Application toolkit

EPCOS SAW resonators and frontend filters

info.ae@epcos.com

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

Edition 2005

EPCOS

Applications for SAW resonators and frontend filters

Automotive


Remote keyless entry


Tire pressure monitoring

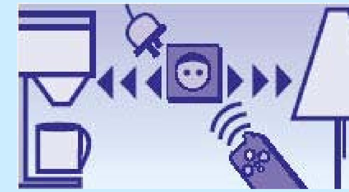
Automotive telematics

Security and access


Fire/burglar alarm


Access control and tagging

Home comfort


Wireless switches


Meter reading

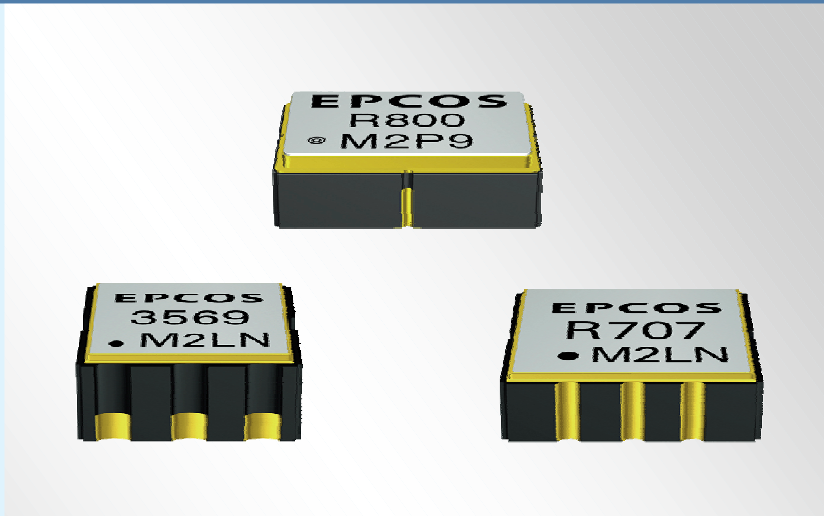

Garage door opener


Wireless audio

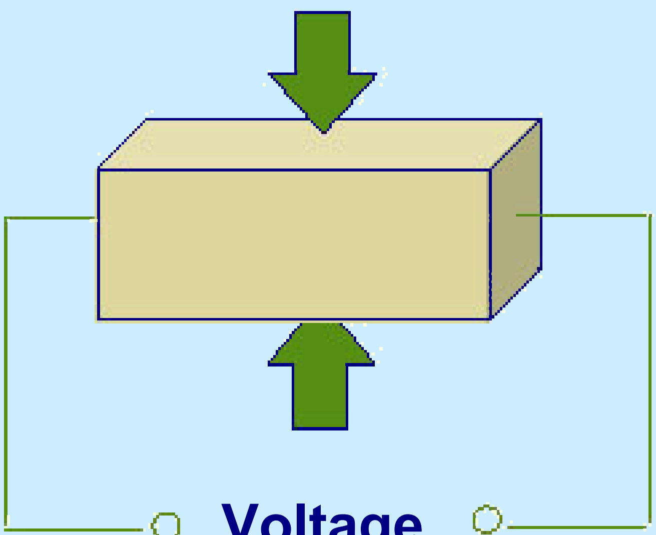
SAW automotive electronics

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



The piezoelectrical effect

describes the transformation

of

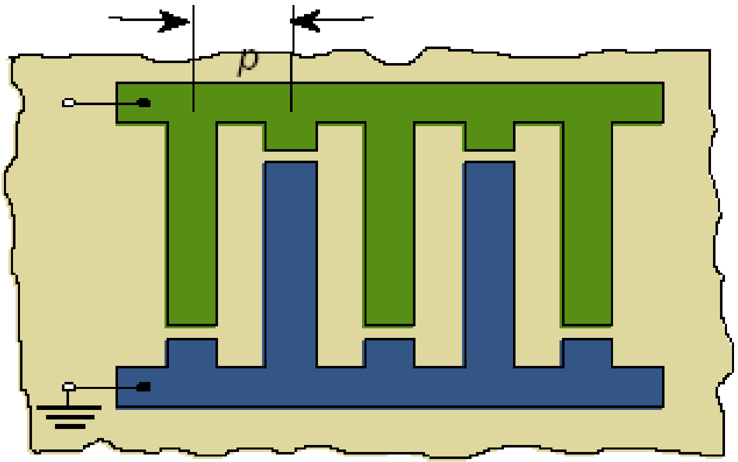
mechanical energy

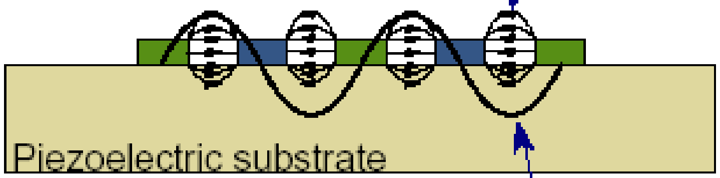
into

electrical energy

and vice versa

InterDigital Transducer (IDT)





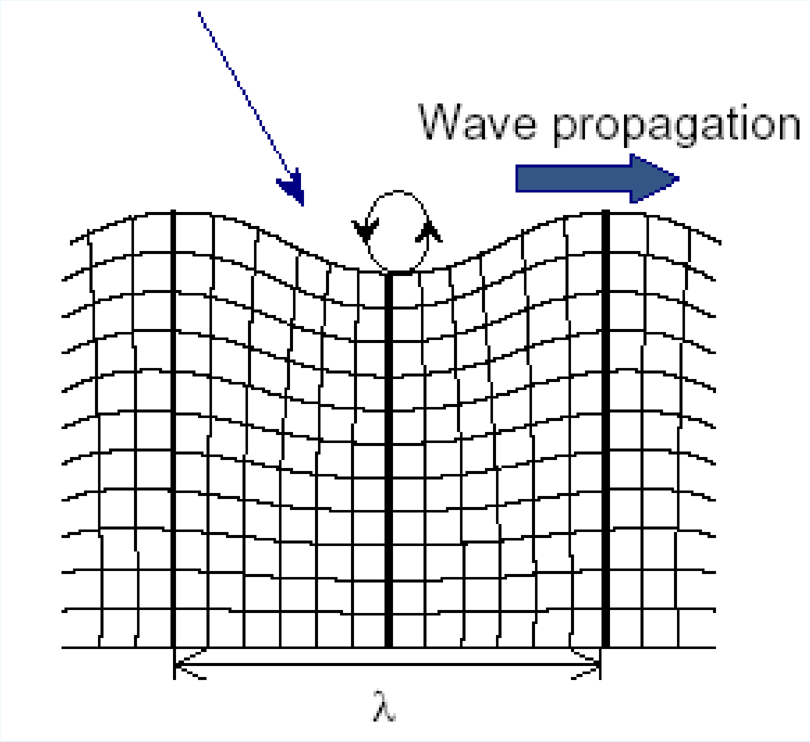
The electromechanical energy conversion via surface acoustic wave (SAW) takes place in the Interdigital Transducer (IDT). Therefore, the IDT acts as:

- Transmitter: reverse piezoelectric effect ➔ electric RF field generates SAW
- Receiver: piezoelectric effect ➔ SAW generates electric RF field

Maximum coupling strength for $l_{SAW} = v_{SAW} / f = 2 \cdot p$

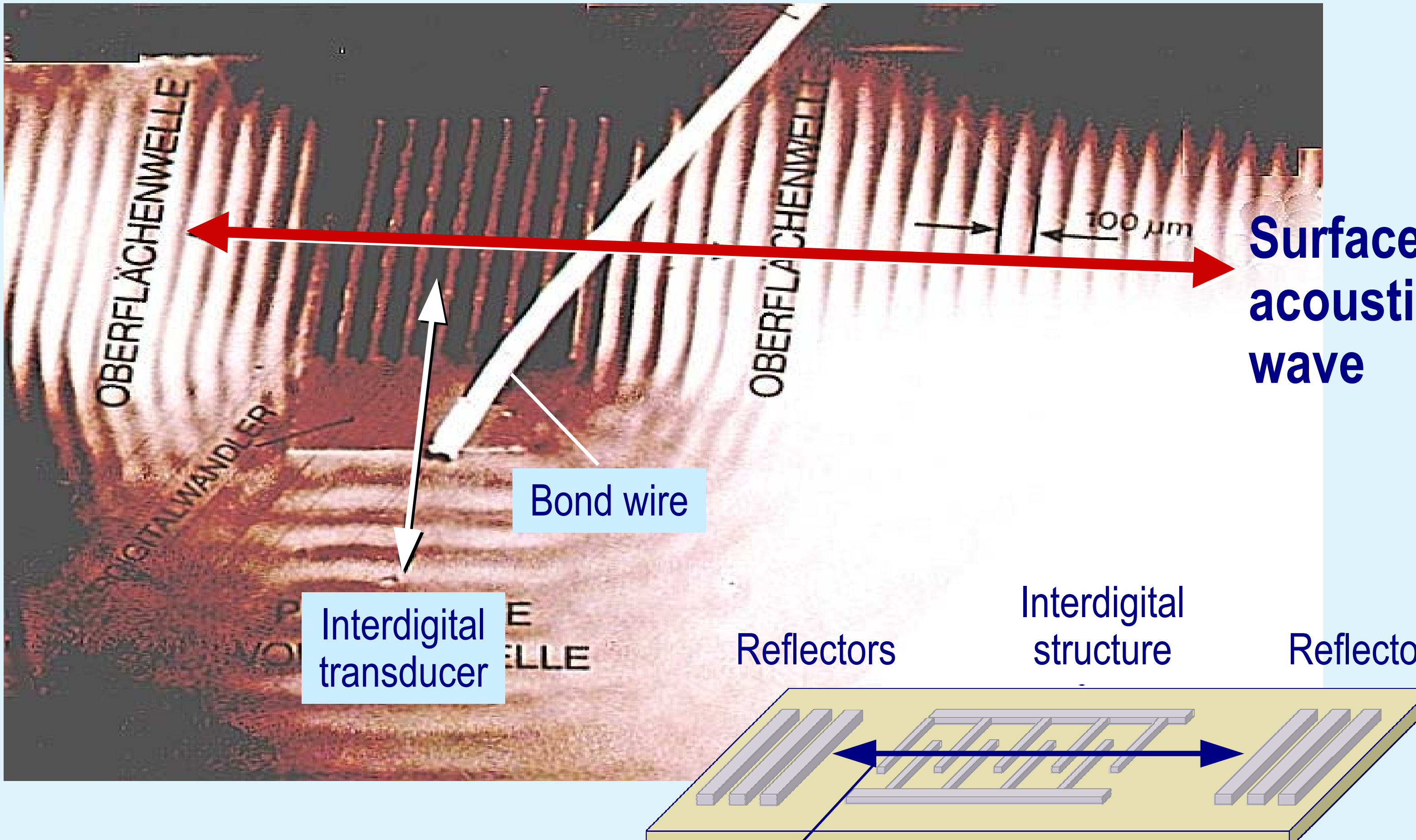
Basics on Surface Acoustic Wave

For Rayleigh waves:
Elliptical particle trajectory



- Depth of penetration about 1 wavelength
- v_{SAW} » 3000 m/s » 10^{-5} v_{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



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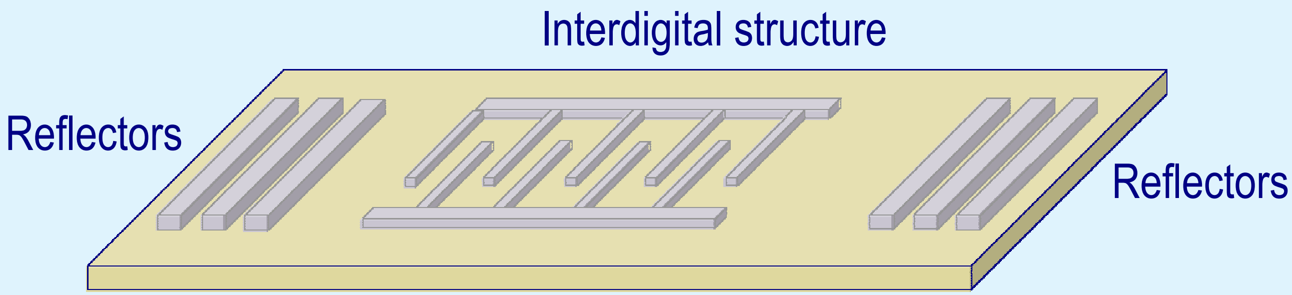
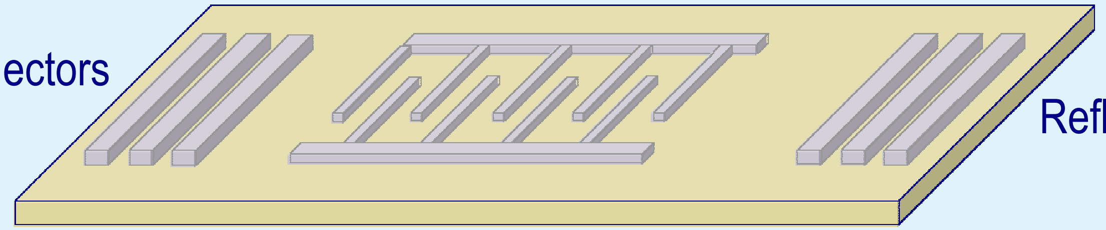
How SAW resonators and frontend filters work



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

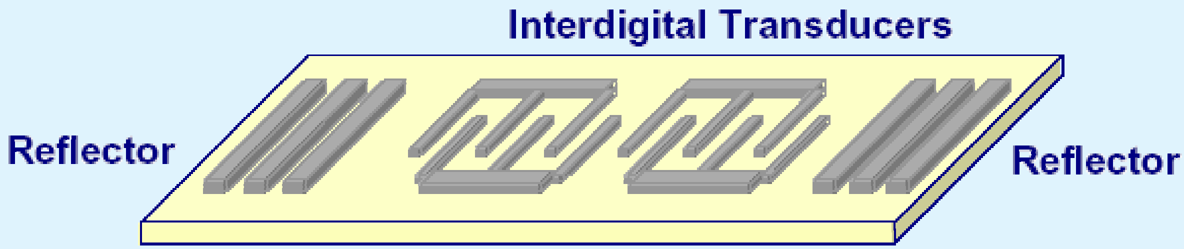


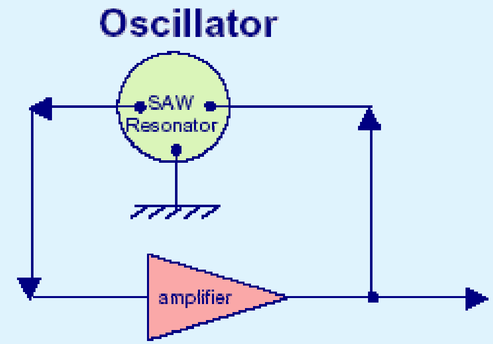
SAW filters are very flexible concerning design: Frequency and bandwidth can be determined by:

- 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 - superimposion of the surface waves. The result is, put simply, the characteristic bandpass response of SAW filters.

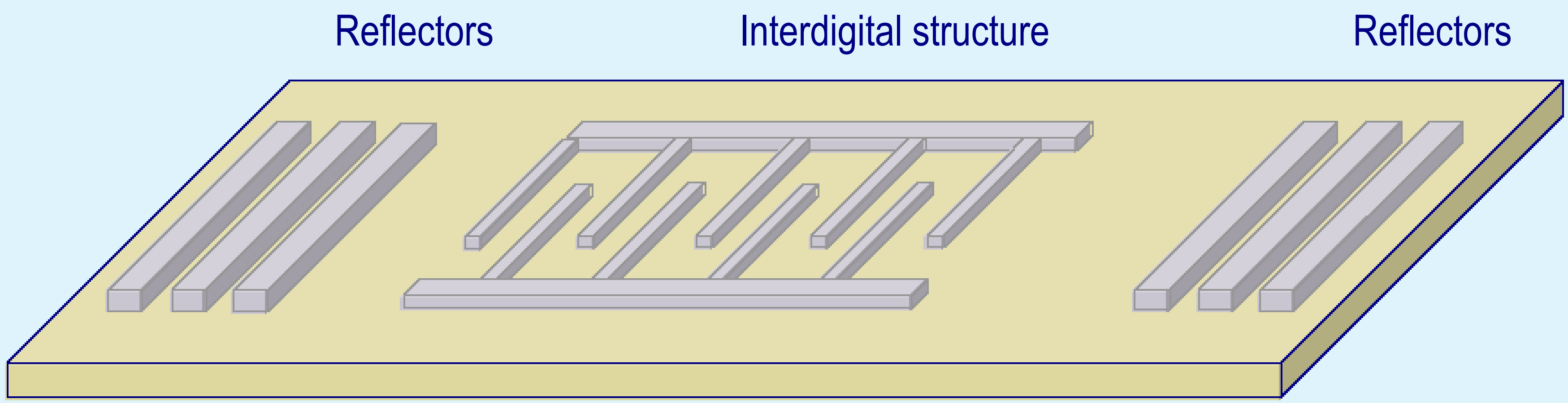
How SAW resonators work

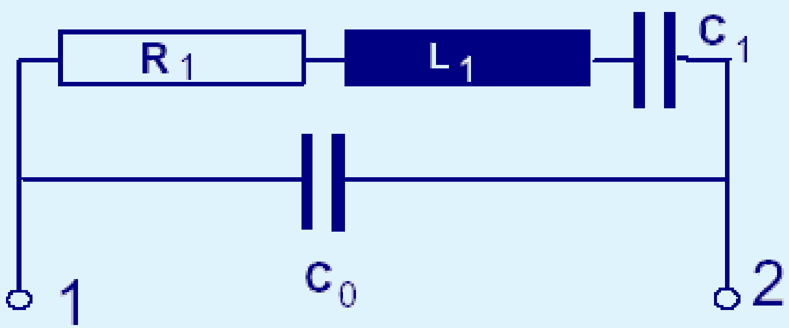




In an oscillator circuit (e.g. Pierce or Colpitts oscillator) the ambient thermal noise is being amplified and fed back through the feedback loop into the oscillator system. A built-in SAW resonator attenuates most of this noise spectrum, only a very narrow frequency band can pass:
If the wave length corresponds to the finger spacing and resonance occurs, there is a constructive - otherwise destructive - superimposion 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





R_1 = motional resistance
L_1 = motional inductance
C_1 = motional capacitance
C_0 = static capacitance

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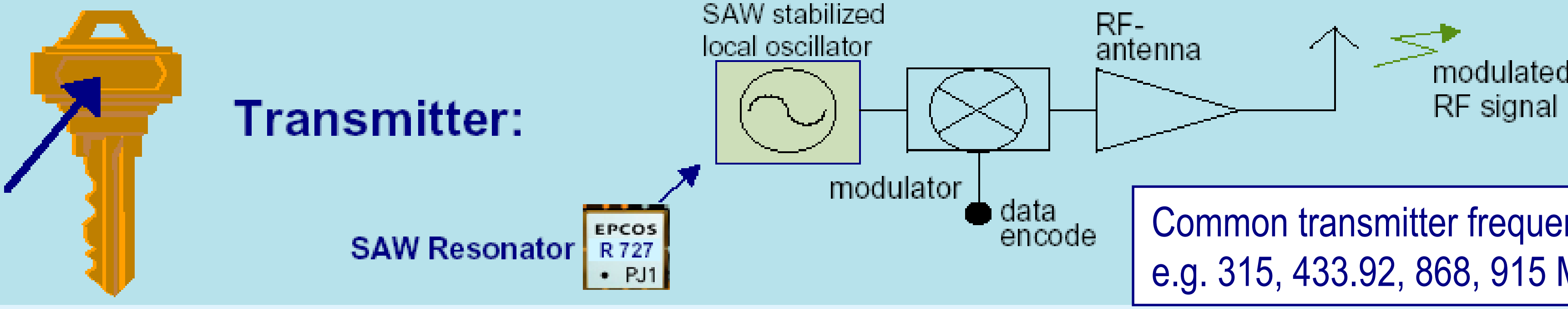
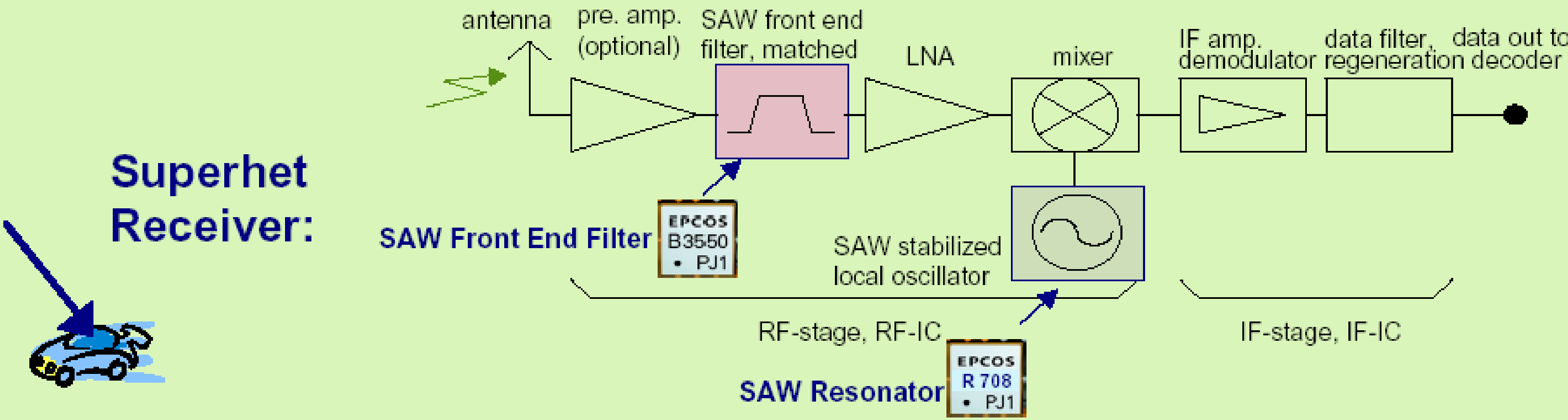
Architecture of a SAW resonator stabilized remote control transmitter



Common transmitter frequencies:
e.g. 315, 433.92, 868, 915 MHz

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.

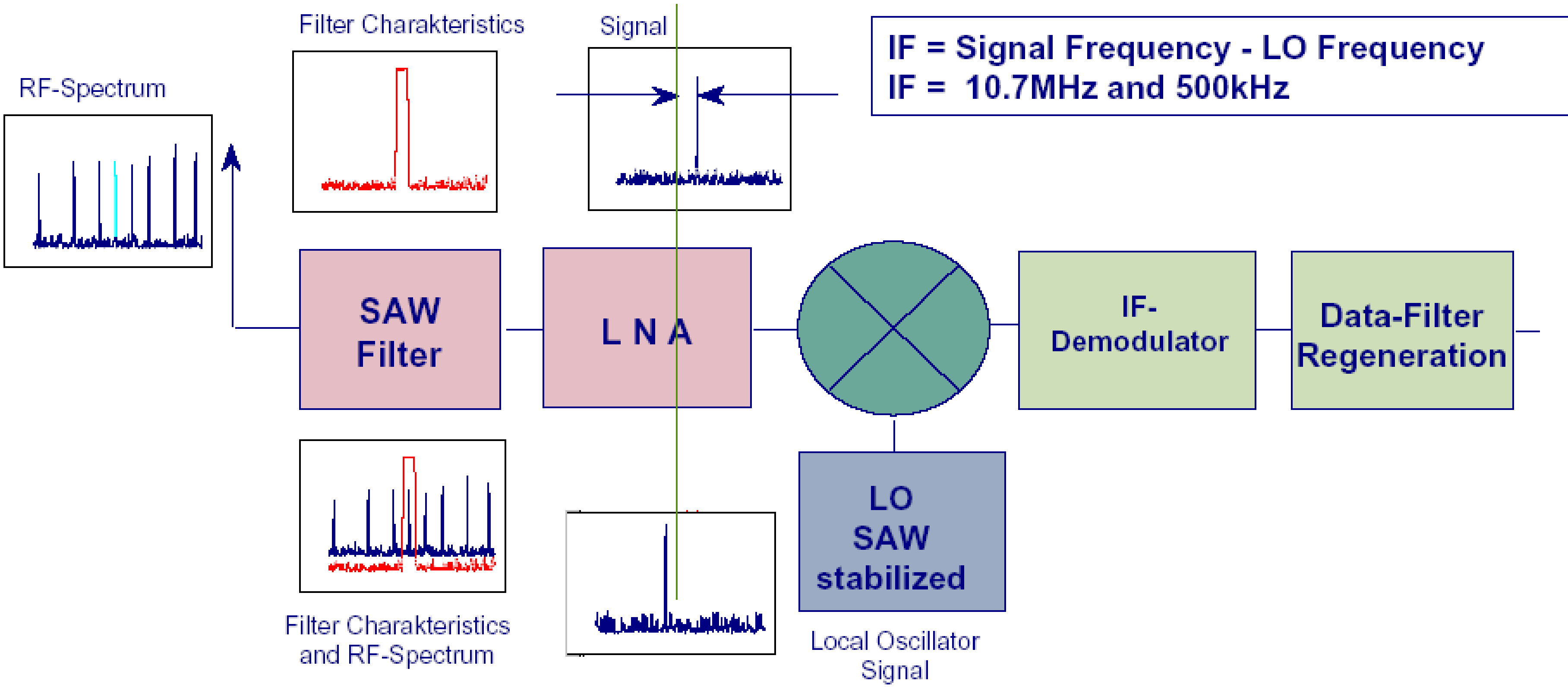
Architecture of a SAW resonator stabilized remote control receiver with SAW frontend filter



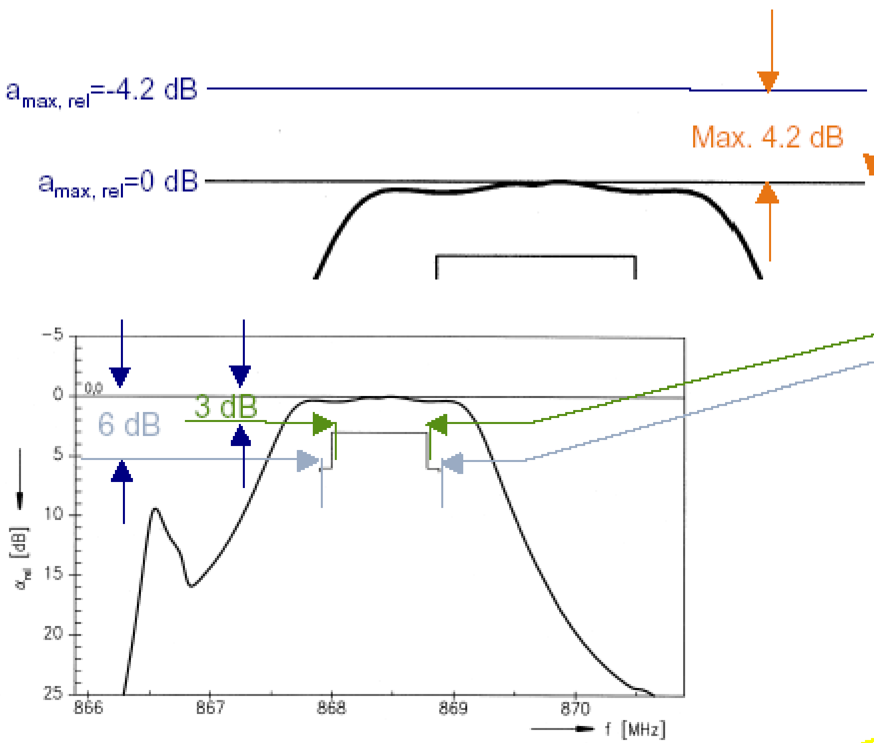
The modulated RF signal (encoded message) sent from the transmitter is received by the antenna of the receiver a few feet away (typically 30 to 300 ft.). Additionally, the receiver will involuntarily pick up environmental noise and spurious emissions which may jam/block the receiver, making it deaf for 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



How to read the filter curve of a frontend filter: Quarz substrate



3 dB bandwidth at room temp= 868.78 MHz-868.00 MHz=780 kHz

Characteristics

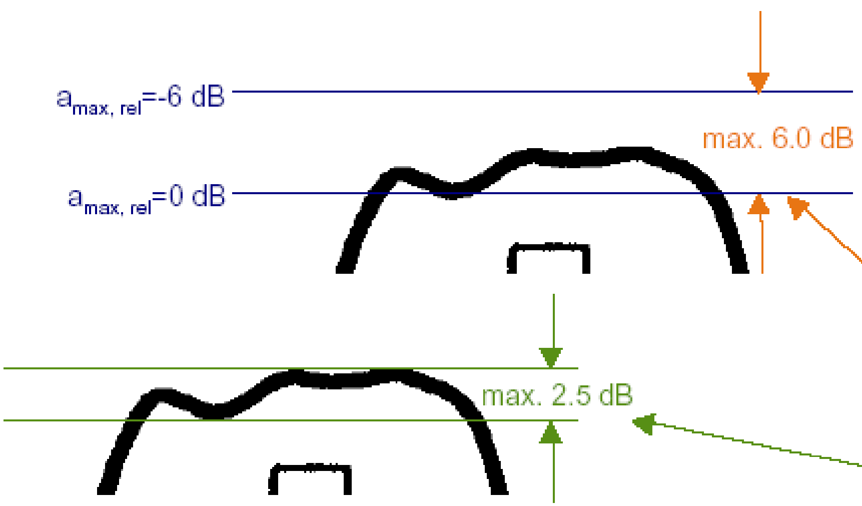
Reference temperature: T_A = 25 °C
Terminating source impedance: Z_S = 50 Ω and matching network
Terminating load impedance: Z_L = 50 Ω and matching network

		min.	typ.	max.	
Center frequency (center frequency between 3 dB points)	f_C	—	868,39	—	MHz
Minimum insertion attenuation	α_{min}				
868,00 ... 868,78 MHz		—	2,7	4,2	dB
Pass band (relative to α_{min})					
868,00 ... 868,78 MHz		—	1,0	3,0	dB
867,90 ... 868,88 MHz		—	1,5	6,0	dB
Relative attenuation (relative to α_{min})	α_{rel}				
10,00 ... 700,00 MHz		50	55	—	dB
700,00 ... 830,00 MHz		35	45	—	dB
830,00 ... 850,00 MHz		32	40	—	dB
850,00 ... 865,20 MHz		25	30	—	dB
871,00 ... 874,50 MHz		11	16	—	dB
874,50 ... 883,00 MHz		22	27	—	dB
883,00 ... 900,00 MHz		30	35	—	dB
900,00 ... 1000,00 MHz		35	40	—	dB
Impedance for pass band matching					
Input: $Z_{IN} = R_{IN} \parallel C_{IN}$		—	216 ll 2,20	—	Ω ll pF
Output: $Z_{OUT} = R_{OUT} \parallel C_{OUT}$		—	222 ll 2,20	—	Ω ll pF
Temperature coefficient of frequency [1]	TC_f	—	-0,03	—	ppm/K²
Frequency inversion point	T_0	15	—	35	°C

[1] Temperature dependance of f_C: $f_C(T_A) = f_C(T_0)(1 + TC_f(T_A - T_0)^2)$

characteristical value for quartz

How to read the filter curve of a frontend filter: Lithium tantalate substrate

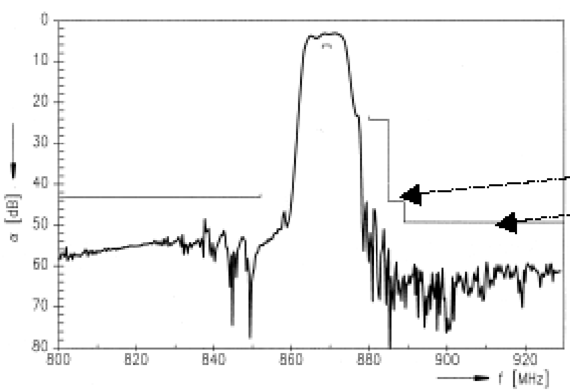


2.5 dB bandwidth over temperature= 870.00 MHz-868.00 MHz=2.00 MHz

Characteristics

Operating temperature range: T = -10 ... 60 °C
Terminating source impedance: Z_S = 50 Ω
Terminating load impedance: Z_L = 50 Ω

		min.	typ.	max.	
Center frequency	f_c	—	869,00	—	MHz
Maximum insertion attenuation	α_{max}				
868,00 ... 870,00 MHz		—	4,0	6,0	dB
Amplitude ripple	$\Delta\alpha$				
868,00 ... 870,00 MHz		—	1,5	2,5	dB
Relative attenuation (relative to α_{max})	α_{rel}				
800,00 ... 852,00 MHz		39,0	44,0	—	dB
880,00 ... 885,00 MHz		20,0	35,0	—	dB
885,00 ... 889,00 MHz		40,0	45,0	—	dB
889,00 ...1000,00 MHz		45,0	50,0	—	dB
Temperature coefficient of frequency	TC_f	—	-30	—	ppm/K



characteristical value for Lithium-Tantalate

Temperature dependence of a quartz filter

Characteristics

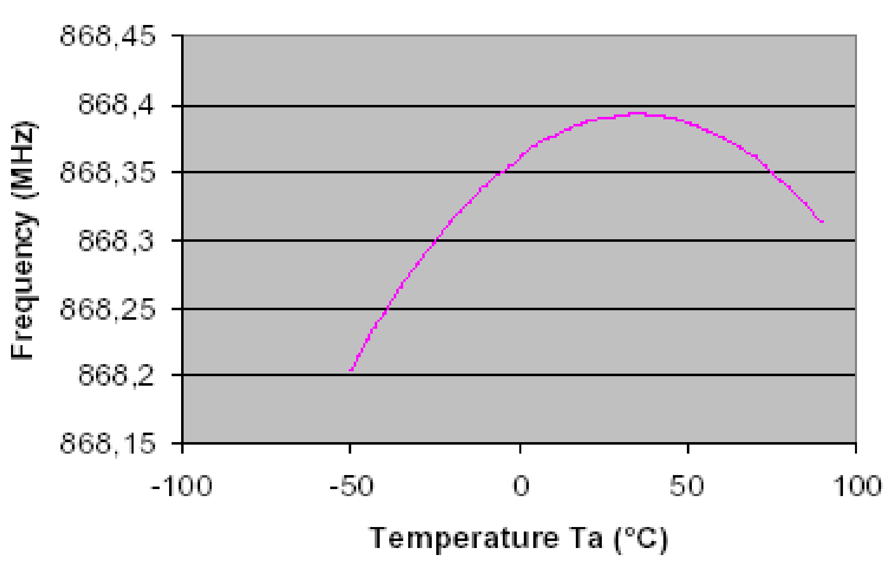
Reference temperature: T_A = 25 °C
Terminating source impedance: Z_S = 50 Ω and matching network
Terminating load impedance: Z_L = 50 Ω and matching network

		min.	typ.	max.	
Center frequency (center frequency between 3 dB points)	f_C	—	868,39	—	MHz
Minimum insertion attenuation	α_{min}				
868,00 ... 868,78 MHz		—	2,7	4,2	dB
Pass band (relative to α_{min})					
868,00 ... 868,78 MHz		—	1,0	3,0	dB
867,90 ... 868,88 MHz		—	1,5	6,0	dB

Characteristics

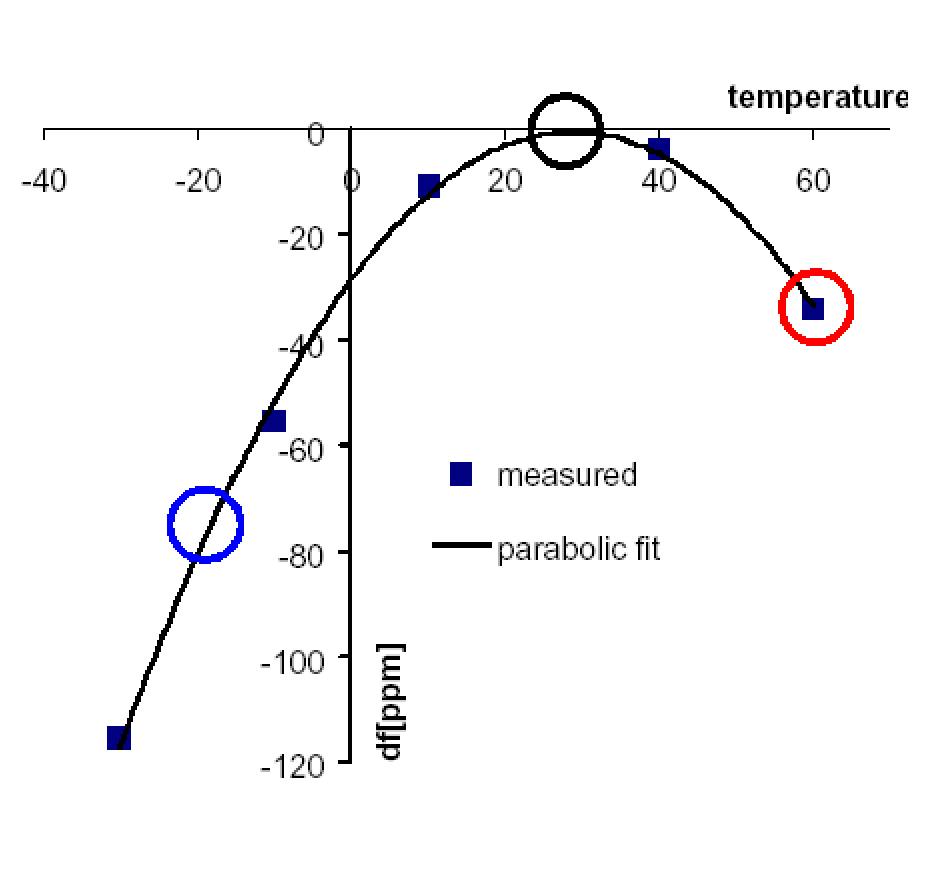
Reference temperature: T_A = -45 ... 90 °C
Terminating source impedance: Z_S = 50 Ω and matching network
Terminating load impedance: Z_L = 50 Ω and matching network

		min.	typ.	max.	
Center frequency (center frequency between 3 dB points)	f_C	—	868,30	—	MHz
Minimum insertion attenuation	α_{min}				
868,00 ... 868,78 MHz		—	2,7	4,7	dB
Pass band (relative to α_{min})					
868,00 ... 868,60 MHz		—	1,0	3,0	dB
867,90 ... 868,70 MHz		—	1,5	6,0	dB



$$f_C(T_A) = f_C(T_0)\,(1 + TC_f(T_A - T_0)^2)$$

Temperature coefficient of quartz substrate

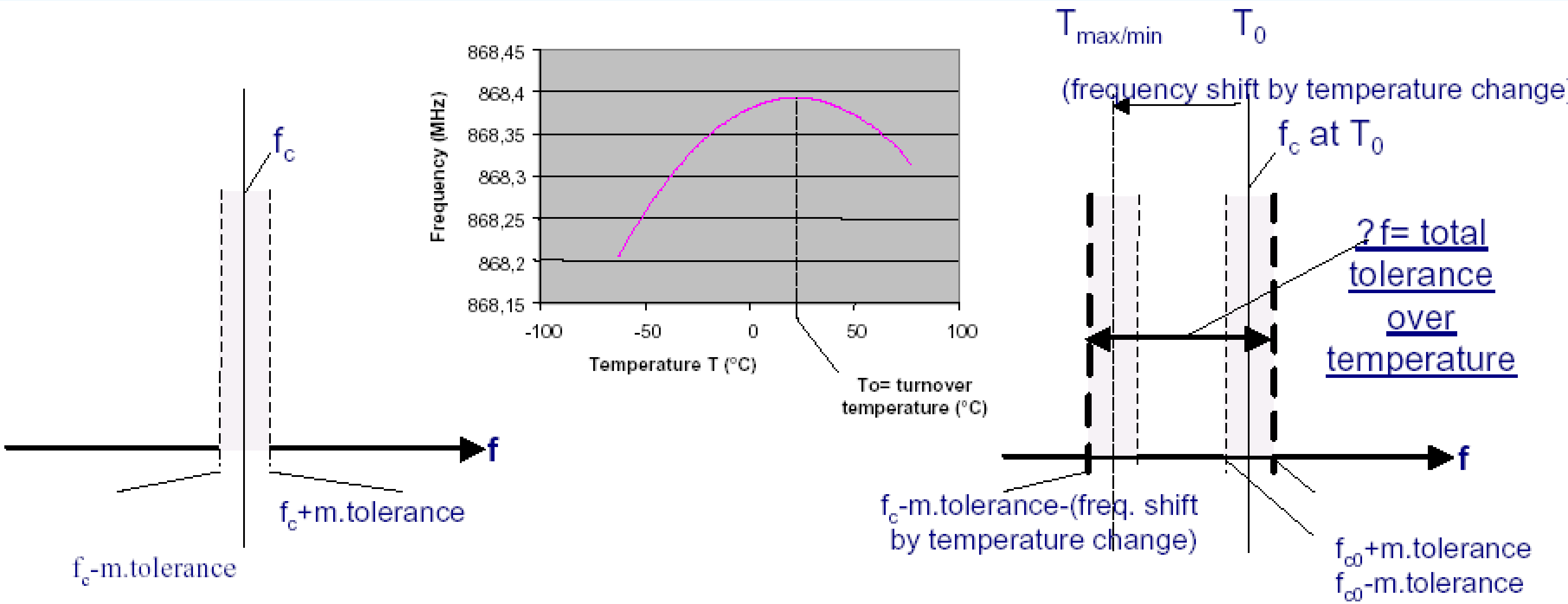


- Quartz has a parabolic temperature behaviour: TC_f = -0.03 ppm/K^2
- The inversion point T_0 can be adjusted by choice of the appropiate cut and metallisation height and ratio (usually: 25 °C)
- Every deviation from T0 leads to a down shift of the center frequency

$$f_C(T_A) = f_C(T_0)\,(1 + TC_f(T_A - T_0)^2)$$

EPCOS

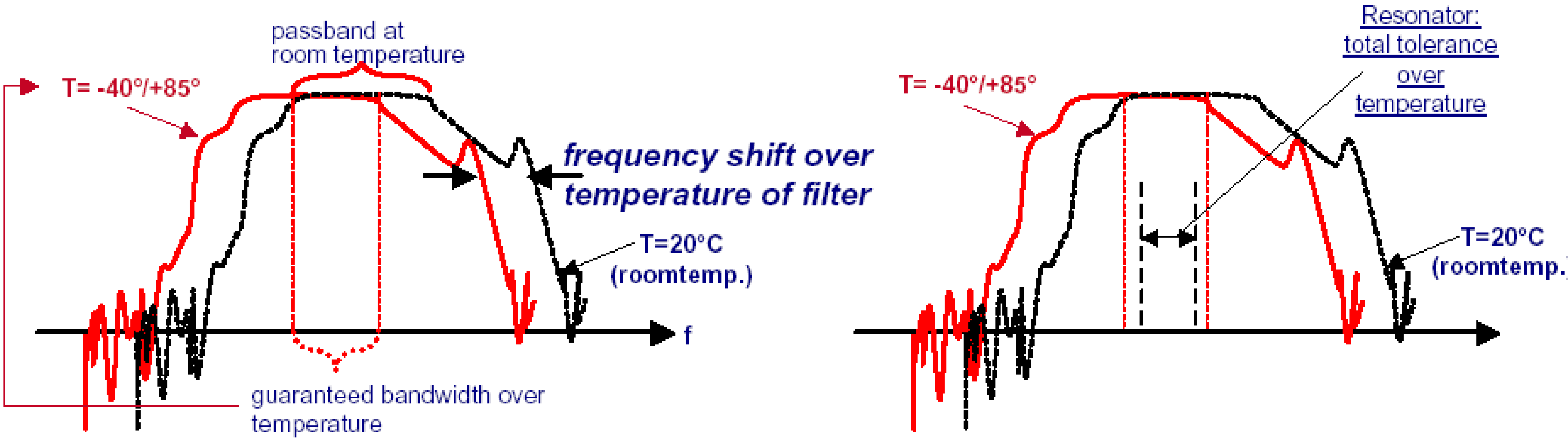
How to calculate the total tolerance over temperature of a SAW resonator



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: ?f = (2 x m.tolerance) + (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 <u>resonator's total tolerance over temperature</u> 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 <u>resonator's total tolerance over temperature</u> in the right drawing needs to be inside the filter's guaranteed bandwidth over temperature everywhere.

Worldwide frequency regulations

UK
~~418.00~~ MHz

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

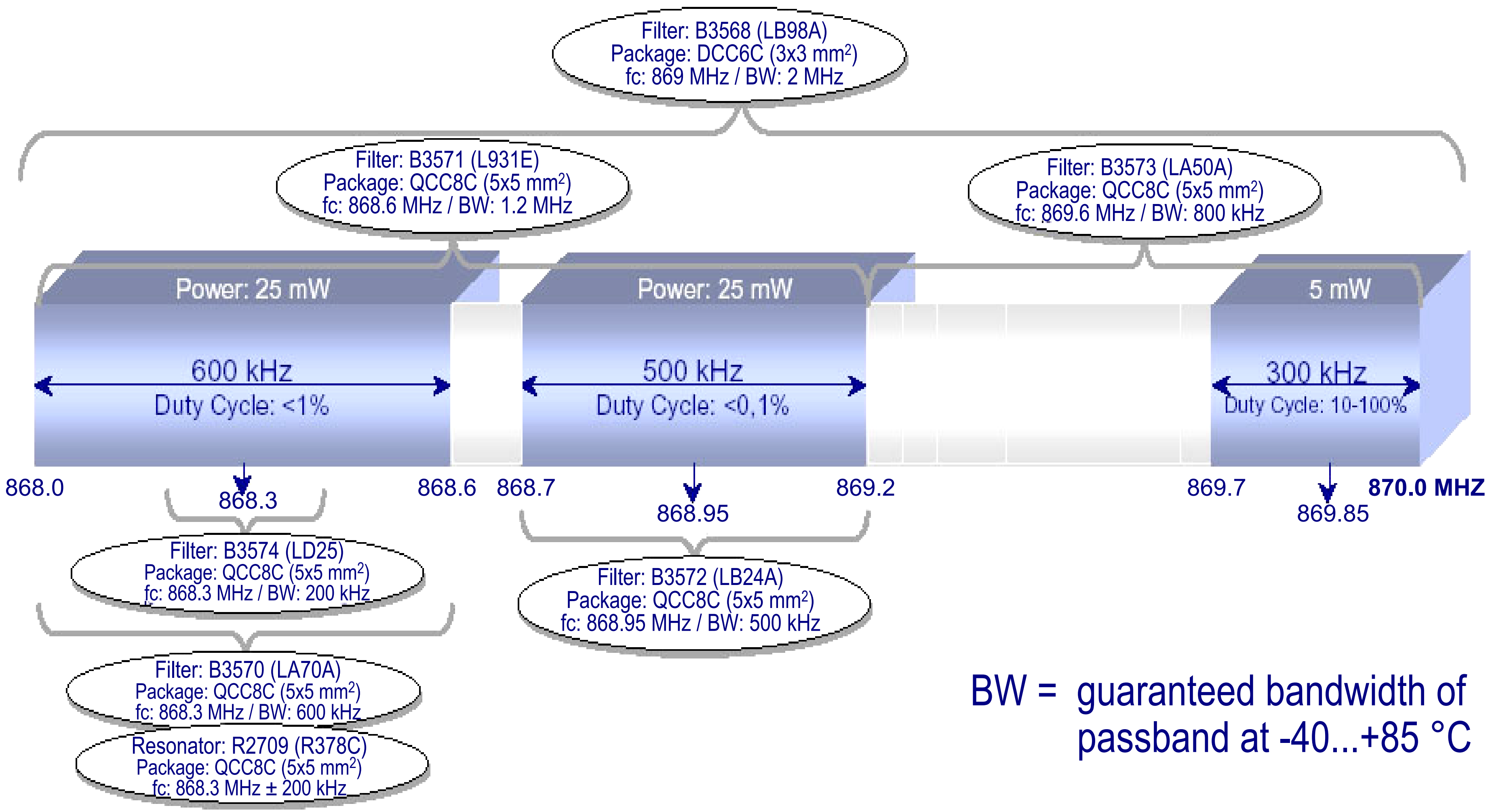
China
Security systems for automobile, precious goods,incl. RKE, TPMS:
430 to 432 MHz
315 to 316 MHz
Now (from 05/2004): also "typical European" systems at 433.92 MHz allowed
Remote control system for House installations:
470 to 566 MHz
606 to 798 MHz

South Africa
403.55
433.92 MHz

Australia
303.825 MHz
433.92 MHz

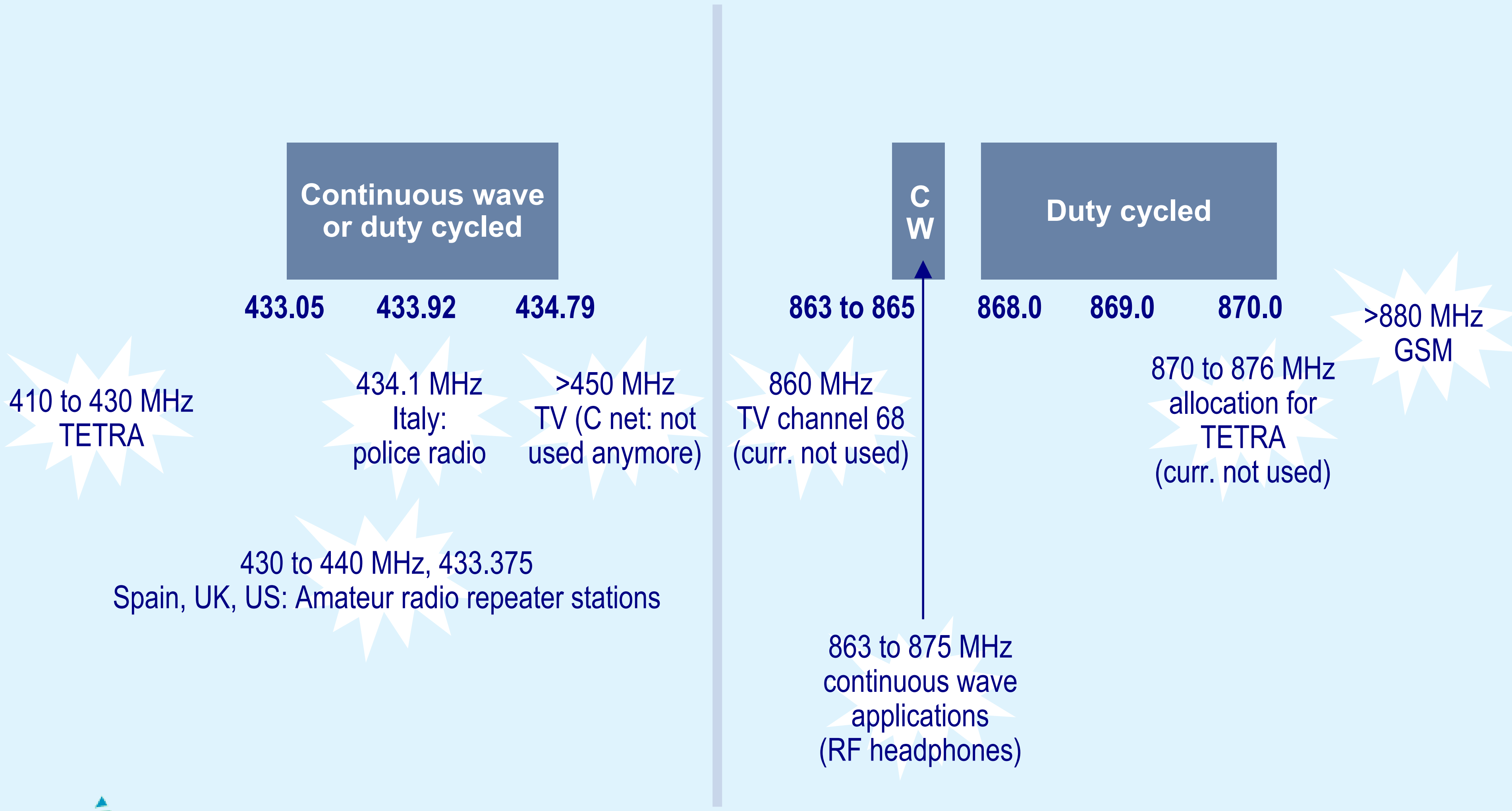
Additionally worldwide: 2.4 GHz

European duty cycled SRD band 868 to 870 MHz

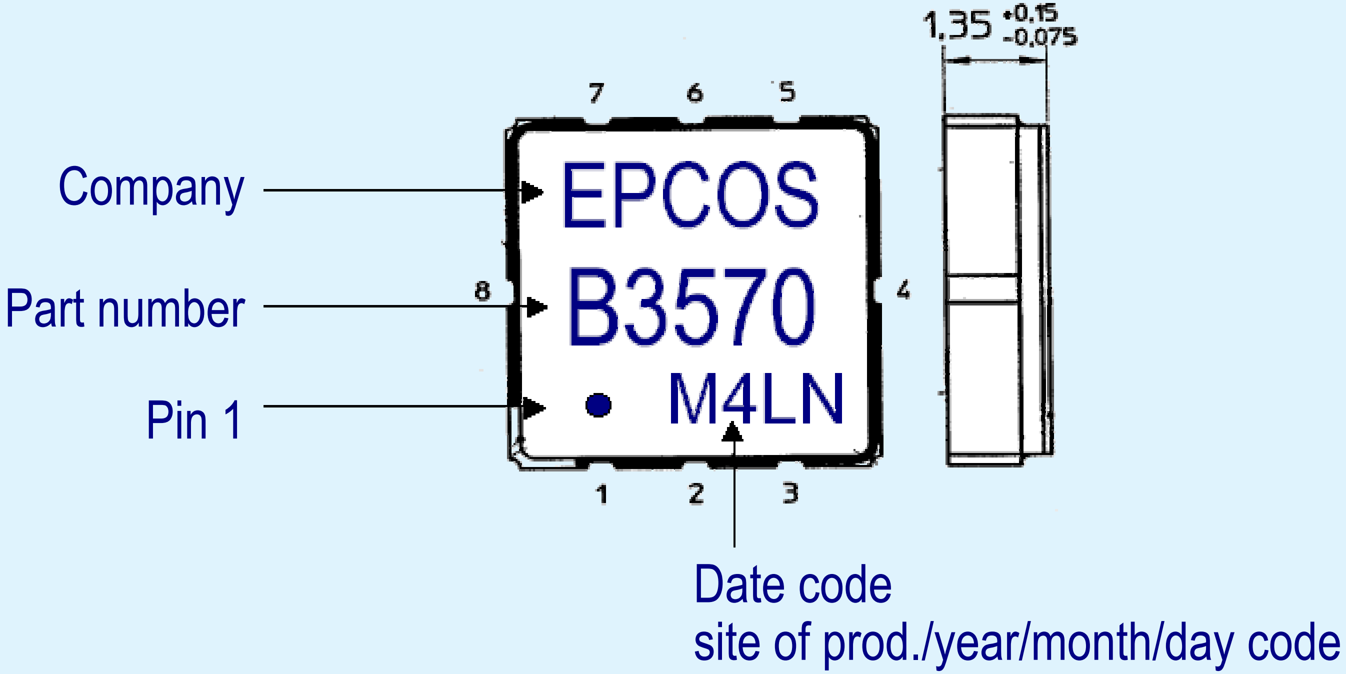


BW = guaranteed bandwidth of passband at -40...+85 °C

European SRD bands 433.92 MHz and 869 MHZ: Most important sources of interference

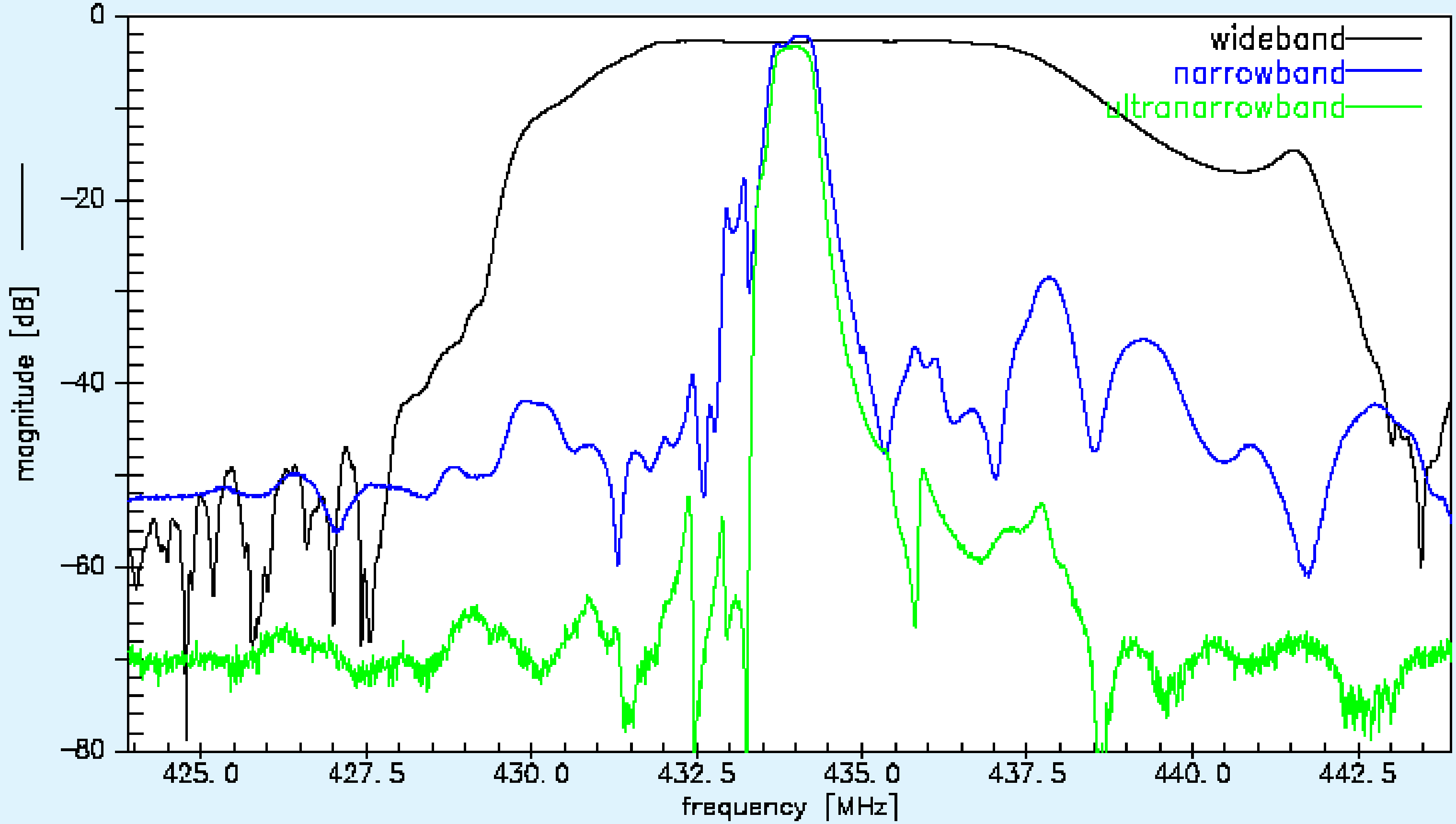


Laser marking on ceramic SMD packages



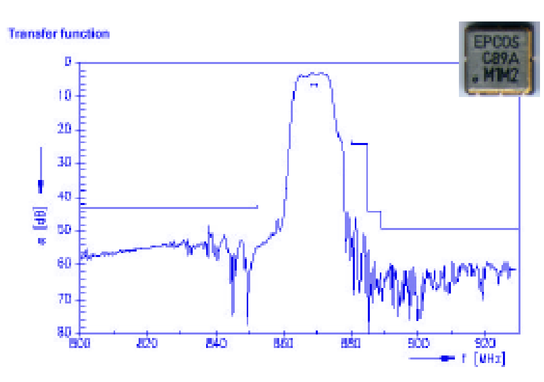
Comparison of frontend filters

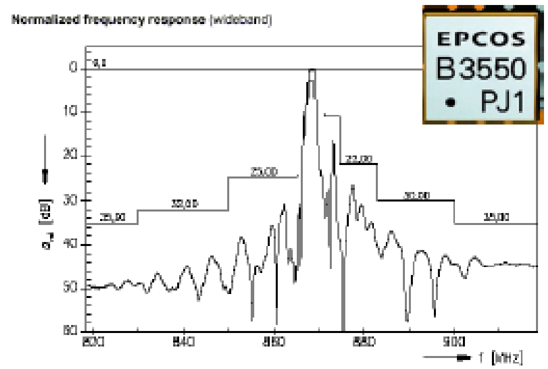
Wide band, narrow band, ultra-narrow band

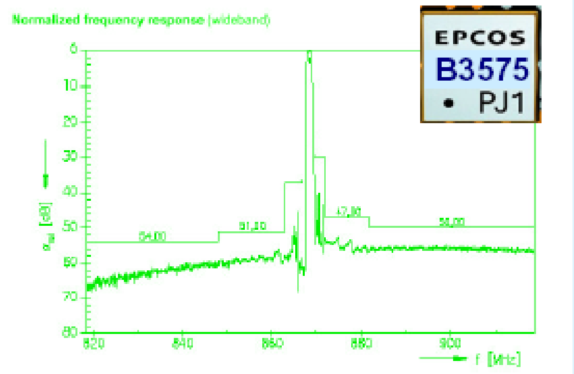


EPCOS

Product portfolio: Frontend filters

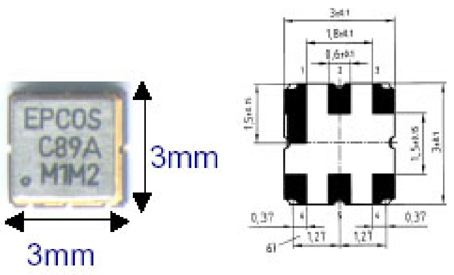


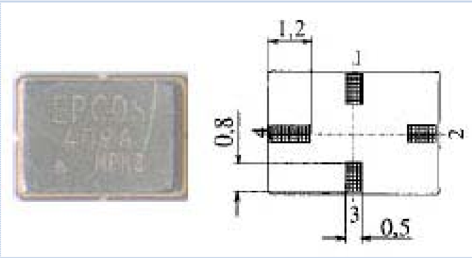


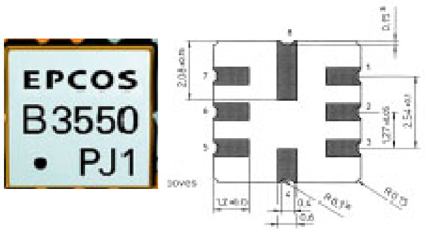


• **Bandwidth**	Wide band	Narrow band	Ultra-narrow band
• **Substrate**	Lithium tantalate	Quartz	Quartz
• **Passivation**	ELPAS	PROTEC / ELPAS	PROTEC
• **Input/output imp.**	50 Ohms matched	>>50 Ohms	>>50 Ohms
• **Temperature shift**	-- high	++ low	++ low
• **Package**	**DCC6C**, 3.0x3.0 **QCC8B**, 3.8x3.8mm	**QCC8B**, 3.8x3.8mm **QCC8C**, 5x5mm	**QCC8C**, 5x5mm
• **Insertion loss**	++ especially good	+ best on the market	o not main focus
• **Nearby selectivity**	- low	+ high	++ very high
• **Overall selectivity**	+ very good	+ very good	++ very good
• **Remark**	mainly used for **non-** automotive applications; easy and cheap to match -> perfect for low-cost applications	necessary for automotive applications in Europe, ++ well suited for **TPMS**	too narrow for SAW res. -- needs ext. coupling coil

Product portfolio: 3 resonator platforms







	DCC6C	QCC4C	QCC8C
	3x3mm^2, 6 pins	3.5x5mm^2, 4 pins	5x5mm^2, 8 pins
• **Frequencies (MHz)**	**All standard frequencies, like 315, 390, 418, 433, 868**		
• **Passivation**	ELPAS	ELPAS or PROTEC	ELPAS or PROTEC
• **Tolerance**		**+-100 kHz, +/- 75 kHz and +/- 50 kHz**	1 port and 2 port
• **Architecture**	1 port and 2 port	1 port	5x5x1.3mm³
• **Package**	3x3x1.1 m³	5x3.5x1.4mm³	QCC8C
	DCC6C	QCC4A	Metal ceramic SMD
• **Technology**	Metal ceramic SMD	Metal ceramic SMD	
	Replacement for TO39		

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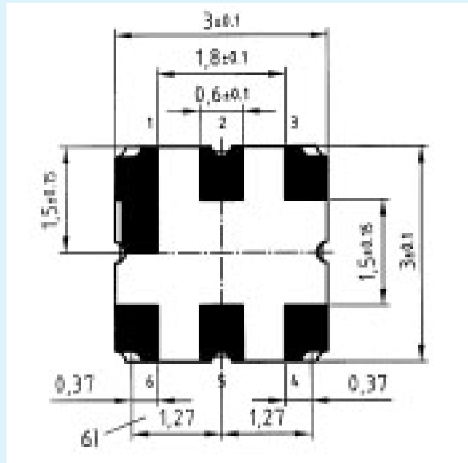
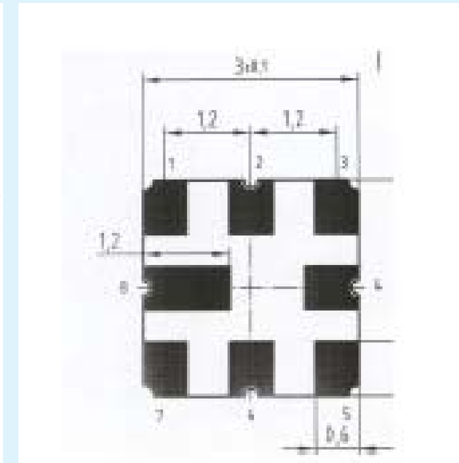
Product portfolio: GPS filter for automotive applications

DCC6C | **QCC8D**





	B3520	B4059/B3521	B4060
Package	DCC6C (3x3mm²) Metal ceramic SMD	QCC8D (3x3mm²) Metal ceramic SMD	QCC8D (3x3mm²) Metal ceramic SMD
Temperature range	-40 to 105 °C specified -40 to 125 °C operable	-40 to 105 °C specified -40 to 125 °C operable	-40 to 105 °C specified -40 to 125 °C operable
Input/output imp.	50 Ohm / 50 Ohm unbal./unbal.	50 Ohm / 50 Ohm unbal./unbal.	50 Ohm / 50 Ohm unbal./bal.
Features	Low insertion loss	High selectivity at AMPS and GSM	Low insertion loss High power durability
Qualification	AEC/Q-200 (in progress)	AEC/Q-200 (in progress)	AEC/Q-200 (in progress)

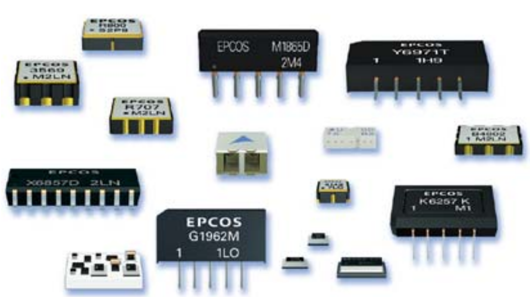
All EPCOS divisions at a glance

Capacitors

Film Capacitors

Inductors

Ceramic Components



SAW Components

Ferrites

Products by divisions

Capacitors

- Aluminum electrolytic capacitors
- Tantalum capacitors
- Polymer capacitors
- Ultracapacitors

Film Capacitors

- Film capacitors
- Power capacitors

Inductors

- Transformers & chokes
- RF chokes
- EMC filters

SAW Components

- Microwave ceramics & modules
- Crystals for acoustic & optical components
- Components for
  - Mobile communications
  - Multimedia applications
  - Consumer electronics
  - Automotive electronics

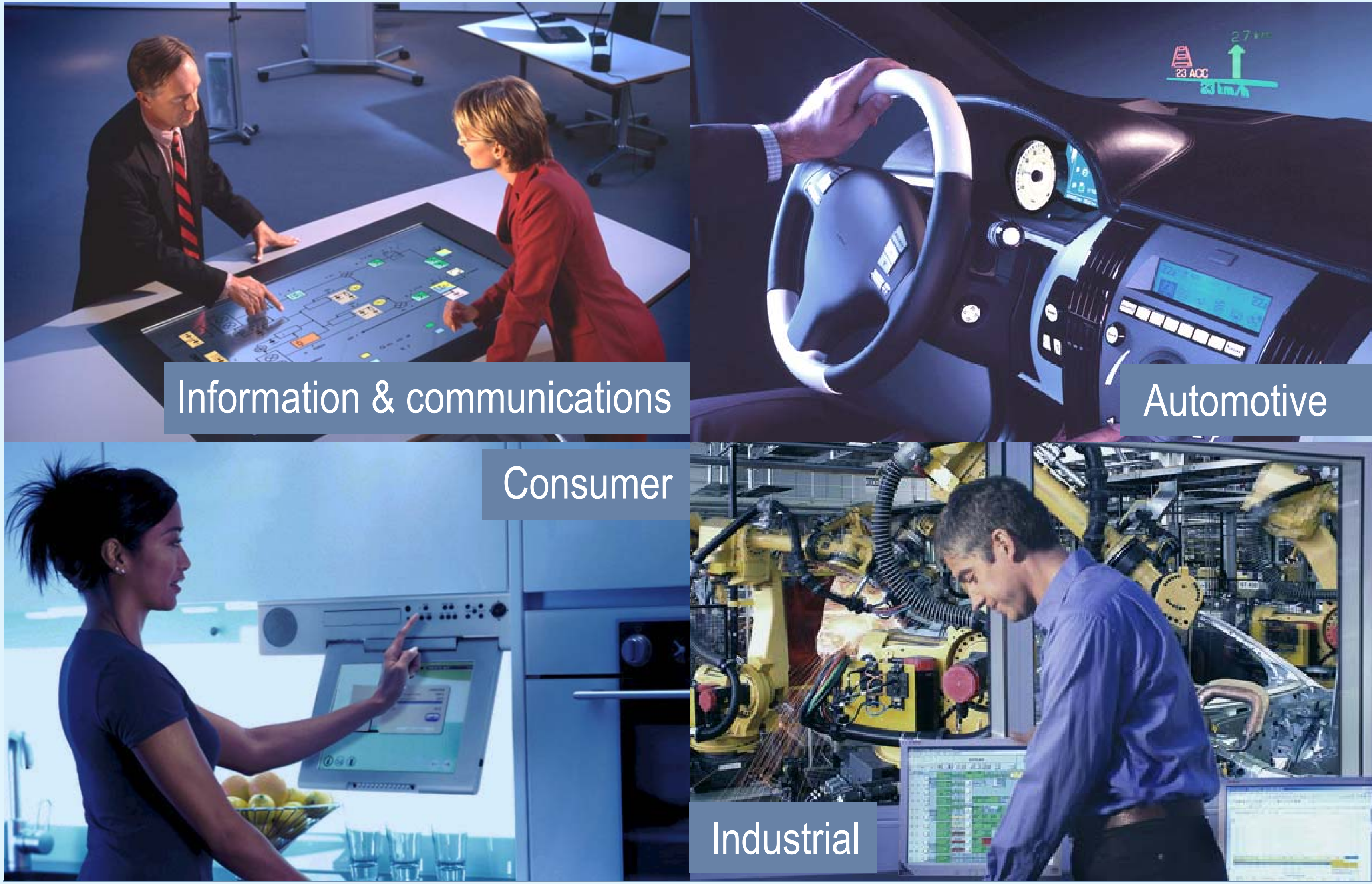
Ceramic Components

- Sensors & sensor elements
- Ceramic semiconductors
- Multilayer ceramic technology
- Piezo technology
- Surge arresters
- Switching spark gaps

Ferrites

- Ferrites
- Accessories

Key components for future applications



Abbreviations

SAW	Surface Acoustic Wave
RKE	Remote Keyless Entry
PLL	Phase Locked Loop
ASK	Amplitude Shifted Keying
FSK	Frequency Shifted Keying
IDT	Interdigital Transducer
RF	Radio Frequency
OOK	On/Off Keying = Amplitude Modulation
LO	Local Oscillator
IF	Intermediate Frequency, achieved by superposition of two slightly different oscillators
LNA	Low Noise Amplifier
SRD	Short Range Device
LT	Lithium Tantalate ($LiTaO^3$)
LN	Lithium Niobate ($LiNbO^3$)
CW	Continuos Wave
TX	Transmitter
RX	Receiver
Duty	Cycle Ratio between On time and Off time

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