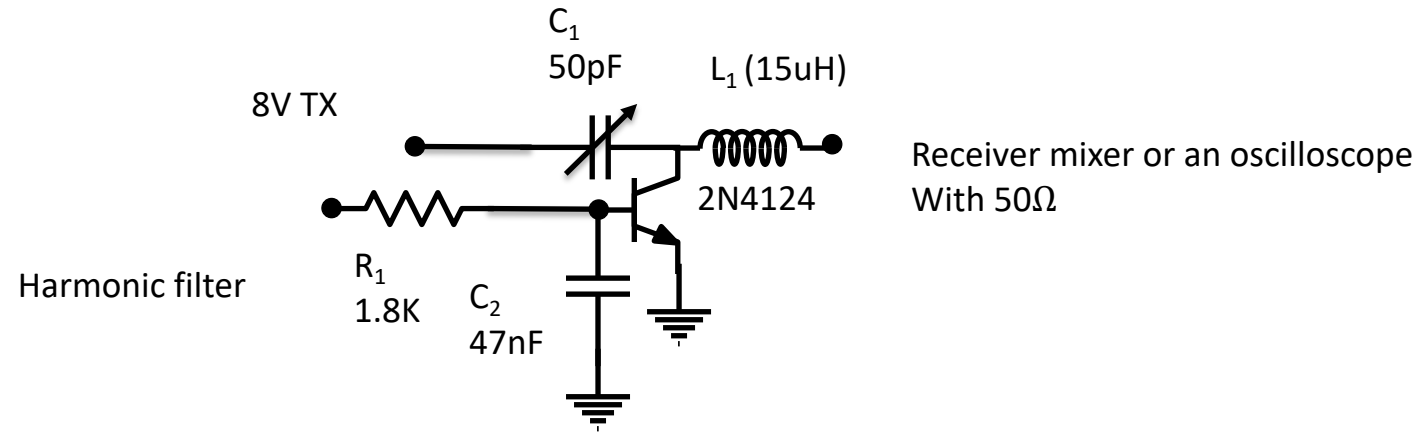
- When key is down, transistor conducts

Transmitter switch



- When key is down, transistor conducts

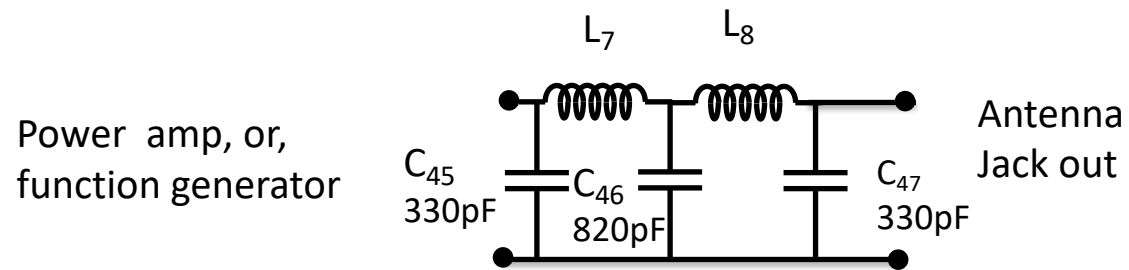
Receiver switch



If using function generator
use a 1.8K resistor

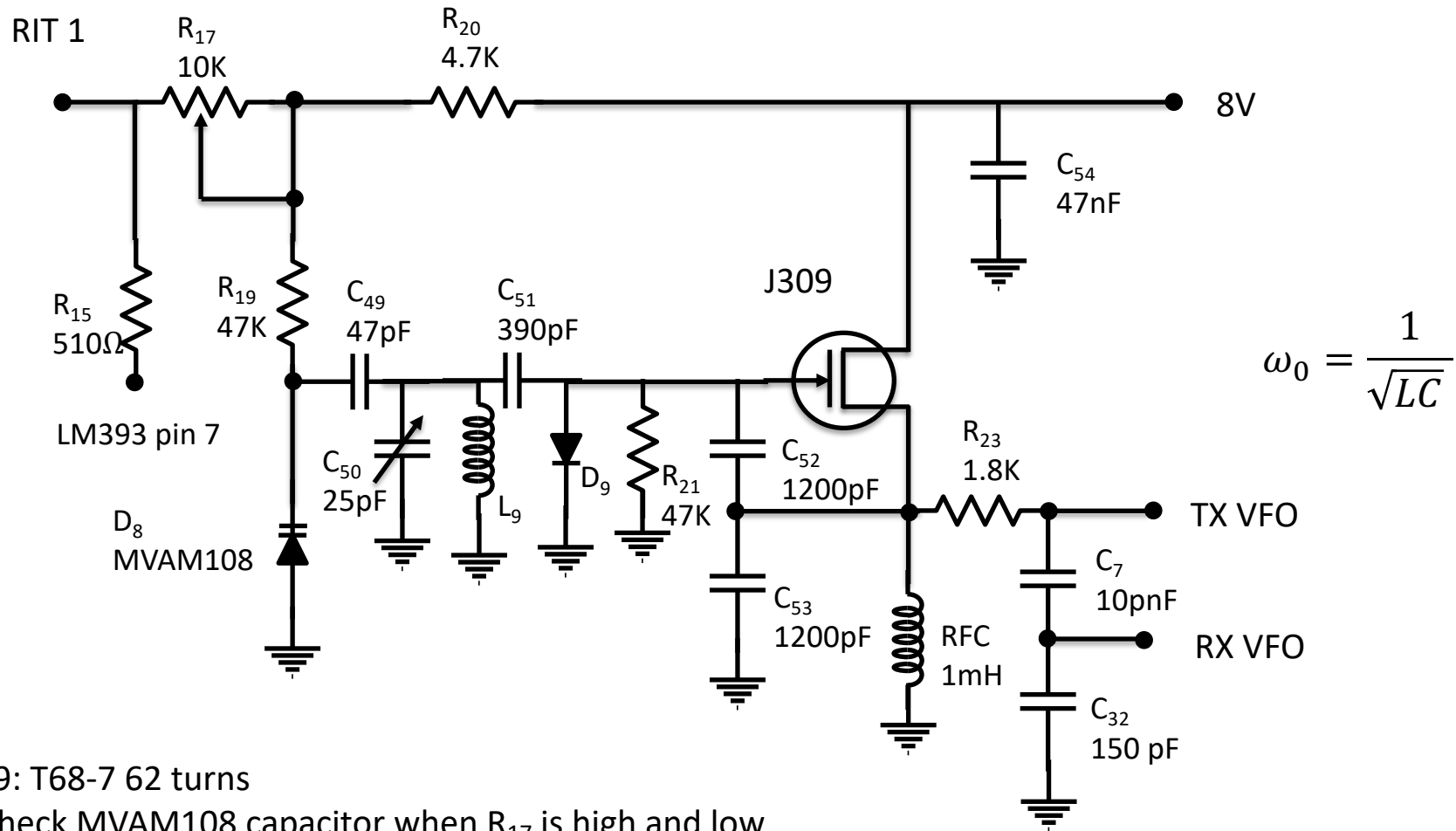
- When transistor conducts the receiver filter shorts

Norcal Harmonic Filter



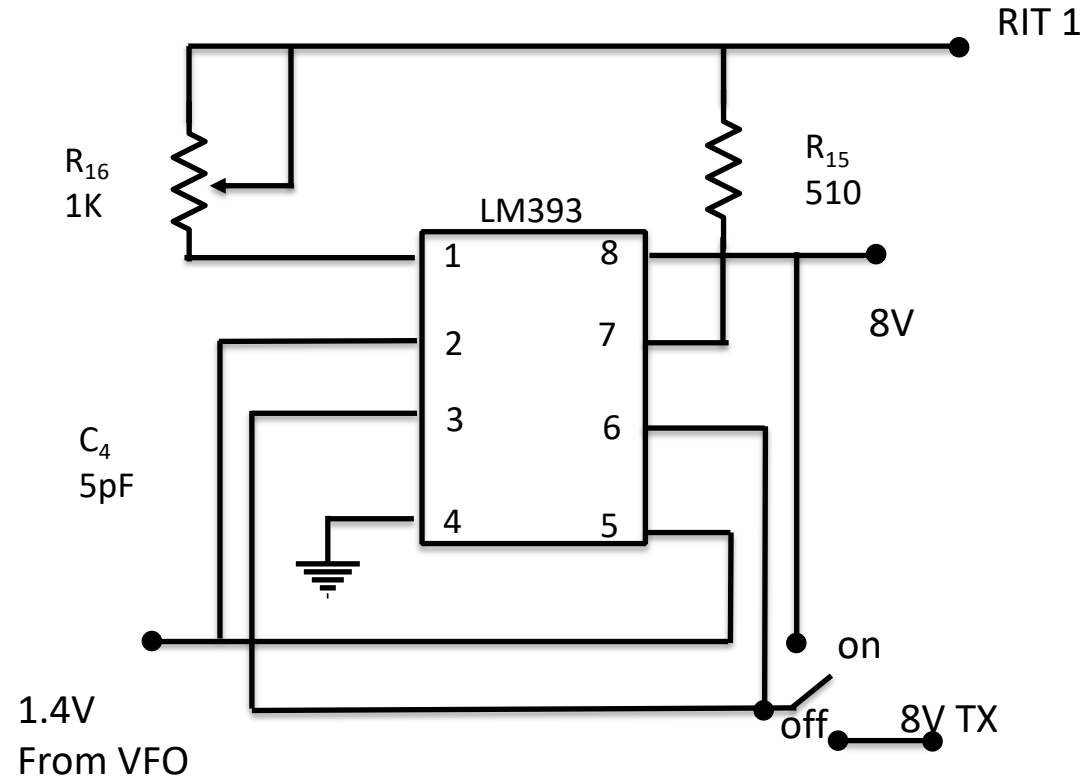
- L_7 , L_8 use T37-2 core, 18 turns, 1.3uH
- Compare loss at 7MHz and 14MHz

Norcal VCO



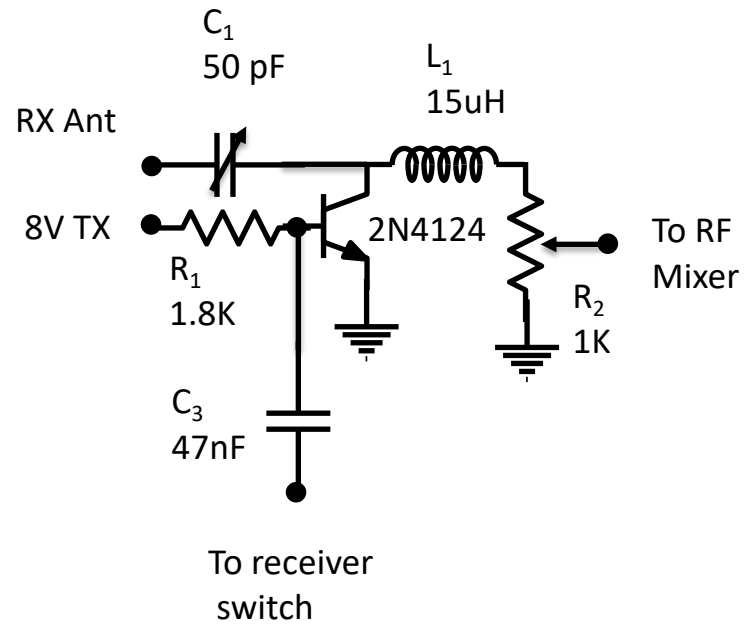
- L9: T68-7 62 turns
- Check MVAM108 capacitor when R₁₇ is high and low
- Start resistor (R₂₁) pulls gat to ground at start
- When gain limiting diode (D9) conducts, it pulls gate negative
- Oscillator keeps growing as long as $g_m > 1/R$

Norcal Receiver Incremental Tuning (RIT)

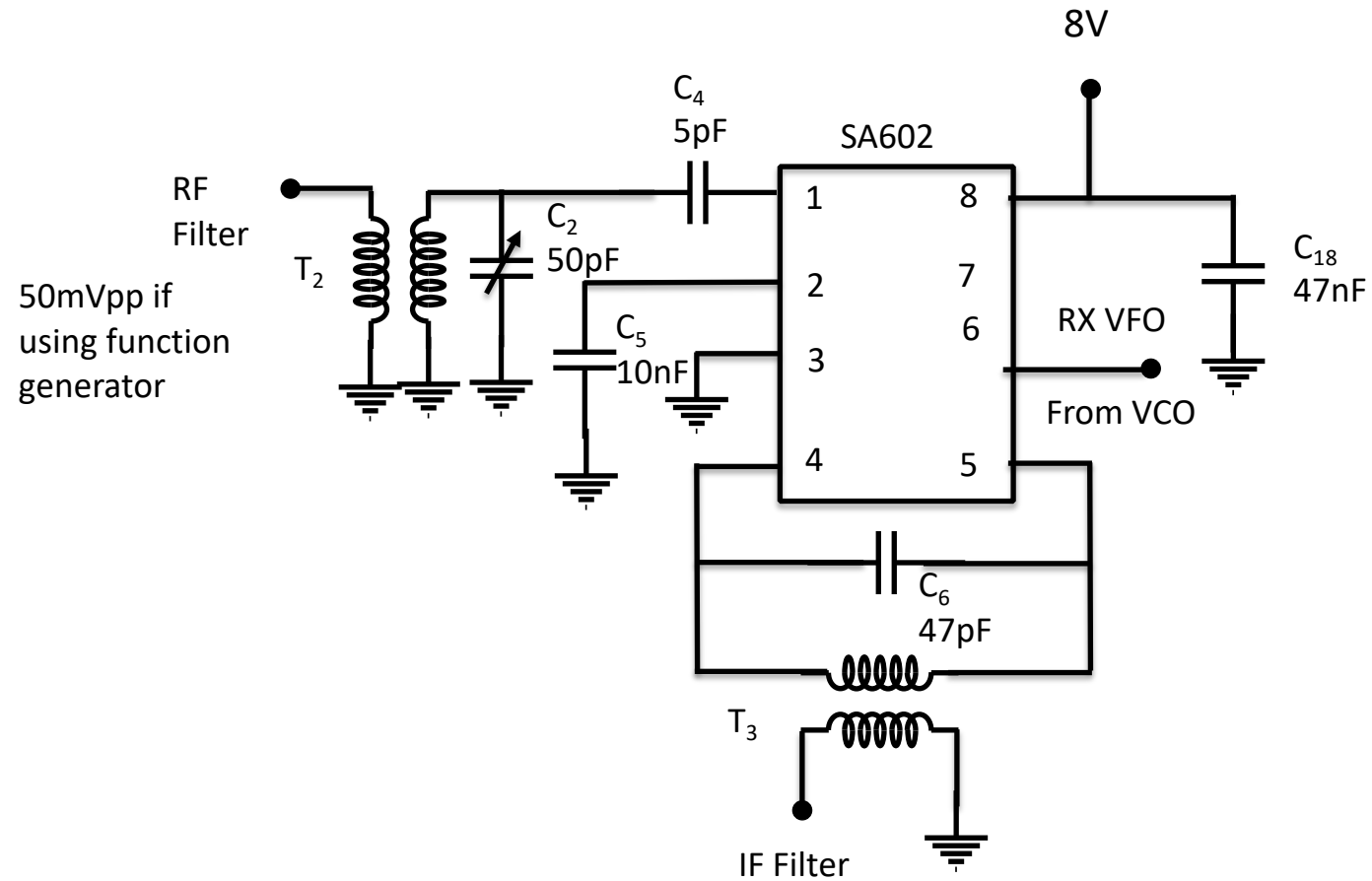


- LM393 is a comparator
- For function generator connect through 1.5K

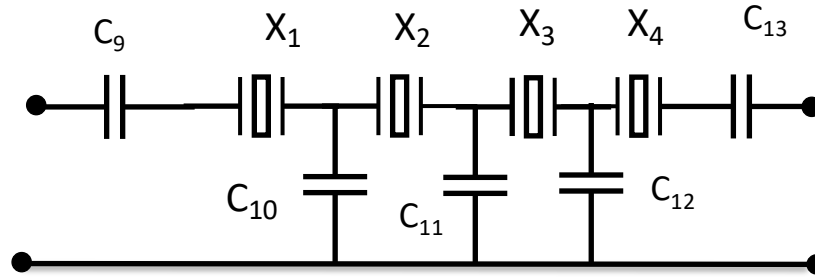
Norcal RF Filter



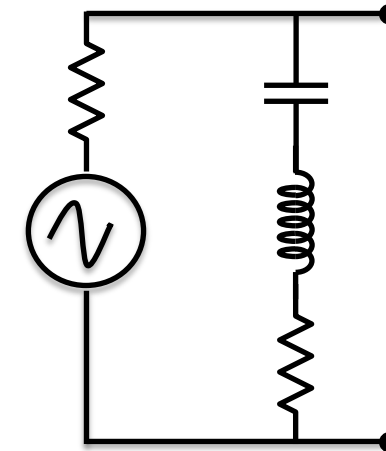
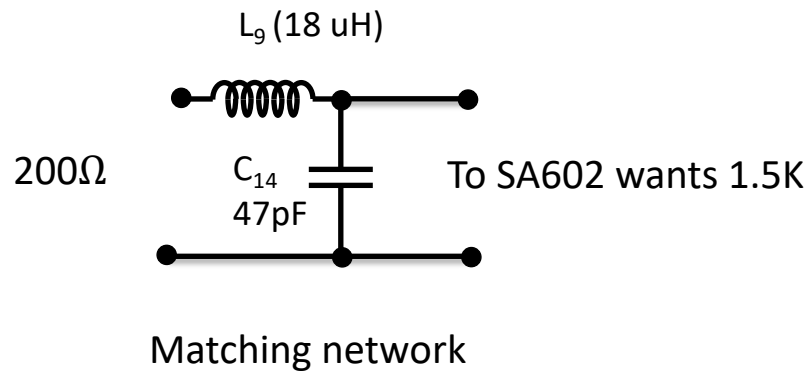
Norcal RF Mixer



Norcal IF Cohn Filter

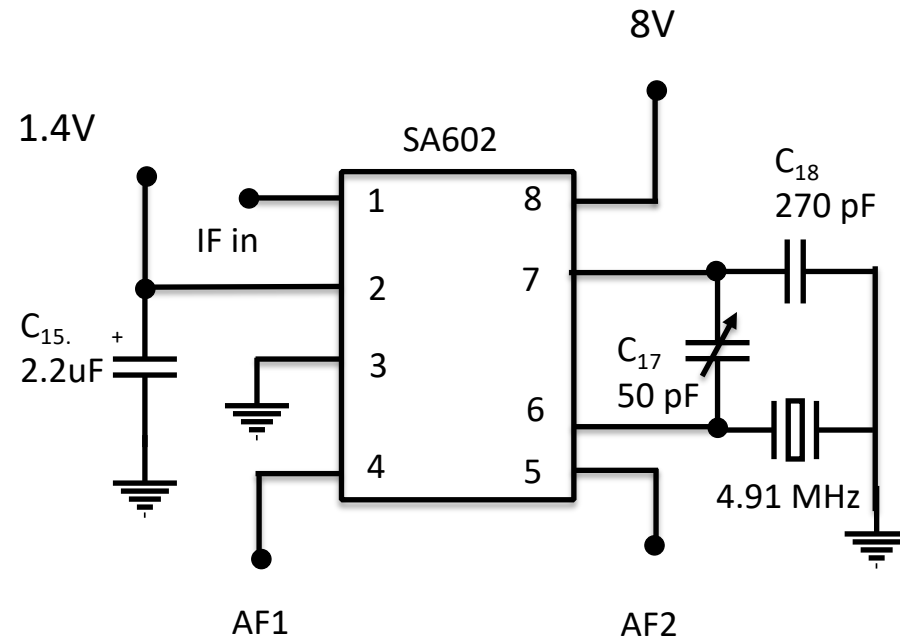


- X_1 through X_4 are 4.91 MHz
- C_{10} , C_{11} , C_{12} are 270 pF
- Set function generator to 50mV_{pp} from function generator
- Calculate R and X for filter



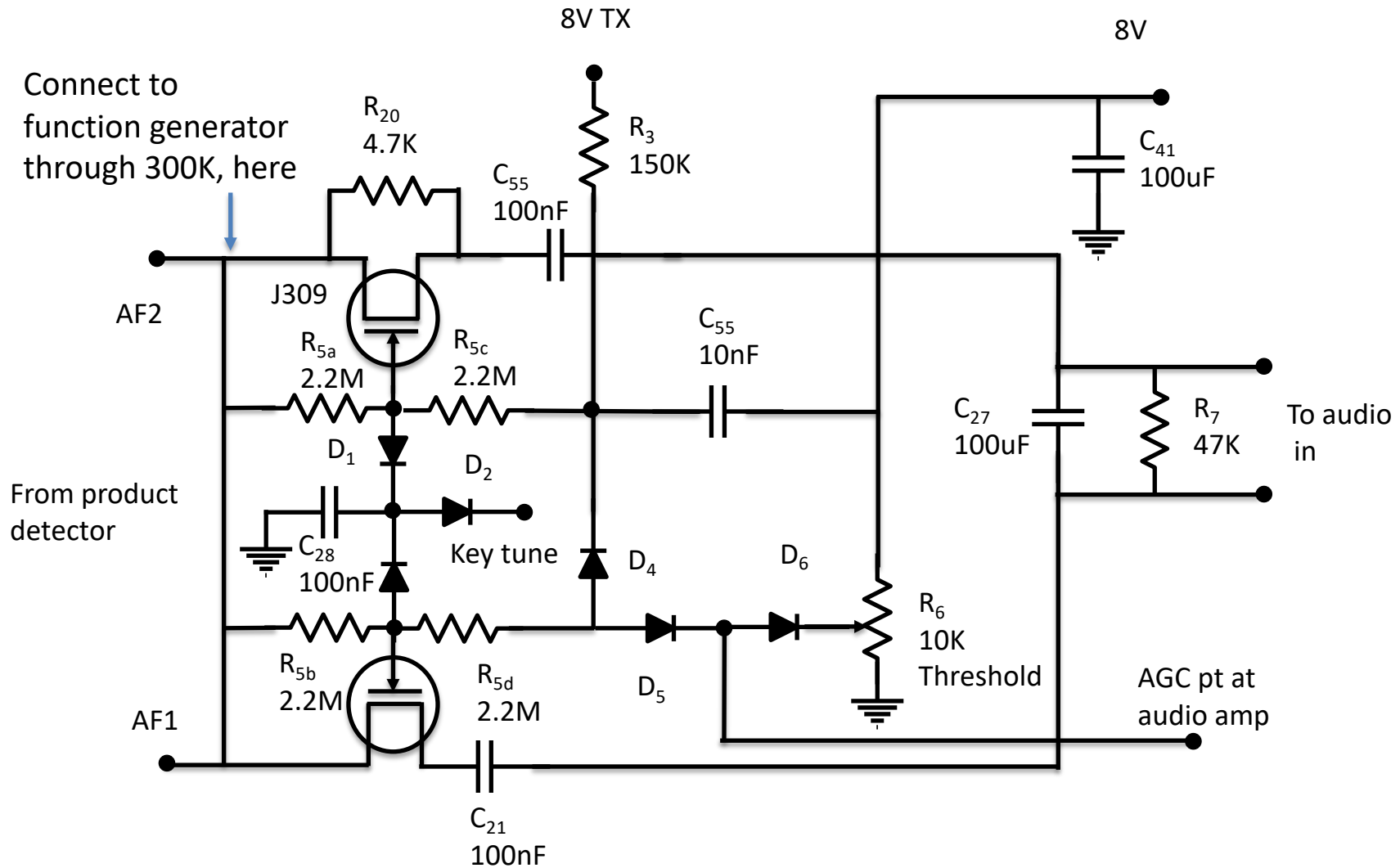
Equivalent circuit for crystal and generator

Norcal Product Detector

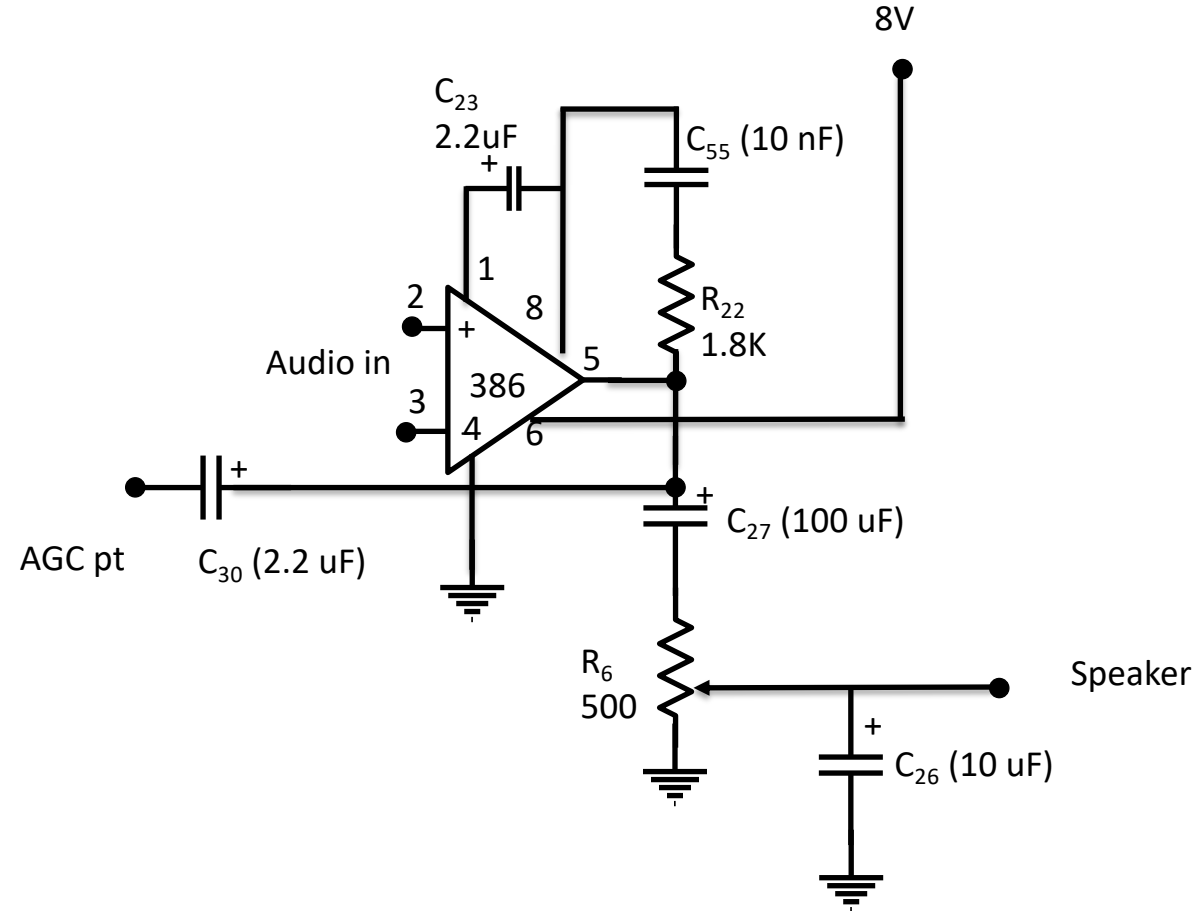


- 620 Hz output through AF1 and AF2

Norcal AGC



Norcal Audio Amp

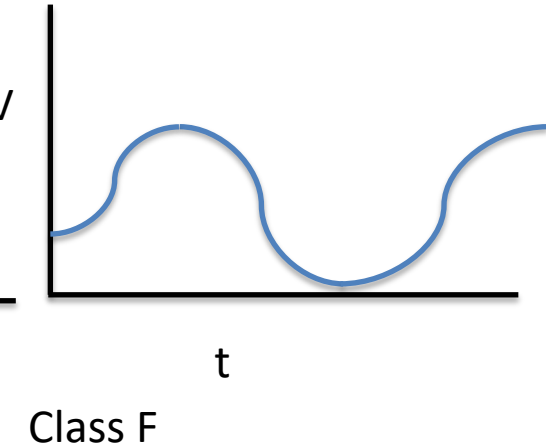
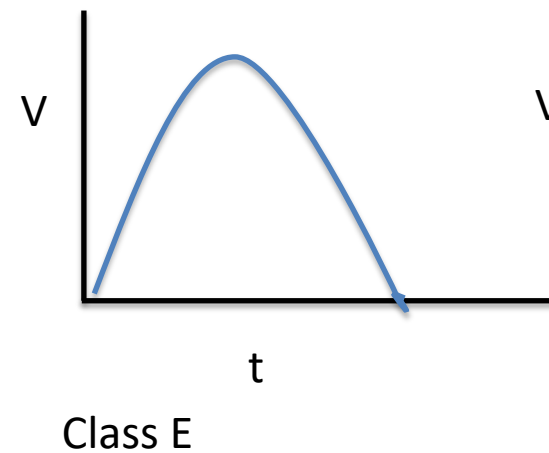
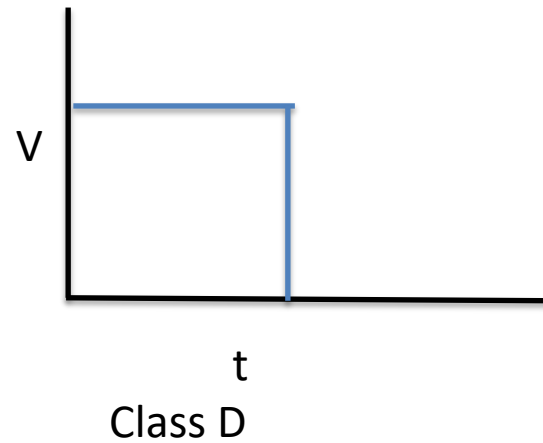
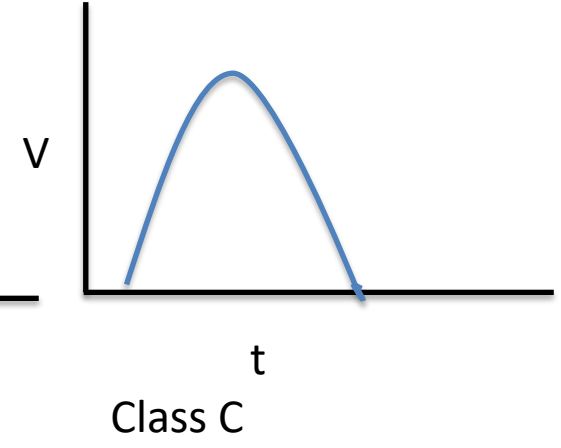
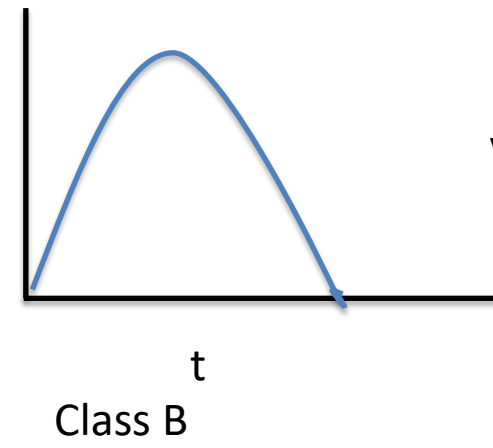
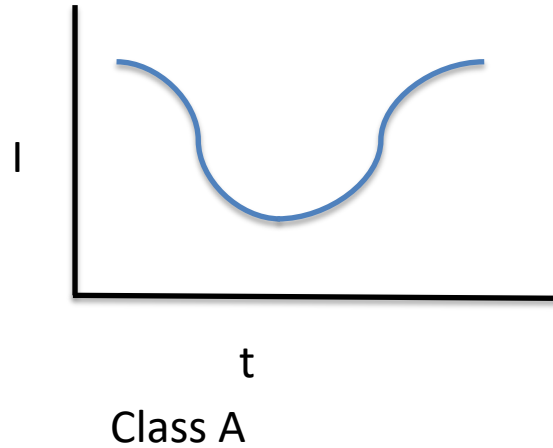


Amplifier classes

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

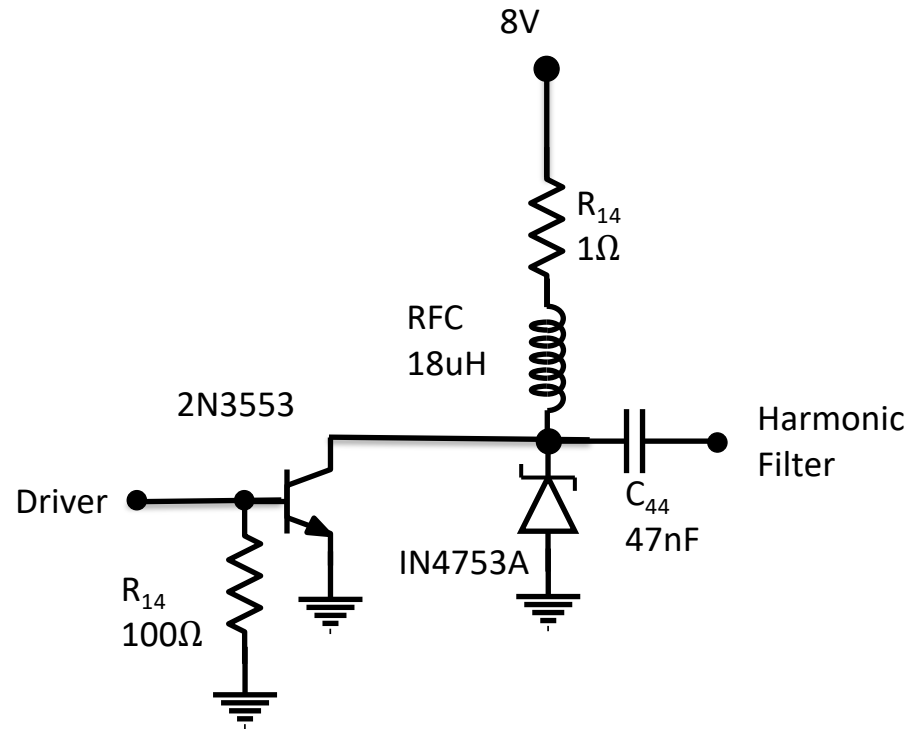
$$\eta = \frac{P}{P_0}, P_d = P_0 - P_i$$

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

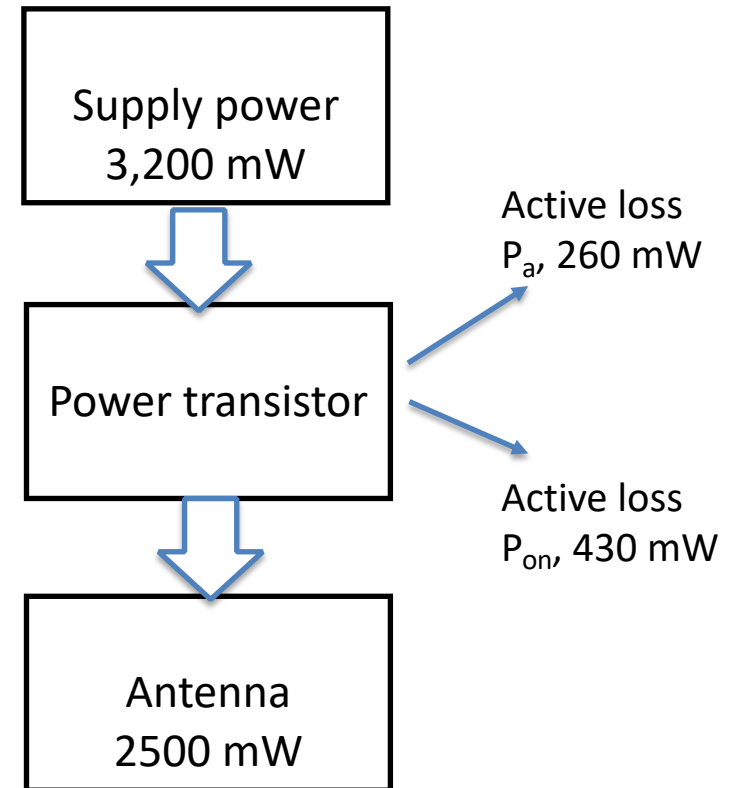


Norcal Power Amp

Norcal-40 Power amp is class C



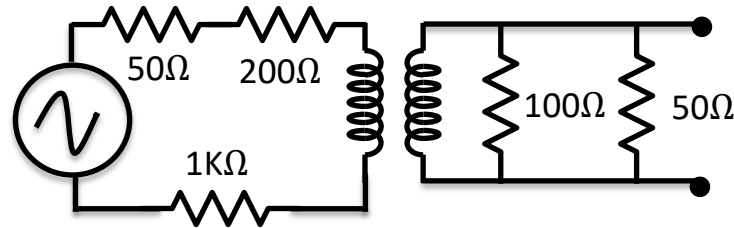
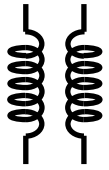
- $R_t = \frac{T - T_0}{P_d}$
- T_0 is ambient temperature, T is heat sink temperature



Norcal matching transformers

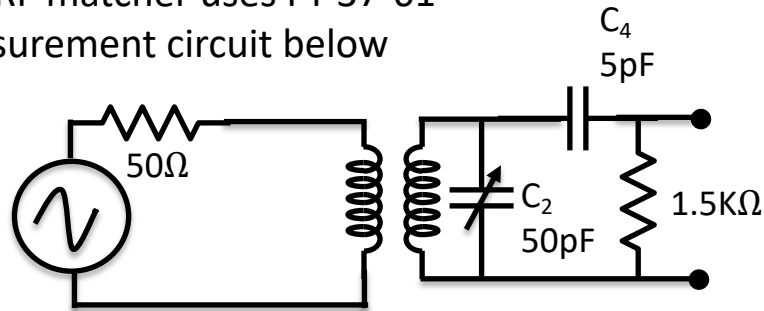
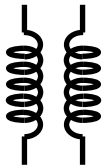
- T_1 is driver matcher uses FT 37-43
- Measurement circuit below

T_1 , 14:4

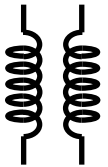


- T_2 is RF matcher uses FT 37-61
- Measurement circuit below

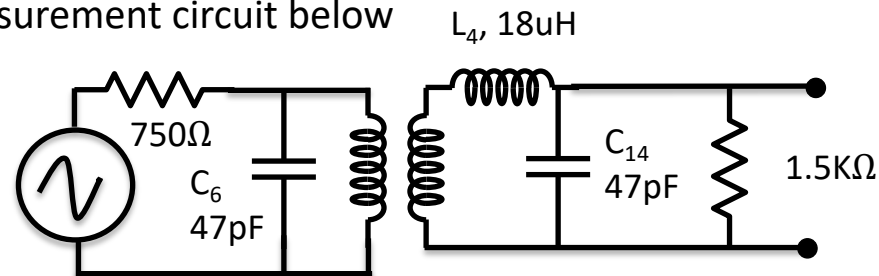
T_2 , 1:20



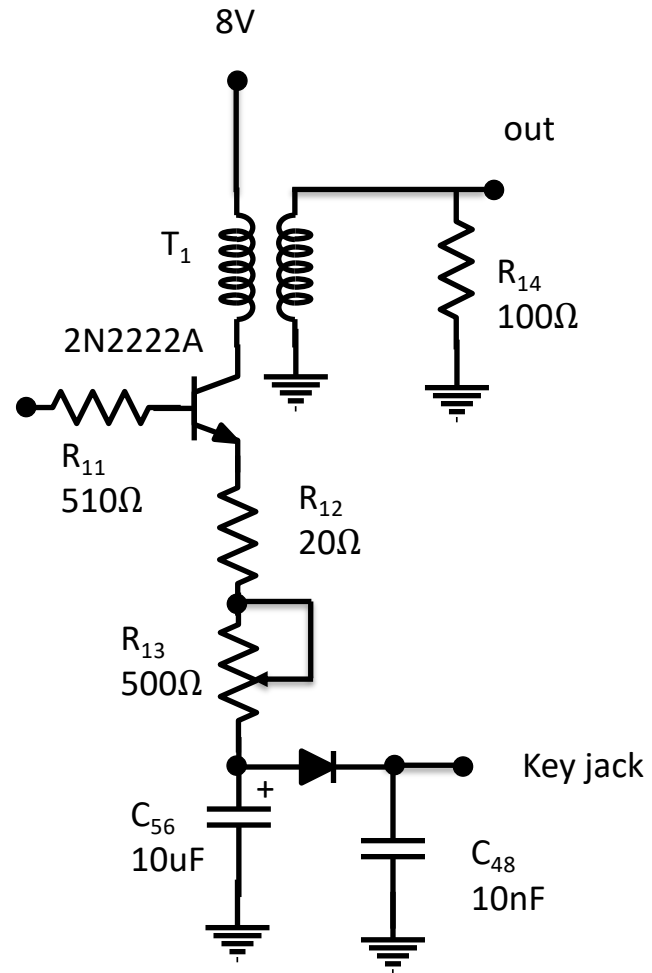
T_3 , 23:6



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

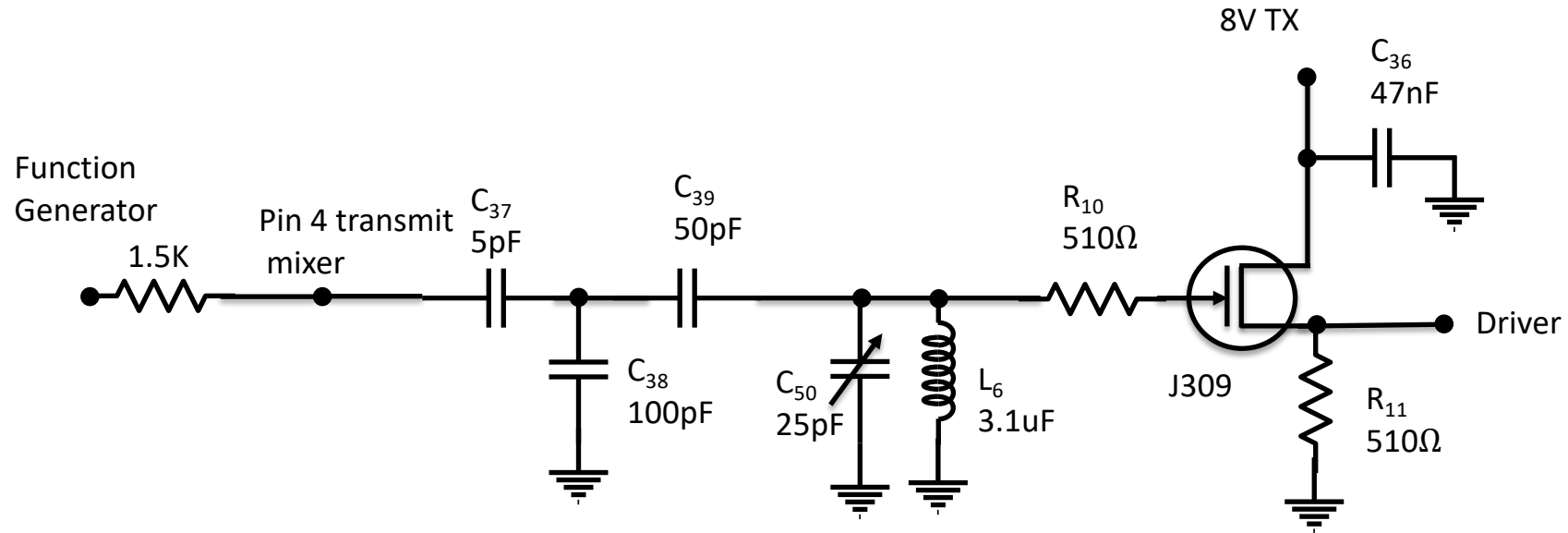


Norcal Driver



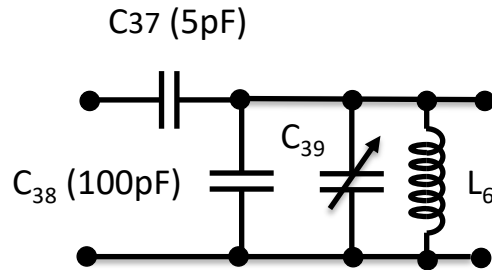
- Use 50 Ω scope probe

Norcal Buffer



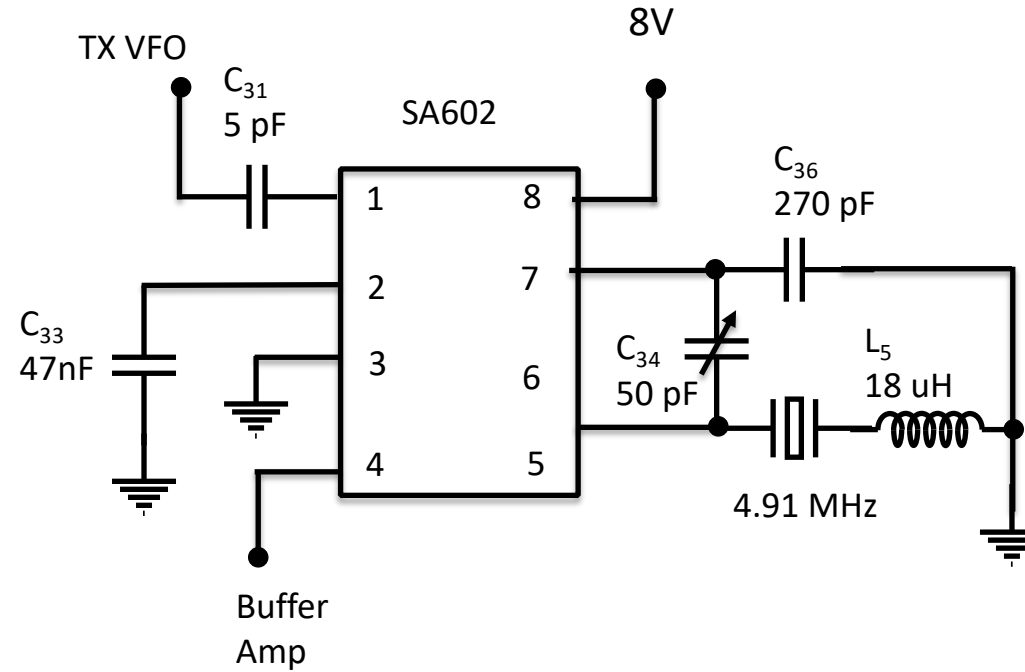
$$G_V = \frac{V}{V_i}$$

Norcal transmit bandpass filter



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

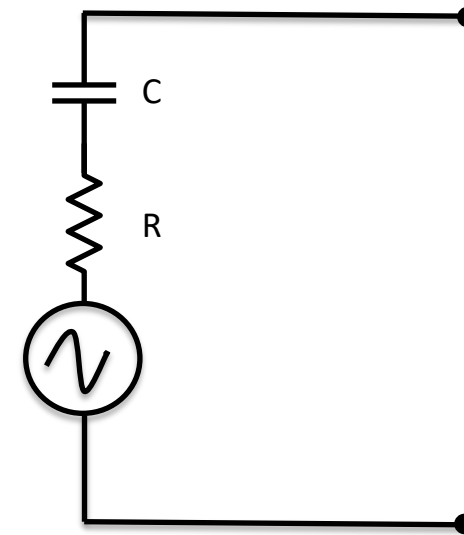
Norcal transmit mixer and oscillator



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: $S = \text{Re} \left(\frac{E_x \overline{H_y}}{2} \right) = \frac{(|E_x|)^2}{2\eta_0}$
- $\eta_0 = \frac{E_x}{H_y} = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega$
- 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

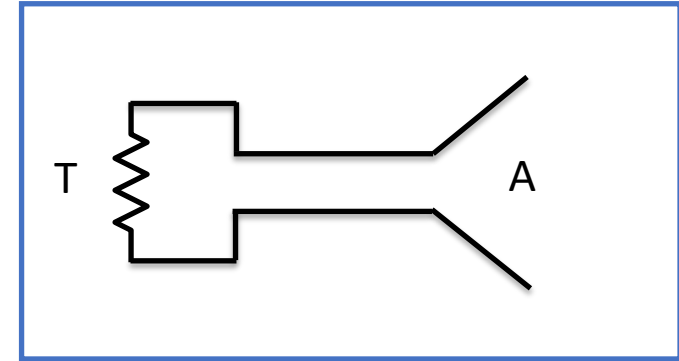


Antennas and propagation

- 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

Insulated cavity

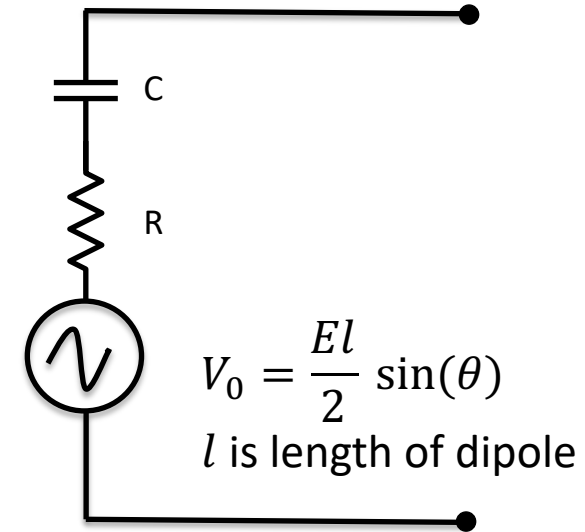


- Antenna theorem: $\oint A d\Omega = \lambda^2$
- For cavity on right, T is constant at thermodynamic equilibrium and the same power is transmitted and emitted, the Johnson noise is kT . The energy received is $E = \frac{4\pi kT}{c\lambda^2}$. Set $B = \frac{kT}{\lambda^2}$. $kT = \oint BA d\Omega = \oint A \frac{kT}{\lambda^2} d\Omega$, 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

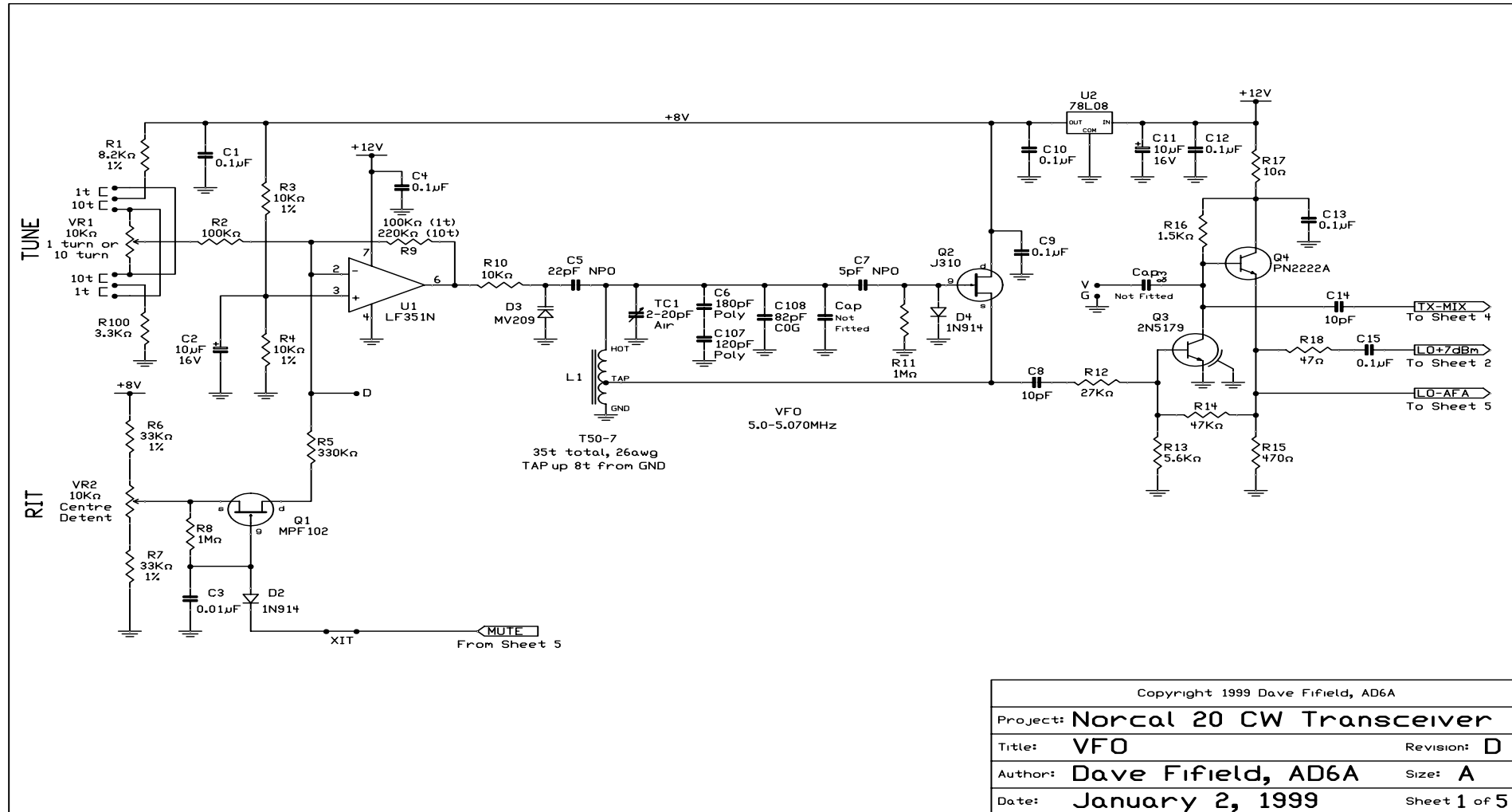
- For dipole (Length: $l = \frac{\lambda}{2}$)
- $\lambda^2 = \int A d\Omega = \int \frac{h^2 \eta_0}{4R_r} d\Omega$, so
- $R_r = \frac{l^2 \eta_0}{16\lambda^2} \int \sin^2(\theta) d\Omega = \eta_0 \frac{\pi}{6} \left(\frac{l}{\lambda}\right)^2$
- $A = \frac{3\lambda^2}{8\pi} \sin^2(\theta)$ and $G =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



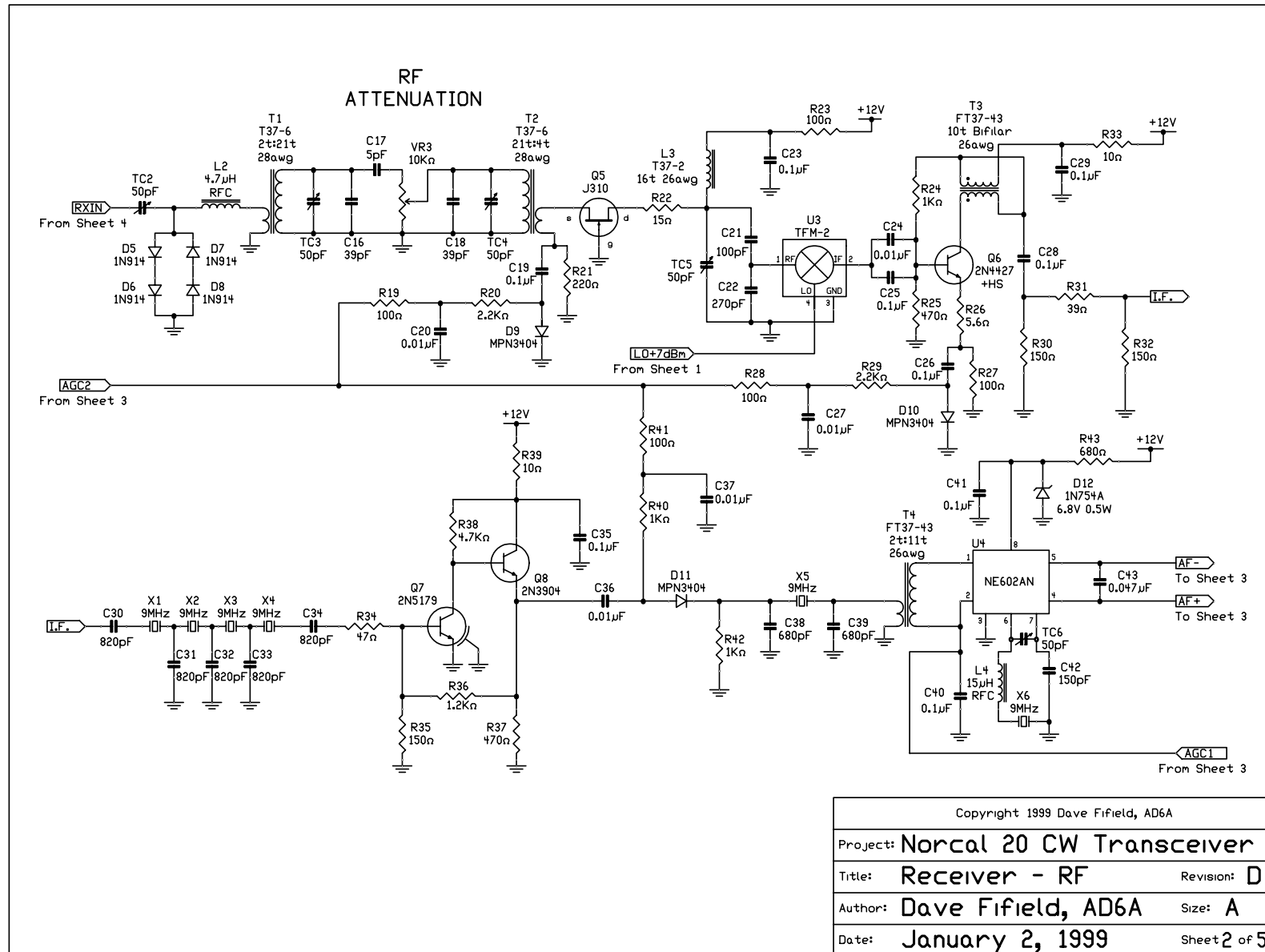
Noise

- $V_{n(rms)} = \sqrt{\frac{1}{\tau} \int_0^\tau V(t)^2 dt}$
- $P_n = \frac{V_{n(rms)}^2}{R}$, 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, $\overline{|V_C|^2} = 8kTR$

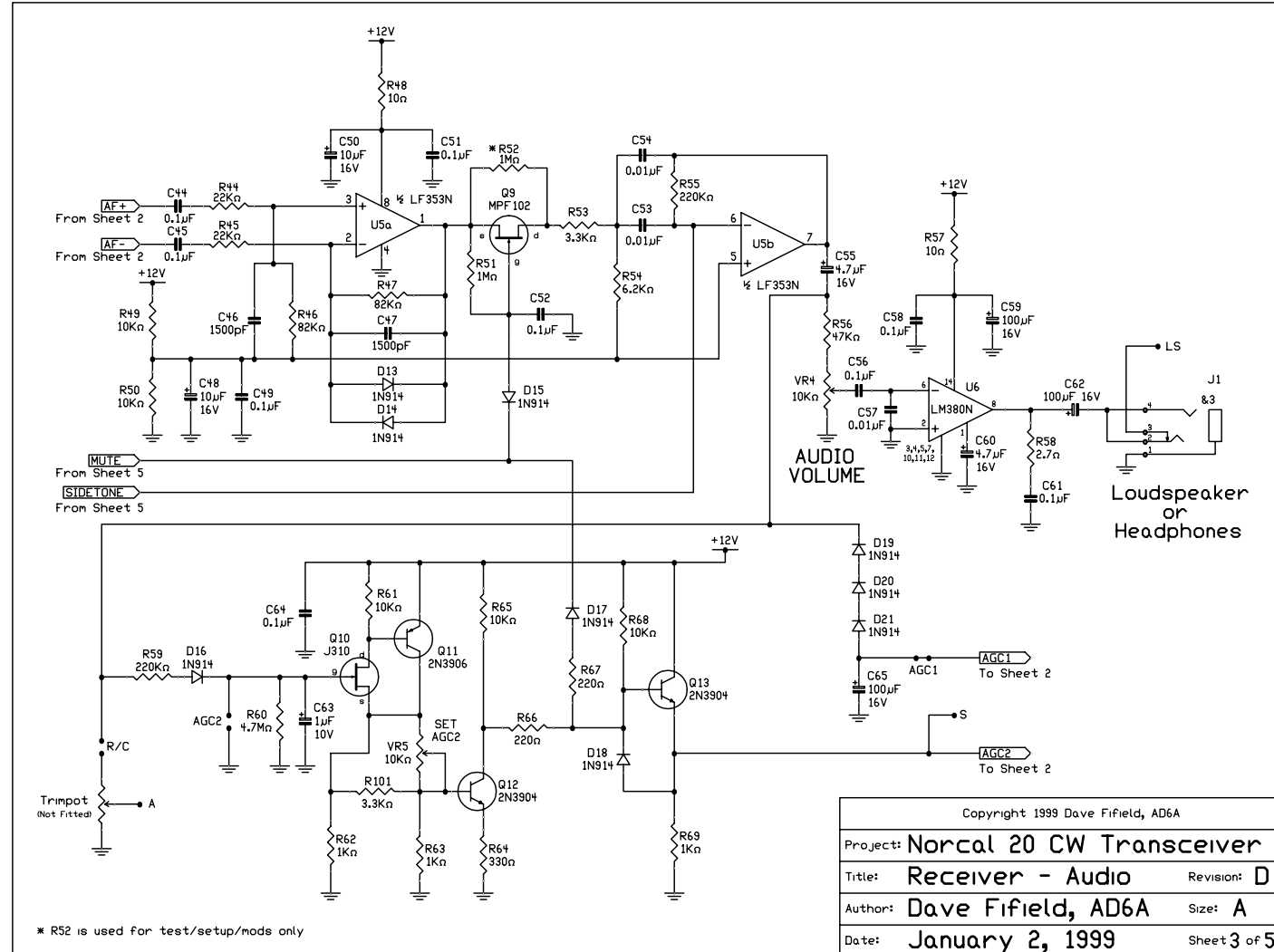
Norcal circuit diagram, 1



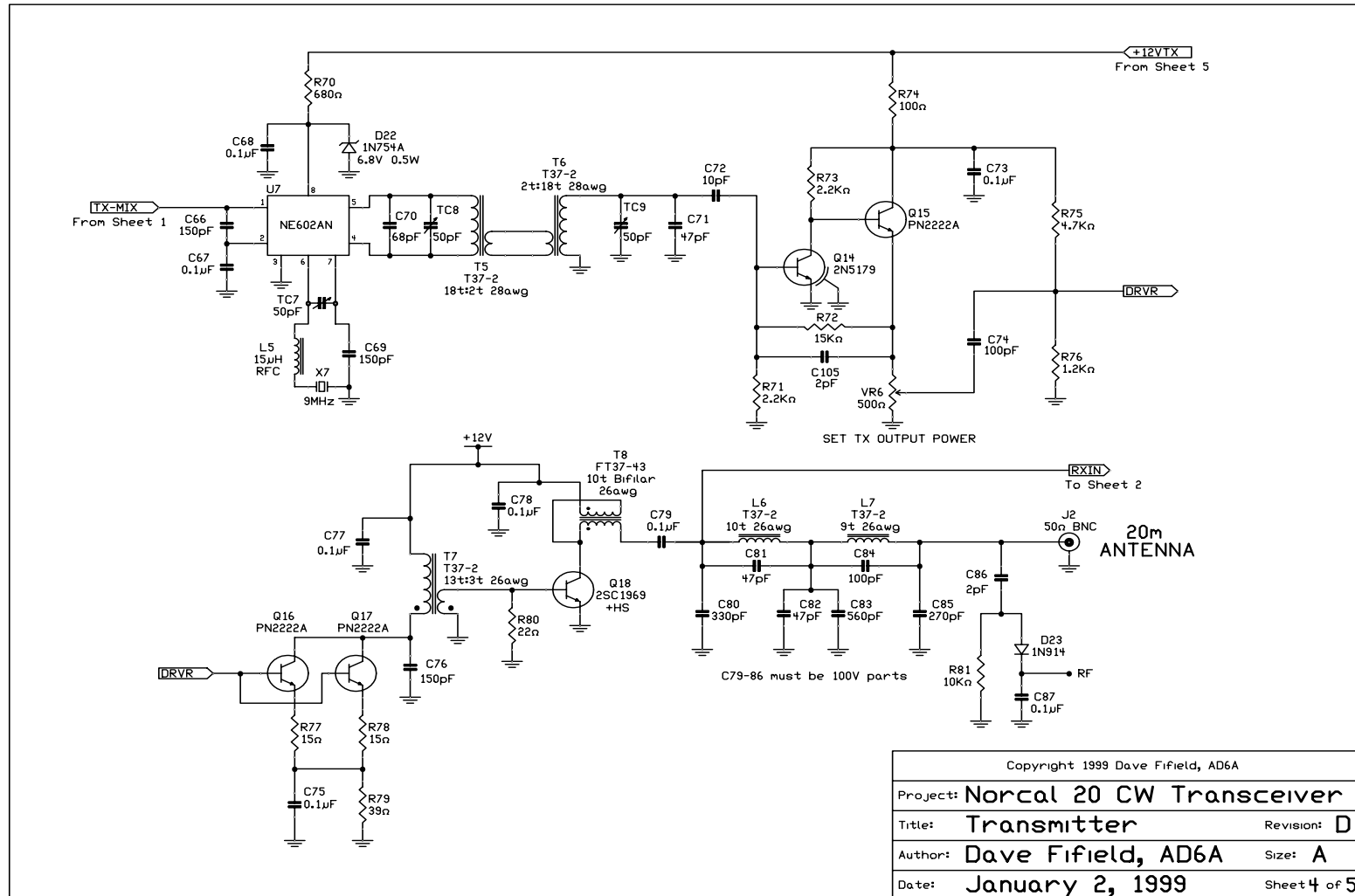
Norcal circuit diagram, 2



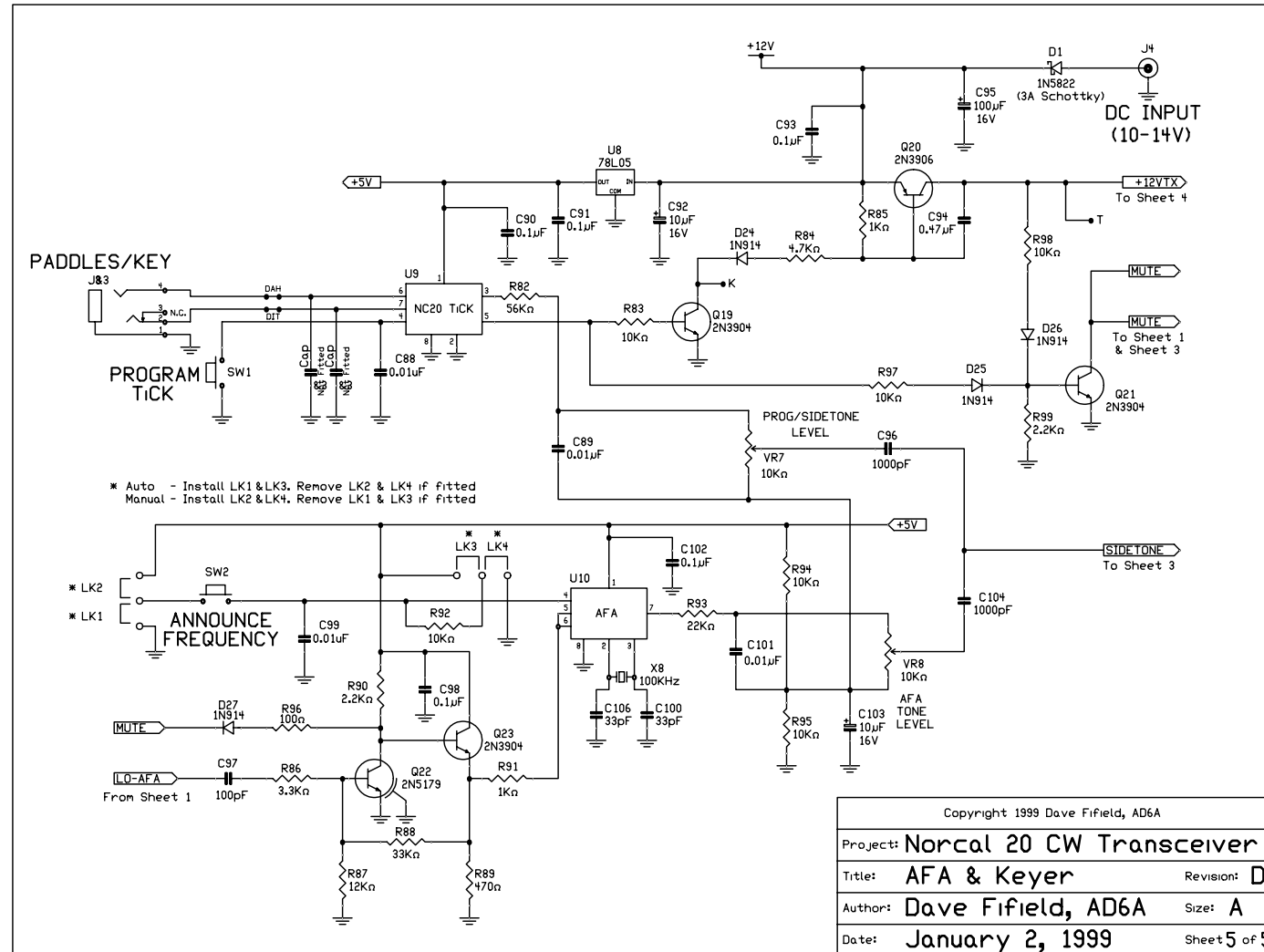
Norcal circuit diagram, 3



Norcal circuit diagram, 4



Norcal circuit diagram, 5



Block Diagram

Block Diagram