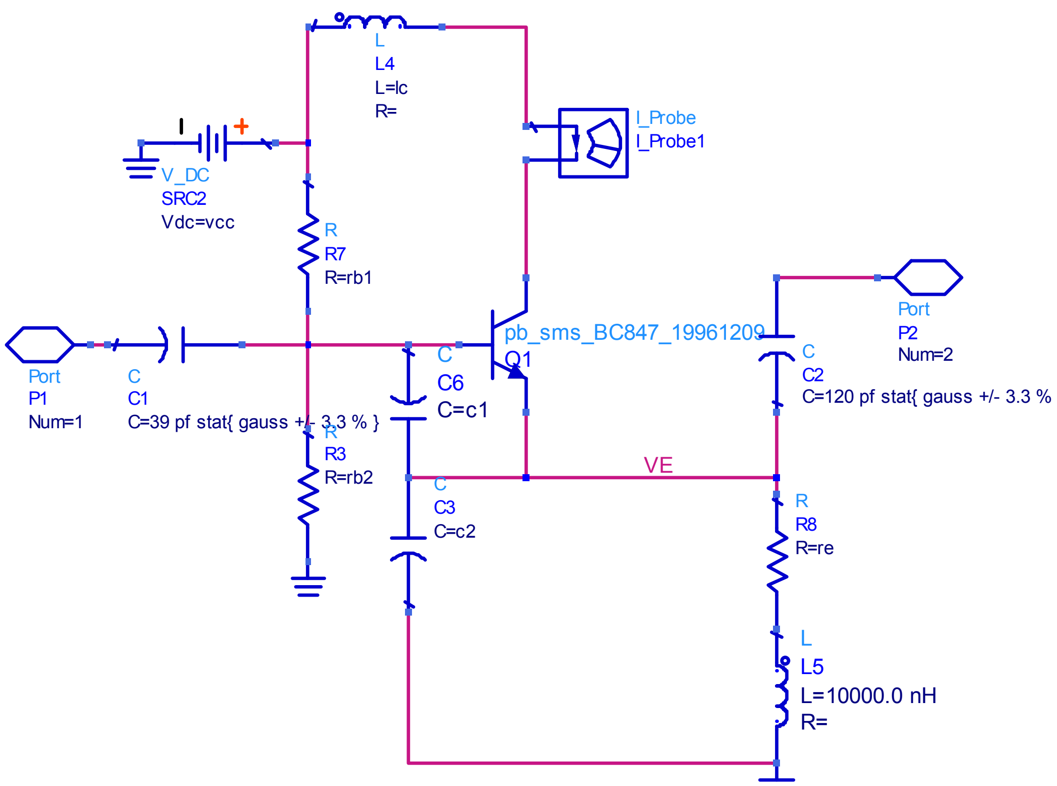
Some Experiments in 10 MHz Reference Oscillator Design

January 7, 2010 Charles Clark

This all started when I was talking about SC cut crystals with Kent WA5VJB. When I mention that they usually came in TO5 packages. Kent called my bluff and gave me 8 that he had found surplus. SC cut crystals often have higher Q than many AT crystals. Higher Q generally means lower phase noise.

So I measured one on a 8753C network analyzer. I didn't find the B mode that is characteristic of the SC cut. So I believe that these are AT cut. I did find that the Q was pretty good (Q=226000).

Colpitts Oscillator Schematic



Transistor Selection

NE85633. The NE856 is a 4 GHz ft transistor which I have often used in oscillator design up to about 1 GHz. It is rare in microwave transistor design with low frequency noise performance specified

2N2857 Old time LNA transistor. Still available in SOT-23 package

2N5179 Many VHF'ers favorite VHF oscillator transistor
2N2369 That's what they were using at CTS when I was in grad school, 30+ years ago.
MPS918 Plastic packaged version of the old 2N918
2N3904 Cheap, popular Audio/HF transistor.
BC847 Cheap low noise audio transistor.
Transistor models were included in ADS packaged parts library. I don't currently have the capability to measure transistors to develop a model.

Simulated Phase Noise Results

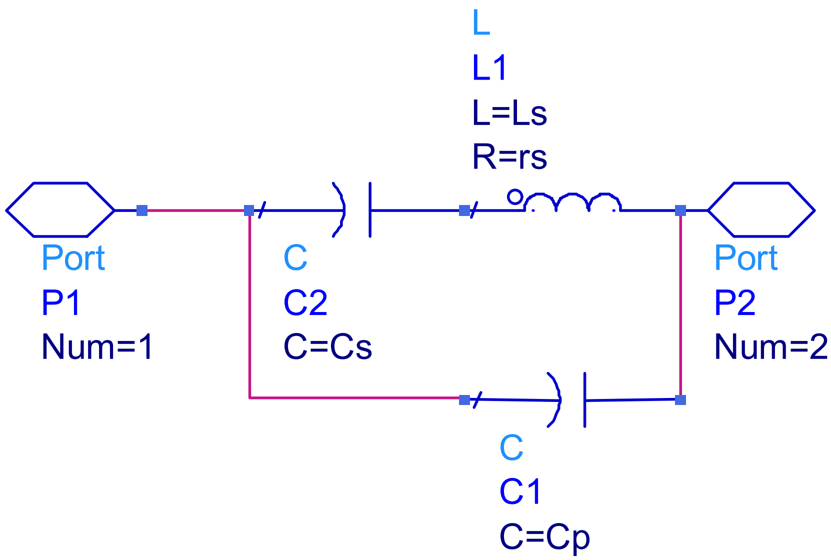
Device	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
NE856	-146	-164	-166	-166	-159
2N2857	-144	-163	-166	-166	-156
2N2369	-146	-164	-166	-166	-158
2N5179	-144	-163	-166	-166	-157
MPS918	-144	-163	-166	-166	-156
MRF5711	-147	-164	-166	-166	-159
2N3904 150/330	-148	-163	-164	-164	-156
BC847 100/150/300	-150	-164	-165	-165	-157

Quick Summary. Not much difference. The 2N3904 has great performance and price 3.7 cents US in quantity, 0.48 in single lots. A nickel or dime each at Tanners Electronic Surplus. The BC847 is just slightly better and available in TO92 or SOT23 packages.

Low noise audio performance is required in oscillators. The audio noise is translated up to the operating frequency of the oscillator. This is referred to as cyclostationary.

Crystal Model

I started using a crystal model provided in the ADS Design Guide.
Rs=7
Co=4 pf
Lm=21.99mh
Cm= 113 fF
Q=20,000



The results weren't as good as other designs. So I switched to models made from a sample of two different 10 MHz crystals.

Crystal Model

Performance of Wenzel 5 MHz Oscillator

Model	100 Hz	1 kHz	10 kHz	100 kHz	
500-01812A	-163.8	-176.3	-178.4	-178.7	dBc/Hz
TO5 crystal	-169.1	-176.1	-176.2	-176.2	
Tyco crystal	-164.4	-176.1	-176.6	-176.6	

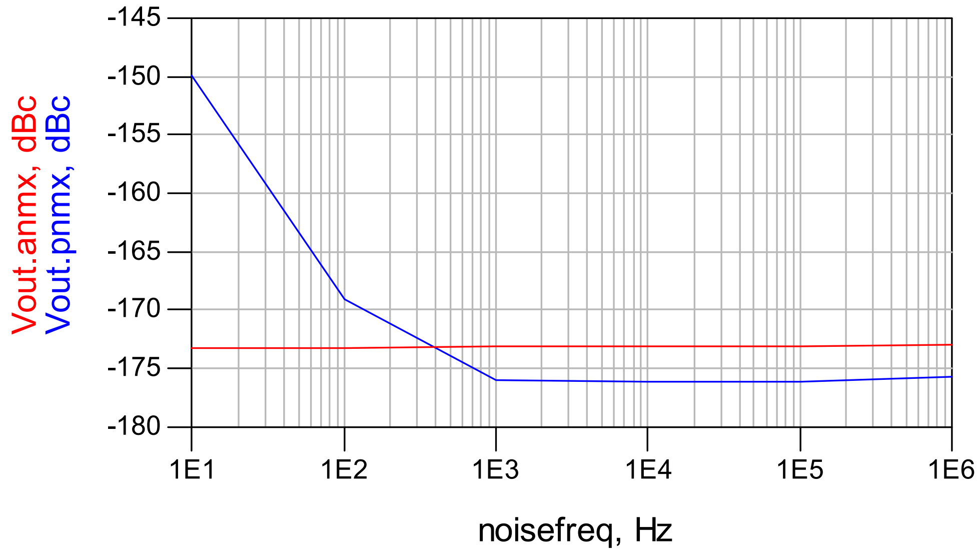
The Wenzel oscillator data is provided to show what best case performance can be expected. Wenzel is considered to be a superior oscillator manufacturer.

The new models:

Crystal	Frequency	Lm	Cm	Rs	Co	Q
T05	$9.997807*10^6$+/-78	$L_m := \frac{1}{4\cdot\pi^2\cdot f^2\cdot C_m}$	9.2 femto farads	8+/- 1.8+/-6	2.28 pf	226,000
Tyco	$9.997213*10^6$ +/- 219	$L_m := \frac{1}{4\cdot\pi^2\cdot f^2\cdot C_m}$	14.7 femto farads	10.4+/- 1_/-3	3.93 pf	104,000

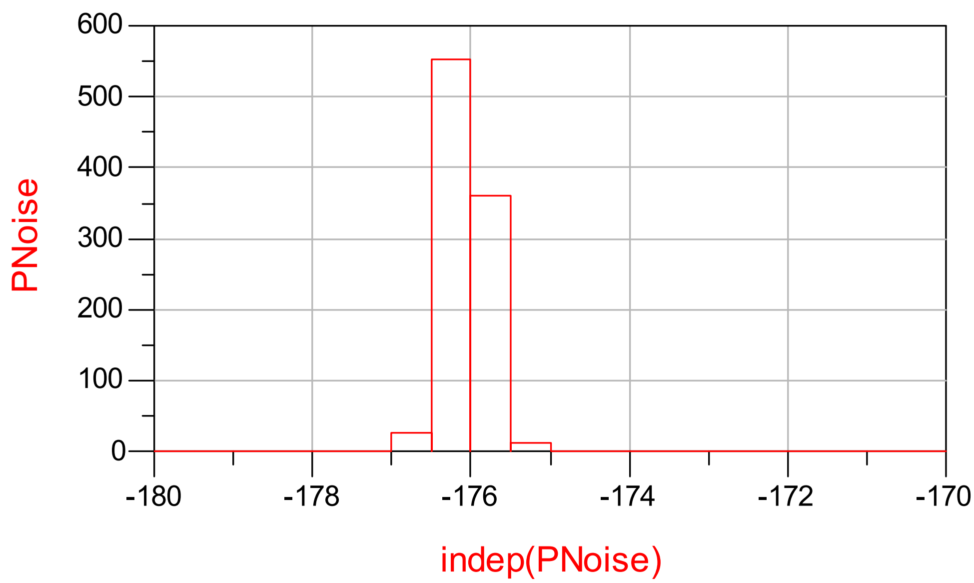
One of the observations is the Q of my samples is much higher than the original model. It turns out the designs need better circuit values to get full performance of the oscillator. The two crystals were enough different to use different values to optimize the oscillator.

Phase Noise Results

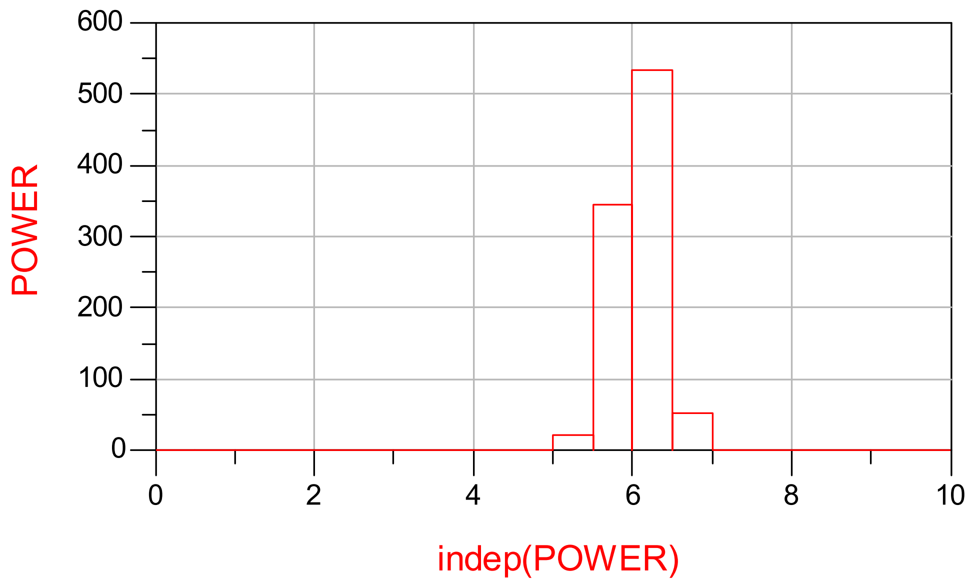


Yield Results

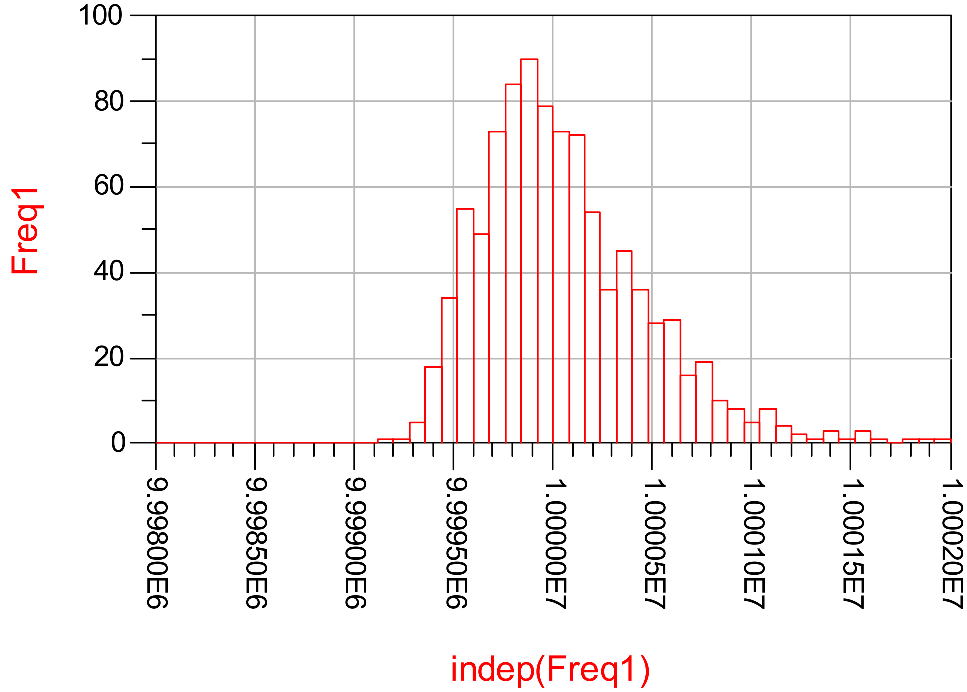
TO5 Crystal



Phase Noise at 1 kHz offset.

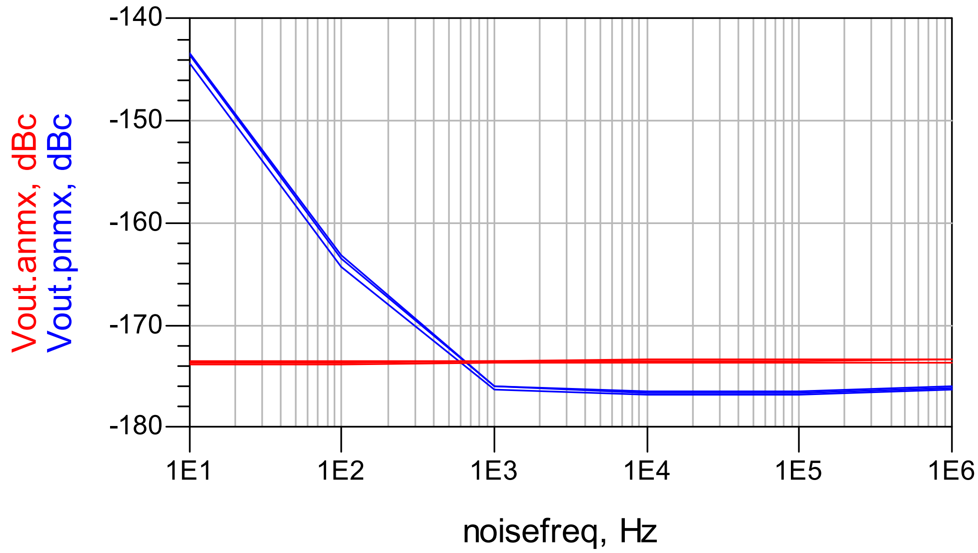


Output Power in dBm.

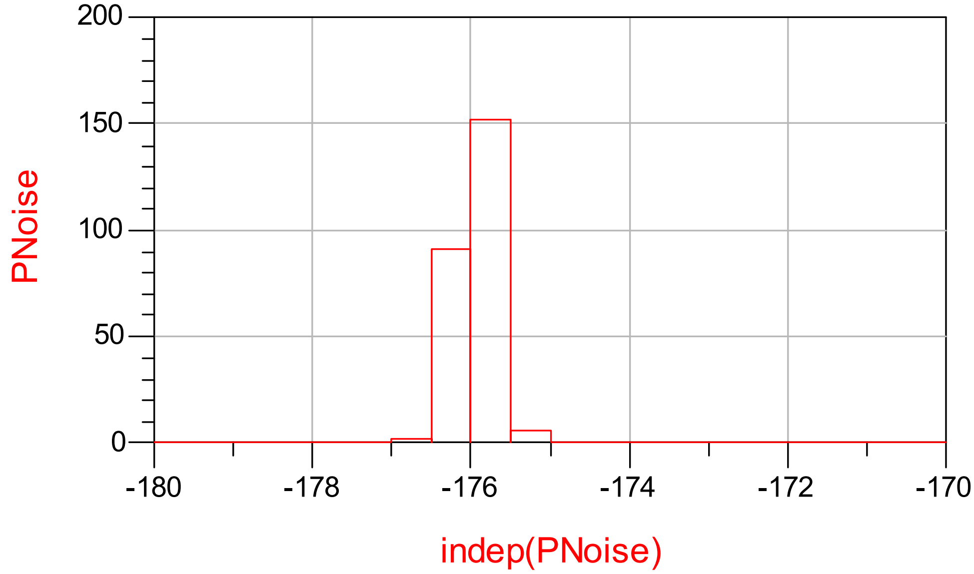


Frequency Histogram

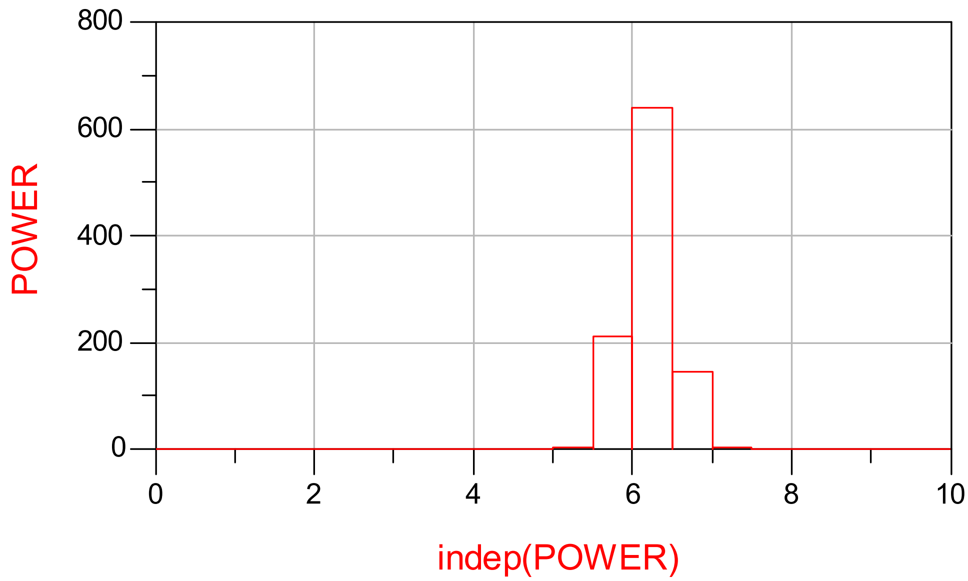
Tyco Crystal



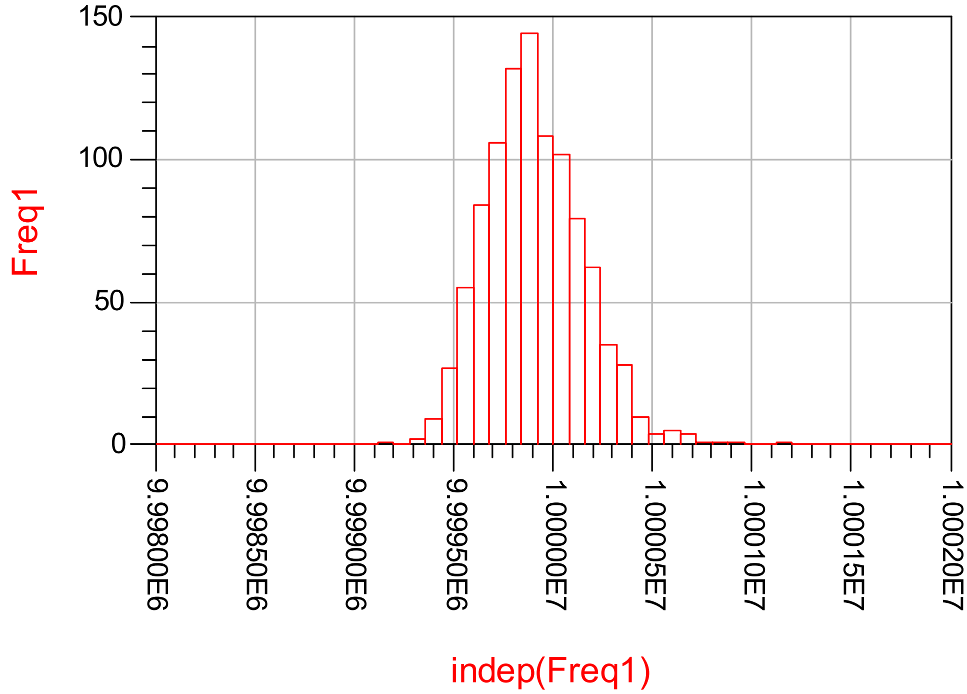
Phase and amplitude noise spectrum. Anmx is amplitude noise, pnmx is the phase noise, both in dBc/Hz.



Phase Noise, Frequency Offset 1 kHz.

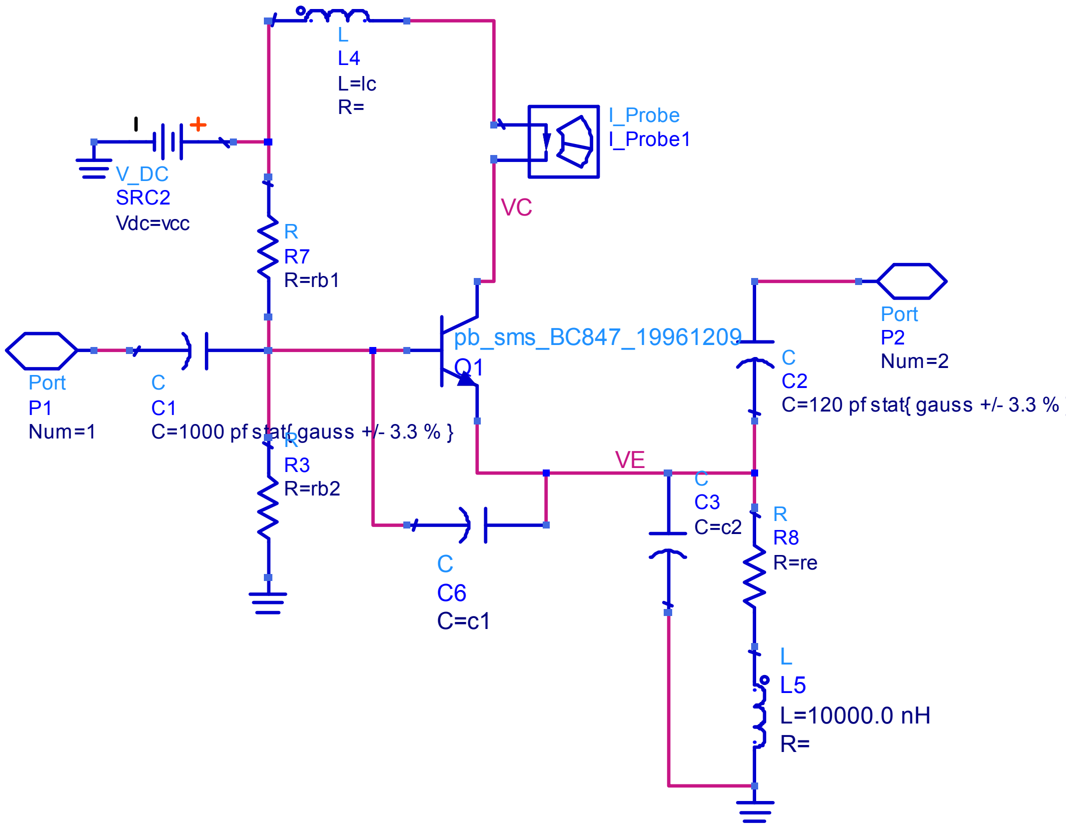


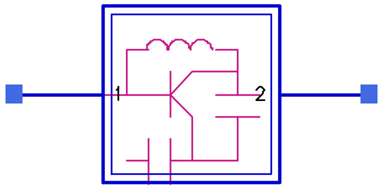
Output Power Histogram



Frequency Histogram

The design is not centered on the desired 10 MHz figure. Tightening the tolerances will not improve the yield. Changing C1 the top capacitor in the voltage divider to a smaller value will improve the frequency yield but increases the phase noise.


L
L4
L=lc
R=
I_Probe
I_Probe1
V_DC
SRC2
Vdc=vcc
VC
R
R7
R=rb1
Port
P2
Num=2
pb_sms_BC847_19961209
Q1
Port
P1
Num=1
C
C1
C=1000 pf stat{ gauss +/- 3.3 % }
C
C2
C=120 pf stat{ gauss +/- 3.3 % }
R
R3
R=rb2
VE
C
C3
C=c2
R
R8
R=re
C
C6
C=c1
L
L5
L=10000.0 nH
R=



cOsCoreRF
G1
vcc=8.0 V stat{ gauss +/- 1.67 % }
rb1=36 kOhm stat{ gauss +/- 3.3 % }
rb2=22 kOhm stat{ gauss +/- 3.3 % }
re=680 Ohm stat{ gauss +/- 3.3 % }
lc=10 nH
c1=33 pF stat{ gauss +/- 3.3 % }
c2=82 pF stat{ gauss +/- 3.3 % }

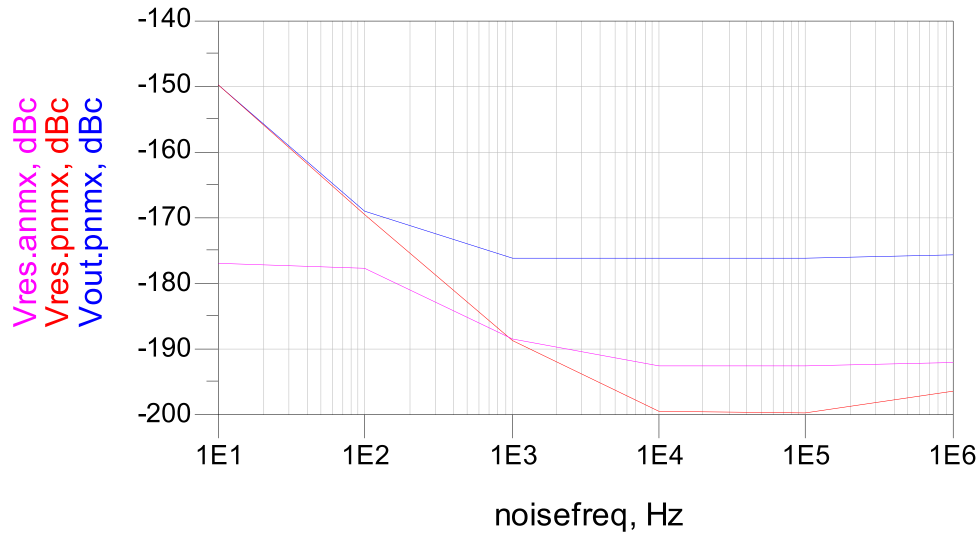
The parameter distribution was Gaussian with one standard deviation being 3.3 percent. This corresponds to a component with Gaussian distribution and a 10% tolerance.

Yield Summary

There were 49 simulations out of 1000 where the oscillator failed to oscillate with the TO5 crystal. All of the Tyco crystals oscillated. The TO5 design needs more design centering to improve the yield.

Further Work

Some authors claim improved performance taking power out of the resonator. Usually this doesn't include how much improvement.



AM and Phase noise in the resonator, with the phase noise taken off the emitter. There is no potential for improvement below 100 Hertz but it looks like we could get 10 dB or more above 1 kHz offset. Since the input to the amplifier will be in series with the crystal it will degrade the Q of the crystal some.

It's not easy to measure the phase noise of such an oscillator, the popular EE5052 signal analyzer is limited to -140—150 dBc/Hz at 1 kHz offset.

References:

http://cp.literature.agilent.com/litweb/pdf/5989-1617EN.pdf

http://yu1lm.qrpradio.com/HF-VHF%20universal%20oscillator-YU1LM.pdf