Application toolkit
EPCOS SAW resonators
and frontend filters

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www.epcos.com/rke
(find application notes, S parameters...)

Edition 2005
## Applications for SAW resonators and frontend filters

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<td>Wireless audio</td>
</tr>
</tbody>
</table>
SAW automotive electronics

Customer benefits

- Complete range of resonators and frontend filters for all standard frequencies and IF concepts
- SAW resonators with tight frequency tolerances: ±50 kHz / ±75 kHz / ±100 kHz
- Most sophisticated wide band, narrow band and ultra narrow band SAW frontend filters worldwide
- Hermetically sealed SMD package for flawless performance in extremely hostile environments
- Enhanced reliability (particle protection) and reduced aging by patented PROTEC® and ELPAS technologies
- Proven and certified reliability complying with stringent QA requirements of the automotive industry worldwide (ISO/TS 16949, AEC-Q200)
The piezoelectrical effect

Pressure
mechanical energy

Voltage
electrical energy

The piezoelectrical effect describes the transformation of mechanical energy into electrical energy and vice versa.
The electromechanical energy conversion via surface acoustic wave (SAW) takes place in the Interdigital Transducer (IDT). Therefore, the IDT acts as:

- **Transmitter**: reverse piezoelectric effect  \[ \Rightarrow \text{electric RF field generates SAW} \]
- **Receiver**: piezoelectric effect  \[ \Rightarrow \text{SAW generates electric RF field} \]

Maximum coupling strength for \( I_{\text{SAW}} = \frac{v_{\text{SAW}}}{f} = 2 \cdot p \)
Basics on Surface Acoustic Wave

For Rayleigh waves:
Elliptical particle trajectory

- Depth of penetration about 1 wavelength
- \( v_{\text{SAW}} \gg 3000 \text{ m/s} \gg 10^{-5} v_{\text{Light}} \)
  At the same frequency, the wave length is 10^{-5} times less than for electromagnetic waves
- Typical values for \( l \):
  at 246 MHz 12 mm
  at 900 MHz 4 mm
  at 1,800 MHz 2 mm
- Principles of wave guide and antenna theories can be used to describe SAWs
Function of a SAW component made visible: REM picture

- Reflectors
- Interdigital structure
- Bond wire
- Interdigital transducer
- Surface acoustic wave = standing wave

Surface acoustic wave
The SAW chip is a piezoelectric single crystal (e.g. quartz, lithium tantalate, lithium niobate), polished on the surface and coated with one or more comb-like, interlocking electrode fingers, so-called interdigital transducers. These usually consist of aluminum and are deposited by photolithographic means. When an electric signal is applied to an electrical transducer, an electrical field is produced between the differently polarized transducer fingers and, because of the (reverse) piezoelectric effect, the chip surface is deformed mechanically. Like tiny seismic waves, a surface acoustic wave spreads out from both sides of the transducer. The reflectors on both sides of the transducer reflect these acoustic waves and thus create a standing wave, which is converted back into an electrical signal at an output transducer (piezoelectric effect).
How SAW frontend filters work

SAW filters are very flexible concerning design: Frequency and bandwidth can be determined by:

- the spacing of the transducer fingers
- their number
- substrate
- design technique

If the wave length corresponds to the finger spacing, there is a constructive - otherwise destructive - superimposition of the surface waves. The result is, put simply, the characteristic bandpass response of SAW filters.
How SAW resonators work

In an oscillator circuit (e.g. Pierce or Colpitts oscillator) the ambient thermal noise is being amplified and fed back through the feedback loop into the oscillator system. A built-in SAW resonator attenuates most of this noise spectrum, only a very narrow frequency band can pass:
If the wave length corresponds to the finger spacing and resonance occurs, there is a constructive - otherwise destructive - superimposition of the surface waves. As a result, due to the resonator's position in the feedback loop of the oscillator, only the noise portion which closely match the resonator's resonance frequency, will be amplified, thus creating a very exact oscillation frequency of the oscillator.
One port resonator and equivalent circuit

Reflectors

Interdigital structure

Reflectors

R₁ = motional resistance
L₁ = motional inductance
C₁ = motional capacitance
C₀ = static capacitance
Architecture of a SAW resonator stabilized remote control transmitter

The code which is supposed to be transmitted to the receiver consists of an encoded identifier (including a rolling code for security reasons) and the message itself to e.g. unlock the central locking system of a car.

An oscillator which is synchronized by a SAW resonator oscillates at an exact frequency. Thereby, it generates an RF carrier signal, which (using the simple on-off-keying procedure, OOK) is modulated according to the transmission code by simply turning the oscillator on and off. This coded, modulated RF signal will be sent out through the antenna of the transmitter.

Common transmitter frequencies: e.g. 315, 433.92, 868, 915 MHz
The modulated RF signal (encoded message) sent from the transmitter is received by the antenna of the receiver a few feet away (typically 30 to 300 ft.). Additionally, the receiver will involuntarily pick up environmental noise and spurious emissions which may jam/block the receiver, making it deaf for any message from the transmitter. To avoid this, a narrow band SAW frontend filter with high selectivity can filter out this unwanted noise.

A local oscillator (stabilized e.g. by a SAW resonator like the transmitter oscillator) generates an LO frequency, typically 500 kHz or 10.7 MHz below transmission frequency. The filtered RF signal from the antenna will now be mixed down in a mixer with this LO frequency to an intermediate frequency (IF), which can be decoded by decoder ICs and microcontrollers.
Principles of a superheterodyne receiver

IF = Signal Frequency - LO Frequency
IF = 10.7MHz and 500kHz
How to read the filter curve of a frontend filter: Quarz substrate

- $a_{\text{max, rel}} = 4.2 \, \text{dB}$
- $a_{\text{max, rel}} = 0 \, \text{dB}$

Characteristics

Reference temperature: $T_A = 25 \, \text{°C}$

Terminating source impedance: $Z_S = 50 \, \Omega$

Terminating load impedance: $Z_C = 50 \, \Omega$

3 dB bandwidth at room temp: 868.78 MHz - 868.00 MHz = 7.8 kHz

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>min</th>
<th>typ</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency $f_c$</td>
<td>—</td>
<td>868.50</td>
<td>—</td>
</tr>
<tr>
<td>Minimum insertion attenuation $a_{\text{min}}$</td>
<td>—</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Pass band (relative to $a_{\text{max}}$)</td>
<td>—</td>
<td>1.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Relative attenuation (relative to $a_{\text{max}}$)</td>
<td>—</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Impedance for pass band matching</td>
<td>—</td>
<td>261 ± 2.20</td>
<td>—</td>
</tr>
<tr>
<td>Frequency inversion point</td>
<td>$T_0$</td>
<td>15</td>
<td>—</td>
</tr>
</tbody>
</table>

1) Temperature dependence of $f_c$: $f_c(T_A) = f_c(T_0)(1 + T_0 / T_A - T_0^2)$
How to read the filter curve of a frontend filter: Lithium tantalate substrate

- $a_{\text{max, ref}} = -6$ dB
- $a_{\text{max, rel}} = 0$ dB
- max. 2.5 dB
- max. 6.0 dB

2.5 dB bandwidth over temperature: 870.00 MHz - 868.00 MHz - 2.00 MHz

- Center frequency $\nu_c$:
  - min.
  - typ. 869.00 MHz
  - max.

- Maximum insertion attenuation $\alpha_{\text{max}}$:
  - 868.00 ... 870.00 MHz
  - min.
  - typ. 4.0 dB
  - max. 6.0 dB

- Amplitude ripple $\Delta \alpha$:
  - 868.00 ... 870.00 MHz
  - min.
  - typ. 1.5 dB
  - max. 2.5 dB

- Relative attenuation (relative to $\alpha_{\text{max}}$) $\alpha_{\text{ref}}$:
  - 868.00 ... 866.00 MHz
  - 868.00 ... 885.00 MHz
  - 868.00 ... 888.00 MHz
  - 868.00 ... 1000.00 MHz
  - min.
  - typ. 40.0 dB
  - max.

- Temperature coefficient of frequency $\tau_{f_{\text{c}}}$
  - min.
  - typ. -30 ppm/K

Characteristics

- Operating temperature range:
  $T = -10 \ldots 60^\circ\text{C}$
- Terminating source impedance $Z_s = 50\ \Omega$
- Terminating load impedance $Z_L = 50\ \Omega$

EPCOS

SAW CE AE PM 2005
Temperature dependence of a quartz filter

Characteristics

| Reference temperature: $T_A = 25^\circ C$ |
| Terminating source impedance: $Z_S = 50 \Omega$ and matching network |
| Terminating load impedance: $Z_L = 50 \Omega$ and matching network |

<table>
<thead>
<tr>
<th>Center frequency ($f_C$) (center frequency between 3 dB points)</th>
<th>min.</th>
<th>typ.</th>
<th>max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_C$</td>
<td>668,39</td>
<td>668,39</td>
<td>MHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minimum insertion attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{\text{min}}$</td>
</tr>
<tr>
<td>$868,00 \ldots 868,78$ MHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pass band (relative to $\alpha_{\text{min}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$868,00 \ldots 868,78$ MHz</td>
</tr>
<tr>
<td>$867,90 \ldots 868,88$ MHz</td>
</tr>
</tbody>
</table>

Characteristics

| Reference temperature: $T_A = -45 \ldots 90^\circ C$ |
| Terminating source impedance: $Z_S = 50 \Omega$ and matching network |
| Terminating load impedance: $Z_L = 50 \Omega$ and matching network |

<table>
<thead>
<tr>
<th>Center frequency ($f_C$) (center frequency between 3 dB points)</th>
<th>min.</th>
<th>typ.</th>
<th>max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_C$</td>
<td>668,39</td>
<td>668,39</td>
<td>MHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minimum insertion attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{\text{min}}$</td>
</tr>
<tr>
<td>$868,00 \ldots 868,78$ MHz</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Pass band (relative to $\alpha_{\text{min}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$868,00 \ldots 868,69$ MHz</td>
</tr>
<tr>
<td>$867,90 \ldots 868,70$ MHz</td>
</tr>
</tbody>
</table>

\[ f_C(T_A) = f_C(T_0) \left(1 + TC(f)(T_A - T_0)^2\right) \]
Temperature coefficient of quartz substrate

- Quartz has a parabolic temperature behaviour: $\text{TC}_f = -0.03 \text{ ppm/K}^2$
- The inversion point $T_0$ can be adjusted by choice of the appropriate cut and metallisation height and ratio (usually: 25 °C)
- Every deviation from $T_0$ leads to a down shift of the center frequency

$$f_C(T_A) = f_C(T_0) (1 + \text{TC}_f(T_A - T_0)^2)$$
Quartz has a square temperature characteristic and a negative temperature coefficient of -0.03. Therefore a change in temperature always results in a drop of center frequency. For worst case calculation, this frequency shift due to temperature needs to be added to the manufacturing tolerances (=m.tolerance, typ. +-75 kHz). The total tolerance over temperature of a SAW resonator needs to be calculated: 

$$\Delta f = (2 \times m.\text{tolerance}) + (\text{frequency shift at max/min temperature})$$

(see example!) In the datasheet EPCOS only specifies the manufacturing tolerance (=m.tolerance).
How to calculate total tolerance of a SAW resonator and filter

Transmitters and receivers may have different temperatures (e.g. transmitter in the car key: room temperature. Receiver in the car in winter: -20 °C). Therefore for worst case calculation, the minimum bandwidth of the filter has to take into account both the resonator's total tolerance over temperature and filter's frequency shift over temperature.

The left drawing shows the frequency shift over temperature of a filter and the resulting usable (or guaranteed) bandwidth. In order to work properly, the resonator's total tolerance over temperature in the right drawing needs to be inside the filter's guaranteed bandwidth over temperature everywhere.
Worldwide frequency regulations

Additionally worldwide: 2.4 GHz

USA/Canada
260 to 470MHz (typ. 315 MHz)
902 to 928MHz (typ. 915 MHz)

902 to 928MHz (typ. 915 MHz)

UK
418.00 MHz

Europe
433.92 MHz

863 to 865 MHz (continuous wave)
868 to 870 MHz (duty cycled)

Korea
311 MHz
447.77 MHz

Japan
< 322 MHz

China
Security systems for automobile,
precious goods, incl. RKE, TPMS:
430 to 432 MHz
315 to 316 MHz

Now (from 05/2004): also
“typical European” systems at 433.92 MHz allowed

Remote control system for House installations:
470 to 566 MHz
606 to 798 MHz

South Africa
403.55
433.92 MHz

Australia
303.825 MHz
433.92 MHz
European duty cycled SRD band 868 to 870 MHz

- **Filter**: B3568 (LB98A)
  - Package: DCC6C (3x3 mm²)
  - fc: 868.6 MHz / BW: 1.2 MHz
- **Filter**: B3568 (L931E)
  - Package: QCC8C (5x5 mm²)
  - fc: 868.6 MHz / BW: 1.2 MHz
- **Filter**: B3573 (LA50A)
  - Package: QCC8C (5x5 mm²)
  - fc: 868.3 MHz / BW: 600 kHz
- **Filter**: B3570 (LA70A)
  - Package: QCC8C (5x5 mm²)
  - fc: 868.3 MHz / BW: 200 kHz
- **Resonator**: R2709 (R378C)
  - Package: QCC8C (5x5 mm²)
  - fc: 868.3 MHz ± 200 kHz
- **Filter**: B3572 (LB24A)
  - Package: QCC8C (5x5 mm²)
  - fc: 868.95 MHz / BW: 500 kHz
- **Filter**: B3574 (LD25)
  - Package: QCC8C (5x5 mm²)
  - fc: 868.3 MHz / BW: 200 kHz

**Power: 25 mW**
- Duty Cycle: <1%
- 868.0 868.3 868.6 868.7 868.95 869.2

**Power: 25 mW**
- Duty Cycle: <0.1%
- 869.7 869.85 870.0 MHz

**5 mW**
- Duty Cycle: 10–100%
- 868.3 868.6 868.7 868.95 869.2 869.7 869.85

**BW** = guaranteed bandwidth of passband at -40...+85 °C

- **SAW CE AE PM**
- 2005
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European SRD bands 433.92 MHz and 869 MHz: Most important sources of interference

433.05 MHz - Continuous wave
433.92 MHz - Duty cycled
434.79 MHz - Duty cycled

410 to 430 MHz - TETRA
434.1 MHz - Italy: police radio
>450 MHz - TV (C net: not used anymore)

863 to 865 MHz - Continuous wave applications
860 MHz - TV channel 68 (curr. not used)

868.0 MHz - Duty cycled
869.0 MHz - Duty cycled
870.0 MHz - Duty cycled

>880 MHz - GSM

430 to 440 MHz, 433.375 MHz - Spain, UK, US: Amateur radio repeater stations

870 to 876 MHz - Allocation for TETRA (curr. not used)
863 to 875 MHz - Continuous wave applications (RF headphones)
Laser marking on ceramic SMD packages

Company

Part number

Pin 1

Date code
site of prod./year/month/day code
Comparison of frontend filters

Wide band, narrow band, ultra-narrow band
## Product portfolio: Frontend filters

<table>
<thead>
<tr>
<th>Type</th>
<th>Bandwidth</th>
<th>Substrate</th>
<th>Passivation</th>
<th>Input/output imp.</th>
<th>Temperature shift</th>
<th>Package</th>
<th>Insertion loss</th>
<th>Nearby selectivity</th>
<th>Overall selectivity</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide band</td>
<td></td>
<td>Lithium tantalate</td>
<td>ELPAS</td>
<td>50 Ohms matched</td>
<td>-- high</td>
<td>DCC6C, 3.0x3.0</td>
<td>++ especially good</td>
<td>- low</td>
<td>+ very good</td>
<td>mainly used for <strong>non-</strong> automotive applications; easy and cheap to match -&gt; perfect for low-cost applications</td>
</tr>
<tr>
<td>Narrow band</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>QCC8B, 3.8x3.8mm</td>
<td>+ best on the market</td>
<td>+ high</td>
<td>+ very good</td>
<td>necessary for automotive applications in Europe, ++ well suited for TPMS</td>
</tr>
<tr>
<td>Ultra-narrow band</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>QCC8C, 5x5mm</td>
<td>+ high</td>
<td>++ very high</td>
<td>++ very good</td>
<td>too narrow for SAW res. -- needs ext. coupling coil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>QCC8C, 5x5mm</td>
<td>++ low</td>
<td>++ low</td>
<td>++ low</td>
<td></td>
</tr>
</tbody>
</table>

**Remark**
- Lithium tantalate: **ELPAS50** Ohms matched – high
- Quartz: **PROTEC**, 3.8x3.8mm
- **QCC8B**, 3.0x3.0mm
- **QCC8C**, 3.8x3.8mm
- **QCC8C**, 5x5mm
- **QCC8C**, 5x5mm
- + best on the market
- + high
- + very good
- necessary for automotive applications in Europe, ++ well suited for TPMS
- ++ very high
- ++ very good
- too narrow for SAW res.
- needs ext. coupling coil
Product portfolio: 3 resonator platforms

- **Frequencies (MHz)**: All standard frequencies, like 315, 390, 418, 433, 868
- **Passivation**: ELPAS
- **Tolerance**: +/- 100 kHz, +/- 75 kHz and +/- 50 kHz
- **Architecture**: 1 port and 2 port
- **Package**: 3x3x1.1 m³ (DCC6C), 3.5x5x1.4mm³ (QCC4C), 5x5x1.3mm³ (QCC8C)
- **Technology**: Metal ceramic SMD (DCC6C), Metal ceramic SMD (QCC4A), Metal ceramic SMD (QCC8C)

---

**DCC6C**
- 3x3mm², 6 pins

**QCC4C**
- 3.5x5mm², 4 pins

**QCC8C**
- 5x5mm², 8 pins

Replacement for TO39
# Product portfolio: GPS filter for automotive applications

<table>
<thead>
<tr>
<th>Package</th>
<th>Temperature range</th>
<th>Input/output imp.</th>
<th>Features</th>
<th>Qualification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DCC6C</strong></td>
<td>-40 to 105 °C specified</td>
<td>50 Ohm / 50 Ohm</td>
<td>Low insertion loss</td>
<td>AEC/Q-200 (in progress)</td>
</tr>
<tr>
<td><strong>QCC8D</strong></td>
<td>-40 to 105 °C specified</td>
<td>50 Ohm / 50 Ohm</td>
<td>High selectivity at AMPS and GSM</td>
<td>AEC/Q-200 (in progress)</td>
</tr>
</tbody>
</table>

B3520

- Package: DCC6C (3x3mm²)
- Temperature range: -40 to 105 °C specified
- Input/output imp. 50 Ohm / 50 Ohm
- Features: Low insertion loss
- Qualification: AEC/Q-200 (in progress)

B4059/B3521

- Package: QCC8D (3x3mm²)
- Temperature range: -40 to 105 °C specified
- Input/output imp. 50 Ohm / 50 Ohm
- Features: High selectivity at AMPS and GSM
- Qualification: AEC/Q-200 (in progress)

B4060

- Package: QCC8D (3x3mm²)
- Temperature range: -40 to 105 °C specified
- Input/output imp. 50 Ohm / 50 Ohm
- Features: High power durability
- Qualification: AEC/Q-200 (in progress)
### All EPCOS divisions at a glance

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<thead>
<tr>
<th>Capacitors</th>
<th>Film Capacitors</th>
<th>Inductors</th>
</tr>
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<tbody>
<tr>
<td><img src="image1" alt="Capacitors" /></td>
<td><img src="image2" alt="Film Capacitors" /></td>
<td><img src="image3" alt="Inductors" /></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Ceramic Components</th>
<th>SAW Components</th>
<th>Ferrites</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4" alt="Ceramic Components" /></td>
<td><img src="image5" alt="SAW Components" /></td>
<td><img src="image6" alt="Ferrites" /></td>
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</tbody>
</table>
### Products by divisions

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<tr>
<th>Capacitors</th>
<th>Film Capacitors</th>
<th>Inductors</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Aluminum electrolytic capacitors</td>
<td>• Film capacitors</td>
<td>• Transformers &amp; chokes</td>
</tr>
<tr>
<td>• Tantalum capacitors</td>
<td>• Power capacitors</td>
<td>• RF chokes</td>
</tr>
<tr>
<td>• Polymer capacitors</td>
<td></td>
<td>• EMC filters</td>
</tr>
<tr>
<td>• Ultracapacitors</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ceramic Components</strong></td>
<td><strong>SAW Components</strong></td>
<td><strong>Ferrites</strong></td>
</tr>
<tr>
<td>• Sensors &amp; sensor elements</td>
<td>• Microwave ceramics &amp; modules</td>
<td>• Ferrites</td>
</tr>
<tr>
<td>• Ceramic semiconductors</td>
<td>• Crystals for acoustic &amp; optical components</td>
<td>• Accessories</td>
</tr>
<tr>
<td>• Multilayer ceramic technology</td>
<td>• Components for</td>
<td></td>
</tr>
<tr>
<td>• Piezo technology</td>
<td>- Mobile communications</td>
<td></td>
</tr>
<tr>
<td>• Surge arresters</td>
<td>- Multimedia applications</td>
<td></td>
</tr>
<tr>
<td>• Switching spark gaps</td>
<td>- Consumer electronics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Automotive electronics</td>
<td></td>
</tr>
</tbody>
</table>

**EPCOS Group**
Key components for future applications

Information & communications

Automotive

Consumer

Industrial

EPCOS Group
<table>
<thead>
<tr>
<th>Abbreviations</th>
<th>Description</th>
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</thead>
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<td>SAW</td>
<td>Surface Acoustic Wave</td>
</tr>
<tr>
<td>RKE</td>
<td>Remote Keyless Entry</td>
</tr>
<tr>
<td>PLL</td>
<td>Phase Locked Loop</td>
</tr>
<tr>
<td>ASK</td>
<td>Amplitude Shifted Keying</td>
</tr>
<tr>
<td>FSK</td>
<td>Frequency Shifted Keying</td>
</tr>
<tr>
<td>IDT</td>
<td>Interdigital Transducer</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>OOK</td>
<td>On/Off Keying = Amplitude Modulation</td>
</tr>
<tr>
<td>LO</td>
<td>Local Oscillator</td>
</tr>
<tr>
<td>IF</td>
<td>Intermediate Frequency, achieved by superposition of two slightly different oscillators</td>
</tr>
<tr>
<td>LNA</td>
<td>Low Noise Amplifier</td>
</tr>
<tr>
<td>SRD</td>
<td>Short Range Device</td>
</tr>
<tr>
<td>LT</td>
<td>Lithium Tantalate (LiTaO₃)</td>
</tr>
<tr>
<td>LN</td>
<td>Lithium Niobate (LiNbO₃)</td>
</tr>
<tr>
<td>CW</td>
<td>Continuous Wave</td>
</tr>
<tr>
<td>TX</td>
<td>Transmitter</td>
</tr>
<tr>
<td>RX</td>
<td>Receiver</td>
</tr>
<tr>
<td>Duty</td>
<td>Cycle Ratio between On time and Off time</td>
</tr>
</tbody>
</table>