Application Note
SAW-Components

Principles of SAWR-stabilized oscillators and transmitters.
App: Note #1

This application note describes the physical principle of SAW-stabilized oscillator.
Oscillator structures for one- and two-port SAW resonators are discussed.
An application example for a 433.92MHz transmitter for keyless entry is given.

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Principles of SAW-stabilized oscillators and transmitters

Physical principle:
An oscillator is a network comprising an active stage (amplifier) and a frequency-sensitive feedback stage (resonator, filter). Part of the output signal is fed to the input of the amplifier passing the feedback. The insertion loss and the phase of the feedback depend on the frequency.
For oscillation, the insertion loss of the feedback is at a minimum and the total phase in the oscillator loop must be n*360°. In this case, there is a positive feedback and an oscillation can be generated.
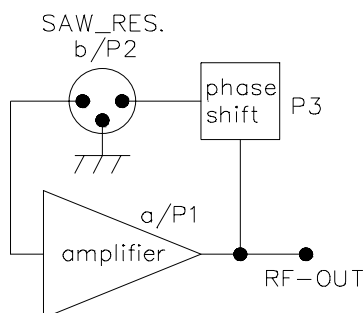

Fig.1: General structure of a RF oscillator

The following conditions must be satisfied for oscillation:

　　　Amplitude:　　$G = a + b > 1$
　　　Phase :　　　$Ptot = P1 + P2 + P3 = n * 360°$　　　(n = 0, 1, 2,...).

The total gain *G* in the loop is greater than 1. So the gain of the amplifier must be greater than the attenuation of feedback and power dissipation in the RF load.
The total phase in the circuit must be n*360° to achieve positive feedback.
The phase slope of the resonator is very steep in the area of the resonance frequency. This steep phase slope is necessary for good frequency stability.
To start up an oscillator, the thermal noise is amplified in the active stage. This very low broadband noise continuum is fed to the amplifier's input by the feedback loop. In this continuum, there are frequency components at the desired oscillating frequency. These frequency components pass the frequency-sensitive feedback stage without strong attenuation. If the phase condition is met, the feedback signal is added to the input signal. This procedure is repeated cycle by cycle, and the output signal increases. The maximum oscillating level is limited by nonlinear effects of the amplifier. When the signal amplitude and the oscillation frequency are fixed, the oscillator is in the steady-state mode.
The transient time (start-up time) depends primarily on the SAW resonator's loaded Q-factor and the characteristic of the active circuitry.

Typical oscillation circuits
Oscillators with one-port resonators

Oscillators with one-port resonatorThe common-base Colpitts oscillator is a preferred circuit for one-port resonators. This type of circuit is used in many applications and ideal for modulation with amplitude shift keying (ASK) and on-off keying (OOK).

The bill of material for a Colpitts oscillator is very short. The transmitter antenna can easily be integrated on the PCB.
The Colpitts oscillator also works with a two-port SAW resonator in a one-port configuration, but a real one-port SAW resonator has many advantages.
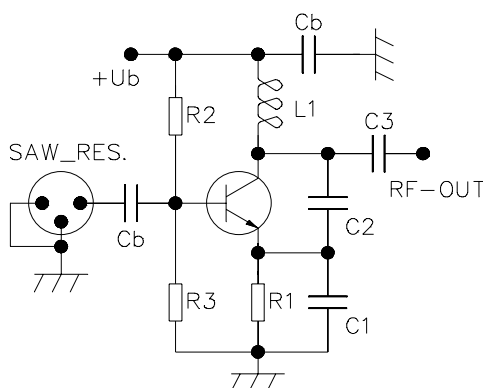

Fig.2: Colpitts oscillator with common base

For oscillation, the resonant frequency of the parallel resonant circuit should be near the SAW resonant frequency. Neglecting the internal transistor capacitance, the load and the parasitic capacitance of the PCB, the resonant frequency *Fp* of the LC circuit comprising capacitors C1, C2 (in series) connected in parallel with L1 is determined by:

$$Fp = \frac{1}{2 * Pi * \sqrt{L1 * \frac{C1 * C2}{C1 + C2}}}$$

This provides merely initial values for further optimization. The circuit is much more complicated, because there are numerous parasitic capacitances (e.g. output capacitance of the transistor, PCB capacitance, etc.).
R1, R2 and R3 are used for DC biasing. C3 matches the high-impedance collector output to the load impedance. The feedback of the oscillator is set by the ratio of C1 to C2, which also determines the transient response and other specific oscillator properties.
As the circuit begins to build up the oscillation, the initial values (DC biasing points, LC circuit, PCB with the antenna) apply. For basic tuning, the SAW resonator is replaced by a 22 Ω resistor and if necessary a DC blocking capacitor
(33 pF...100 pF). The oscillator starts up with an oscillation at the LC circuit. The oscillator frequency is trimmed by C1, C2, C3, L1. The frequency of the free-wheeling LC oscillation should be close to the SAW resonator's frequency.

When the SAW resonator is again used instead of the resistor and capacitor, the frequency is stabilized to the desired value. The signal frequency and the harmonics are optimized by fine tuning.

The SMD transistor should be a high-frequency type with a transit frequency of a few gigahertz. Using a very fast type, the oscillation will start under nearly all conditions, but the harmonics can be very high.

The choke L1 can often be designed like a copper line on the PCB (without grounding to the wiring side). A transmitter antenna can thus be implemented.

Oscillators with two-port resonators

The typical oscillator circuit for two-port resonators is the Pierce oscillator.
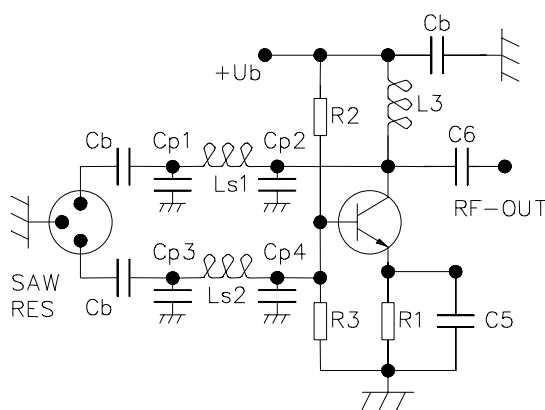

Fig.3: Pierce oscillator

The amplifier stage of the oscillator is a transistor with grounded emitter. The SAW resonator is embedded between two "pi"-type tuning networks. These networks control phase shift in the feedback loop to meet the oscillation conditions. Otherwise they match the input and output impedance of the transistor to the desired load and source impedances of the SAW resonator. In general, the 3 dB bandwidth of the SAW resonator depends on its source and load impedance. Increasing the source and load impedances raises the 3 dB bandwidth of the SAW resonator and reduces the loaded Q-factor. The higher bandwidth makes it possible to trim the resonant frequency of the SAW resonator slightly. In the Pierce oscillator, the RF frequency can be varied by trimming Ls1/Cp1 and Ls2/Cp3. Increasing the 3 dB bandwidth, a lower loaded Q-factor will result in a lower frequency stability and sensitivity to temperature variations and component tolerances will increase.

In the tuning network, the capacitors Cp1, Cp2, Cp3, Cp4 consists of the SAWR´s and the transistor´s input and output capacity and if necessary of concentrated capacitors. C6 is for output matching, L3 for DC bypassing.

<u>Application of a wireless remote control transmitter at 433.92 MHz</u>

SAW resonators are commonly used in remote control transmitters for keyless entry, in security systems and for wireless telemetry.
Fig.3 shows an AM remote control transmitter with a center frequency of 433.92 MHz.
The transmitter is a SAW-stabilized oscillator with a PCB antenna, where a one-port SAW resonator is designed in, using the basic circuit shown in Fig.1. OOK modulation is used. The oscillator is switched on and off in step with the data telegram. The maximum modulation frequency is about 2.5 kHz (or 5 kbit/s in NRZ code). The oscillator's transient time of 30 µs prevents a higher modulation rate.
The additional components L01, C08 belong to the feedback circuit and are designed for harmonic suppression and matching the antenna to the output of the transistor. L02 is for DC biasing. The antenna is a loop antenna integrated on the PCB.
The high ratio of C06/C07 in combination with R07 prevents the oscillator to generate spurious oscillation at 50 to 100 MHz above the desired SAW oscillation frequency. This parasitic oscillation tendency is caused by slightly different LC resonance frequencies in the harmonics suppression - antenna circuit.
The oscillation frequency depends on C06, C07, C08, L01 and the layout of the antenna choke L03. So it is necessary to use components with 5% tolerance. C04 is for DC blocking (33 pF...100 pF), R05 and R03 for biasing.
The transmitter requires a good common RF ground and short connections between the RF components. A closed common GND area at the bottom side of the PCB is very important to keep the critical GND nodes close together. The most important nodes for excellent RF grounding are: SAWR, C06, C08, C05, C01. Separation of the digital from the RF circuitry on the PCB is also recommended. The loop antenna area must be free of the grounding layer.
The circuit has been developed for low power consumption. The supply voltage is 3 V. Current consumption about 3.5 mA for a continuous oscillation (no modulation, continuous wave mode) and falls below 2 mA with a 50% duty cycle modulation frequency. Final current consumption depends on the code sequence. At a supply voltage of 6 V, current consumption is 6.5 mA in CW mode
The EIRP (equivalent isotropic radiated power) output is measured at a distance of 3 m. The EIRP is the product of radiation energy and antenna gain. So the radiated power is normalized on an isotropic radiator with the gain of unity.

EIRP measured at 3 V, 3.5 mA, CW mode

Frequency	433.92 MHz:	2*433.92 MHz	3*433.92 MHz
EIRP	-20 dBm	<-50 dBm	<-50 dBm

EIRP measured at 6 V, 6.5m A, CW mode

Frequency	433.92 MHz:	2*433.92 MHz	3*433.92 MHz
EIRP	-12 dBm	<-40 dBm	<-40 dBm

This circuit can also be used for other frequencies; the values of C6, C7, C8, L01, L03 and the SAW resonator are changed accordingly

Fig.4: Remote-control transmitter for 433.92 MHz

The hand transmitter was implemented on a 1 mm FR4 PCB. The layout schematic and placement schematic are on a scale of 2:1.
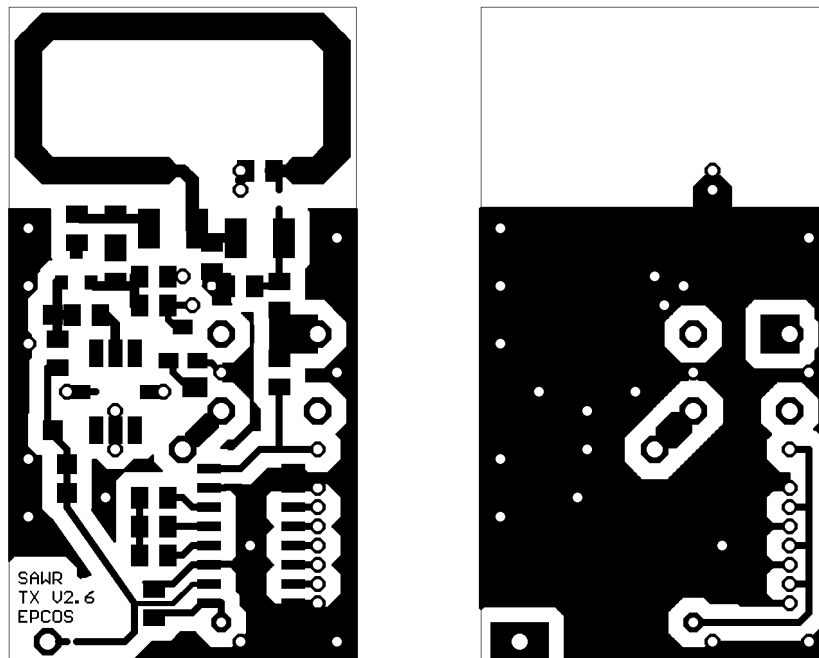

Fig.5: Layout, SMD side, scale 2:1 Layout, wiring side, scale 2:1 (printing on DINA4)
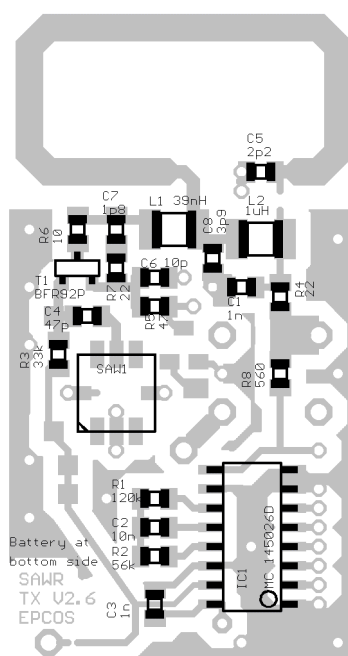

Fig.6: Placement, SMD side Placement, wiring side

The battery and the switch are assembled at the bottom side of the PCB.

Bill of material for the transmitter

Part	Value	Package	
C1	1nF	0805	
C2	10nF	0805	
C3	1nF	0805	
C4	47pF	0805	DC blocking
C5	2p2F	0805	
C6	10pF	0805	RF types 5% tol.
C7	1p8F	0805	RF types 5% tol.
C8	3p9F	0805	RF types 5% tol.
L1	39nH	1210	SMD EPCOS SIMID 02/08
L2	1µH (approx.)	1210	SMD EPCOS SIMID 02/08
L3	antenna approx. 47 nH		about 50 × 1,7 mm (loop)
R1	120kΩ	0805	
R2	56kΩ	0805	
R3	33kΩ	0805	
R4	22Ω	0805	
R5	47Ω	0805	
R6	10Ω	0805	
R7	22Ω	0805	
R8	560Ω	0805	
SAW1	R727	QCC8C	EPCOS
T1	BFR92P	SOT23	Infineon
IC1	MC 145026D	SO-16	Motorola (simple encoder example)

The oscillator can recalculated to different TX frequencies, by changing the SAWR and the component values. Here a set of component values for TX=315 MHz and 418 MHz is given.

The component values for a TX frequency of 315 MHz are:

C05:	3p9 F	L01:	56 nH SIMID 02
C06:	22 pF	L02:	1 µH
C07:	2p7 F	L03:	antenna is the same (about 47 nH)
C08:	5p6 F	SAW resonator:	R705

Because of lower TX frequency, transistor BFS17P can be used here.

For a transmit frequency of 418 MHz, the values of the components in the oscillator circuit are very similar to those for 433.92 MHz version shown above.
A 2p7 F capacitor is used for C05, and SAW resonator is type R703.
If a transmit frequency of 418 MHz is used, special attention must be paid to harmonic radiation because it is more difficult to fulfil the very tuff UK harmonic suppression requirements.
For more application notes, data sheets and SAWF S-parameter, we refer to our internet site http://www.epcos.com/rke

General hints for PDF file printing: Best result using a Post Script printer in PS mode.

Remote Control: SAWR stabilised Colpitz oscillator (transmitter for keyless entry)
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