EPCOS

Application Note
SAW-Components

Fundamentals of a SAWR stabilised Pierce oscillator.
Schematic and PCB layout for a SAWR stabilised oscillator working at 915MHz and at 868.3MHz.
App. Note #21

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Fundamentals of a SAWR stabilised Pierce oscillator

SAWR stabilised oscillators in the range of 400MHZ....1000MHz are often realised in a Pierce oscillator configuration. Especially at the high end of the frequency range the advantage of a Pierce oscillator is the stable design and less parasitic effects. The disadvantage is the higher amount of components (inductivities etc.).

The Pierce oscillator is an unconditional stable amplifier with a signal feedback from the output to the input. The feedback consists of two matching networks and the two-port SAW resonator. For this oscillator a SAWR with 180° degree phase shift between input and output is used.
The load (often 50 Ohm) is connected to the collector by a small capacitor. This capacitor transforms the high impedance level of the collector down to the desired load impedance.
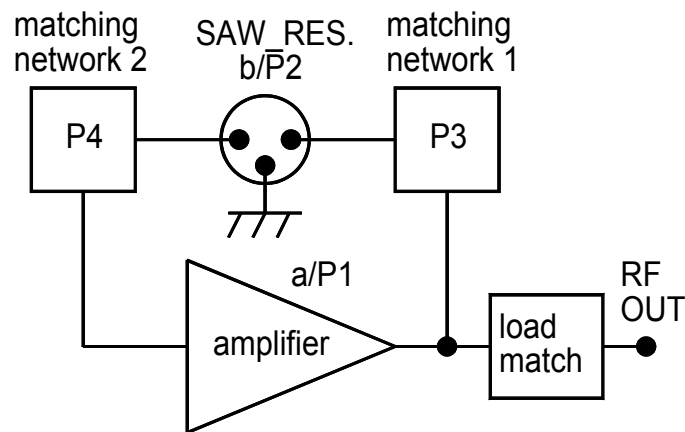

Fig 1: Pierce oscillator working with a SAWR

For starting oscillation the two Barkhausen conditions must be fulfilled.

- amplitude: $G = a + b > 1$
- phase: $Ptot = P1 + P2 + P3 + P4 = n * 360°$ n=0,1,2,...

For a high gain amplifier it is easy to meet the amplitude condition, but if the phase condition is not fulfilled, no oscillation will occur, or the oscillation frequency will be not at the serial resonance frequency of the SAWR. This frequency deviation causes an additional insertion loss of the SAWR. If the deviation is too strong the resulting gain in the oscillator loop is <1 and the oscillation will not grow up from noise level.

Comparing the insertion loss of a two-port SAWR at resonance frequency, it depends on load and source impedance. Increasing the load and source impedance for the SAWR, the insertion loss will be reduced.
On the other hand the loaded Q-factor will be reduced too.
A lower IL will help the designer to realise a high enough gain in the loop, but the frequency stability will be reduced.
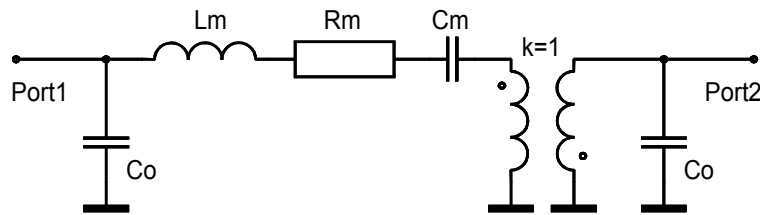
Fig 2: Equivalent circuit of a 2-port SAWR with 180° degree phase shift

$$Ql = \frac{Qu * Rm}{Rm + Rs + Rl}$$

$$IL_{db} = 20 * \log_{10}\left(\frac{Rs + Rl}{Rm + Rs + Rl}\right)$$

Ql   = loaded Q-factor
Qu = unloaded Q-factor
IL   = insertion loss of the SAWR in [dB]
Rl   = load impedance of the SAWR (real value)
Rs = source impedance of the SAWR (real value)
Rm = motional resistance of the SAWR
Cm = motional capacitor of the SAWR
Lm = motional inductivity of the SAWR
Rm, Cm, Lm are characterised in the equivalent circuit of the SAWR
3dB bandwidth of the SAWR (neglecting Co) = fosc/Ql

For the matching networks a "PI" structure with two capacitors and one inductor is used ([Cp1,Ls1,Cp2],[Cp2,Ls2,Cp4]). The internal Co of the SAWR is a part of Cp1 and Cp3. Depending on oscillation-frequency, PCB layout etc. some capacitors can be removed.
The matching network between the collector and the transistor transforms the high collector impedance to a lower source impedance for the SAWR. The second matching network transforms the base impedance to the desired SAWR load impedance. Additional the two matching networks creates a certain phase shift to fulfil the phase condition on the oscillator loop.
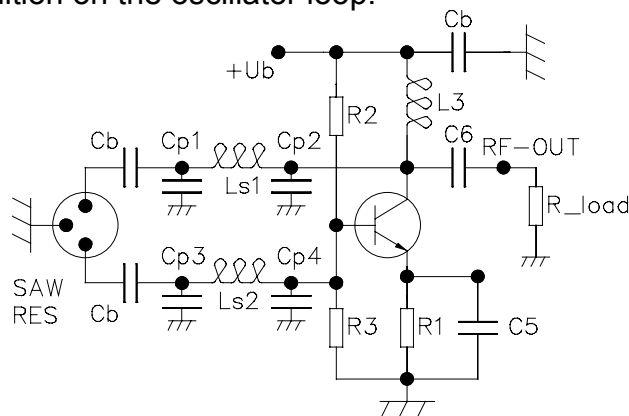

Fig 3: Pierce oscillator in his general form

Calculating the circuit for a certain source and load impedance on an analytical way, often it is not possible, because of the interaction between the different oscillator parts. The best way to start a development of such a Pierce oscillator is to use a RF simulator.

The S-parameter of popular RF transistors are available and the equivalent circuit of the SAWR is specified in the data sheet. It is recommended to use the equivalent circuits for the other components too (parallel capacitor of the inductivities).

The closed oscillator loop is described in the simulation tool and at collector's node S11 and Z1 are measured. It is important to connect the desired load to the collector by a small capacitor.

The oscillation will start, if
- Mag [S11] >1 at the desired oscillation frequency
- Ang [S11] is close to 0°degree at the desired oscillation frequency
  Both conditions must be fulfilled.

The phase of S11 is > 0° degree at lower side of the oscillation frequency, and it will be < 0° degree at higher side of the oscillation frequency.

Additional these following conditions corresponds to the S11 conditions

- Re [Z1]<0 Ohm (negative real part of Z1) at the desired oscillation frequency
- Im [Z1] close to j0° Ohm   at the desired oscillation frequency

The optimisation can be done with a computer.

The 915MHz oscillator, described here, was developed with this CAD technique.

This Pierce oscillator can be used for a LO or for an other RF signal source. For realising a RF-transmitter with a integrated loop antenna, a modified structure is more recommendable.

The component values depends on a equivalent circuit of the devices (inductivities) and on the parasitic effects of the PCB layout.

Starting with our oscillator approach, a changing of the matching network components might be possible to realise a stable oscillation close to the serial resonance frequency of the SAWR. This changing can be in the range of +- 1or 2 steps in the E12 set.

The best working of the SAWR oscillator can be realised with a oscillating frequency close to the SAWR´s serial resonance frequency. At the SAWR´s serial resonance frequency the loaded Q-factor of the SAWR is at his maximum to get the best frequency stability.

To fit into the serial resonance frequency of the SAWR, the following procedure should be used in the development phase of the oscillator.

For this procedure the serial resonance frequency of the SAWR should be known. To detect the serial resonance frequency of the SAWR, a insertion loss (IL, S21) measurement can be done with a scalar network-analysator. The serial resonance frequency of the SAWR (centre frequency) is very close to the minimum insertion loss point. Using this SAWR, place it in the SAWR oscillator and check the oscillation frequency. The oscillation frequency can be moved to the SAWR´s serial resonance frequency by changing the component values a little bit. This procedure should be done for a couple of oscillators in the development phase to fix the component values. In the mass production this procedure will not be necessary.

It is important to have a look at a very good RF PCB layout to create a stable design. For avoiding ground loops, the grounding pins of input-and output transducer (pin 3, 7 of the SAWR) should be isolated from the top grounding area and should be fed together on the system ground (bottom GND) by separated via holes.

The RF output power at 50 Ohm load is about –6dBm @ Vcc=5V, Icc=5mA.

Tuning this oscillator to 868.3MHz, small changes are necessary.
Additional the design was changed to Vcc=3V and 8mA. The oscillator works down lower than Vcc=2V (low end of a 3V Lithium battery).
The component value changing is listed at component list.

Schematic, PCB and placement of a Pierce oscillator (LO), stabilised with a EPCOS SAW resonator at 915MHz / 868.3MHz
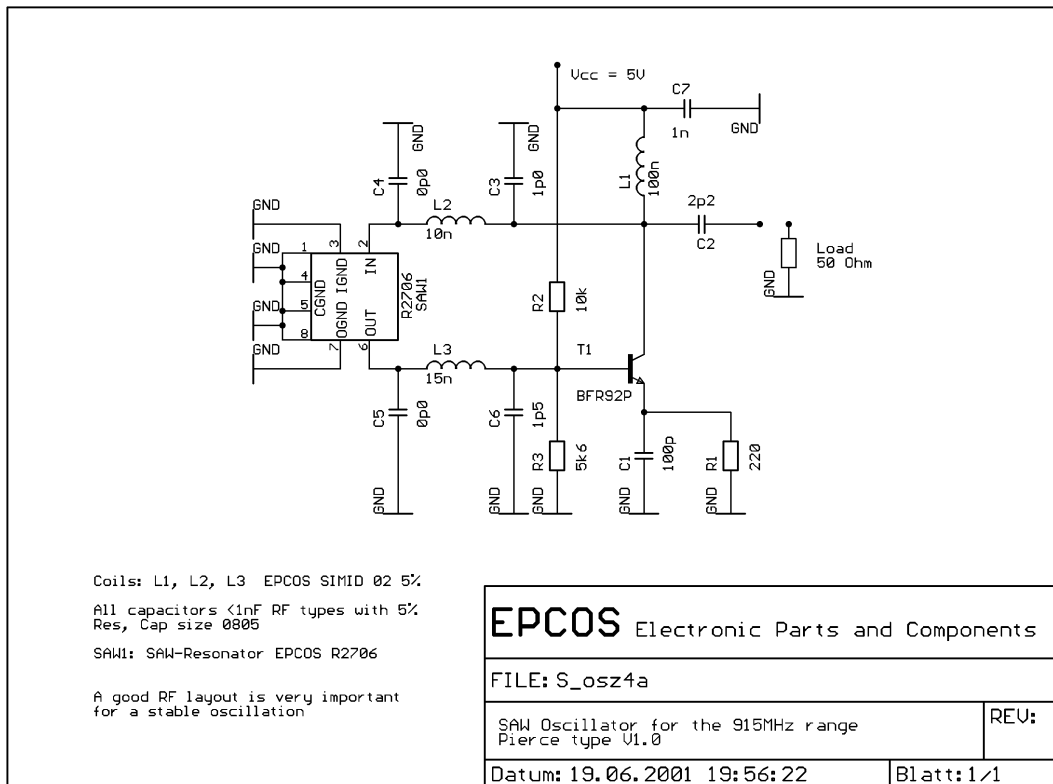

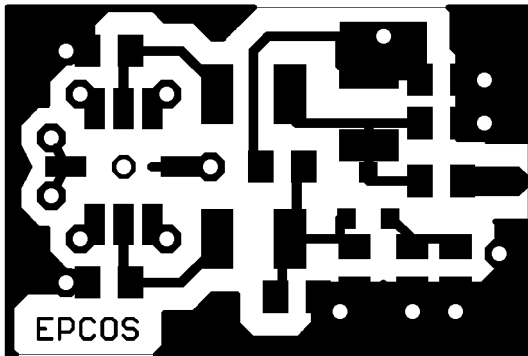Fig 4: SAWR stabilised Pierce oscillator

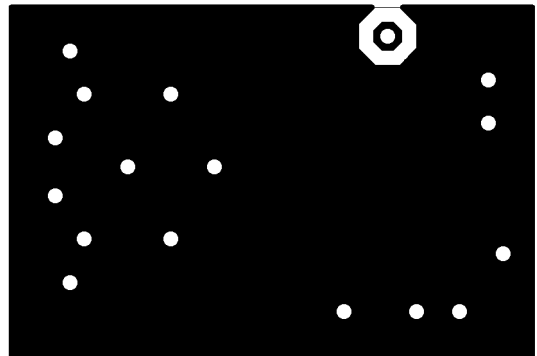Fig 5: SMD Layer side (top-side) (Scale 3:1)
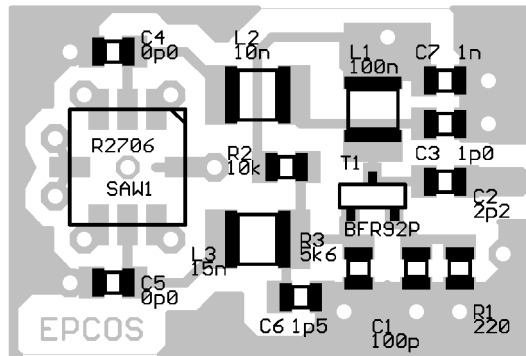

Fig 6: Bottom-side, grounding area (Scale 3:1)

Fig 7: Placement side (top-side) (Scale 3:1)

Fig 8: Top side & bottom side   actual size

Bill of material for the SAWR oscillator

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Part        Value           Package

C1          100p            0805
C2          2p2             0805
C3          1p0             0805
C4          0p0             0805
C5          0p0             0805
C6          1p5             0805
C7          1n              0805
L1          100nH           1210      EPCOS SIMID 02/08   5%
L2          10nH            1210      EPCOS SIMID 02/08   5%
L3          15nH            1210      EPCOS SIMID 02/08   5%
R1          220             0805
R2          10k             0805
R3          5k6             0805
SAW1        R2706           QCC8      2-port SAWR EPCOS
T1          BFR92P          SOT23     Infineon
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Component value changing for working at 868.3MHz and at Vcc=3V.

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C2          2p7             0805
C3          1p5             0805
C6          2p2             0805
L1          100nH           1210      EPCOS SIMID 02/08   5%
L2          12nH            1210      EPCOS SIMID 02/08   5%
R1          100             0805
R3          15k             0805
SAW1        R2709           QCC8      2-port SAWR EPCOS
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General hints for PDF file printing: Best result using a Post Script printer in PS mode.

SAWR stabilised Pierce oscillator at 915MHz and 868.3MHz
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