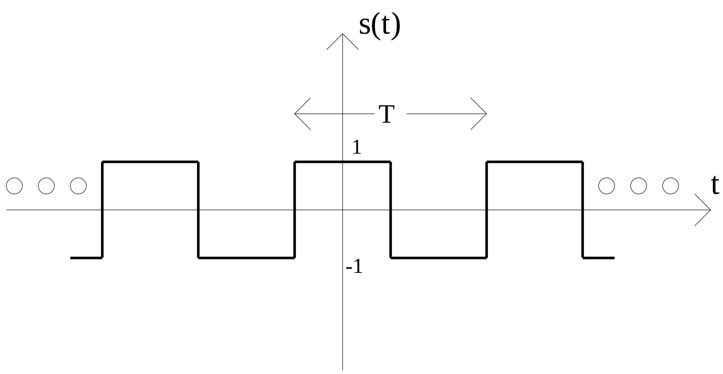
CHAPTER
13

MIXERS

13.1 SINLE-ENDED MIXERS AND BASIC THEORY



$$s(t) = \frac{2}{jp} \sum_{n=\pm odd} \frac{1}{n} e^{jnw_o t} \quad \text{and} \quad S(w) = -4j \sum_{n=\pm odd} \frac{1}{n} d(w - nw_o)$$

$$\text{where } w_o = \frac{2p}{T}$$

$d(w) = 2p\,d(f)$ and $d(w - w_o) = 2p\,d(f - f_o)$ as can be seen since

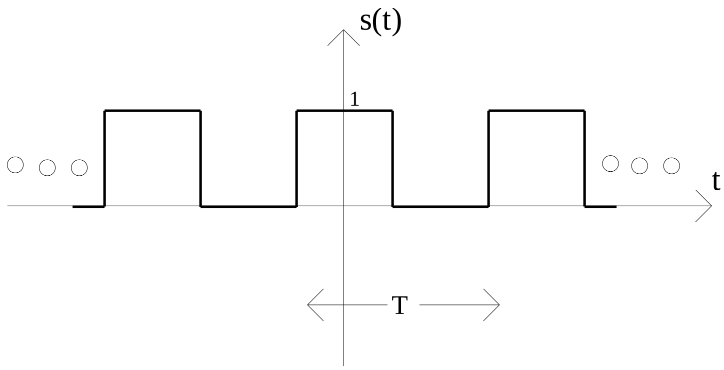
$$\int_{-\infty}^{+\infty} d(w)dw = 1$$

$$\int_{-\infty}^{+\infty} d(2pf)2pdf = 1$$

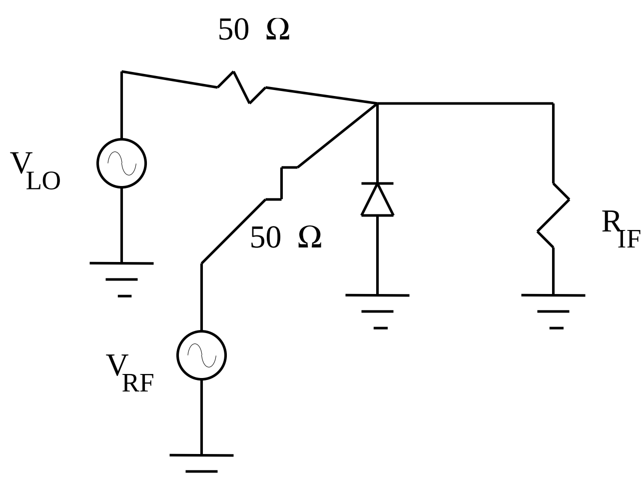
$$\int_{-\infty}^{+\infty} k\,d(f)2pdf = 1$$

$$k\int_{-\infty}^{+\infty} d(f)df = \frac{1}{2p}$$

$$k = \frac{1}{2p}$$



$$s(t) = \frac{1}{2} + \frac{1}{jp} \sum_{n=\pm odd} \frac{1}{n} e^{jnw_o t} \quad \text{and} \quad S(w) = p\,d(w) - 2j \sum_{n=\pm odd} \frac{1}{n} d(w - nw_o)$$



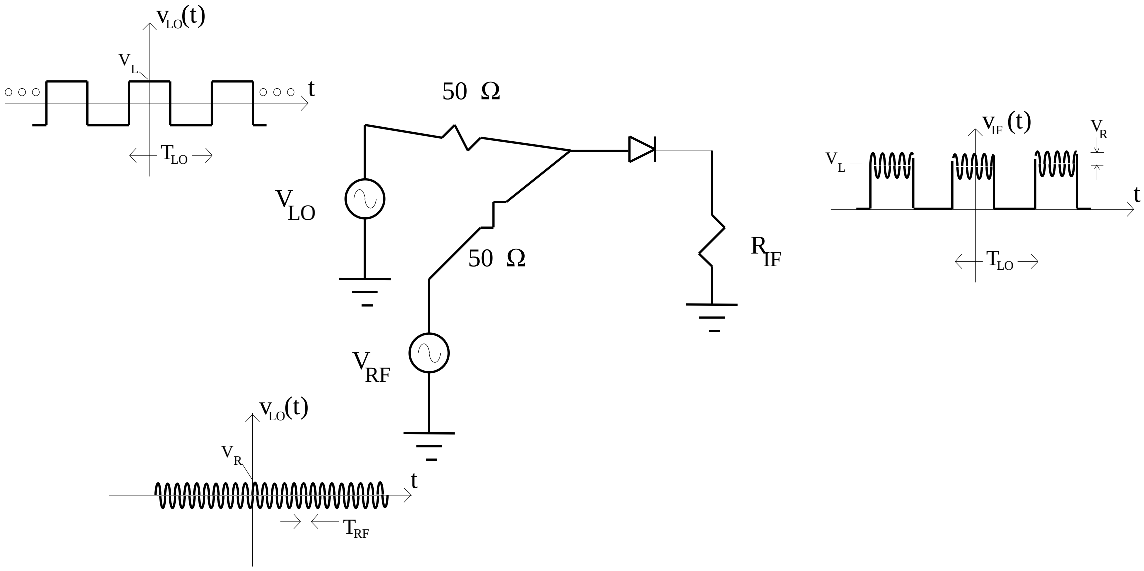
Single Ended Mixer (One Diode)

Assuming ideal diodes (open or short circuit) and assuming that the local oscillator controls the state of the diodes then

$$v_{LO}(t) = \frac{2V_{LO}}{jp} \sum_{n=\pm odd} \frac{1}{n} e^{jnw_o t} \quad \text{and} \quad V_{LO}(w) = -4jV_{LO} \sum_{n=\pm odd} \frac{1}{n} d(w - nw_o)$$

If

$$v_{RF}(t) = V_R \cos w_R t = \frac{V_R}{2}\left(e^{+jw_R t} + e^{-jw_R t}\right)$$



$$v_{IF}(t) = [V_{LO} + v_{RF}(t)] \cdot s(t) = \left[V_{LO} + \frac{V_R}{2}\left(e^{+jw_R t} + e^{-jw_R t}\right)\right] \cdot \left[\frac{1}{2} + \frac{1}{jp}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t}\right]$$

$$= V_{LO}\left[\frac{1}{2} + \frac{1}{jp}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t}\right] + \frac{V_R}{2}\left(e^{+jw_R t} + e^{-jw_R t}\right)\left[\frac{1}{2} + \frac{1}{jp}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t}\right]$$

$$v_{IF}(t) = \frac{V_{LO}}{2} + \frac{V_{LO}}{jp}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t} + \frac{V_R}{4}\left(e^{+jw_R t} + e^{-jw_R t}\right) + \frac{V_R}{j2p}\left(e^{+jw_R t} + e^{-jw_R t}\right)\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t}$$

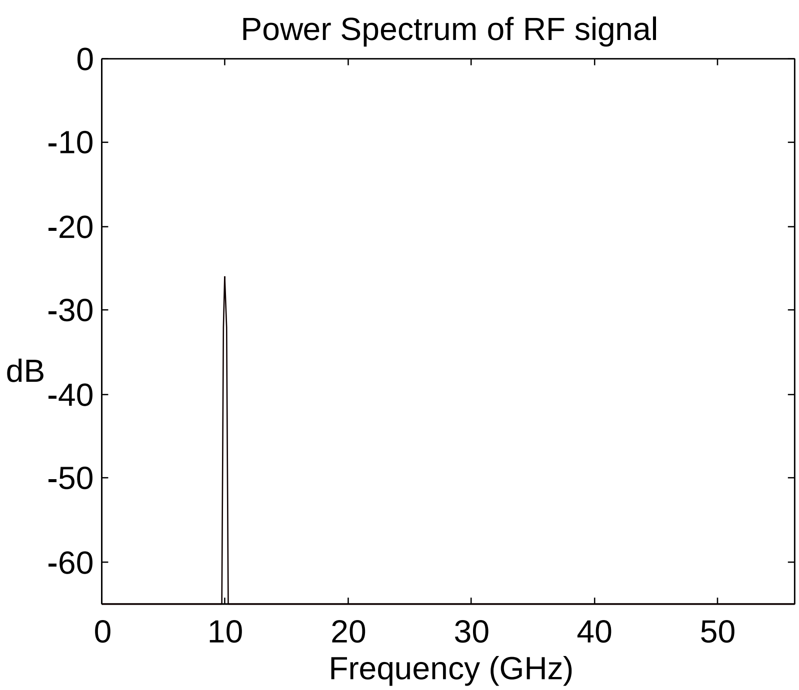
$$= \frac{V_{LO}}{2} + \frac{V_{LO}}{jp}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t} + \frac{V_R}{4}\left(e^{+jw_R t} + e^{-jw_R t}\right) + \frac{V_R}{j2p}e^{+jw_R t}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t} + \frac{V_R}{j2p}e^{-jw_R t}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t}$$

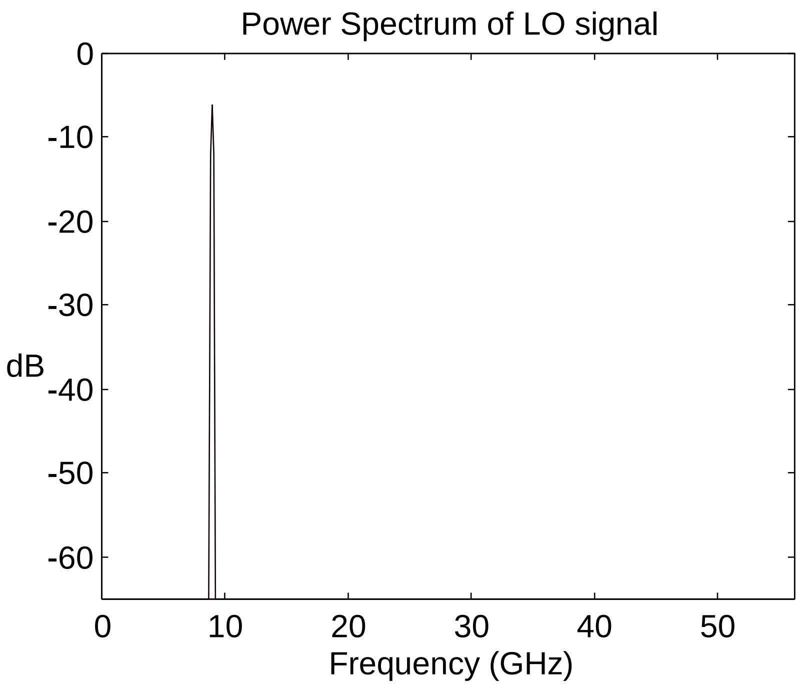
$$= \frac{V_{LO}}{2} + \frac{V_{LO}}{jp}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t} + \frac{V_R}{4}\left(e^{+jw_R t} + e^{-jw_R t}\right) + \frac{V_R}{j2p}\sum_{n=\pm odd}\frac{1}{n}e^{j(w_R + nw_L)t} + \frac{V_R}{j2p}\sum_{n=\pm odd}\frac{1}{n}e^{j(nw_L - w_R)t}$$

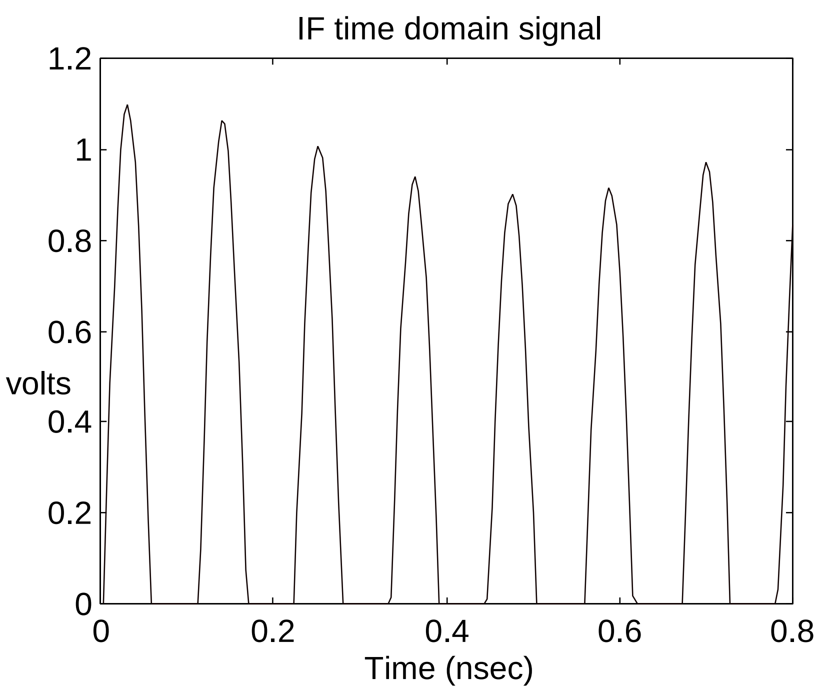
$$V_{IF}(w) = --Fix--- \frac{V_{LO}}{2} + \frac{V_{LO}}{jp}\sum_{n=\pm odd}\frac{1}{n}e^{jnw_L t} + \frac{V_R}{4}\left(e^{+jw_R t} + e^{-jw_R t}\right) + \frac{V_R}{j2p}\sum_{n=\pm odd}\frac{1}{n}e^{j(w_R + nw_L)t} + \frac{V_R}{j2p}\sum_{n=\pm odd}\frac{1}{n}e^{j(nw_L - w_R)t}$$

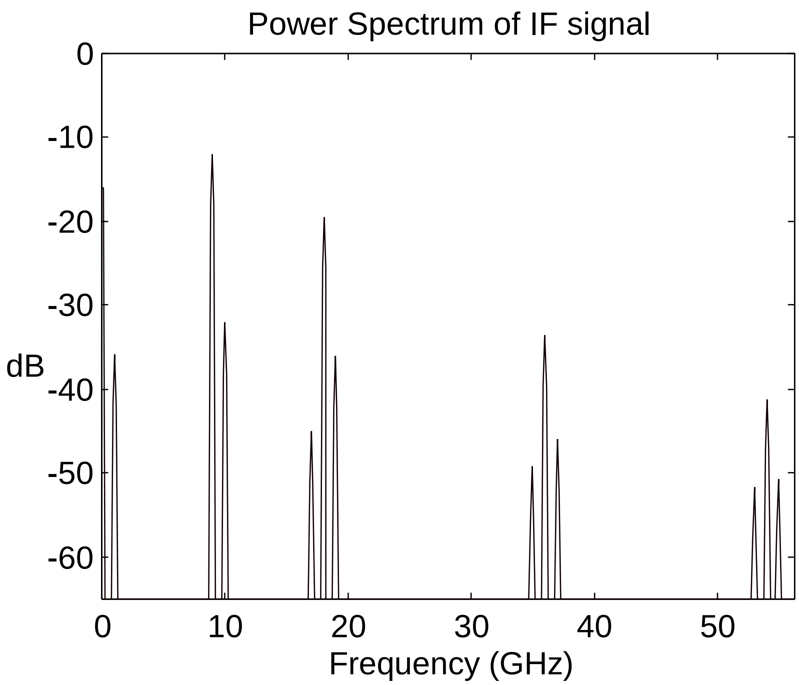
```
function mixer2()
% to illustrate mixer as a switching action
% where LO close to RF in frequency
%units
ns=1e-9; GHz=1e9;
fRF=10*GHz; wRF=2*pi*fRF;
Fpts=[1:451];
dBlimit=-65;
Tpts=[1:200];
fLO=9*GHz;  wLO=2*pi*fLO;
deltat=.004*ns;
t=[0:1999]'*deltat;
Nt=length(t);
RF=.1*sin(wRF*t);
%plot(t/ns,RF);
psRF=abs(fft(RF.*hanning(Nt))*2/Nt);
psRF(1)=psRF(1)/2;
psRFdB=20*log10(psRF);A=find(psRFdB<dBlimit);
psRFdB(A)=dBlimit*ones(size(A));
FREQ=(1/max(t))*[0:Nt-1]/GHz;

figure; plot(FREQ(Fpts),psRFdB(Fpts))
axis([0,max(FREQ(Fpts)),dBlimit, 0])
ylabel('dB');xlabel('Frequency (GHz)')
title('Power Spectrum of RF signal')


LO=sin(wLO*t);% LO=2*(LO>=0)-1;

psLO=abs(fft(LO.*hanning(Nt))*2/Nt);
psLO(1)=psLO(1)/2;
psLOdB=20*log10(psLO);A=find(psLOdB<dBlimit);
psLOdB(A)=dBlimit*ones(size(A));

figure; plot(FREQ(Fpts),psLOdB(Fpts))
axis([0,max(FREQ(Fpts)),dBlimit, 0])
ylabel('dB');xlabel('Frequency (GHz)')
title('Power Spectrum of LO signal')

Combine=RF+LO;
IFt=Combine.*(Combine>0);
figure; plot(Tpts*deltat/ns,IFt(Tpts))
ylabel('volts');Xlabel('Time (nsec)')
title('IF time domain signal')

psIF=abs(fft(IFt.*hanning(Nt))*2/Nt);
psIF(1)=psIF(1)/2;
psIFdB=20*log10(psIF);A=find(psIFdB<dBlimit);
psIFdB(A)=dBlimit*ones(size(A));

figure; plot(FREQ(Fpts),psIFdB(Fpts))
axis([0,max(FREQ(Fpts)),dBlimit, 0])
ylabel('dB');xlabel('Frequency (GHz)')
title('Power Spectrum of IF signal')

RFp=RF.*(LO>0);
figure; plot(Tpts*deltat/ns,RFp(Tpts))
ylabel('volts');Xlabel('Time (nsec)')
title('RFp time domain signal')

psRFp=abs(fft(RFp.*hanning(Nt))*2/Nt);
psRFp(1)=psRFp(1)/2;
psRFpdB=20*log10(psRFp);A=find(psRFpdB<dBlimit);
psRFpdB(A)=dBlimit*ones(size(A));

figure; plot(FREQ(Fpts),psRFpdB(Fpts))
axis([0,max(FREQ(Fpts)),dBlimit, 0])
ylabel('dB');xlabel('Frequency (GHz)')
title('Power Spectrum of Pulsed RF signal')
```

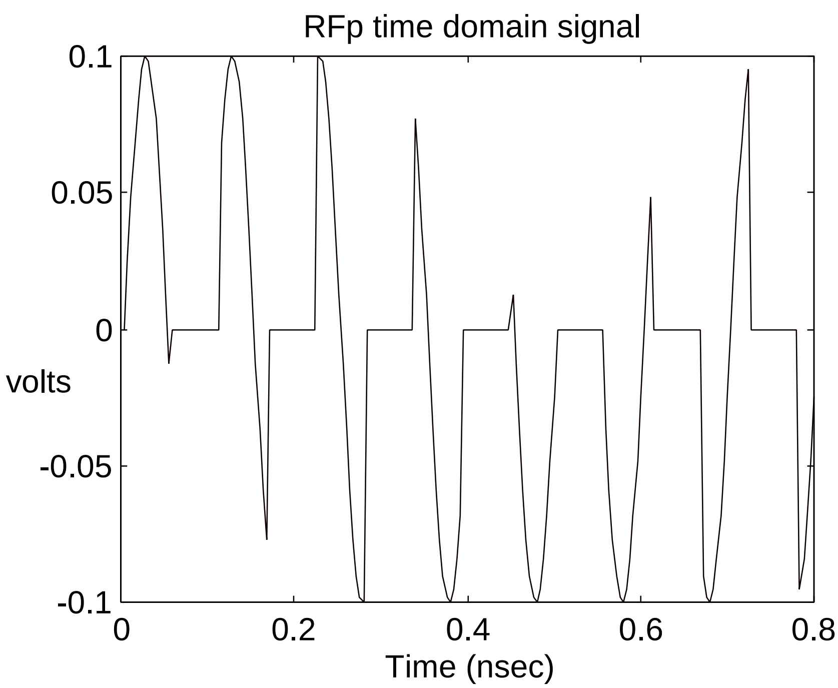
```
LOp=LO.*(LO>0);
figure; plot(Tpts*deltat/ns,LOp(Tpts))
ylabel('volts');Xlabel('Time (nsec)')
title('LOp time domain signal')

psLOp=abs(fft(LOp.*hanning(Nt))*2/Nt);
psLOp(1)=psLOp(1)/2;
psLOpdB=20*log10(psLOp);A=find(psLOpdB<dBlimit);
psLOpdB(A)=dBlimit*ones(size(A));

figure; plot(FREQ(Fpts),psLOpdB(Fpts))
axis([0,max(FREQ(Fpts)),dBlimit, 0])
ylabel('dB');xlabel('Frequency (GHz)')
title('Power Spectrum of Pulsed LO signal')

RFsw=RF.*(LO>0)-RF.*(LO<0);
figure; plot(Tpts*deltat/ns,RFsw(Tpts))
ylabel('volts');Xlabel('Time (nsec)')
title('RFsw time domain signal')

psRFsw=abs(fft(RFsw.*hanning(Nt))*2/Nt);
psRFsw(1)=psRFsw(1)/2;
psRFswdB=20*log10(psRFsw);A=find(psRFswdB<dBlimit);
psRFswdB(A)=dBlimit*ones(size(A));

figure; plot(FREQ(Fpts),psRFswdB(Fpts))
axis([0,max(FREQ(Fpts)),dBlimit, 0])
ylabel('dB');xlabel('Frequency (GHz)')
title('Power Spectrum of PSK RF signal')
```

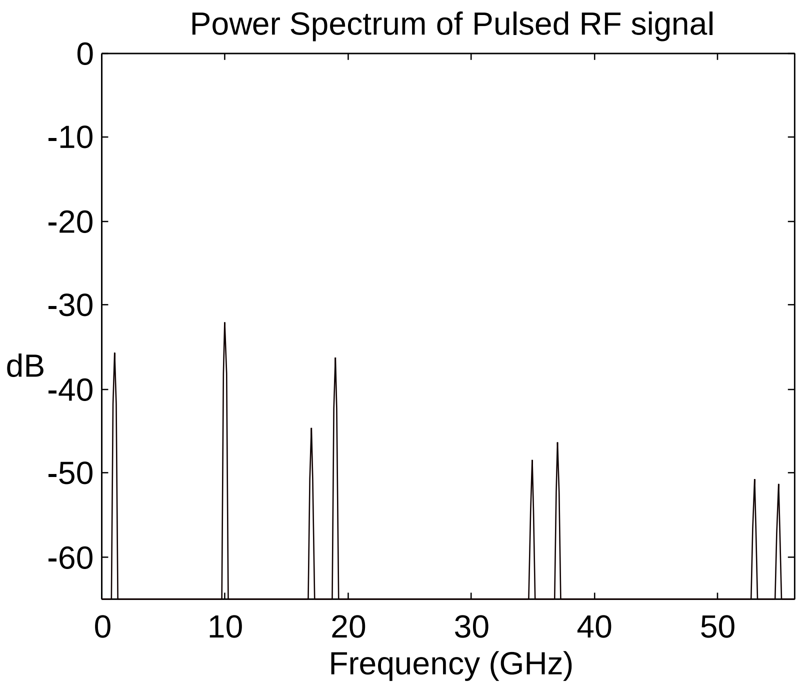


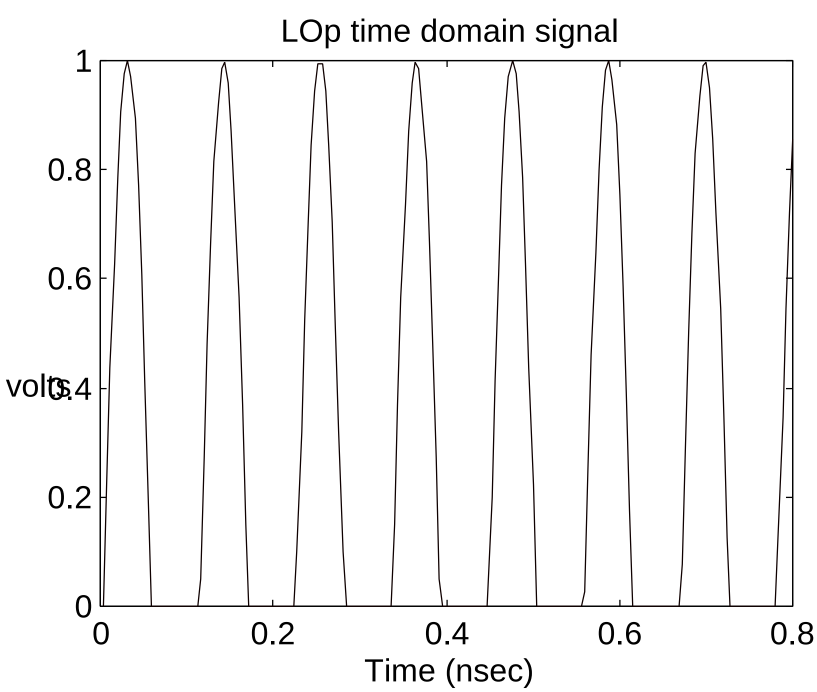

Power Spectrum of LO signal
0
-10
-20
-30
-40
-50
-60
dB
0
10
20
30
40
50
Frequency (GHz)

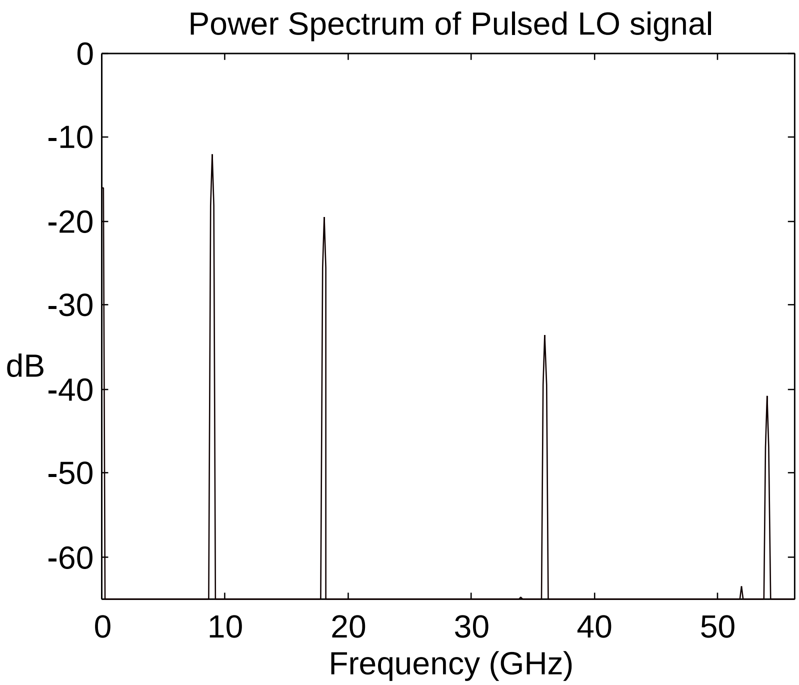

IF time domain signal
1.2
1
0.8
0.6
0.4
0.2
0
volts
0
0.2
0.4
0.6
0.8
Time (nsec)

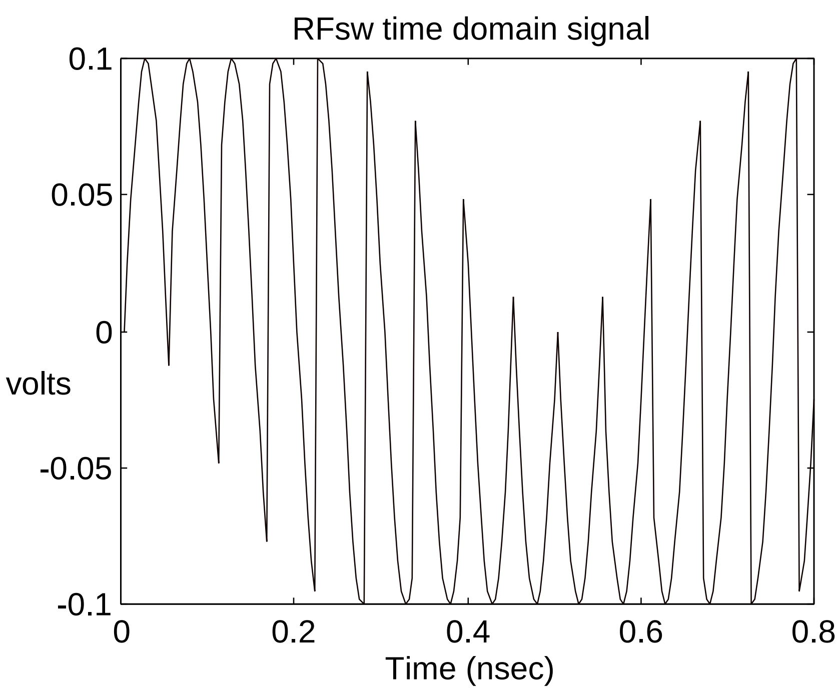

Power Spectrum of IF signal
0
-10
-20
-30
-40
-50
-60
dB
0
10
20
30
40
50
Frequency (GHz)

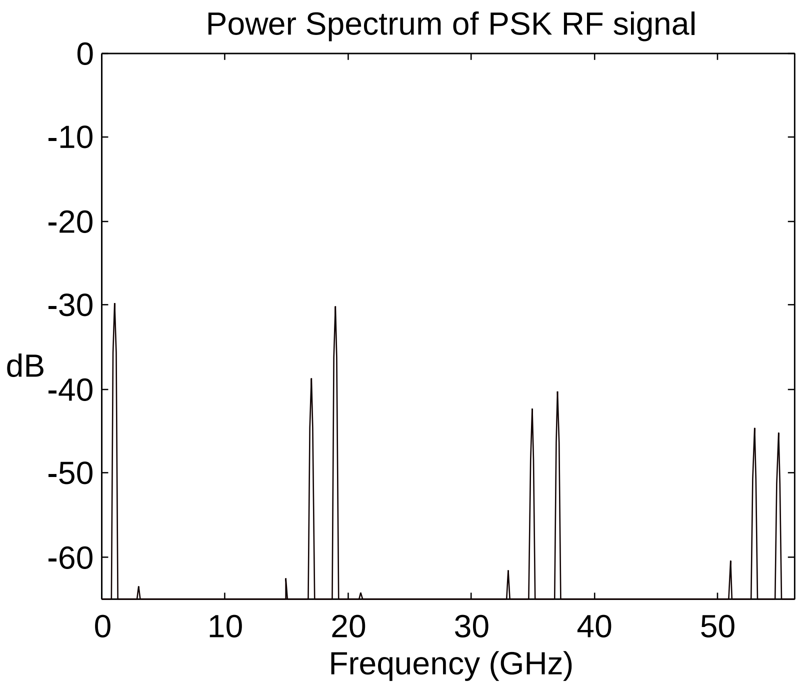

RFp time domain signal
0.1
0.05
0
-0.05
-0.1
volts
0
0.2
0.4
0.6
0.8
Time (nsec)


Power Spectrum of Pulsed RF signal
dB
0
-10
-20
-30
-40
-50
-60
0
10
20
30
40
50
Frequency (GHz)


LOp time domain signal
volts
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
Time (nsec)


Power Spectrum of Pulsed LO signal
0
-10
-20
-30
dB
-40
-50
-60
0
10
20
30
40
50
Frequency (GHz)


RFsw time domain signal
0.1
0.05
0
volts
-0.05
-0.1
0
0.2
0.4
0.6
0.8
Time (nsec)


Power Spectrum of PSK RF signal
0
-10
-20
-30
-40
-50
-60
dB
0
10
20
30
40
50
Frequency (GHz)

