April 2, 2019

Introduction to Surface Acoustic Wave (SAW) Devices

Part 1: What is SAW Device?

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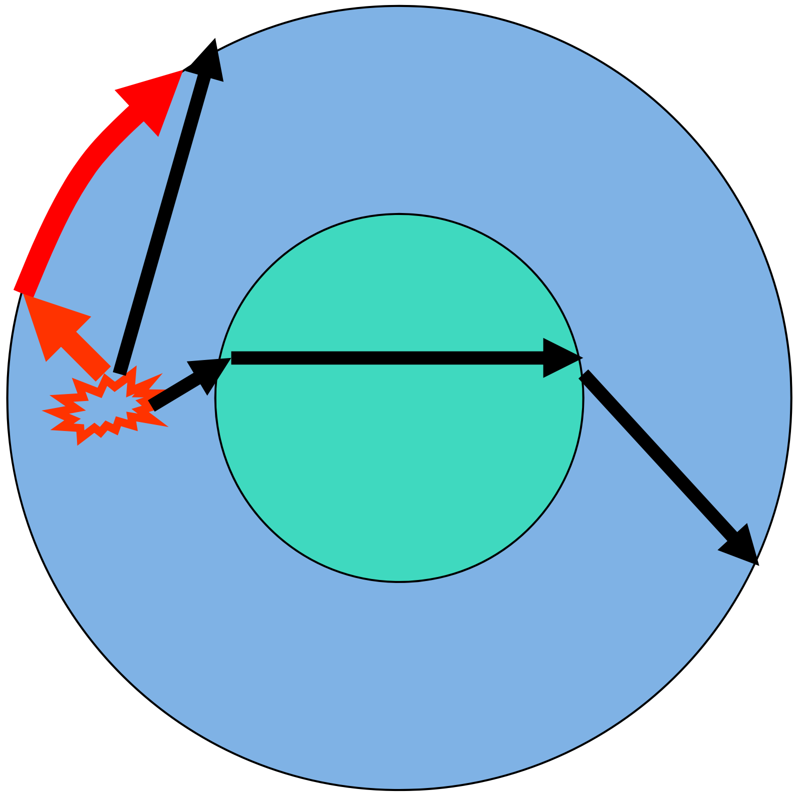
Contents

- SAW Transversal Filter
- SAW Unidirectional IDT Filters
- SAW Resonator Filters
- Duplexers
- Oscillators
- SAW Wireless Tags and Sensors

Contents

- SAW Transversal Filter

Surface Acoustic Wave



Propagation of
Seismological Waves

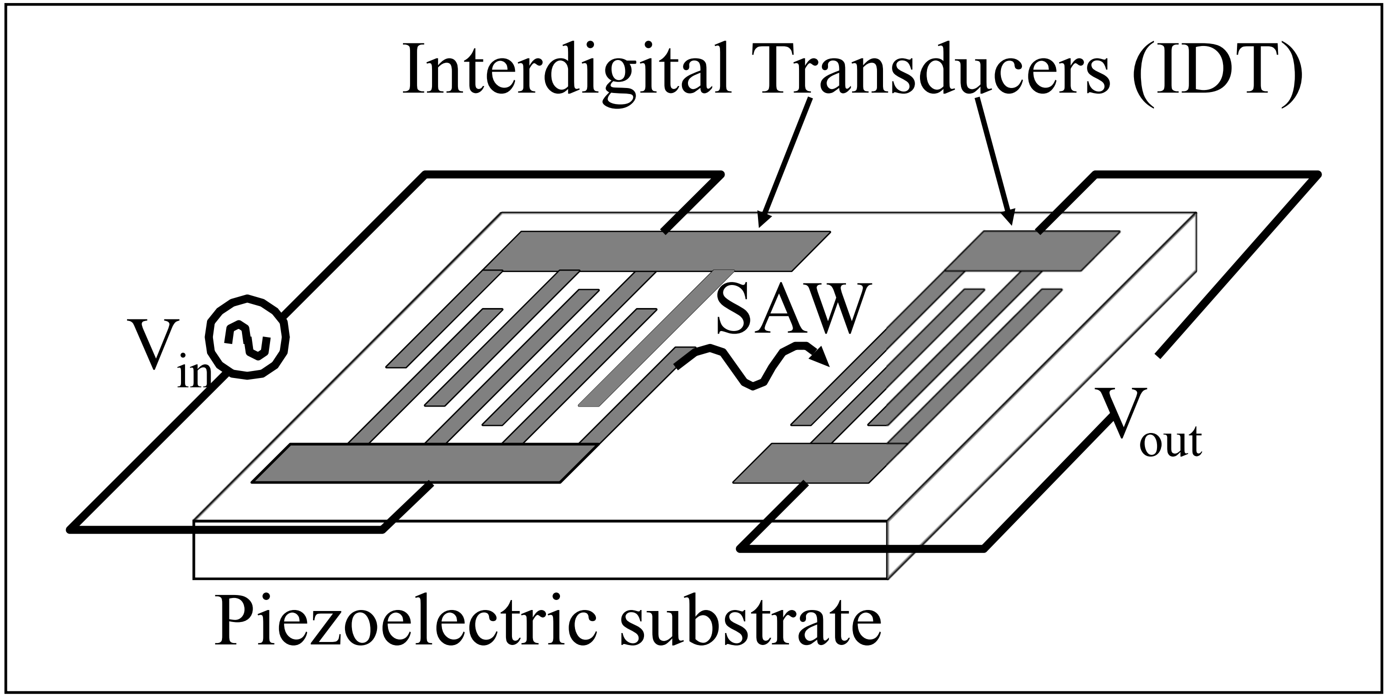
Bulk Acoustic Wave (BAW):

•Longitudinal Wave (Primary Wave)

•Transverse Wave (Shear Wave, Secondary Wave)

Surface Acoustic Wave (SAW): (Rayleigh SAW)

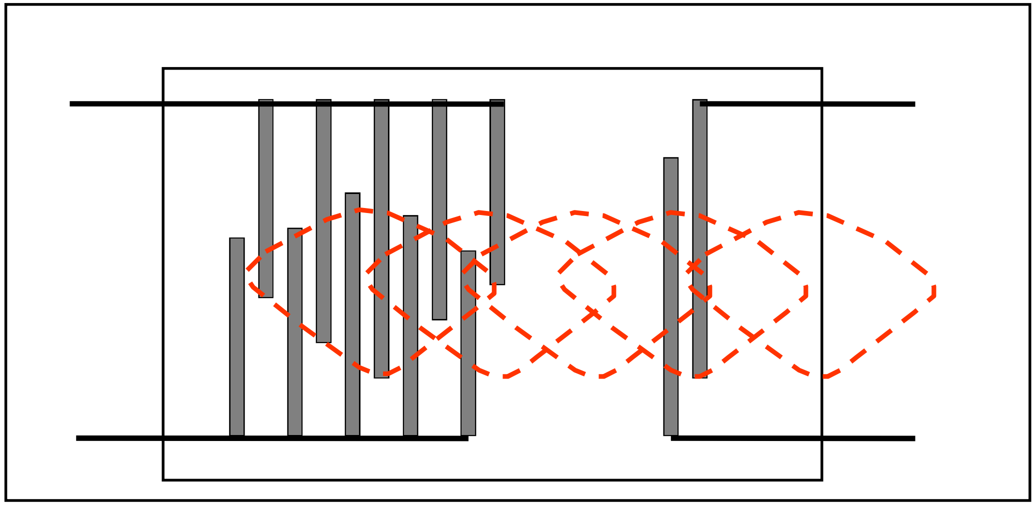
Surface Acoustic Wave (SAW) Device



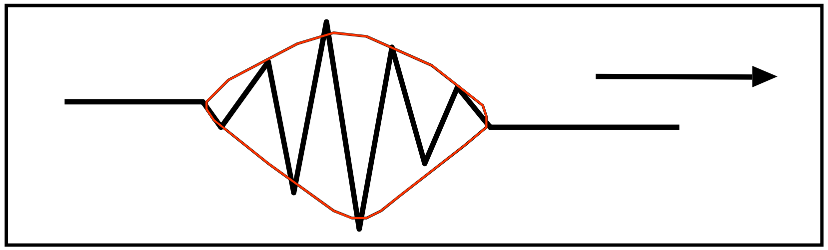
- Mass Production by Photolithography
- Low loss, Miniature & Low price
- Operation inVHF-UHF ranges

Line width $\lambda/4=0.5\mu m$ (f=2GHz)

SAW Transversal Filters

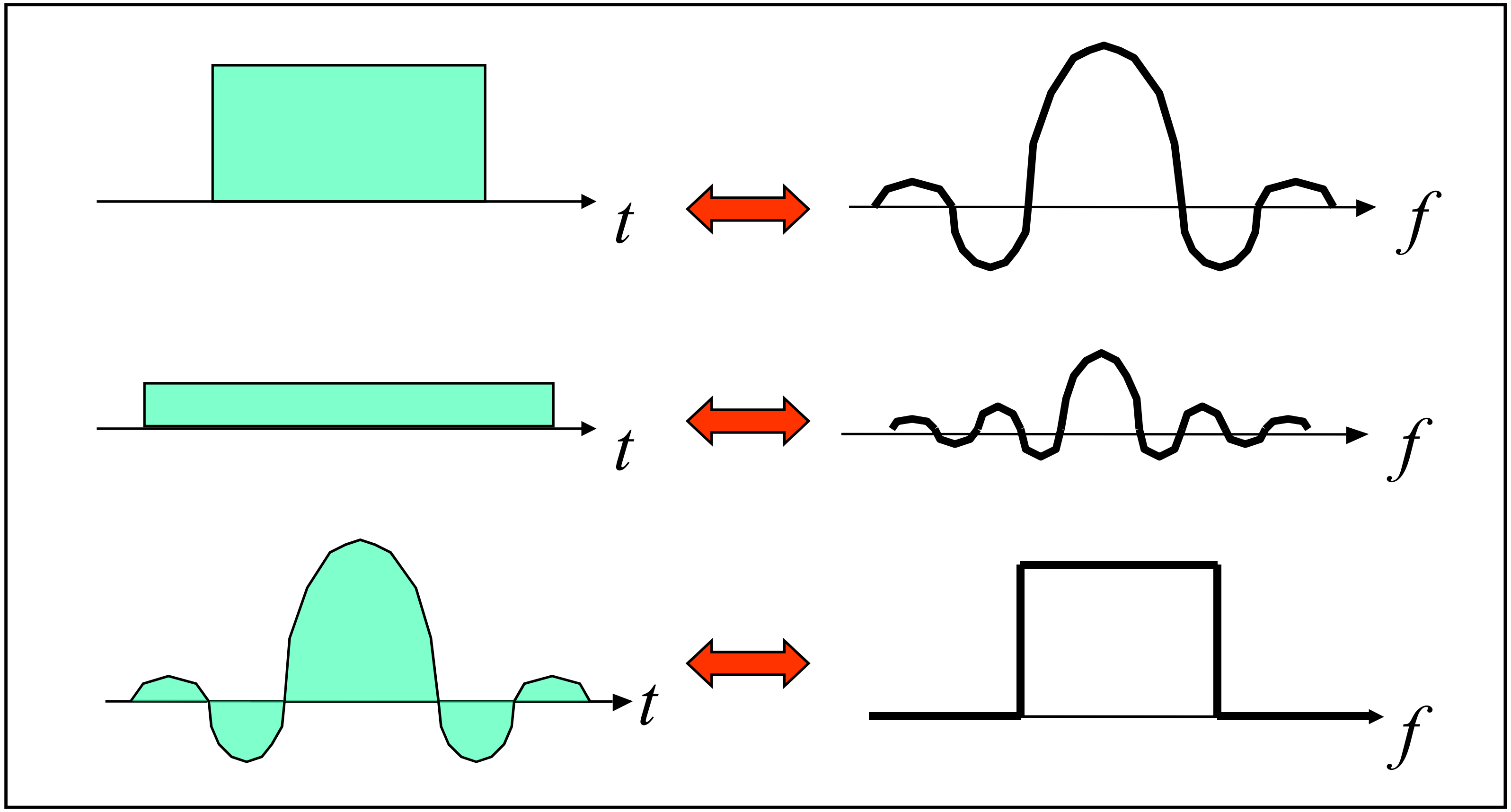


Impulse Response



- Independent Control of Amplitude and Phase Responses

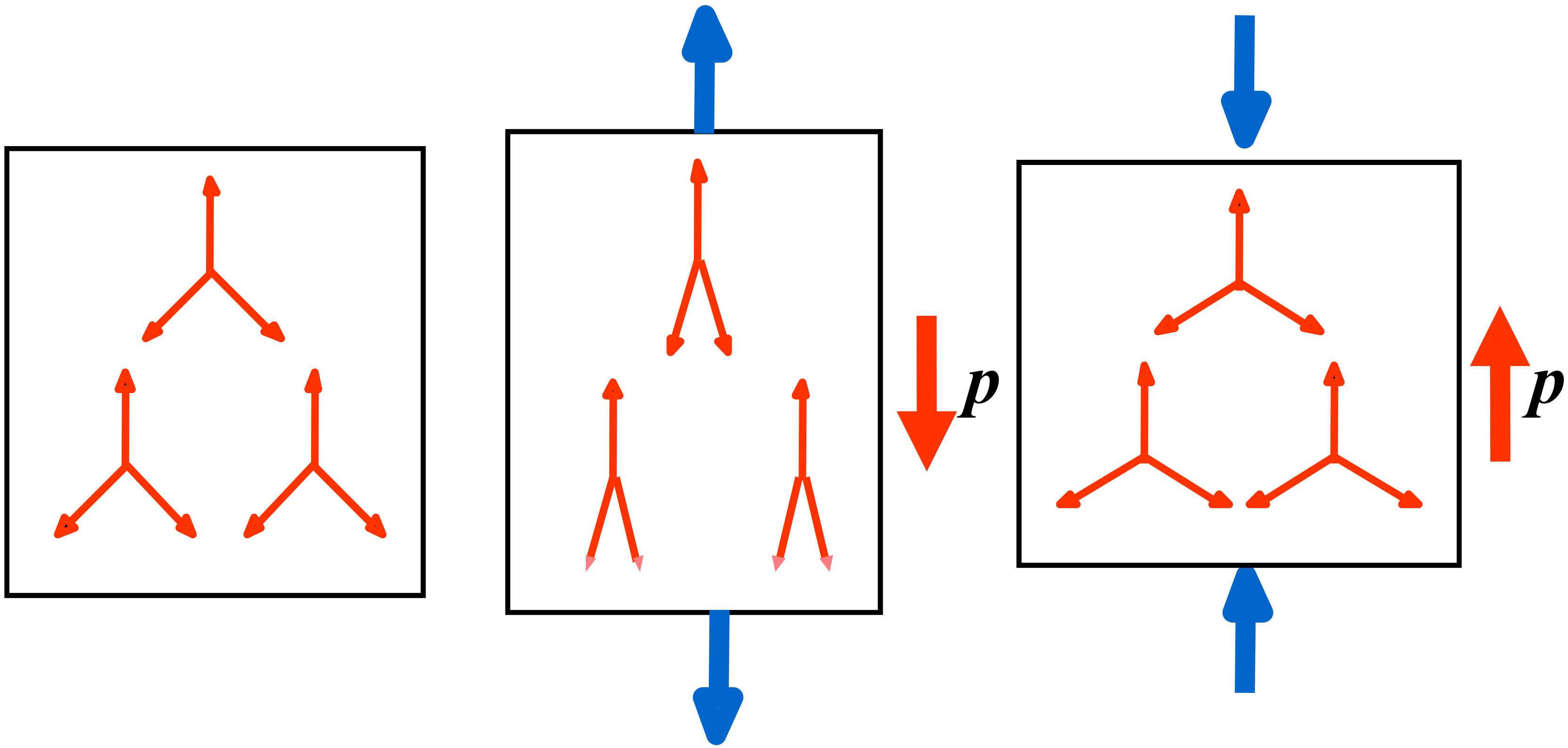
Impulse Response *Frequency Response*



$$h(t) = \int_{-\infty}^{+\infty} H(f)\exp(+2\pi jft)\,df \qquad H(f) = \int_{-\infty}^{+\infty} h(t)\exp(-2\pi jft)\,dt$$

Piezoelectricity

Electric Flux (Electric Field) ∝ Stress (Strain)



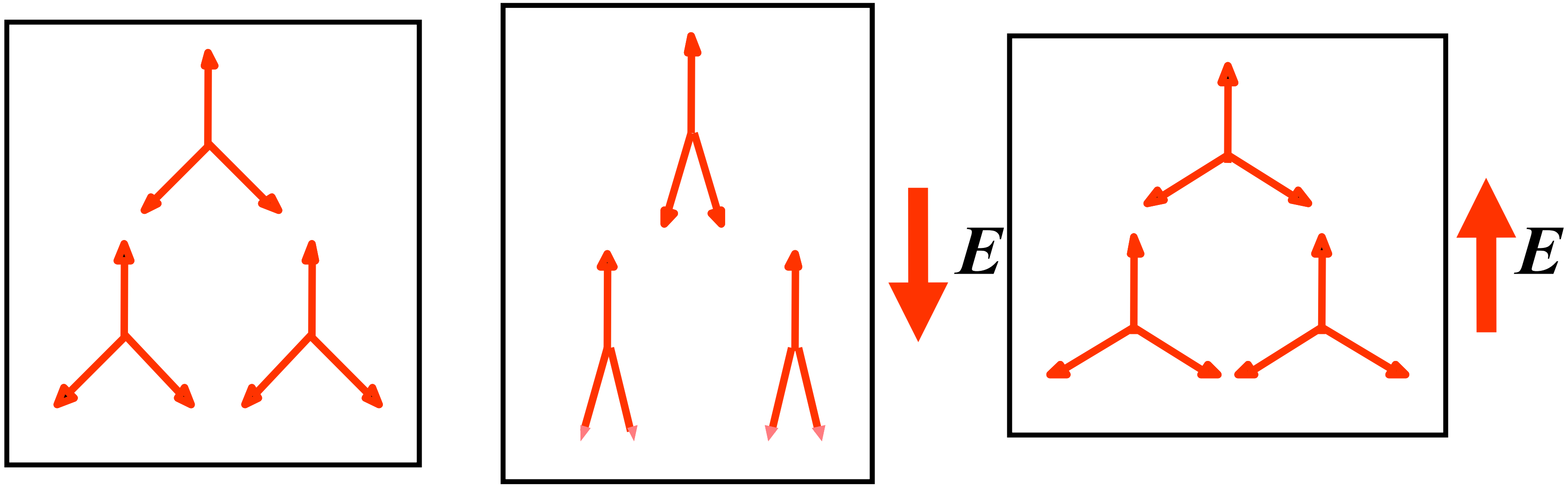
(a) Equilibrium (b) Extension (c) Compression

***p*: Dipole Moment**

Necessity of Crystalline Asymmetry
Depending on Crystal Orientation

Piezoelectricity

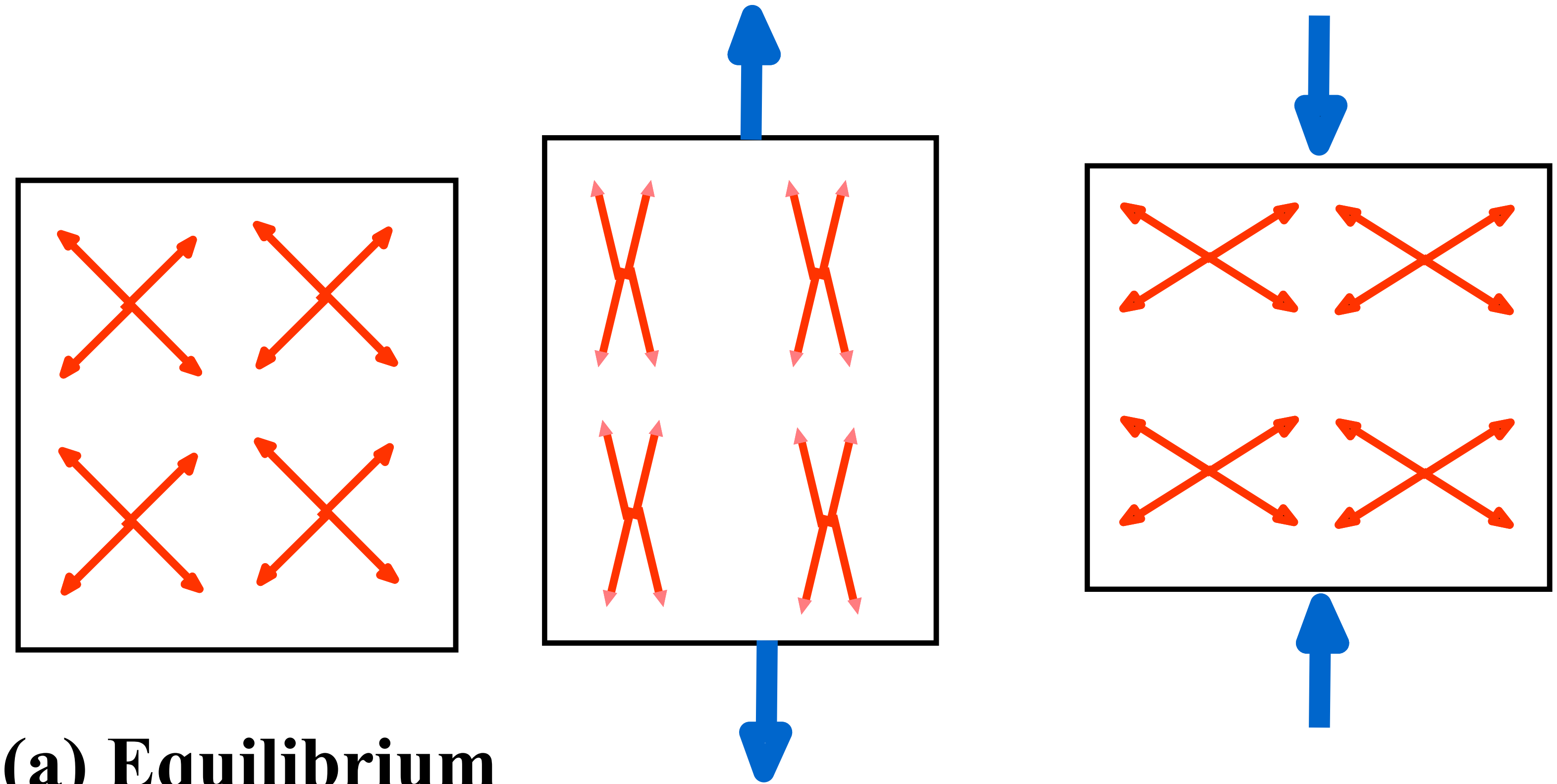
Stress (Strain) ∝ Electric field (Electric Flux)



(a) Equilibrium (b) Extension (c) Compression

***E*: Electric Field**

Non-Piezoelectric Case



(a) Equilibrium

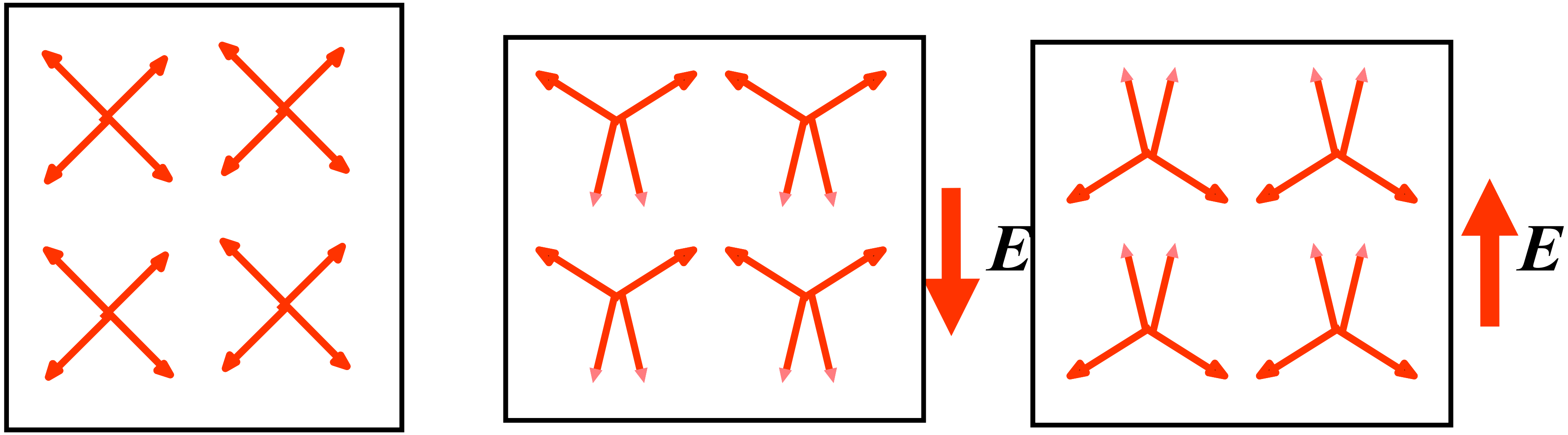
(b) Extension

(c) Compression

No Electric Output

Electrostriction

Stress (Strain) ∝ {Electric field (Electric Flux)}^{2}



(a) Equilibrium (b) Compressive (c) Compressive

***p*: Dipole Moment**

Negligible for Weak Electric field

Why Acoustic Wave Devices?

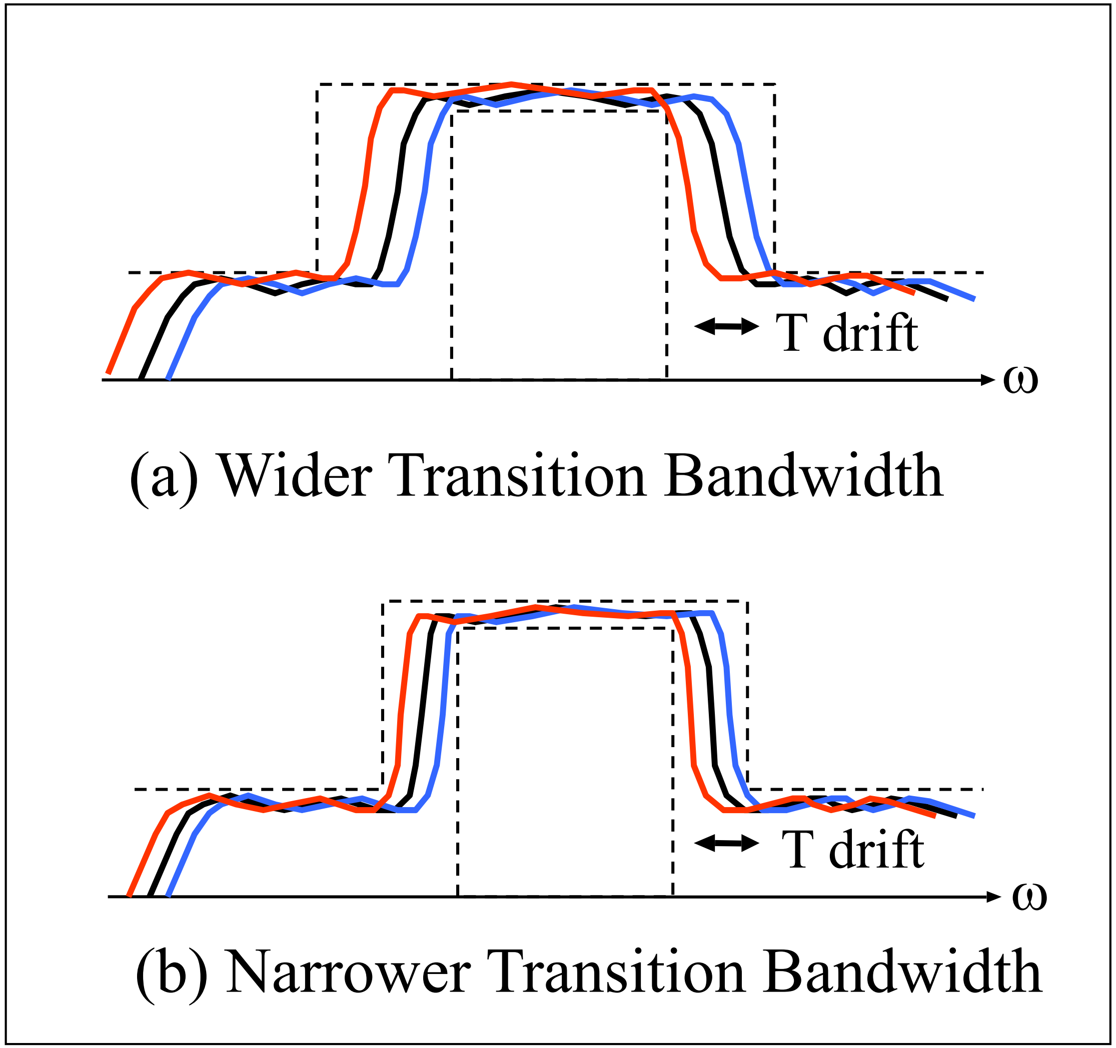
- Temperature Stability

For watch, $$\frac{1\,\text{sec.}}{1\,\text{day}} \cong 10\,\text{ppm}$$

cf. For Si, 3000ppm/^{o}C

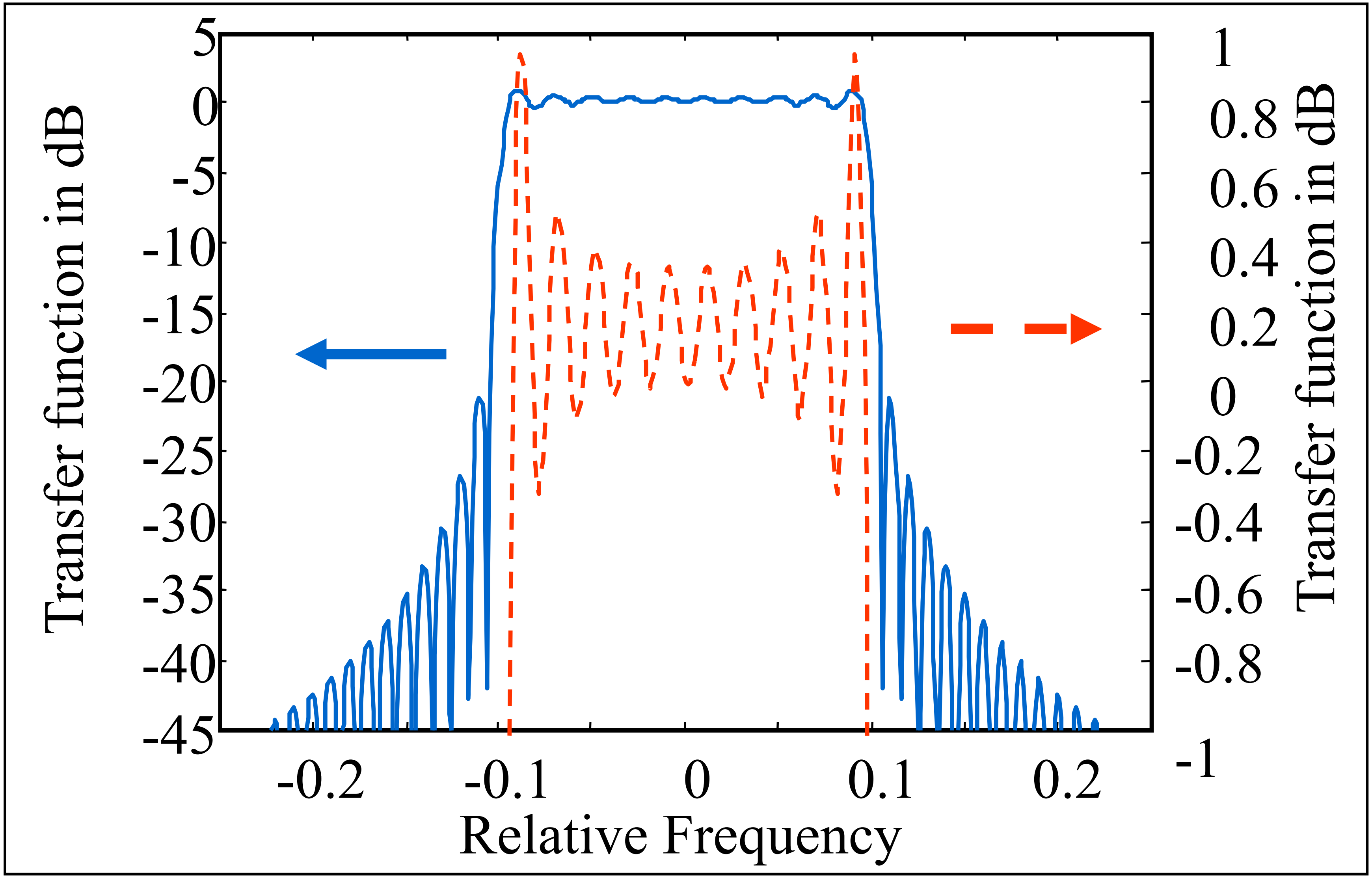
$$I = I_0[\exp(qV/kT) - 1]$$

Trade-Off Between Temp. Stability & Bandwidth



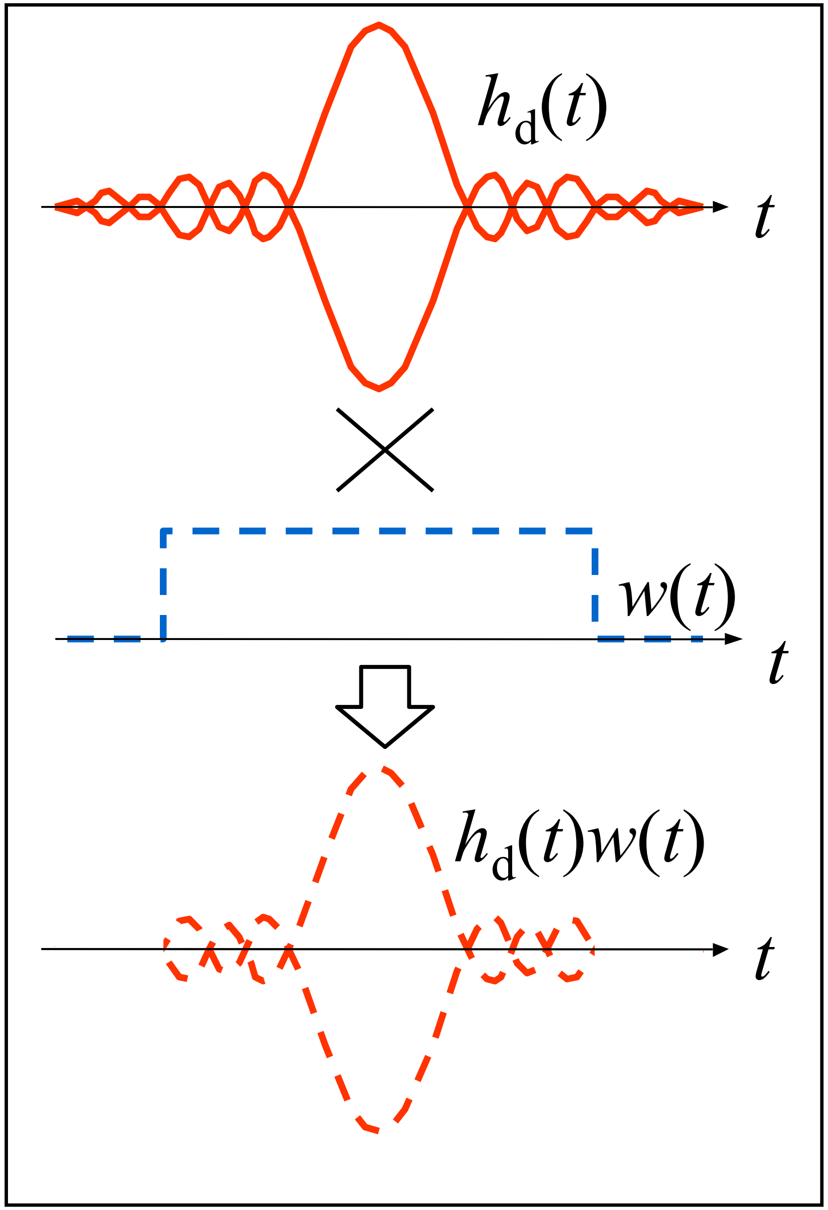
Efficient Use of Frequency Resources ⇔ Narrow Transition Bandwidth (Or Improve Production Yield)

Fourier-Transform-Based Design



Ripple due to truncation [Gibb's Phenomenon]

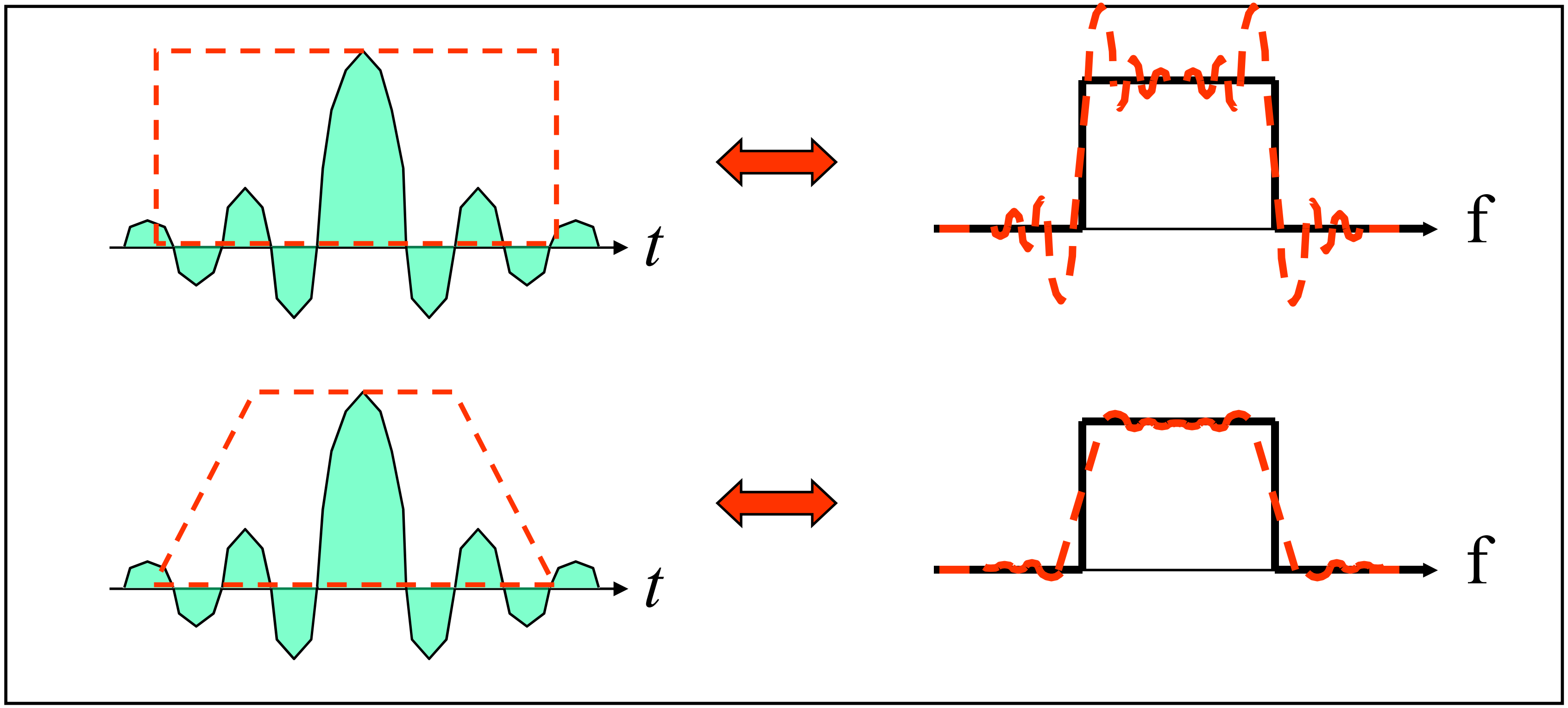
Influence of Truncation



Convolution Relation

$$H_w(f) = \int_{-\infty}^{+\infty} H_d(\xi) W(\xi - f) d\xi$$

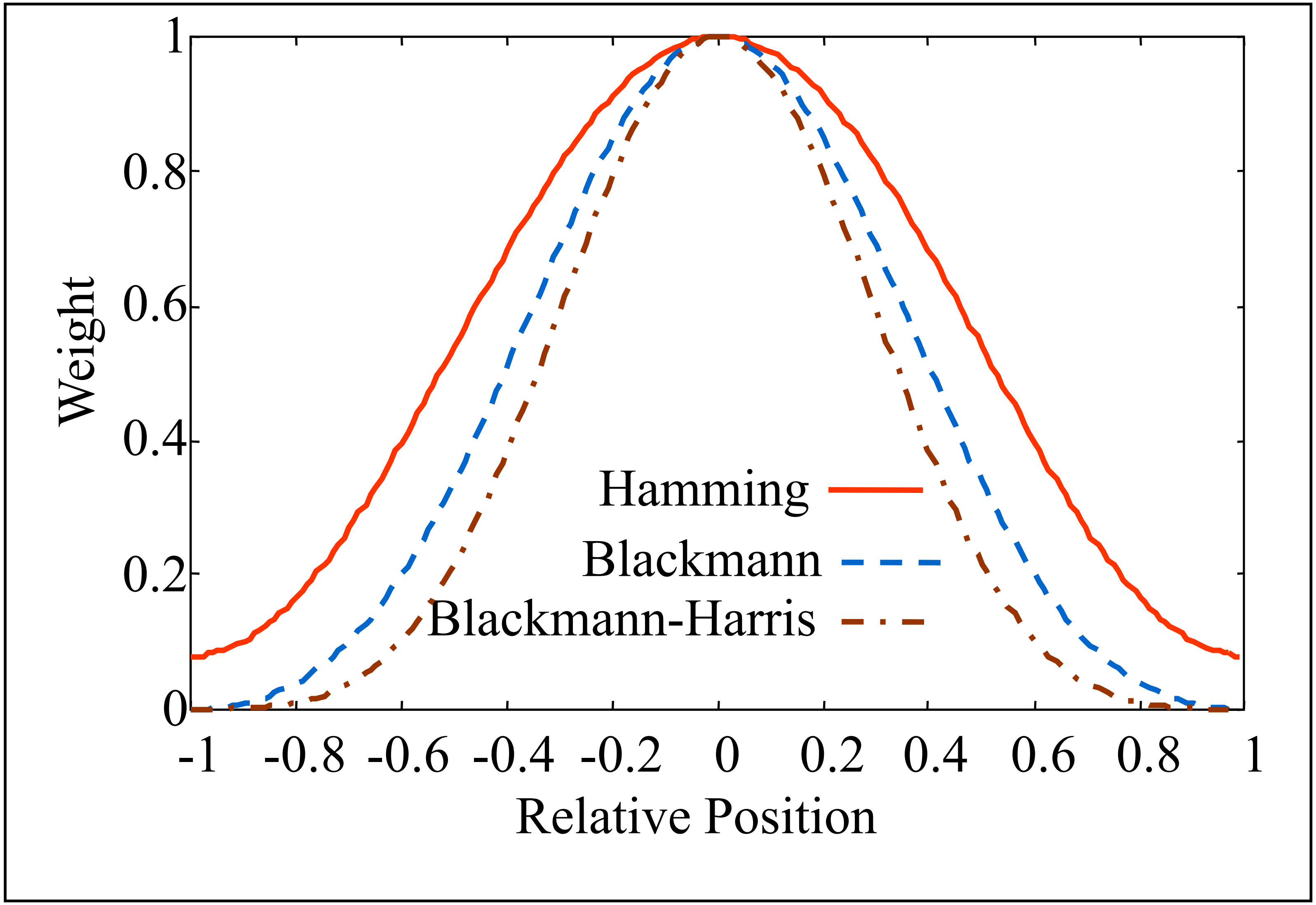
Window Functions



Hamming: $w(t)=0.54+0.46\cos(2\pi t/T)$

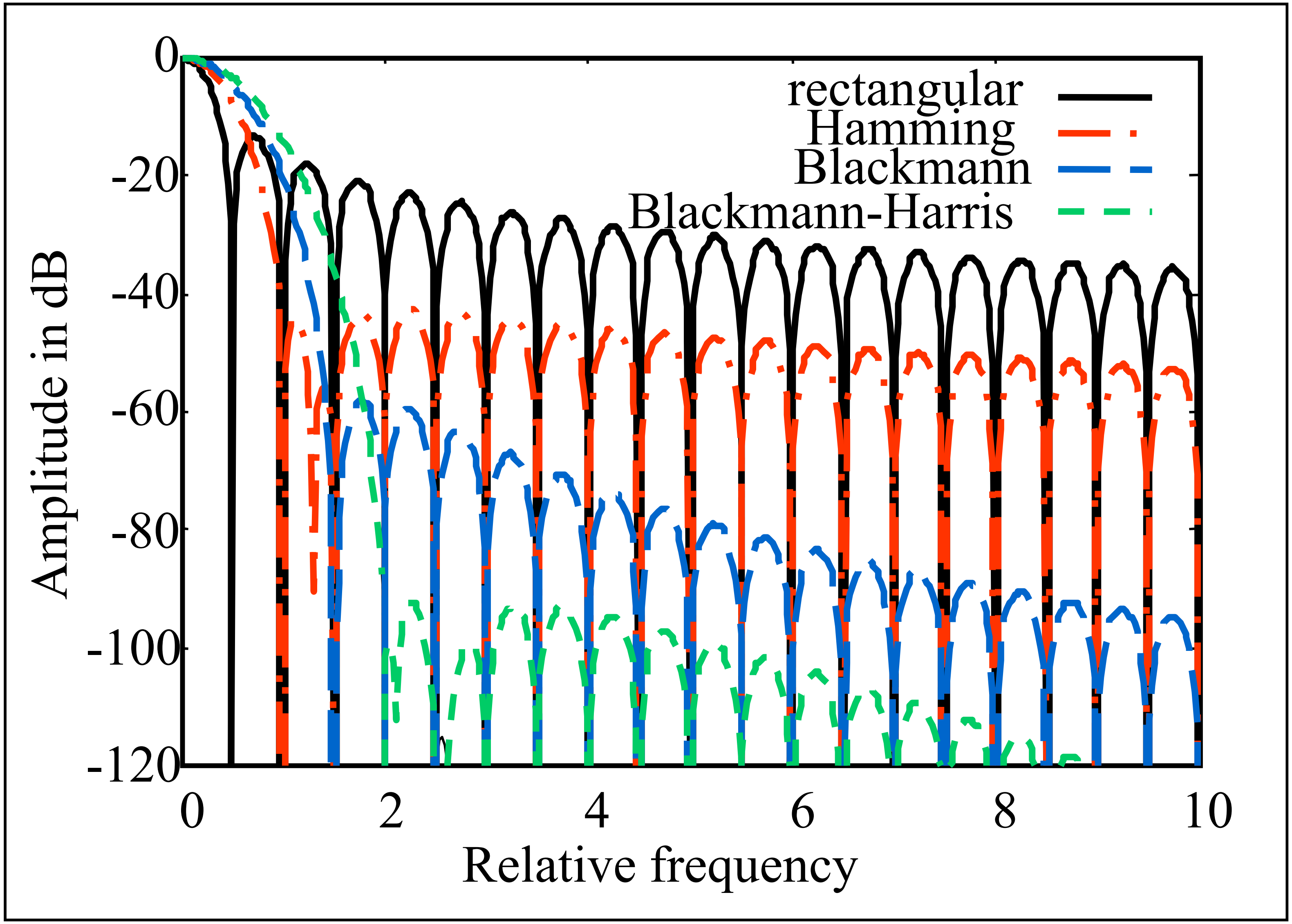
Blackmann: $w(t)=0.42+0.5\cos(2\pi t/T)+0.08\cos(4\pi t/T)$

Blackmann-Harris: $w(t)=0.35875+0.48829\cos(2\pi t/T)+0.14128\cos(4\pi t/T)+0.01168\cos(6\pi t/T)$

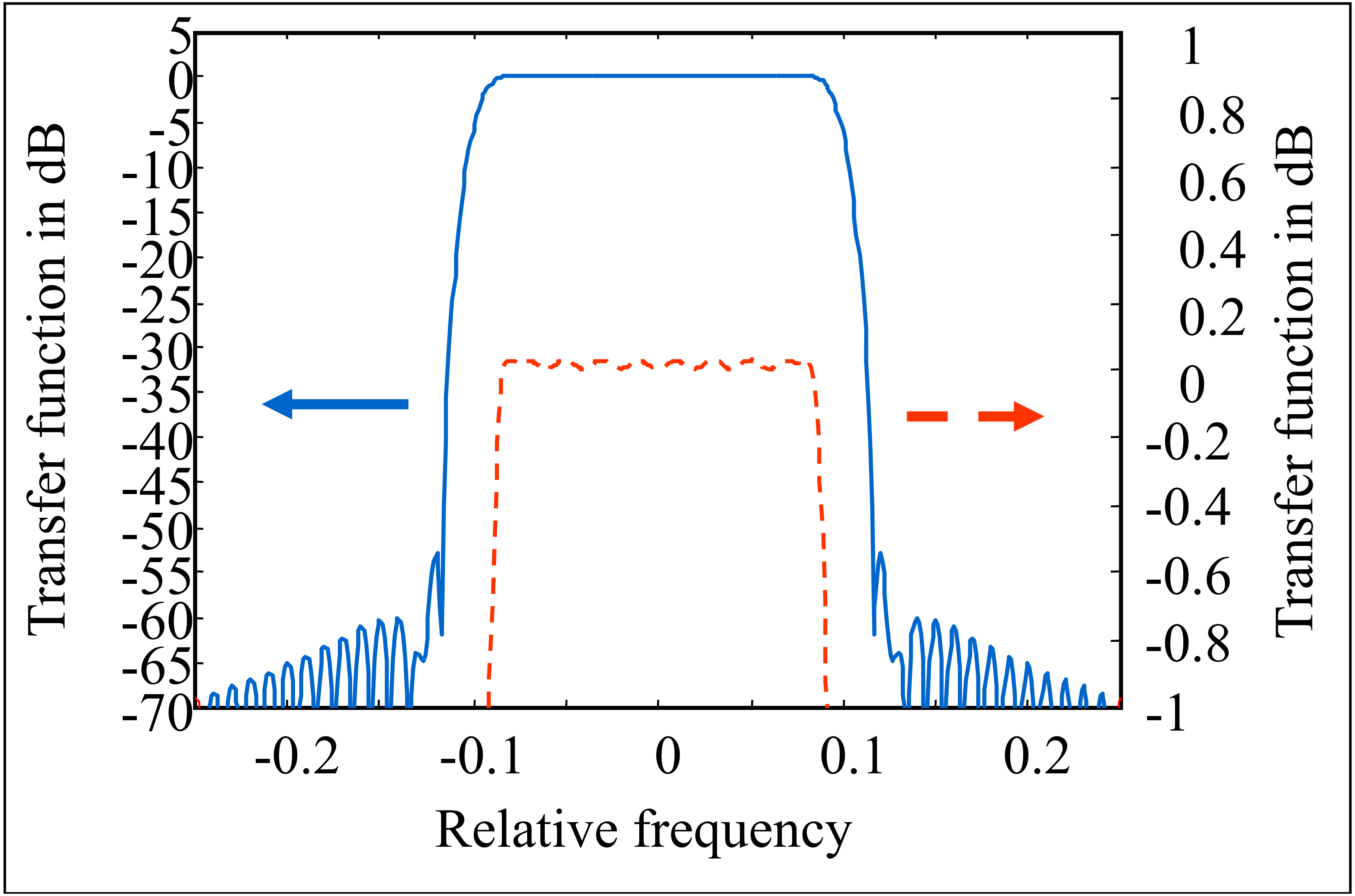


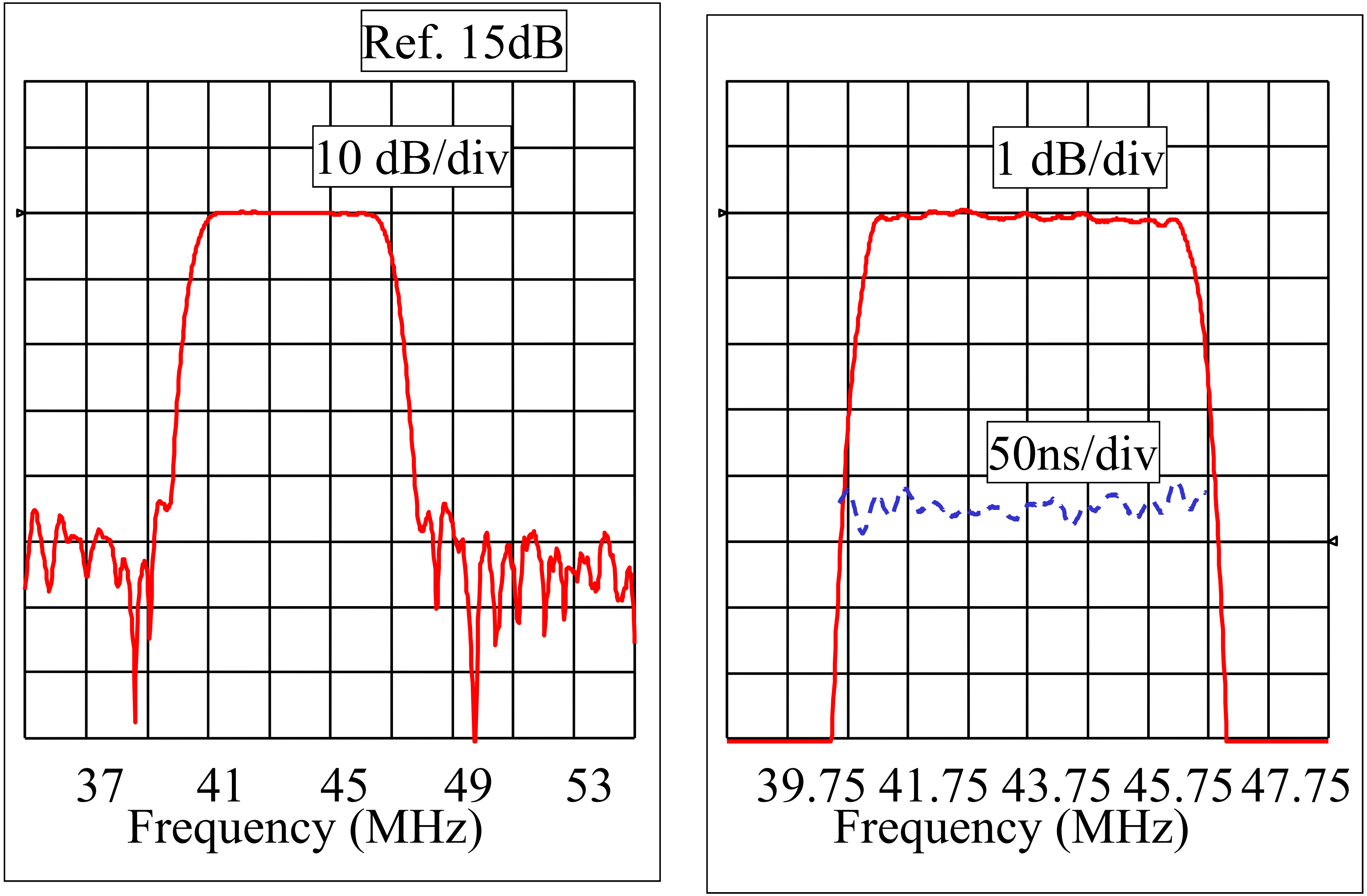
1
0.8
0.6
0.4
0.2
0
Weight
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Relative Position
Hamming
Blackmann
Blackmann-Harris

Frequency Response of Window Functions with same T



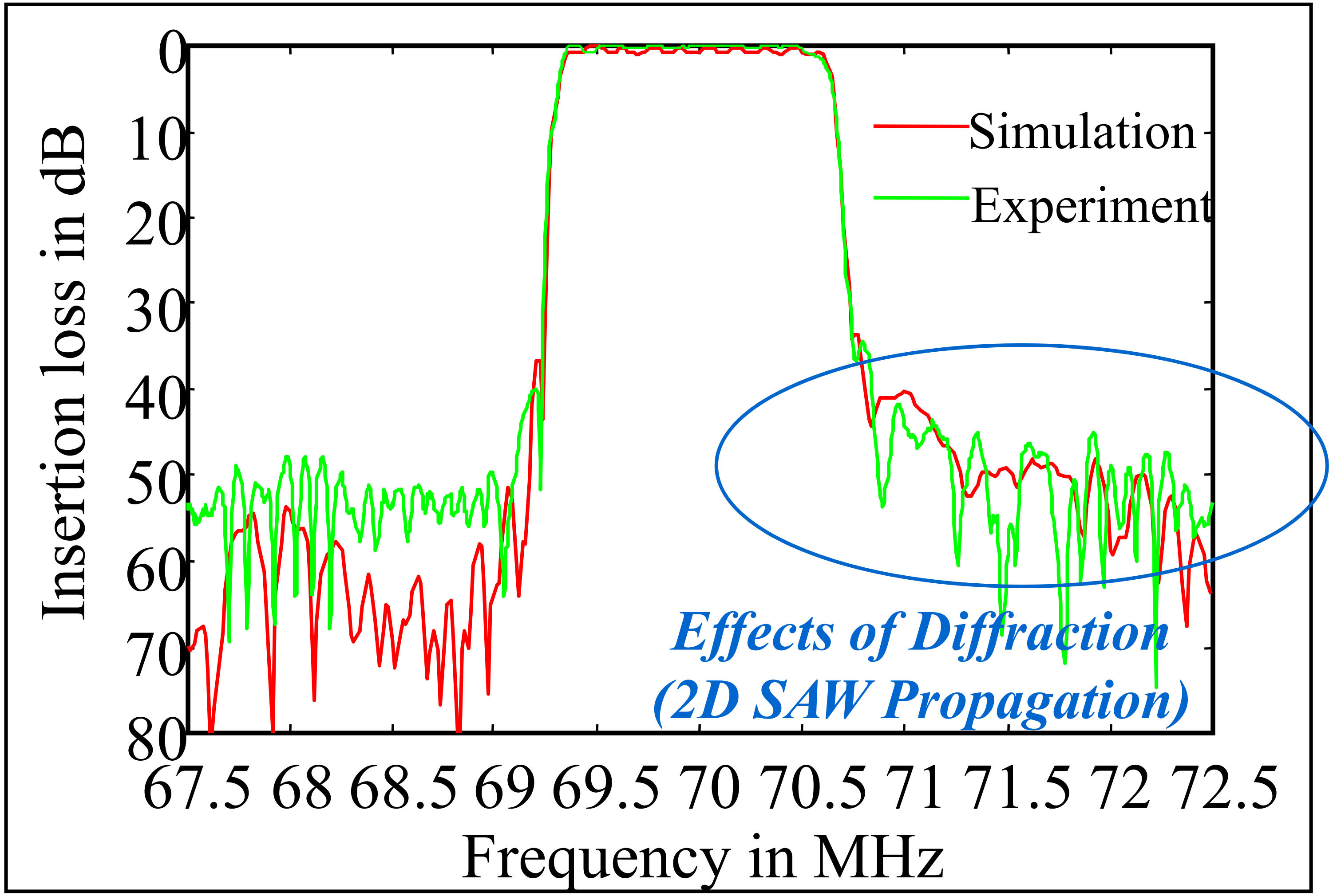
Design by Fourier Transform + Window Function



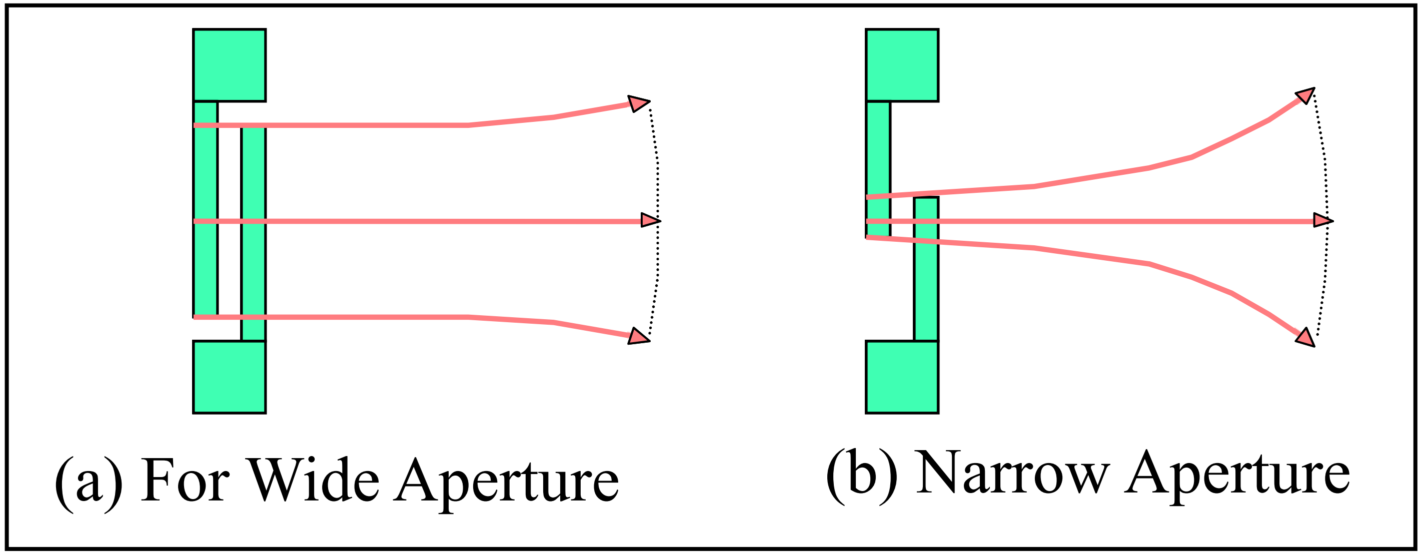


SAW Transversal Filter for CATV

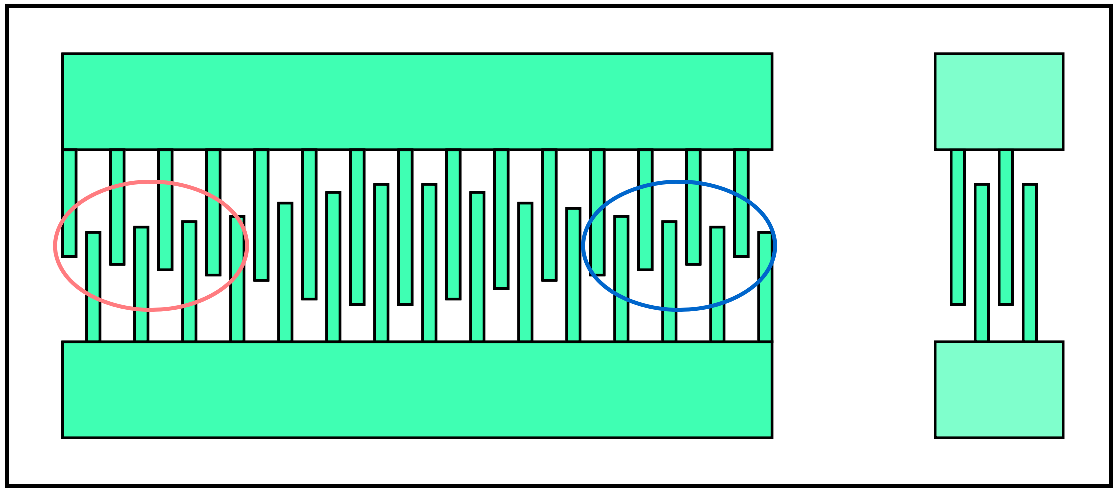
SAW IF Filter for IS-95



Courtesy of Fujitsu Labs.

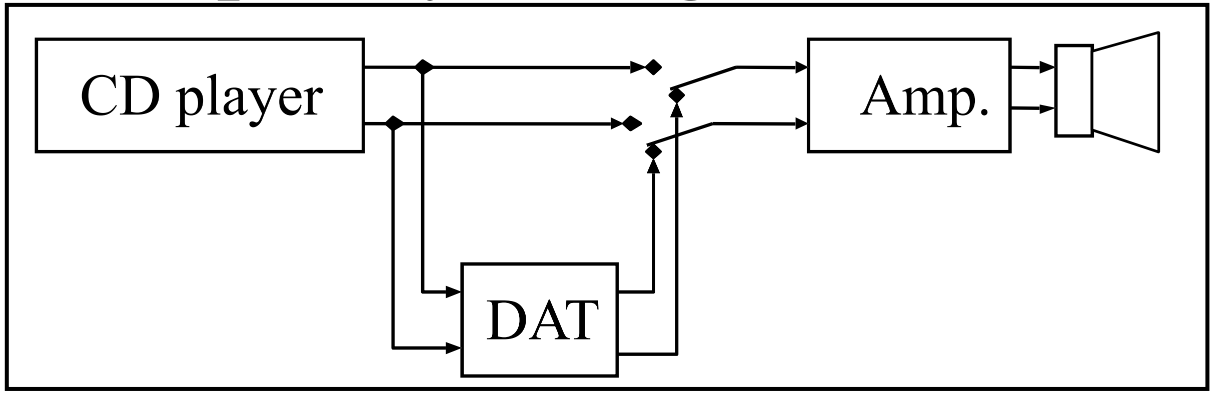


Variation with Aperture Size



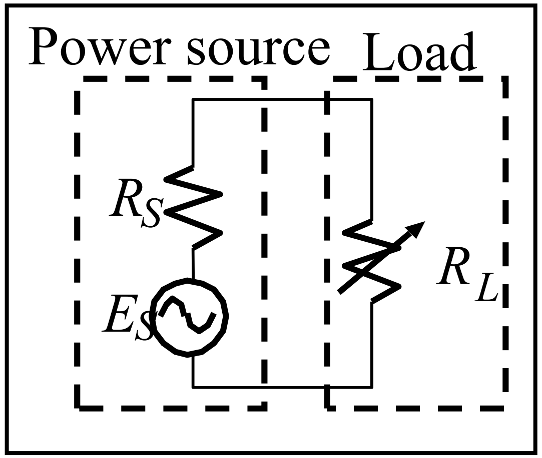
For Weighted IDT

Low Frequency Design

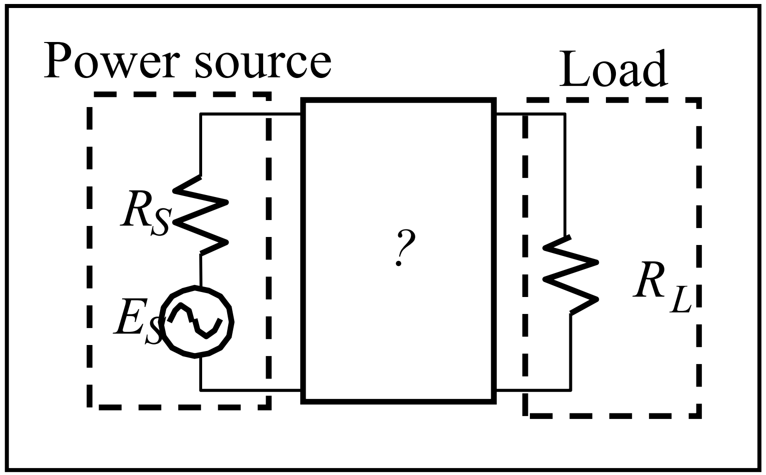


High Z_{in} and Low Z_{out} for Minimum Interference

High Frequency Design

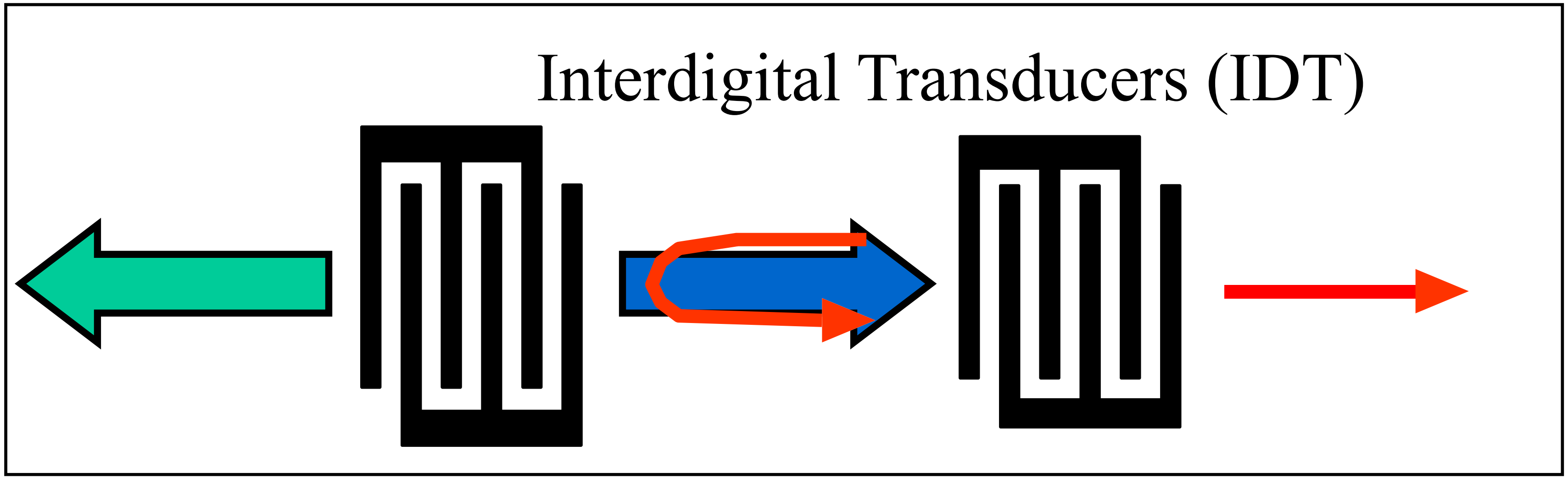


$R_L = R_S$ for Maximum Power Transfer



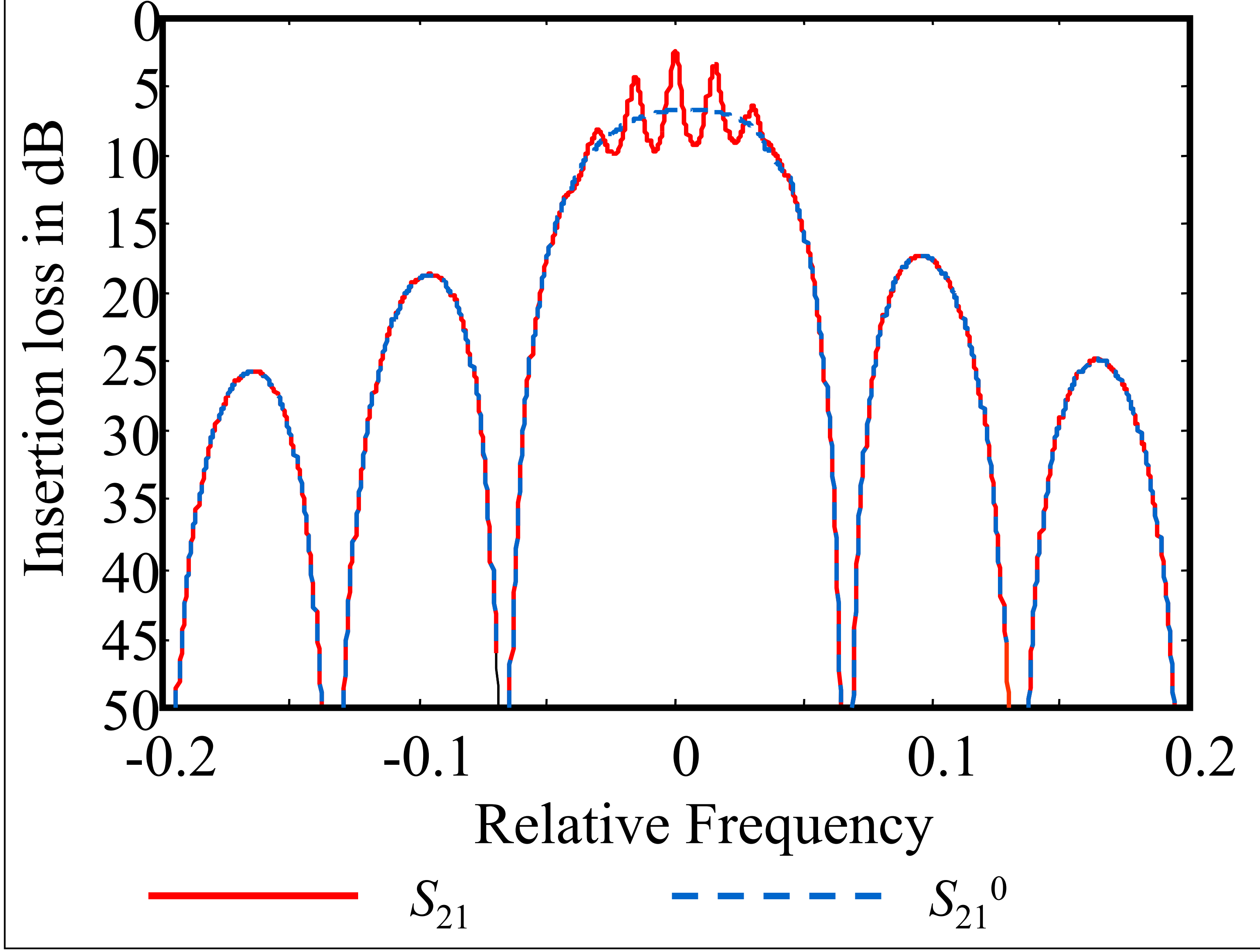
How about this case?

Triple Transit Echo (TTE)

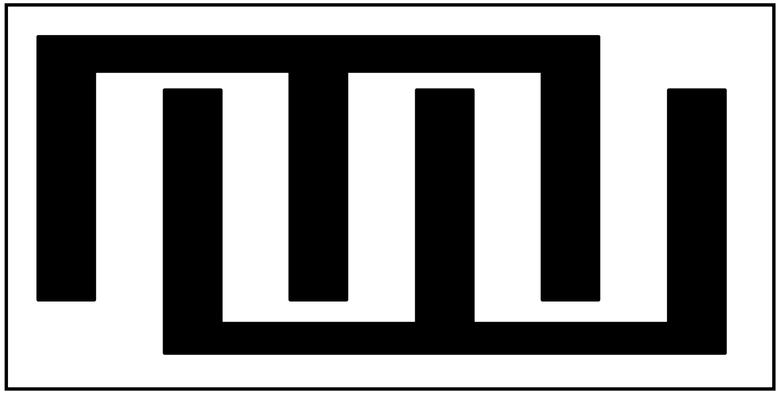


- Mechanical Reflection + Electrical Regeneration ⇒ Mutual-Connection Dependent
- Trade-Off: TTE ⇔ Insertion Loss
- Intrinsic for Bidirectional IDTs

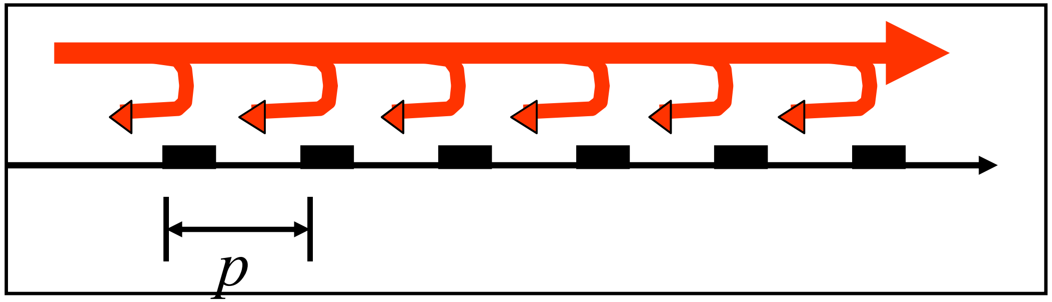
Influence of TTE



Bragg Reflection

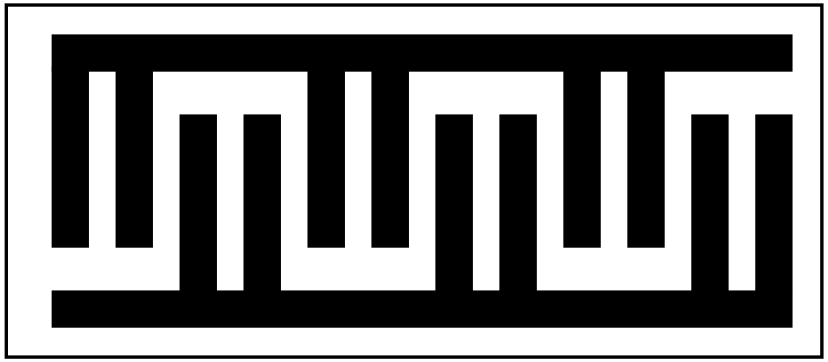


Single-Electrode IDT



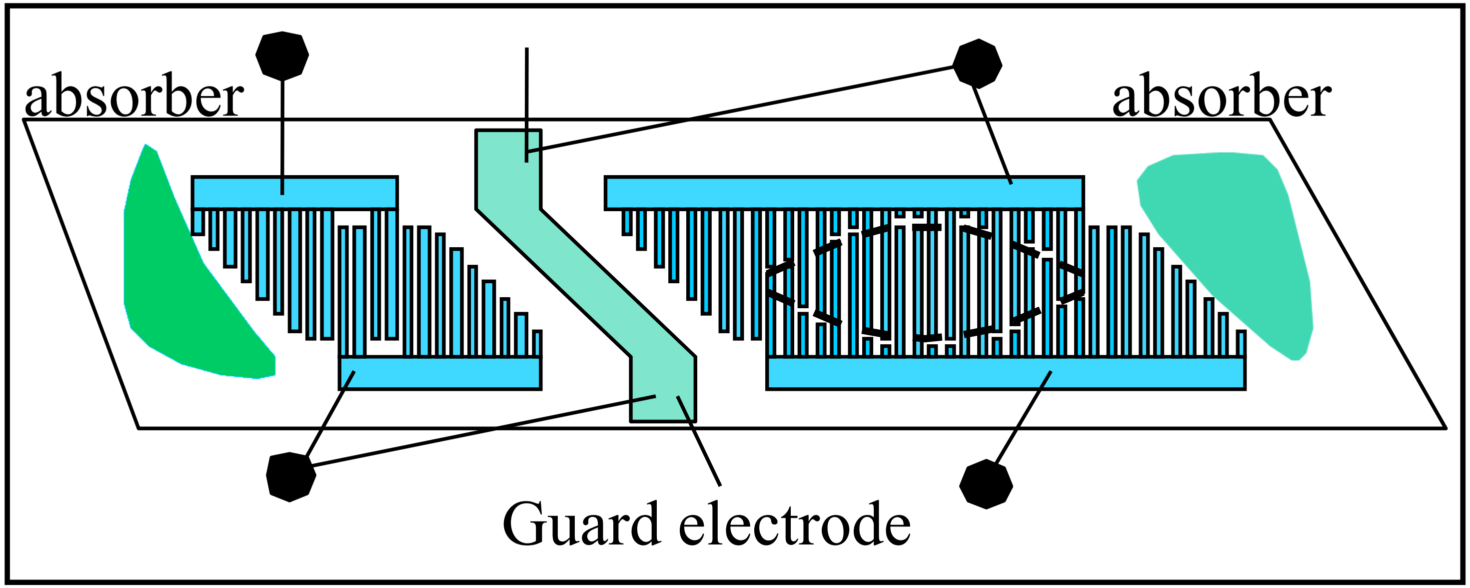
Bragg Condition

$p = n\lambda/2$



Double-Electrode IDT

Transversal SAW Filter



·Absorbers for Suppression of Reflection at Substrate Edges

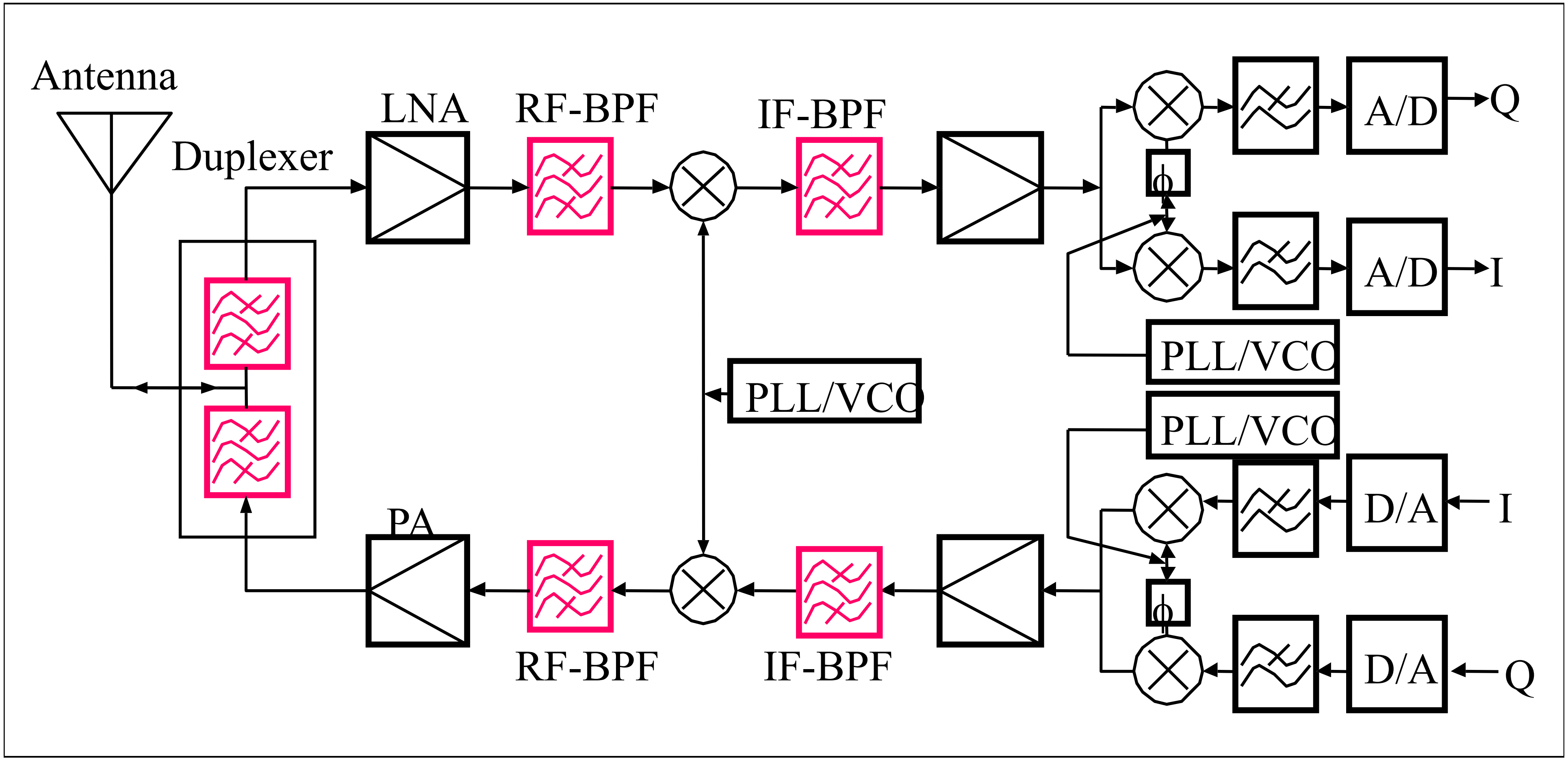
·Dummy Electrode for Suppression of Reflection and Charge Concentration at Edges

·Guard Electrode for Suppression of EM Feedthrough

Contents

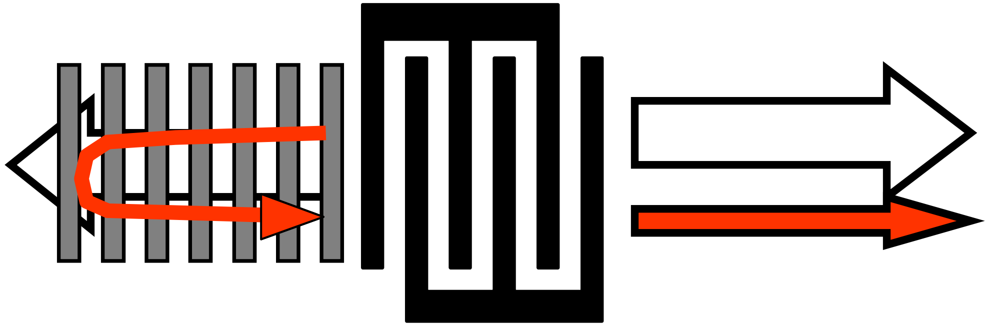
- SAW Unidirectional IDT Filters

Heterodyne Transceiver

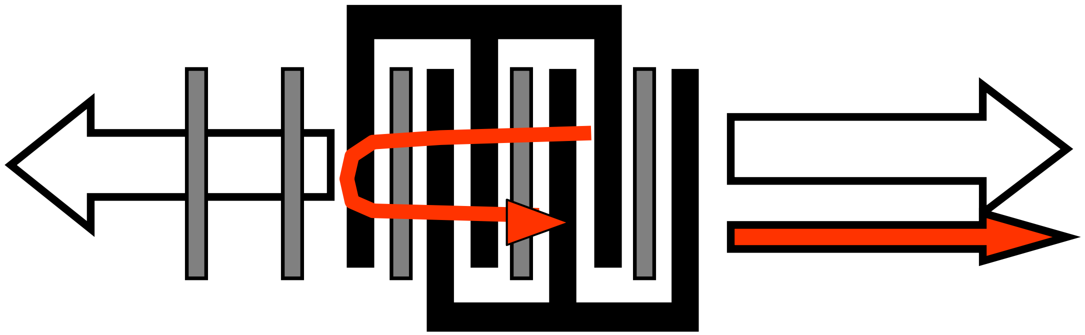


Red：SAW Devices

Single Phase Unidirectional Transducer (SPUDTs)



(a) Combination with Reflector
(Simple but Narrowband)

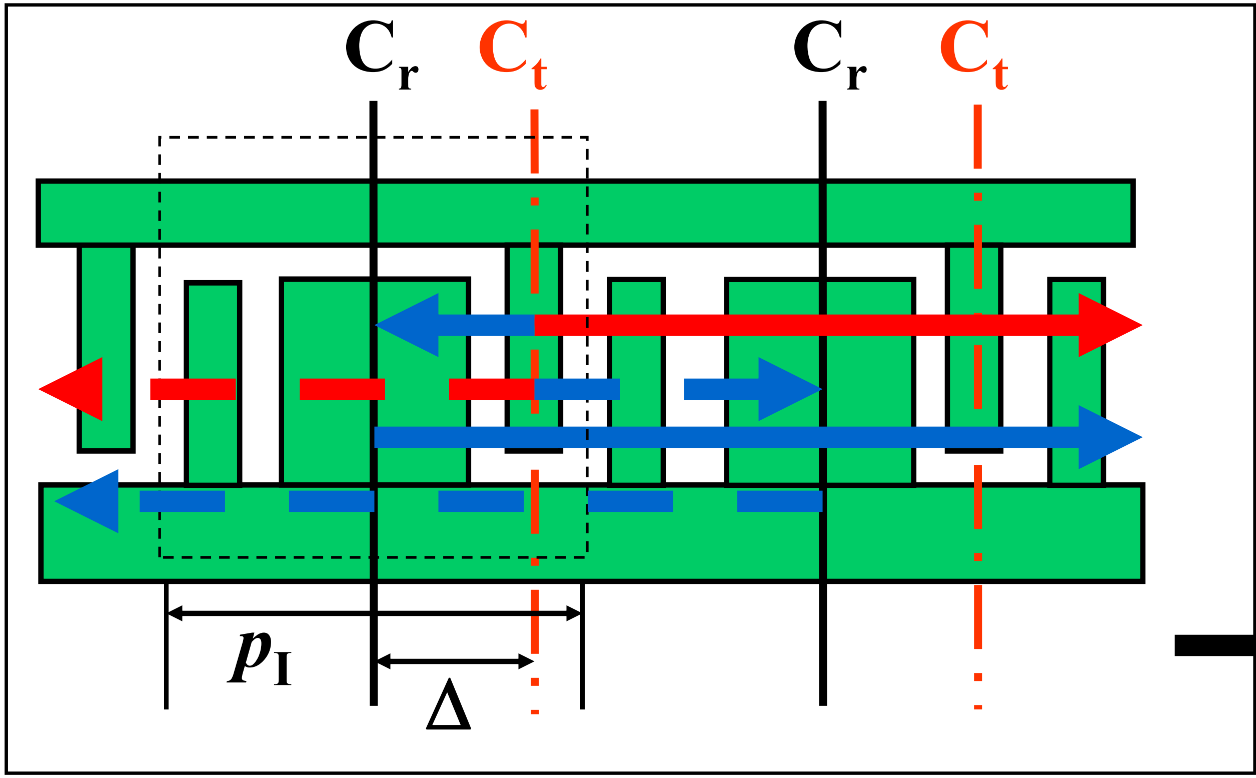


(b) Embedded Reflector
(Complex but Wideband)

- TTE Suppression
- Low Loss
- Frequency Response $\Rightarrow$ Weighting for Excitation Profile
- Reflection Bandwidth < IDT Bandwidth $\Rightarrow$ Reflector Weighting

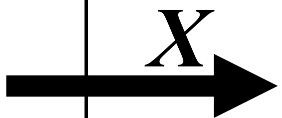
Independent Weighting to both Excitation and Reflection

Unidirectional Condition



C_t: Excitation Center

C_r: Reflection Center

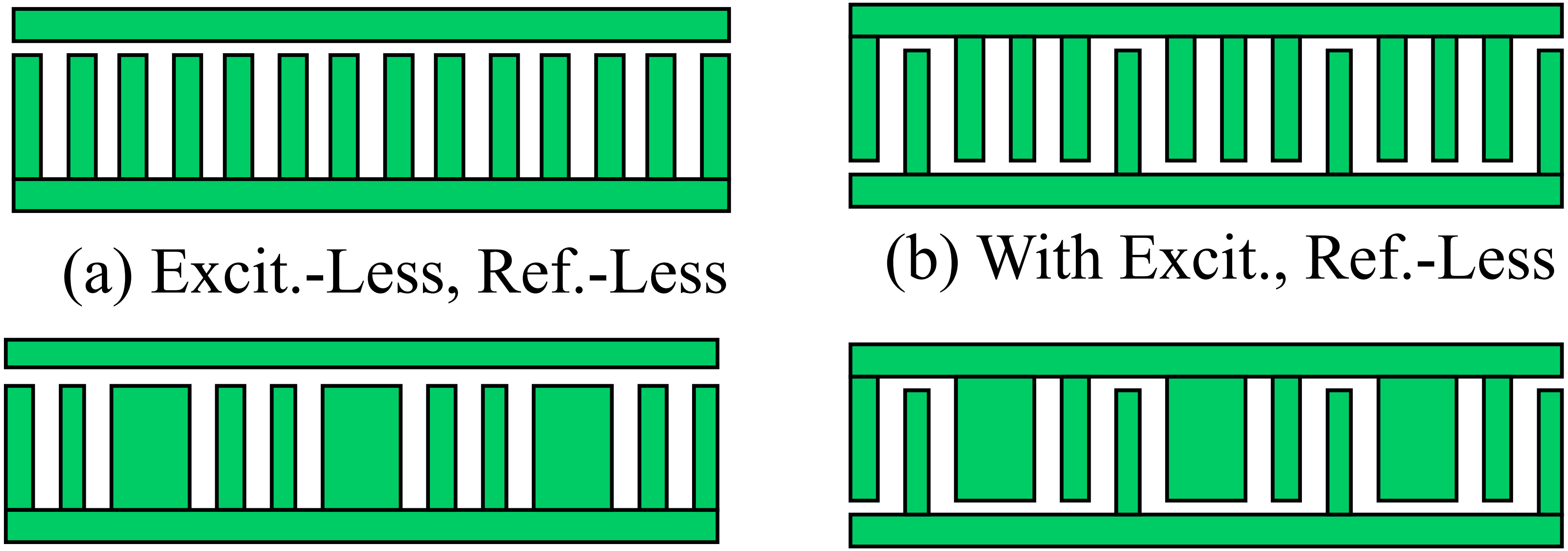


For $+X$ Direction, $\quad -2\beta\Delta + \angle\Gamma = 2m\pi$

For $-X$ Direction $\quad -2\beta(p_I - \Delta) + \angle\Gamma = (2n+1)\pi$

Unidirectional Cond. $\angle\Gamma = \pm\pi/2,\ \Delta = \pm\lambda/8$

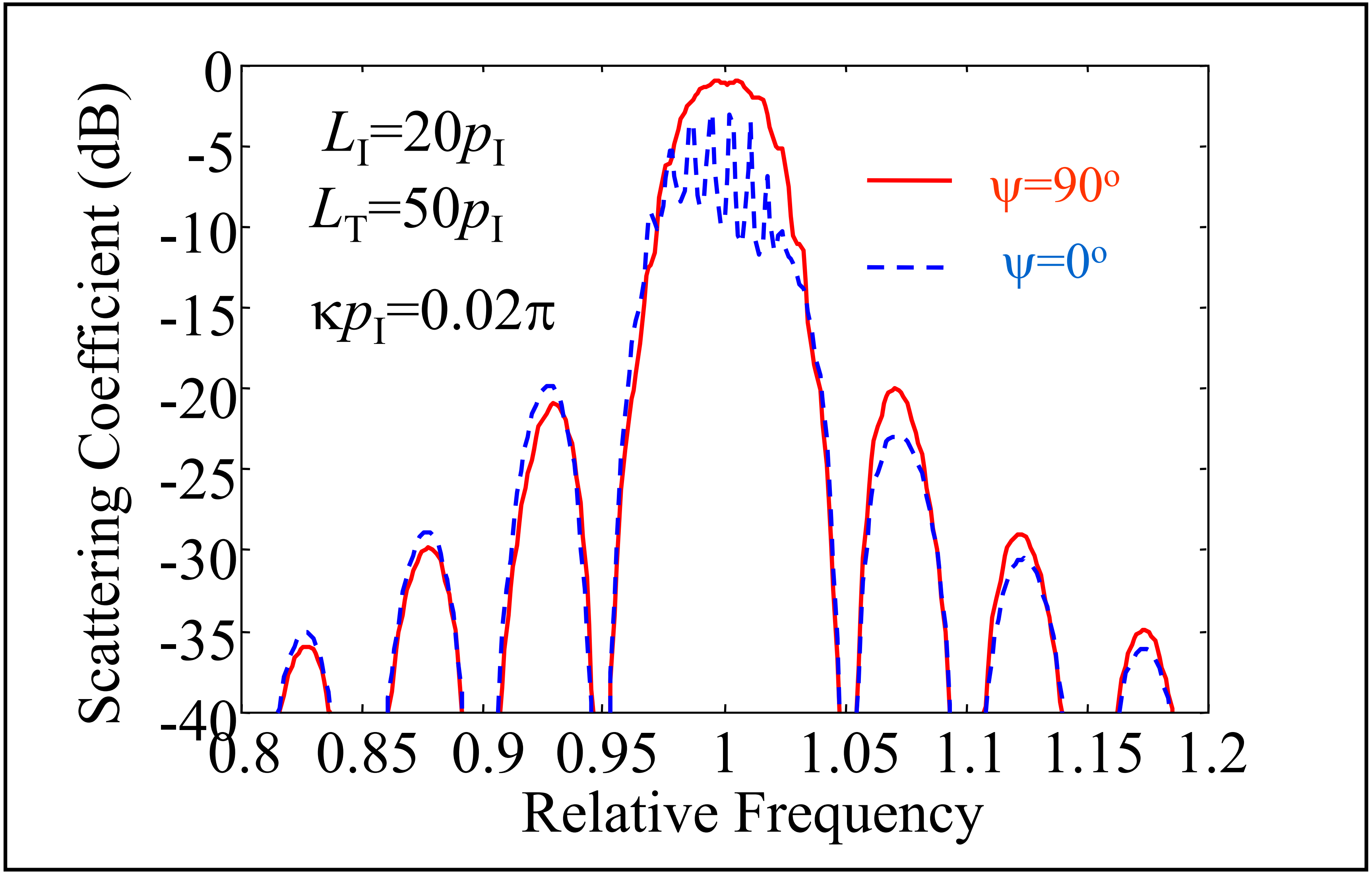
For Independent Weighting to Excitation and Reflection



(a) Excit.-Less, Ref.-Less
(b) With Excit., Ref.-Less
(c) Excit.-Less, With Ref.
(d) With Excit. & Ref.

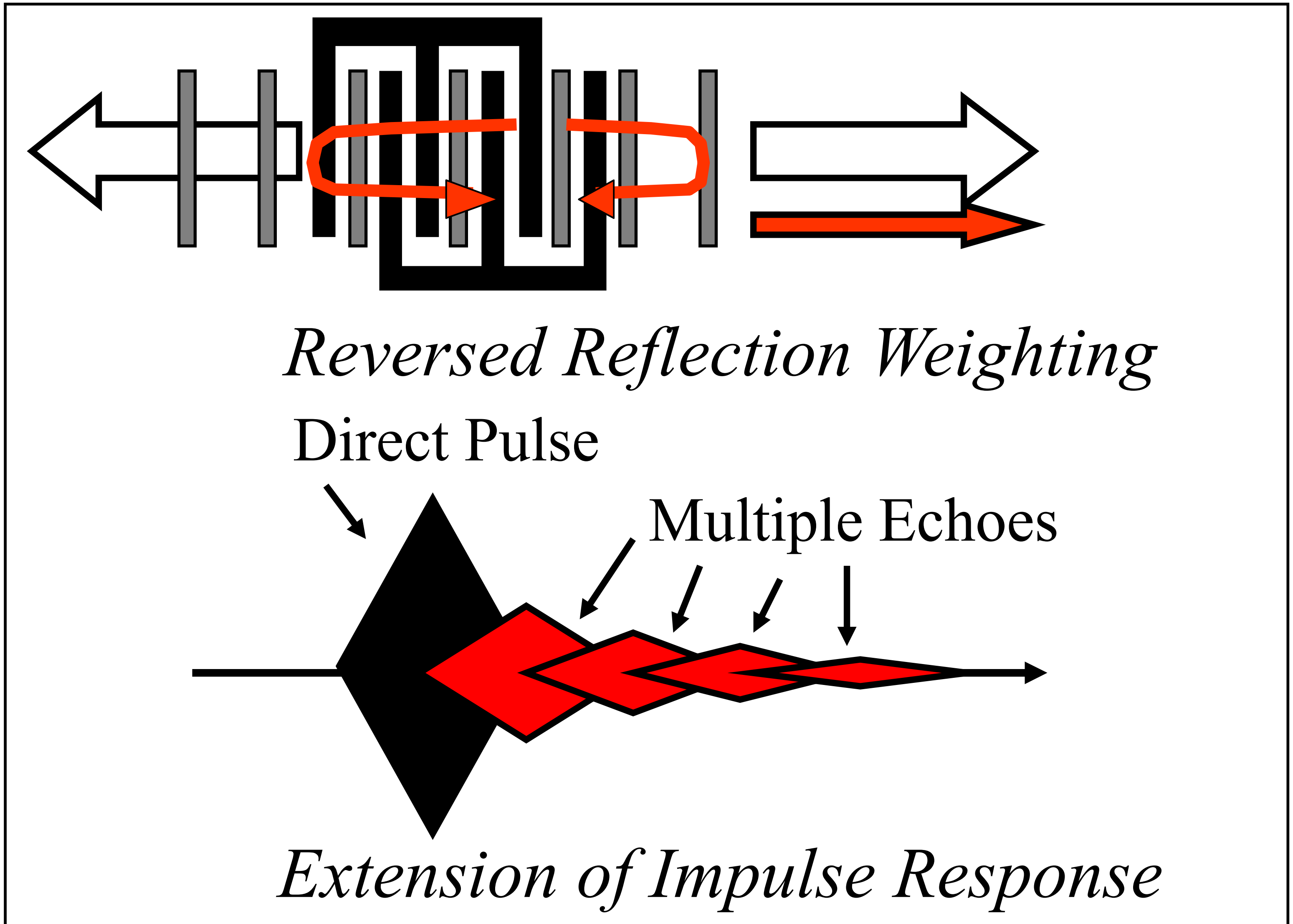
EWC(Electrode-Width-Control)/SPUDT

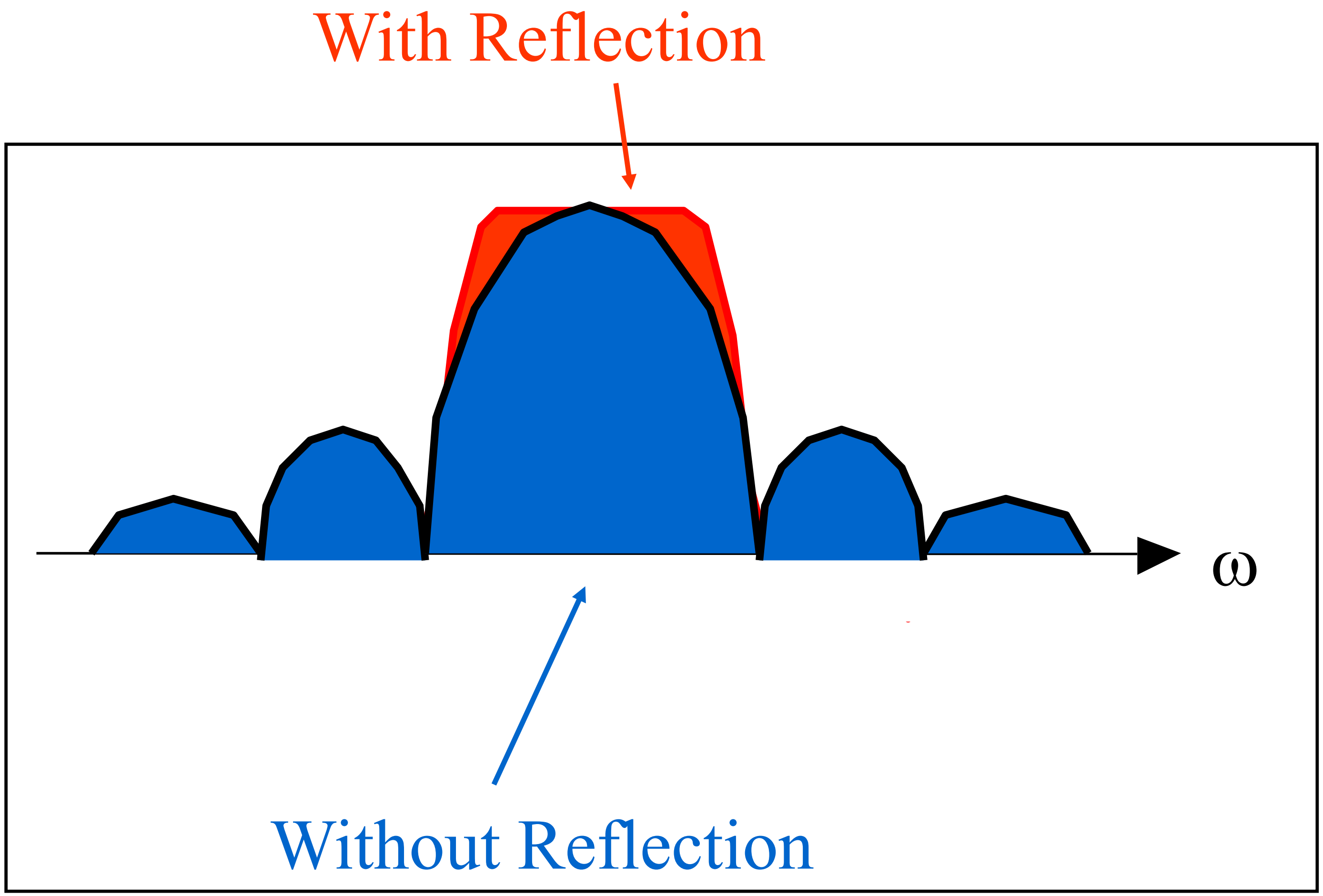
Filter Response with Reduced TTE



Low Loss and Suppressed TTE

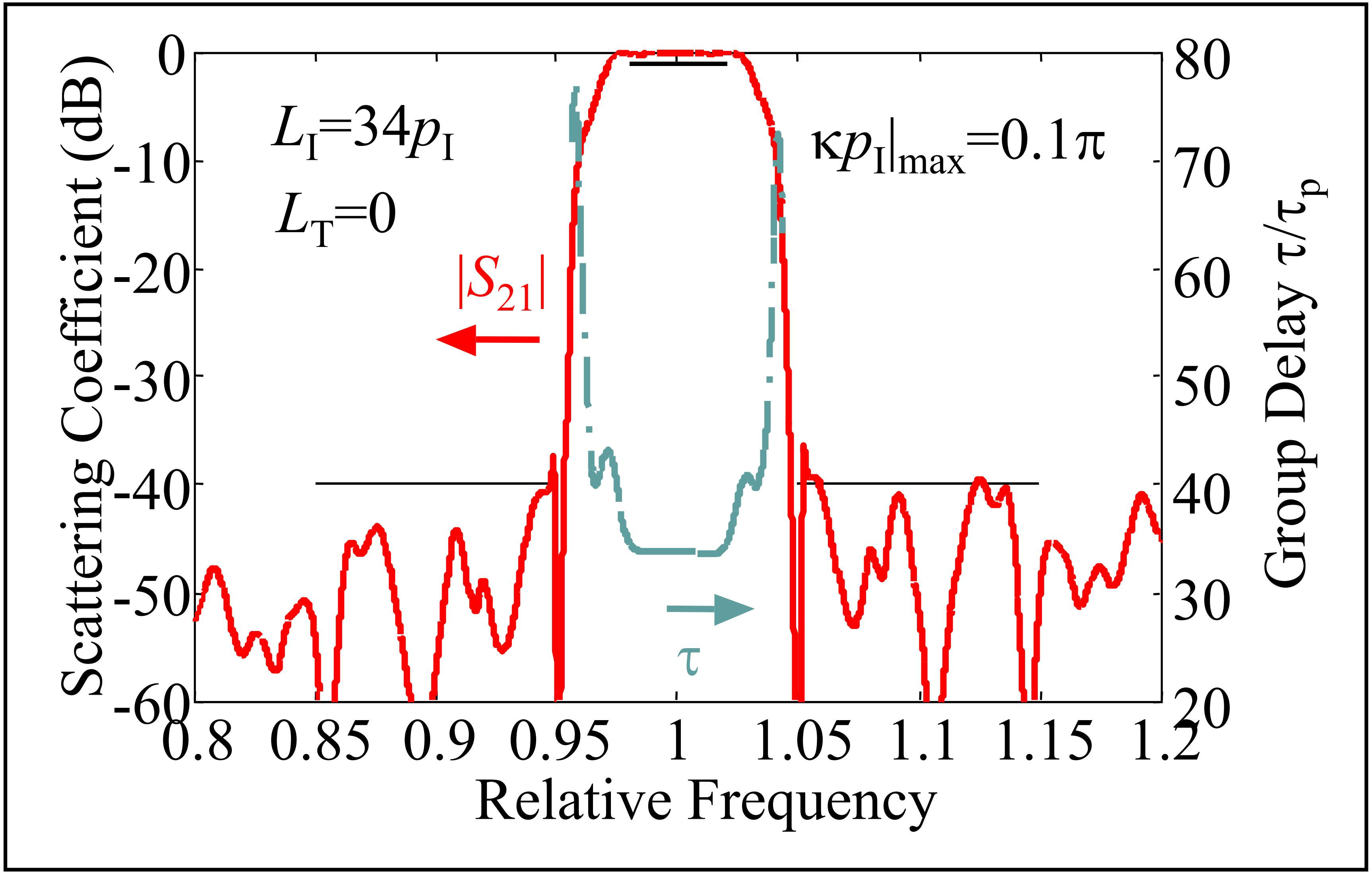
Resonant SPUDT (R-SPUDTs)





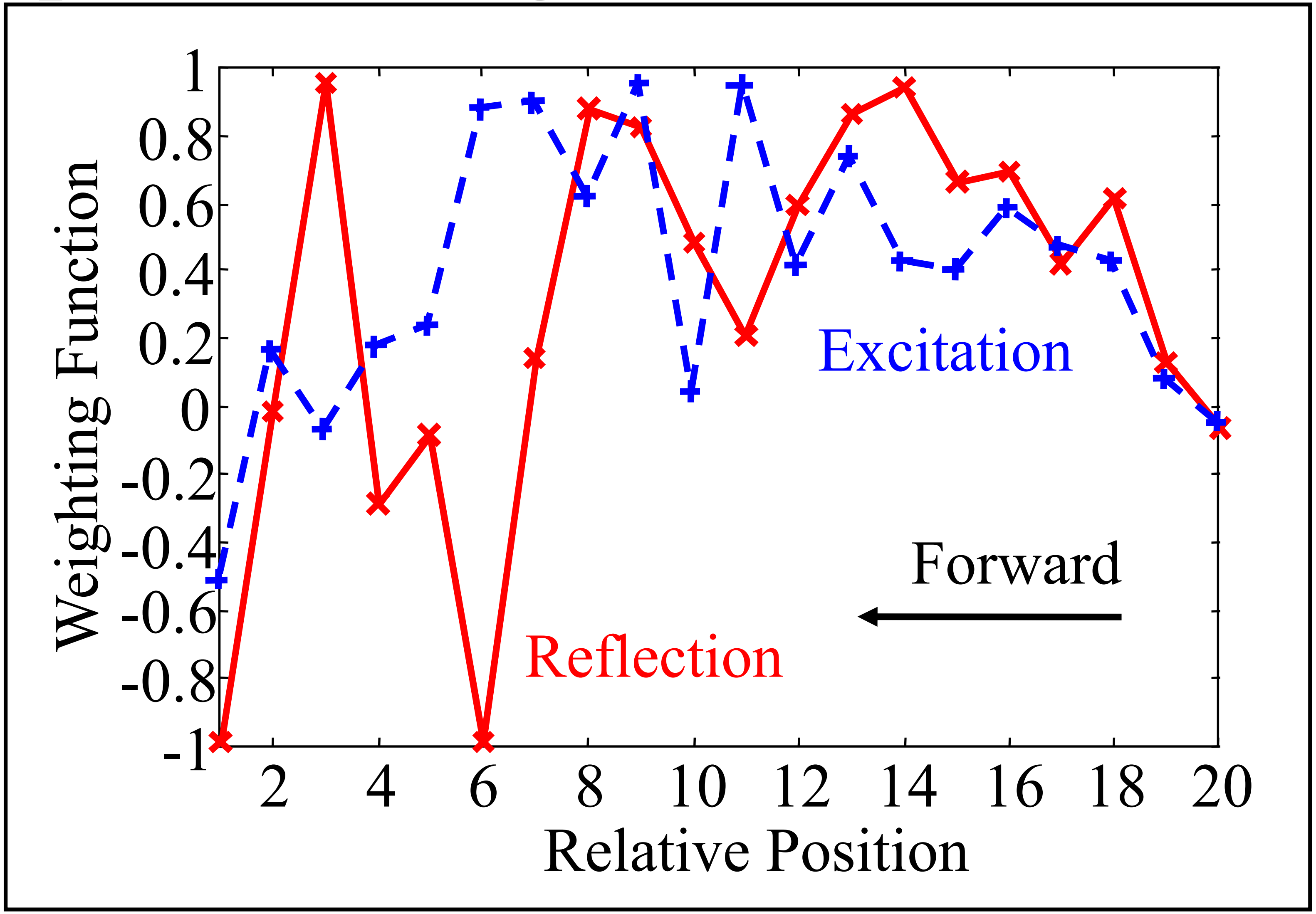
- **Skirt Characteristics are Defined by Impulse Response Length**
- **Out-of-Band Characteristics are Defined by Excitation Profile**

Designed Example

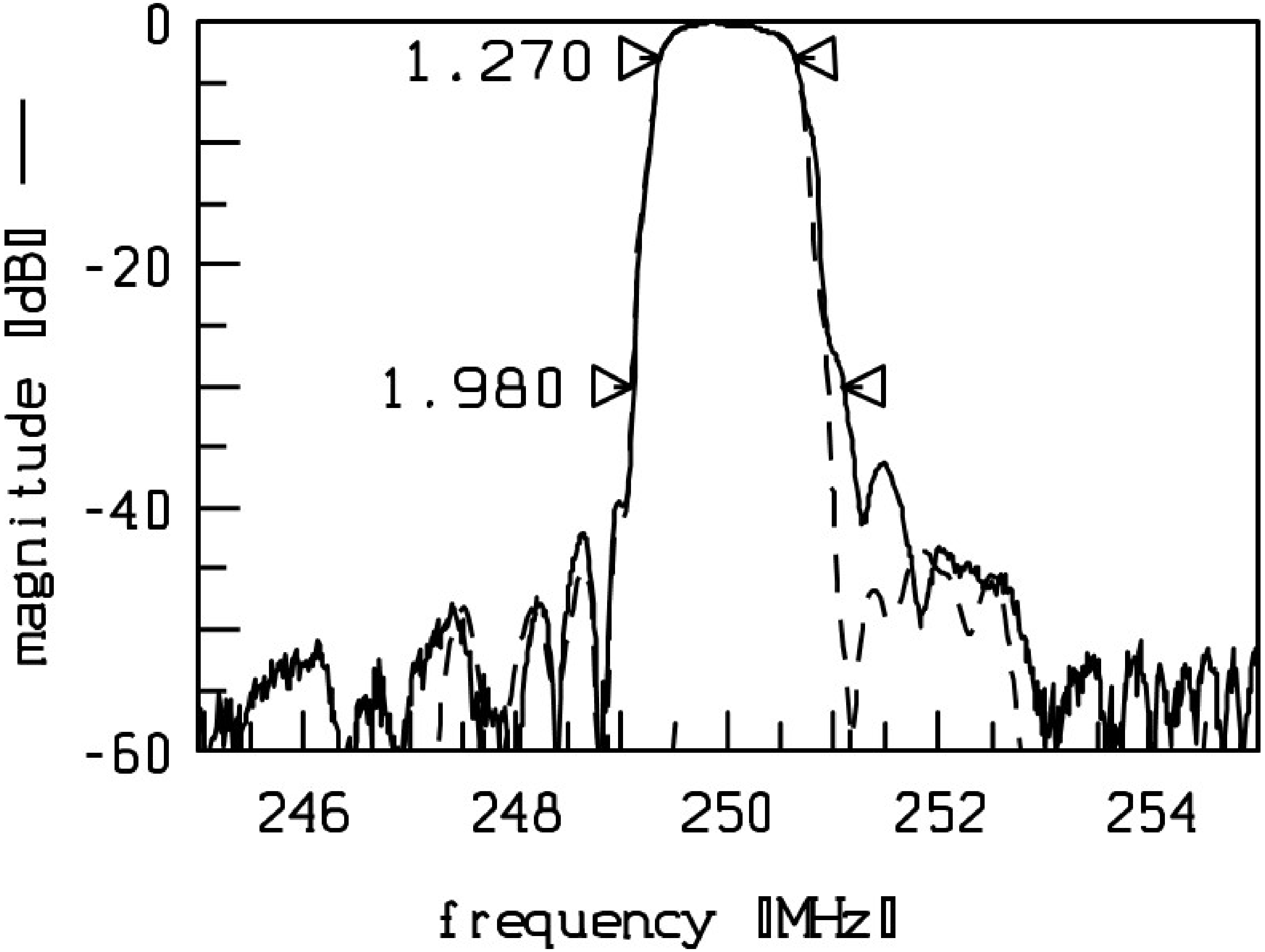


Sharp Passband Shape + Flat Group Delay

Optimized weighted function

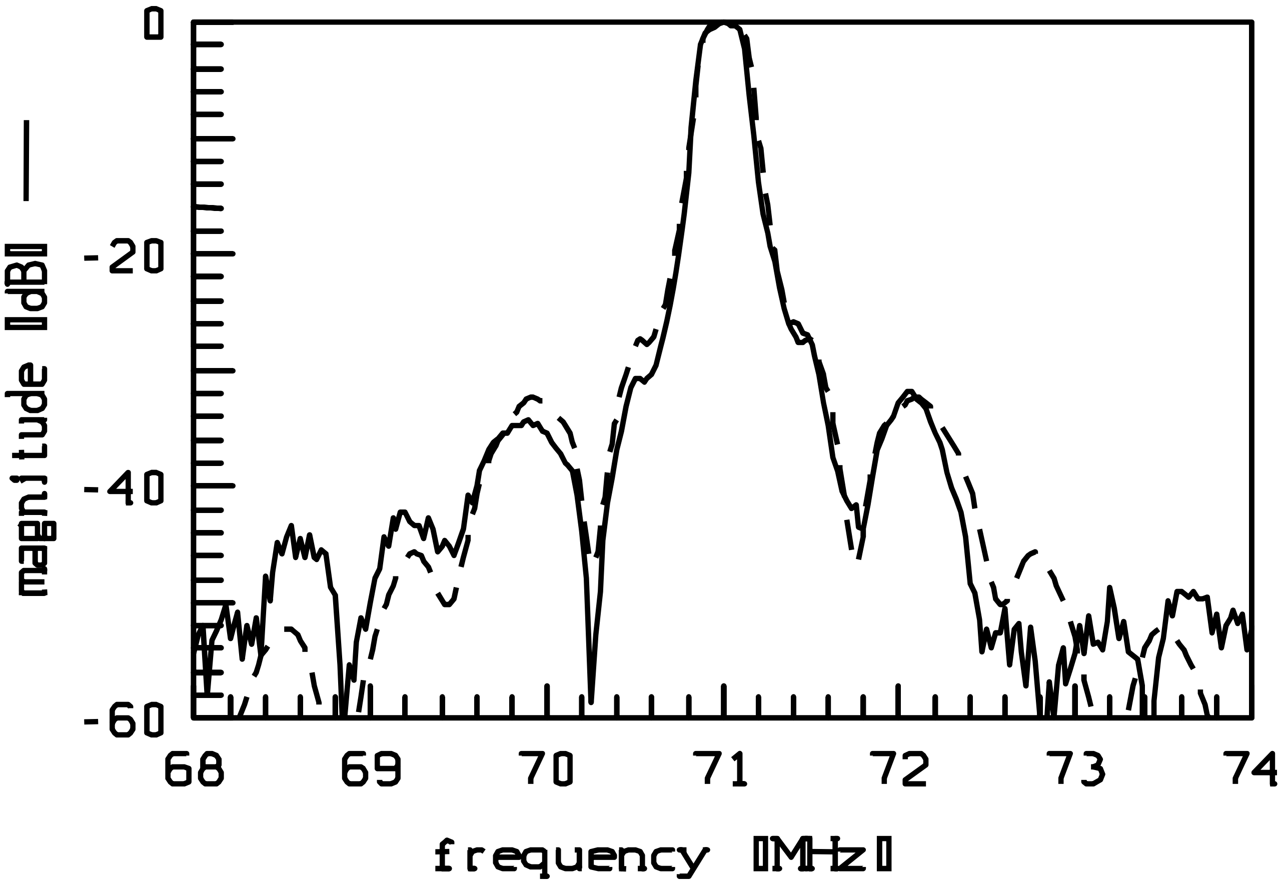


Weak Resonant SPUDT Filter



Courtesy of EPCOS AG

Strong Resonant SPUDT Filter

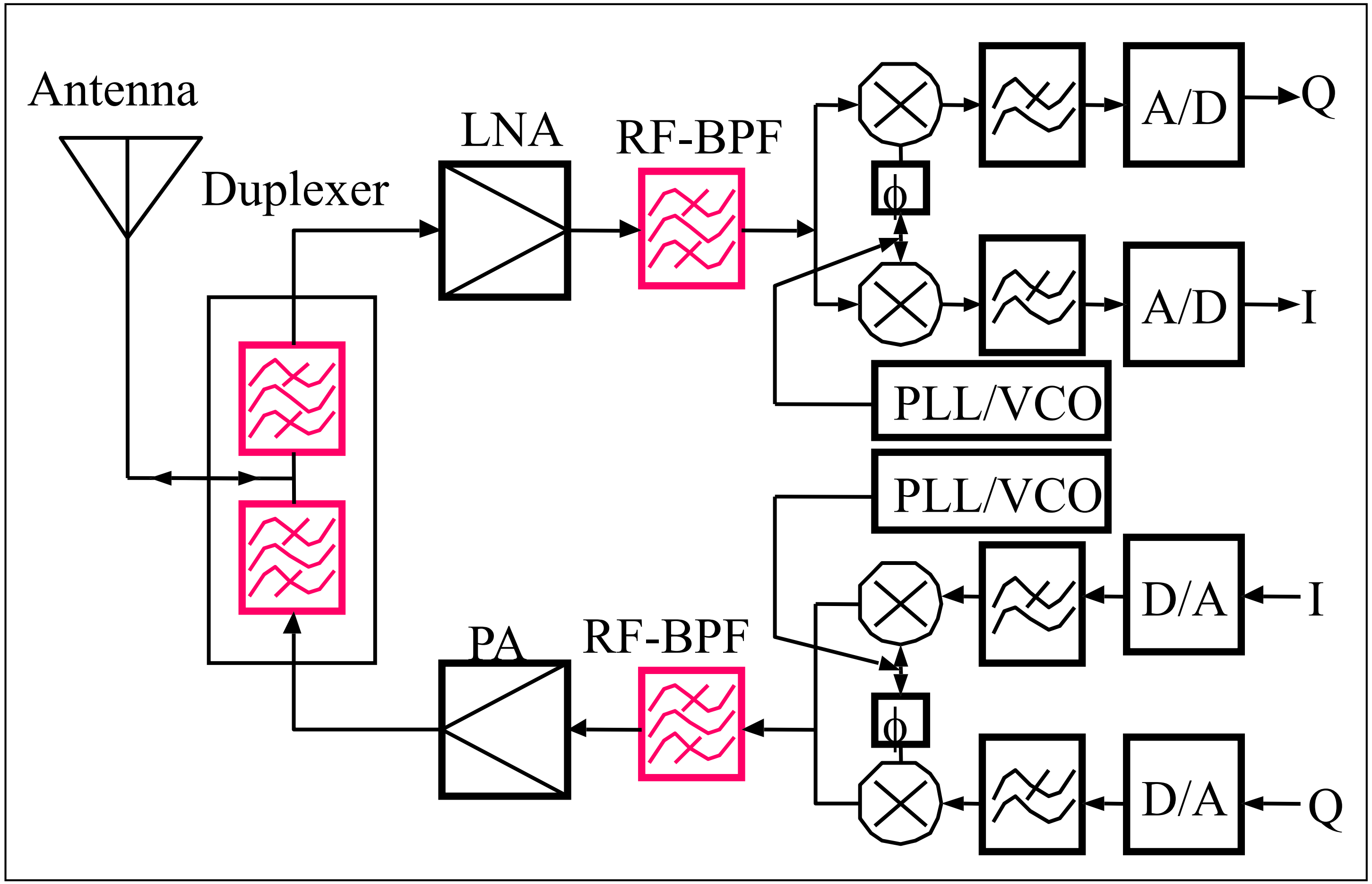


Courtesy of EPCOS AG

Contents

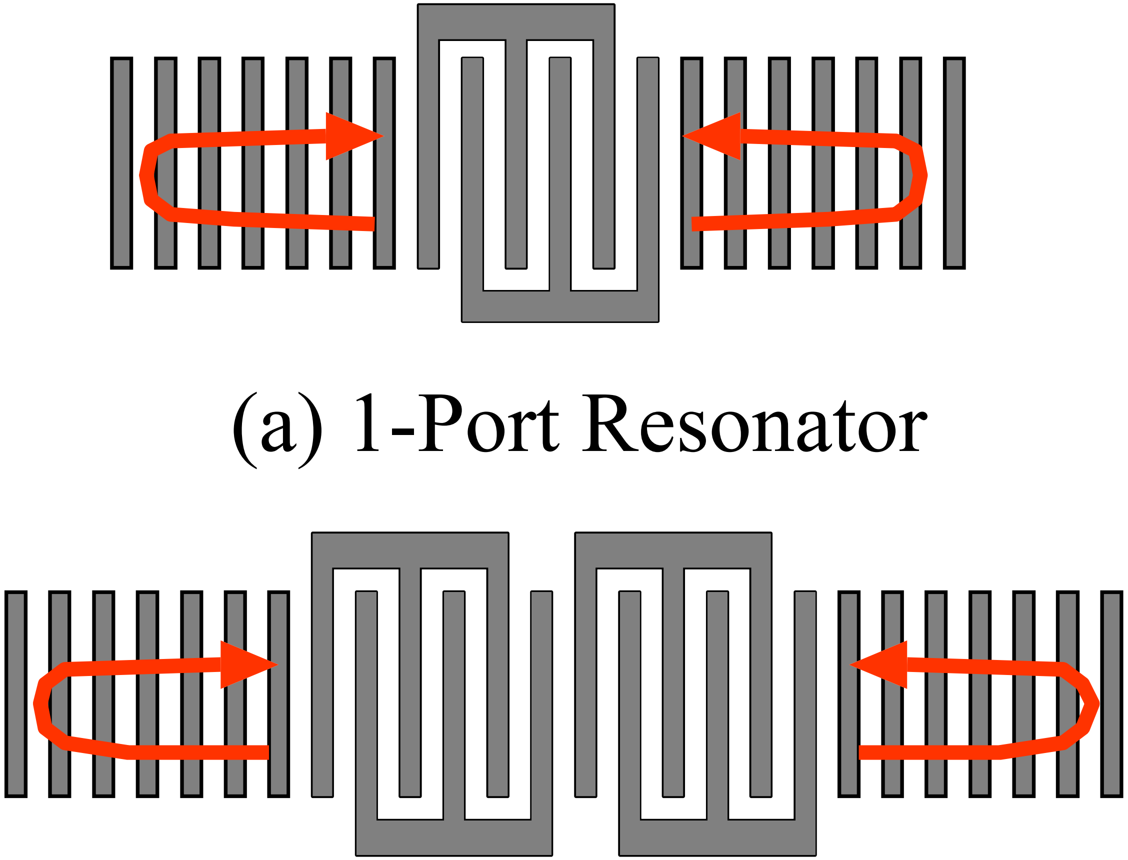
- SAW Resonator Filters

Homodyne Transceiver



- Circuit Simplification ⇒ Reducing Component Number
- No Image Signal ⇒ Relaxing Specs to RF Filters

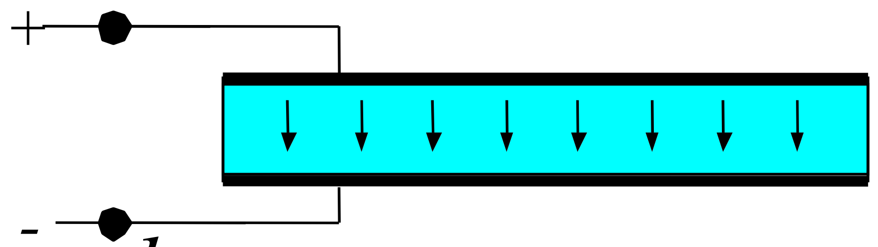
SAW Resonator



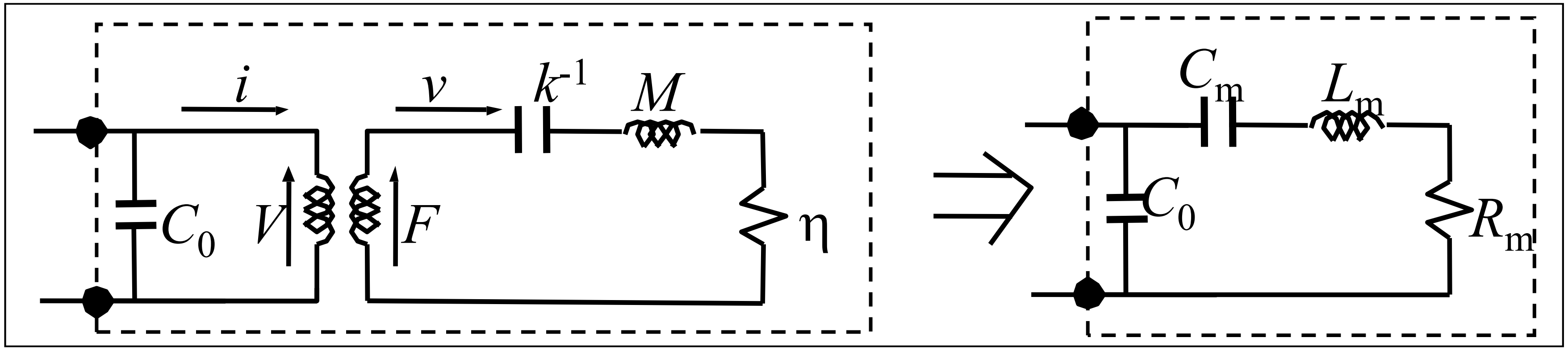
(a) 1-Port Resonator

(b) 2-Port Resonator Filter

Application of Electric Field to Piezoelectric Material,



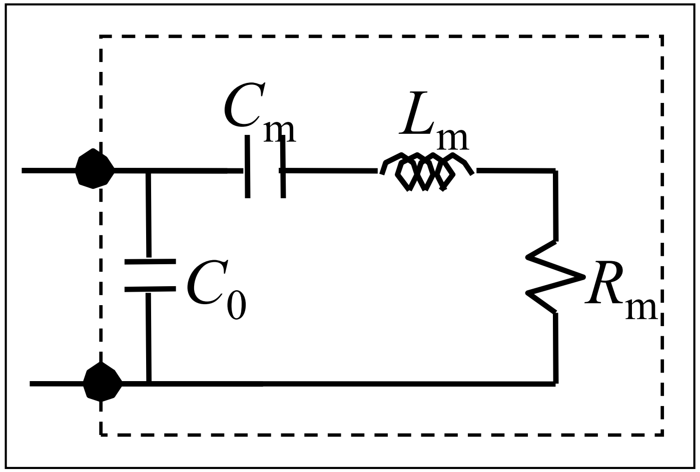
$$M\frac{dv}{dt}+\eta v+k\int v\,dt=F\propto V$$



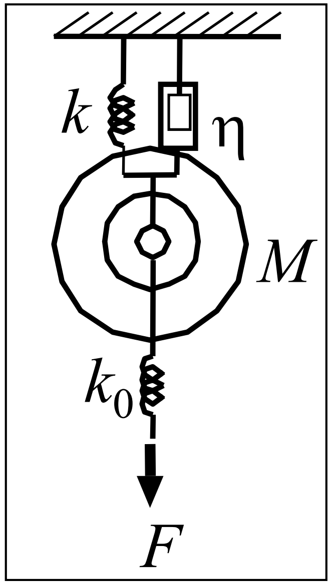
(a) Electric + Mechanical Circuit ***(b) Electrical Equiv. Circuit***

Analogies between $V \Leftrightarrow F$ and $I \Leftrightarrow v$ *reduce to*

$$M \Leftrightarrow L,\ \eta \Leftrightarrow R,\ k \Leftrightarrow 1/C$$



(a) **Electrical Equiv. Circuit**



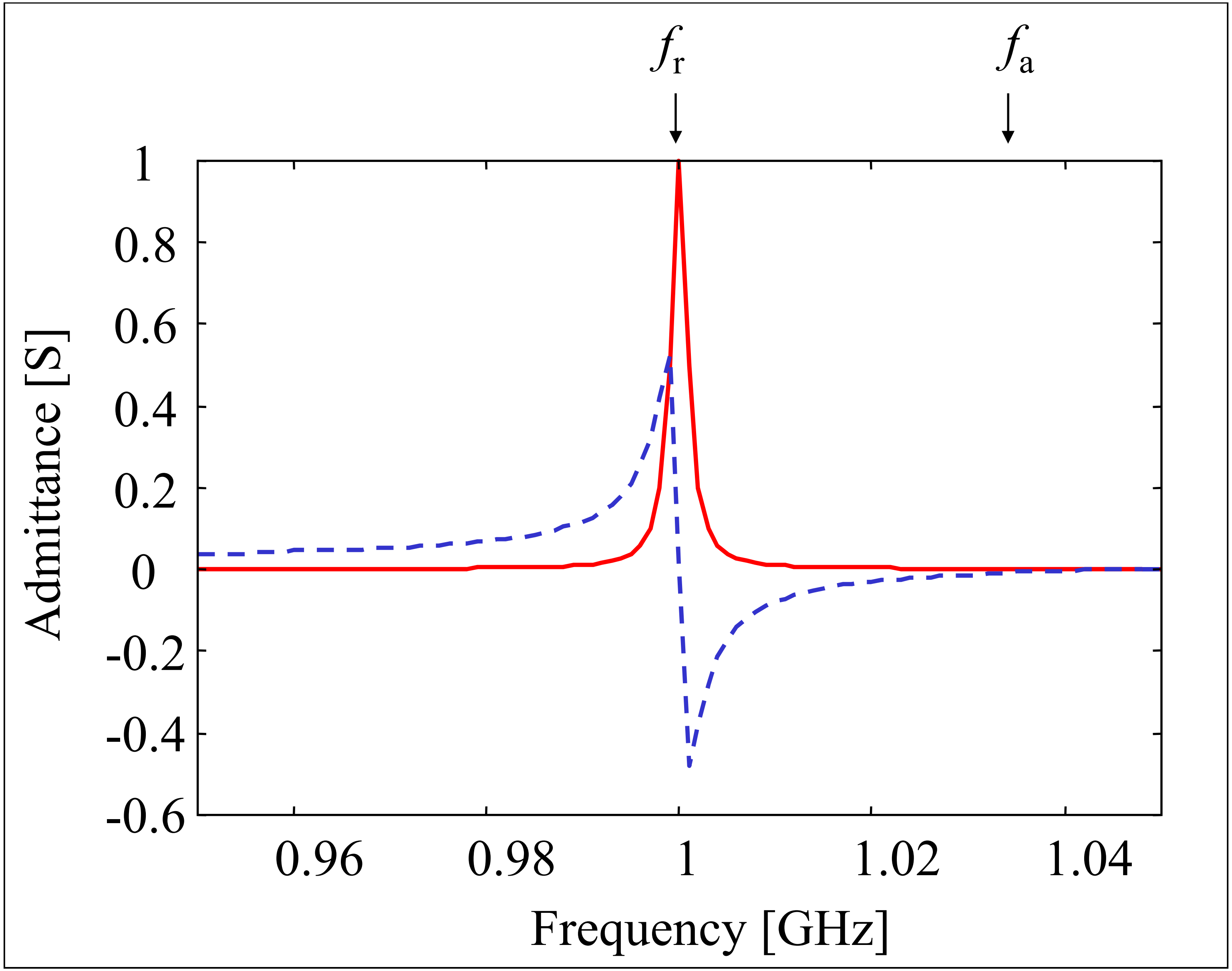
(b) **Equiv. Mechanical Circuit**

- Resonance Frequency $\omega_r = 1/\sqrt{C_m L_m}$
- Anti-Resonance Frequency $\omega_a = 1/\sqrt{L_m (C_m^{-1} + C_0^{-1})^{-1}}$
- Resonance Q (Steepness of Resonance) $Q = \omega_r L_m / R_m$

  ⇒ Determine Insertion Loss and Skirt Characteristics
- Capacitance Ratio (Weakness of Piezoelectricity)

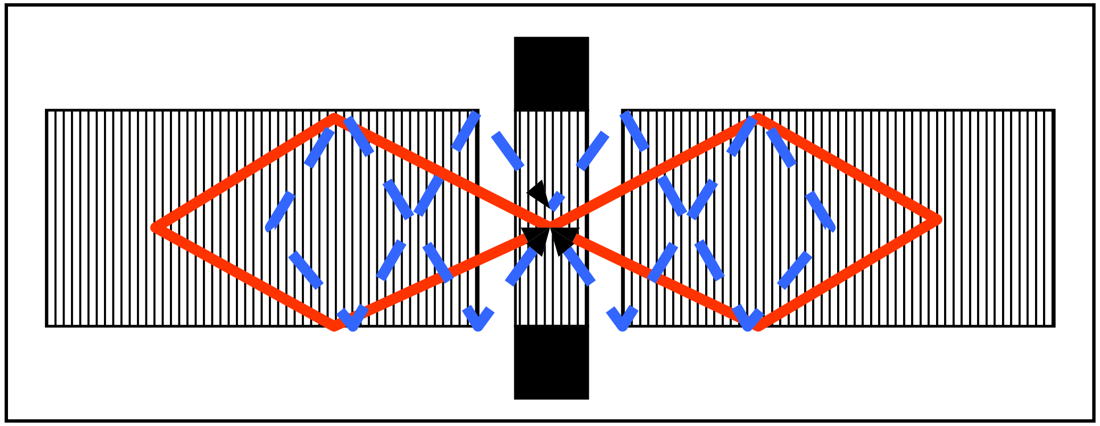
$$\gamma = C_0/C_m = [(\omega_a/\omega_r)^2 - 1]^{-1}$$

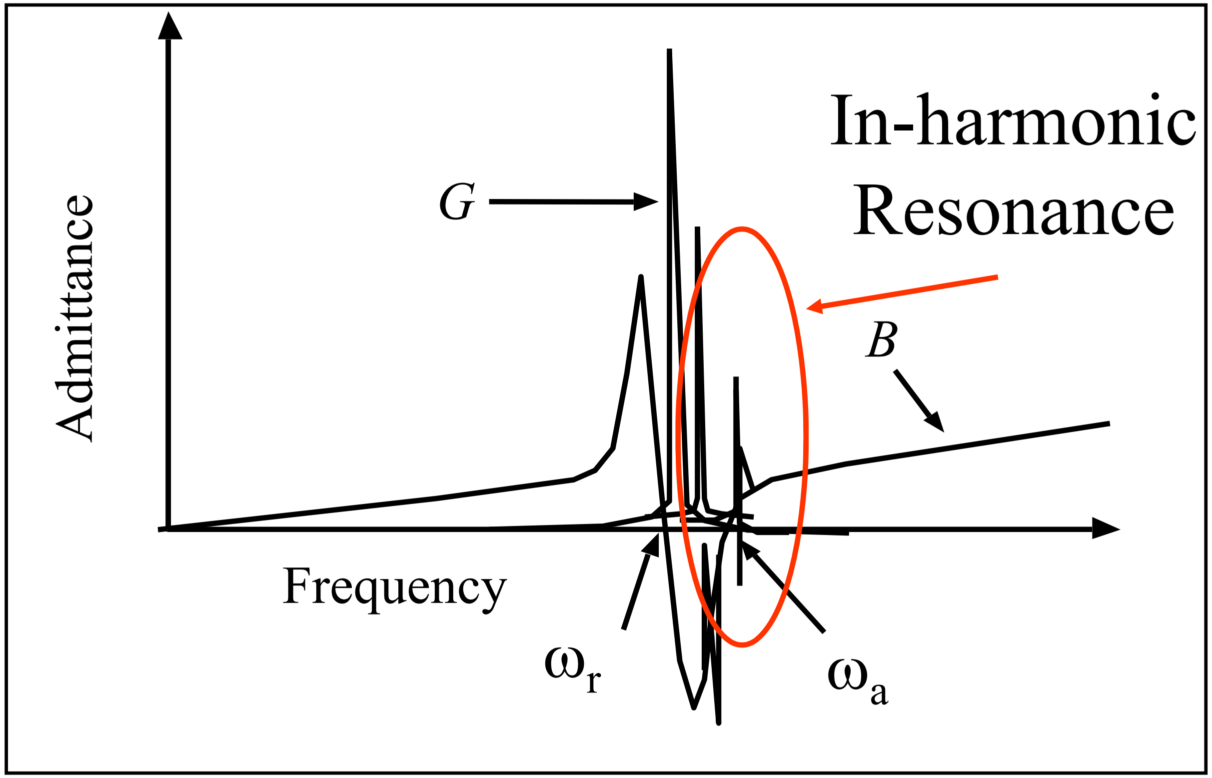
  ⇒ Determine Insertion Loss and Bandwidth



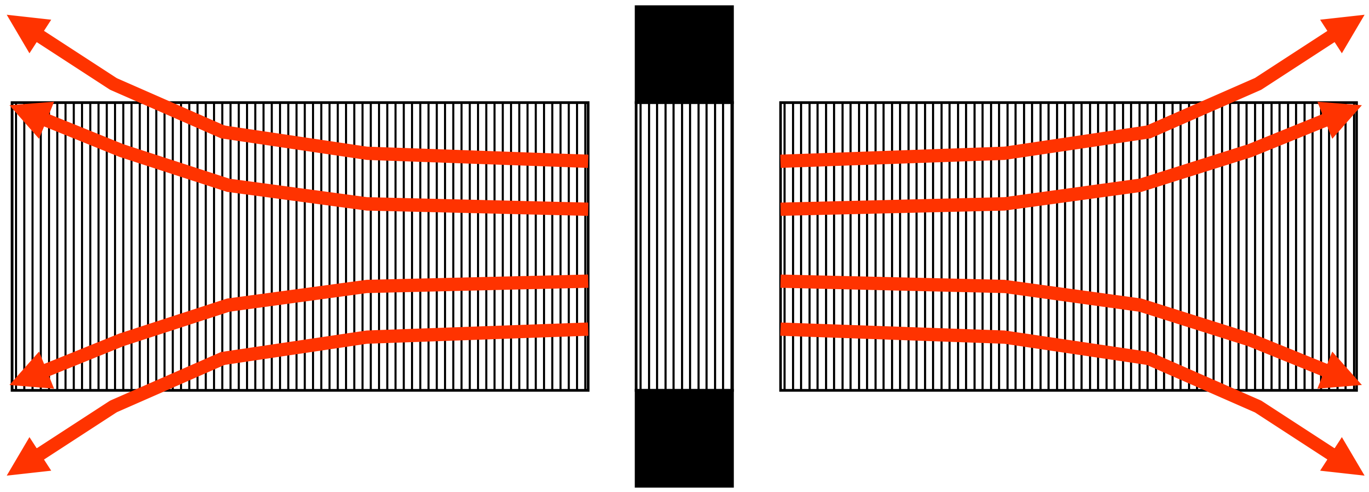
- Resonance Frequency $\omega_r = 1/\sqrt{C_m L_m}$
- Anti-Resonance Frequency $\omega_a = 1/\sqrt{L_m (C_m^{-1} + C_0^{-1})^{-1}}$

Transverse Mode

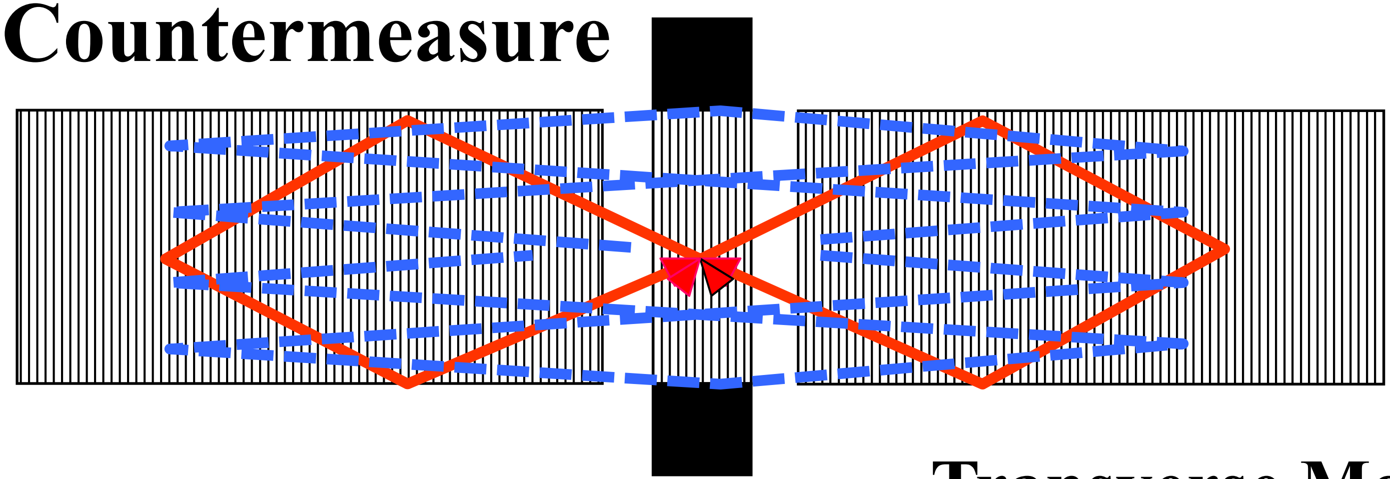




Influence of Diffraction

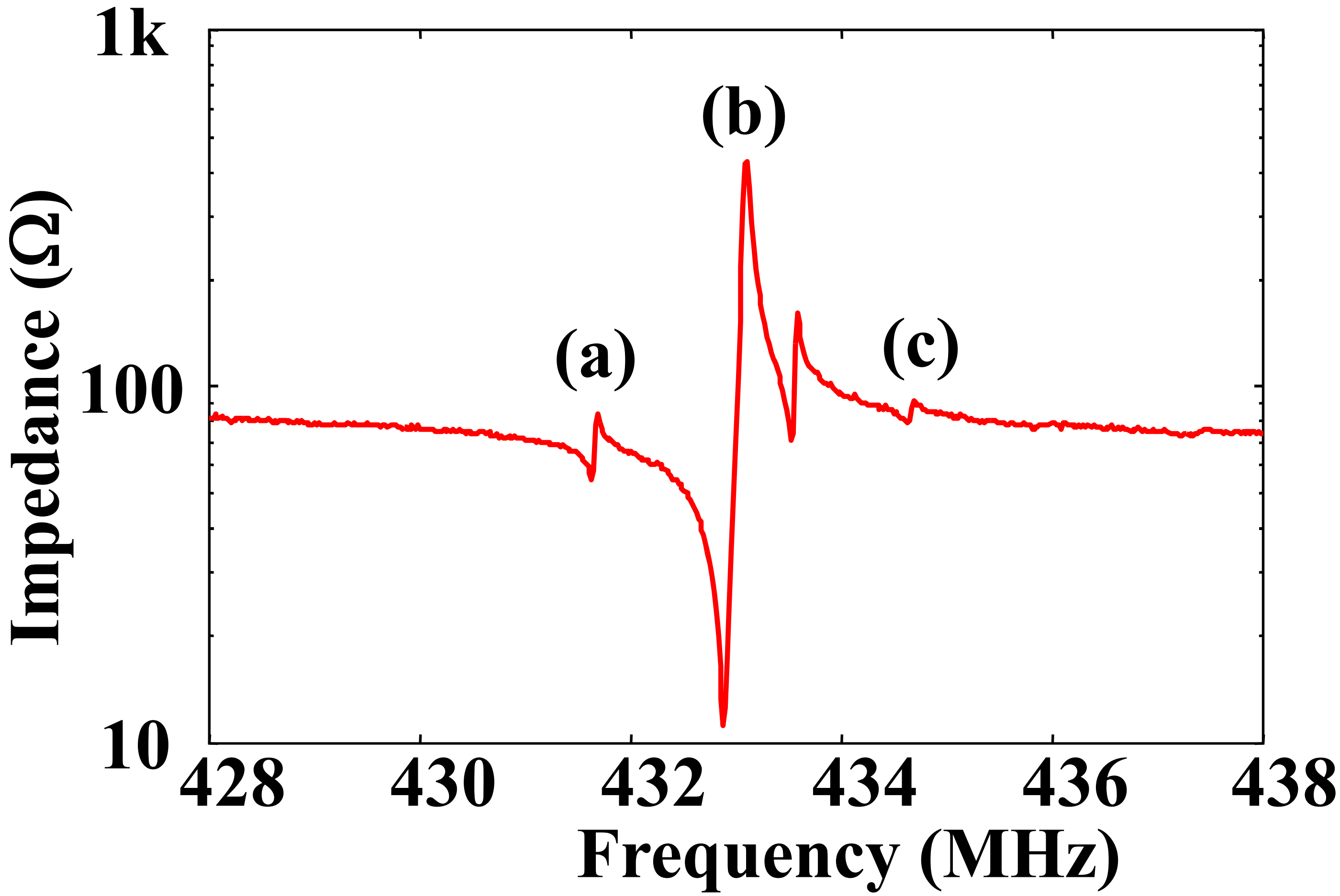


Countermeasure

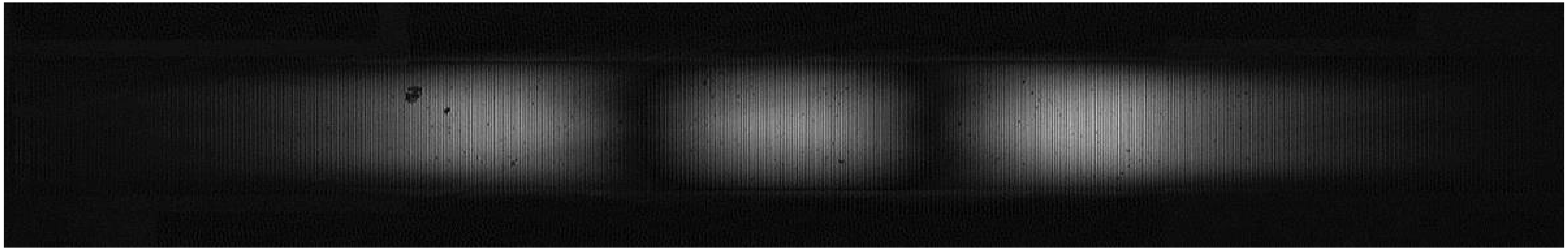


Transverse Modes

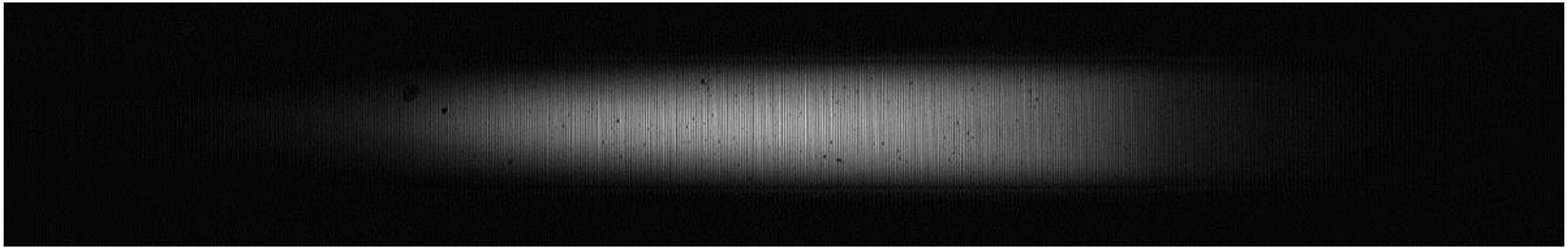
SAW Resonator on Quartz



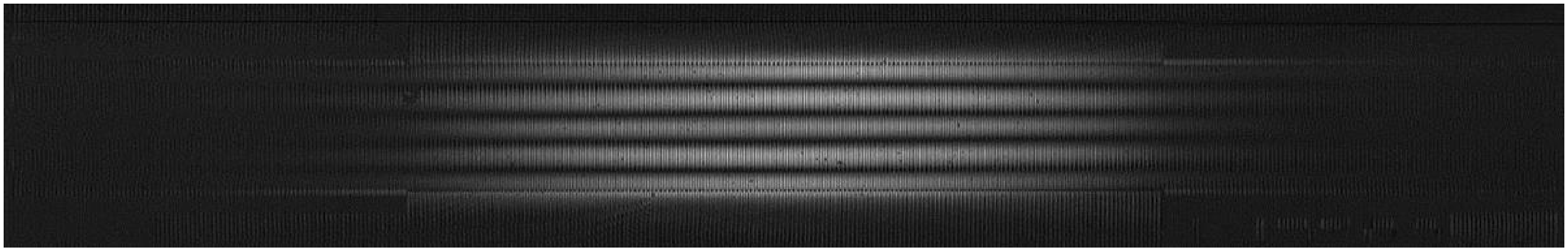
Field Distribution Observed by Laser Probe



431.625 MHz

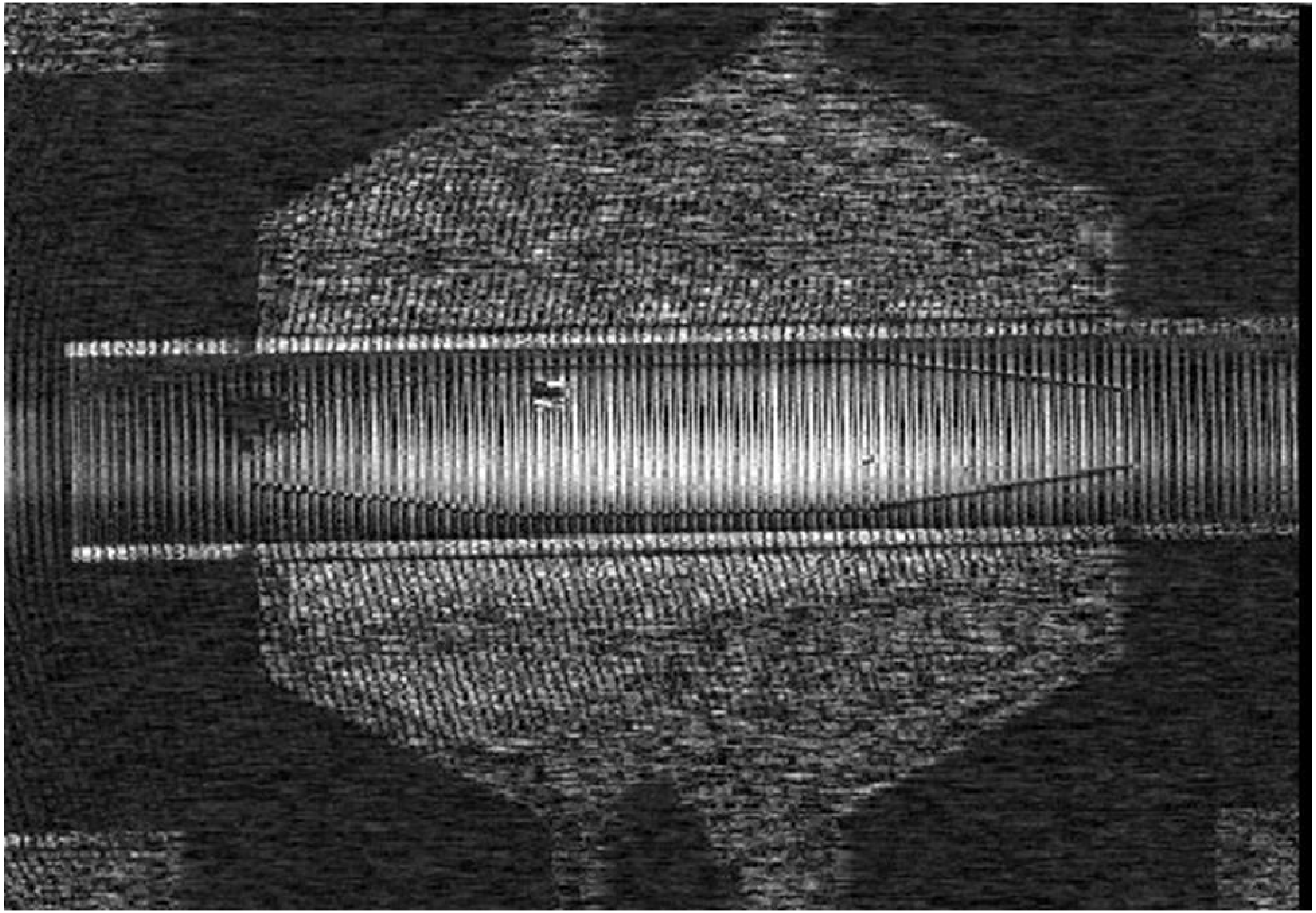


433.00 MHz

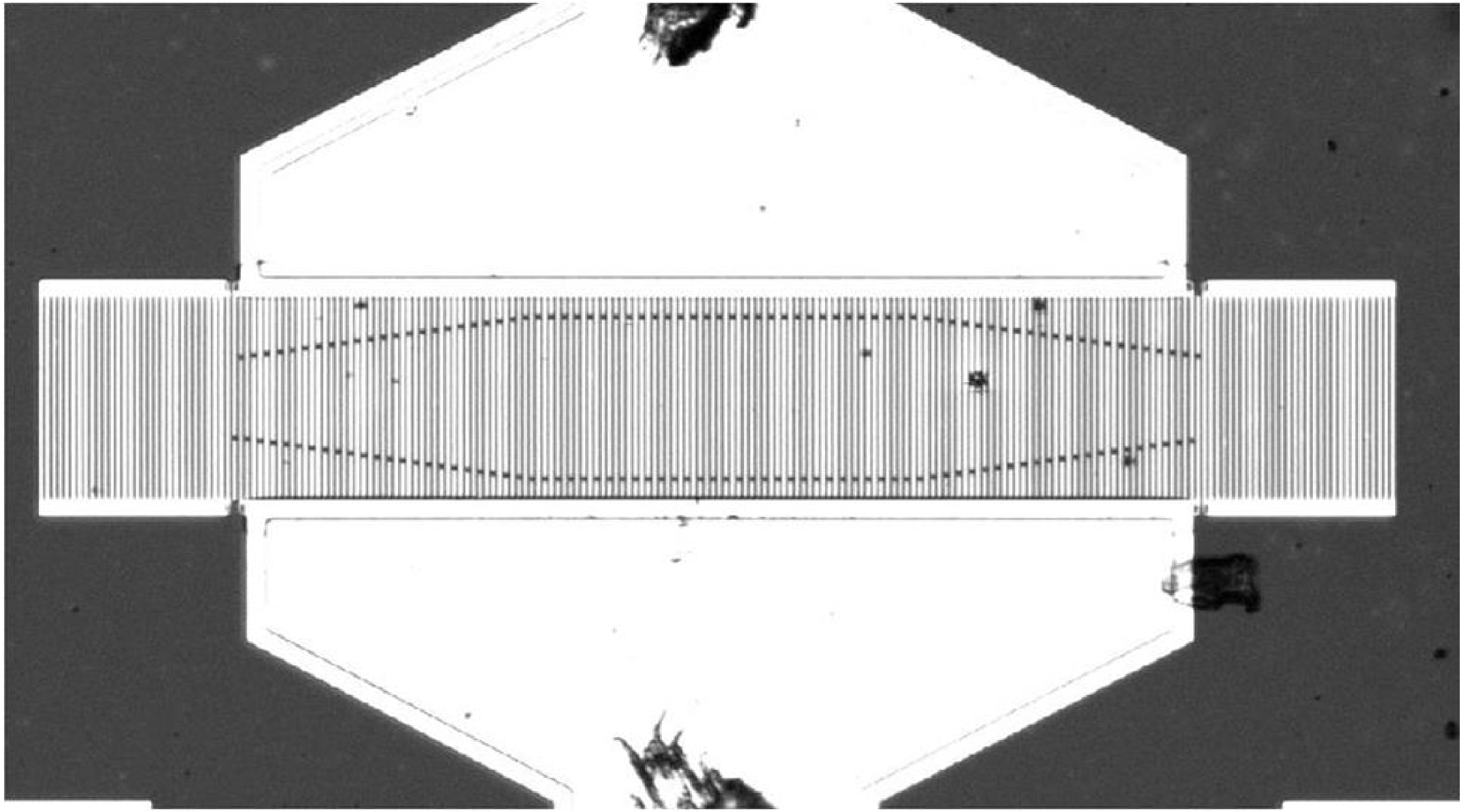


434.635 MHz

Power Leakage to Bus Bar Regions



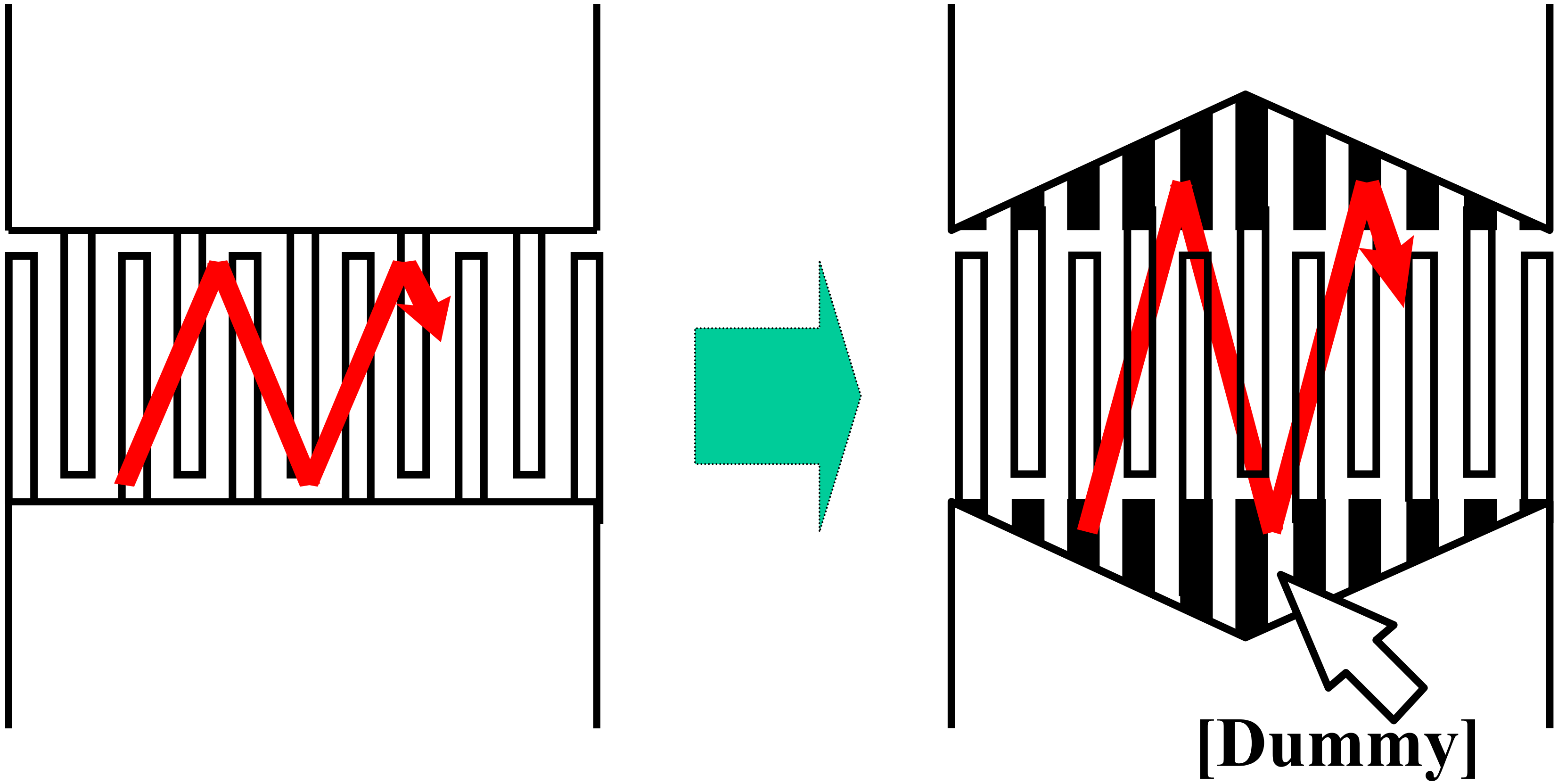
IDT Apodize



Reduction of Excitation Efficiency for Higher Modes

Loss Increase by Scattering at Discontinuities

Dummy Electrode Weighting

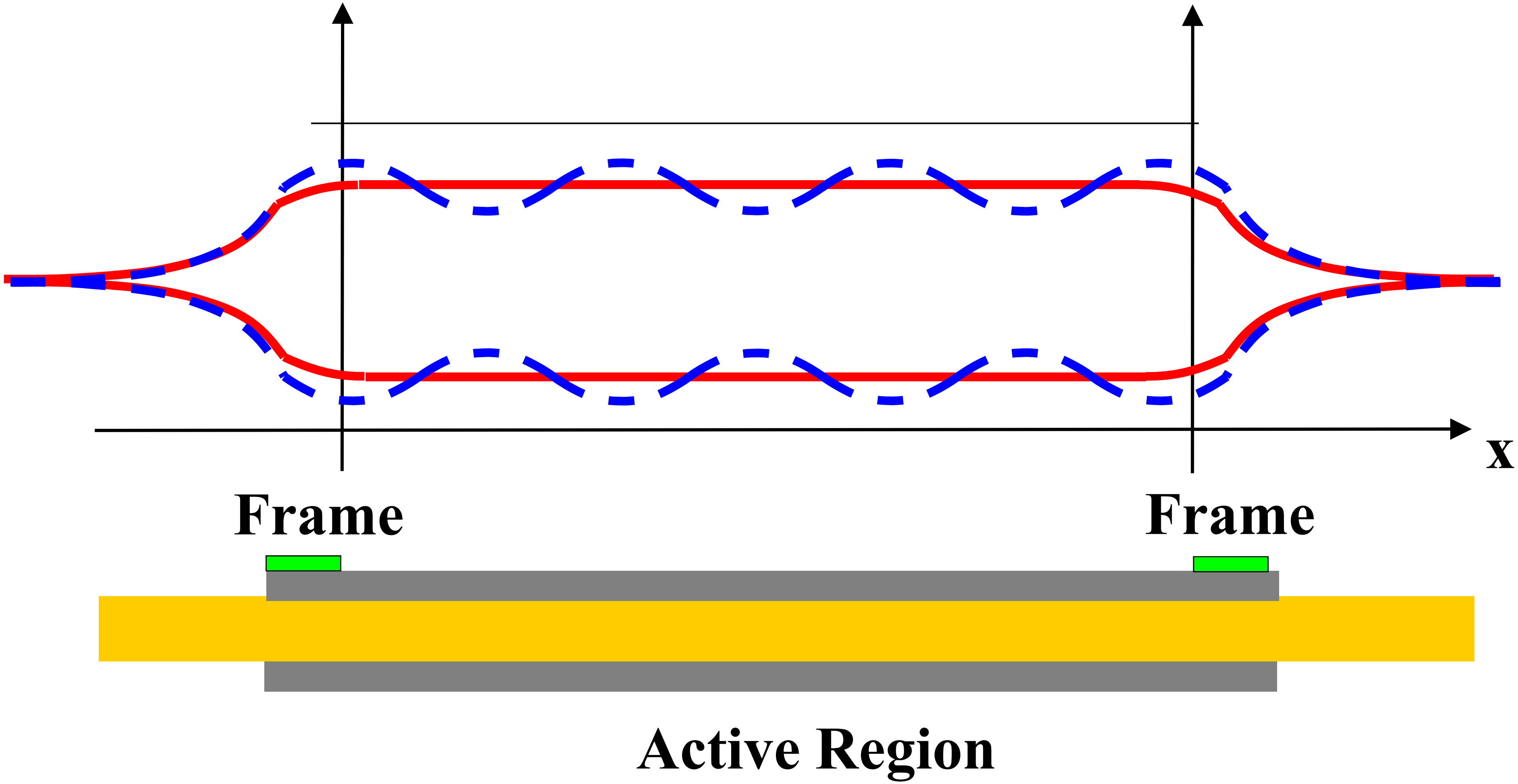


Reflection at Gaps ⇒ Strong Wave Confinement

Spurious Modes Penetration ⇒ Leakage to Bus Bar Regions

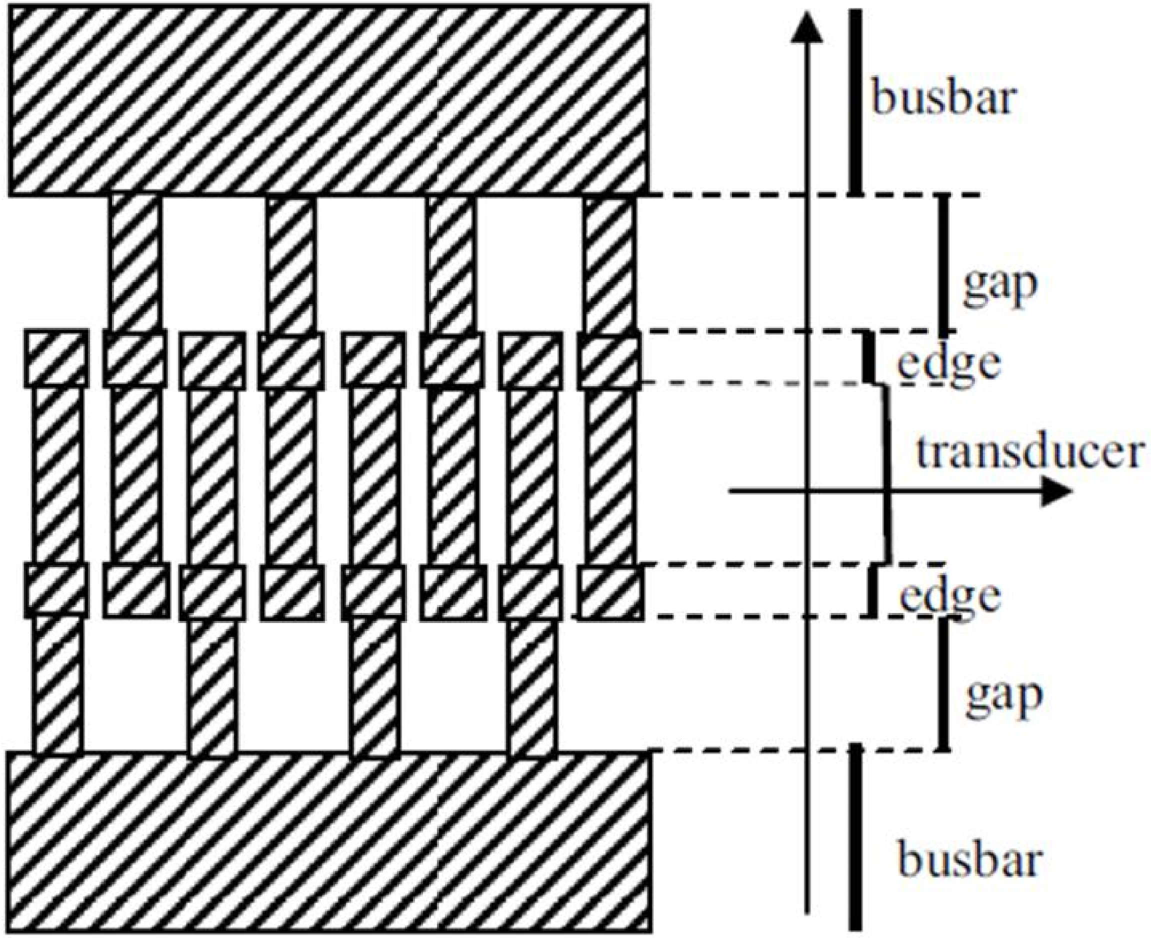
T.Omori, K.Matsuda, N.Yokoyama, K.Hashimoto, and M.Yamaguchi, "Suppression of Transverse Mode Responses in Ultra-Wideband SAW Resonators Fabricated on a Cu-grating/15^{o}YX-LiNbO$_3$ Structure", IEEE Trans. Ultrason., Ferroelec., and Freq. Contr., 54, 10 (2007) pp. 1943-1948.

Piston Mode BAW Resonator



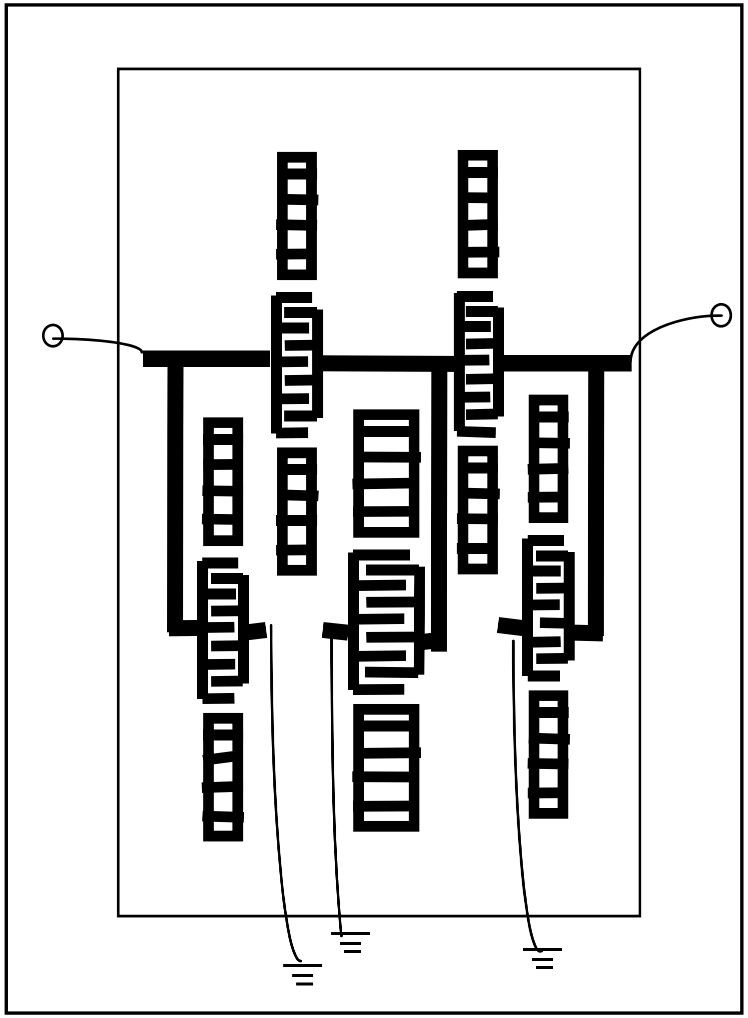
R.Thalhammer, J.Kaitila, S.Zieglmeier, and L.Elbrecht, "Spurious mode suppression in BAW resonators," Proc. IEEE Ultrason. Symp. (2006) pp. 456-459

Piston Mode SAW Resonator

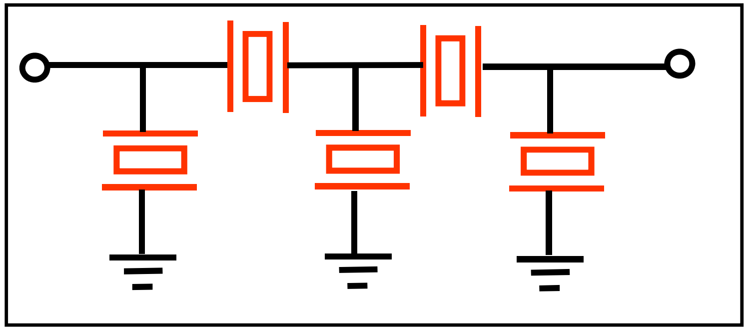


M.Solal , J.Gratier, R.Aigner, K.Gamble, B.Abbott, T.Kook, A.Chen, and K.Steiner, "Transverse modes suppression and loss reduction for buried electrodes SAW devices," Proc. IEEE Ultrason. Symp. (2010) pp. 624-628

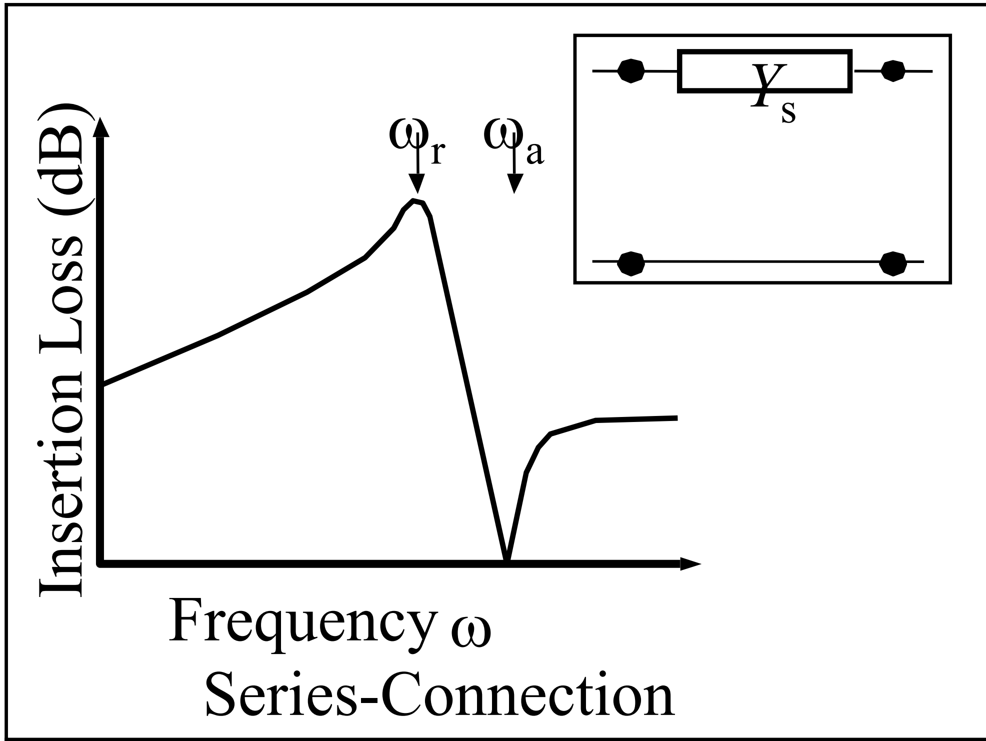
Ladder-Type SAW Filter

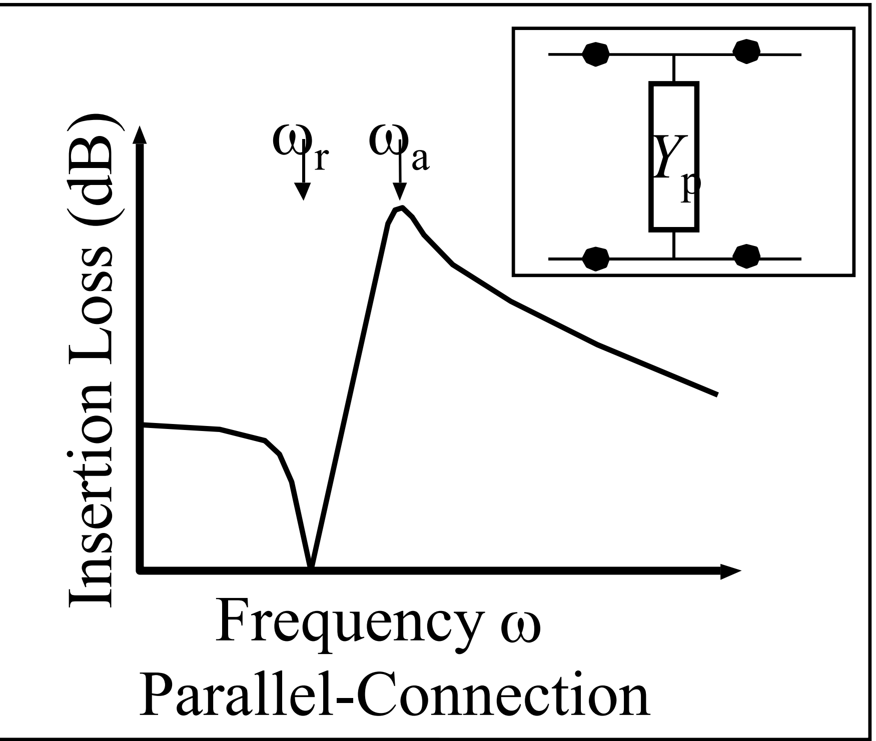


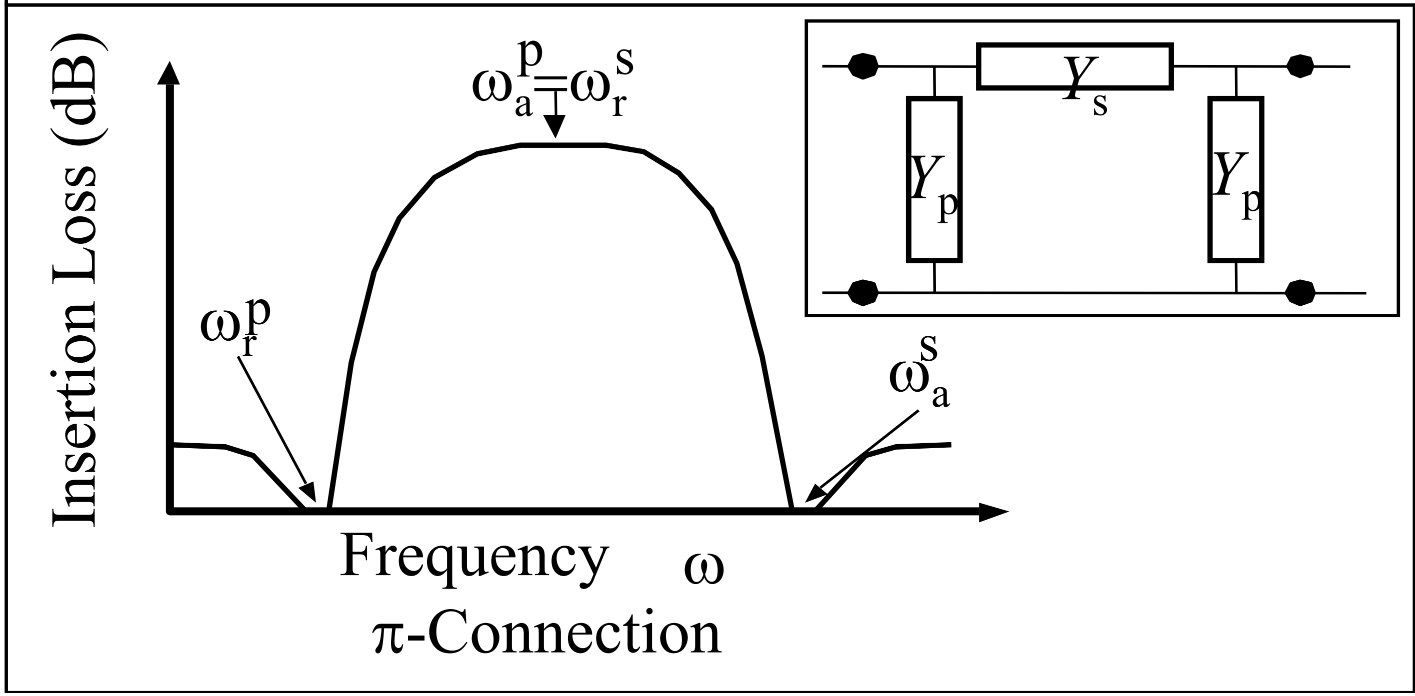
- Low Loss
- High Power Durability
- Moderate Out-of-Band Rejection



Topology

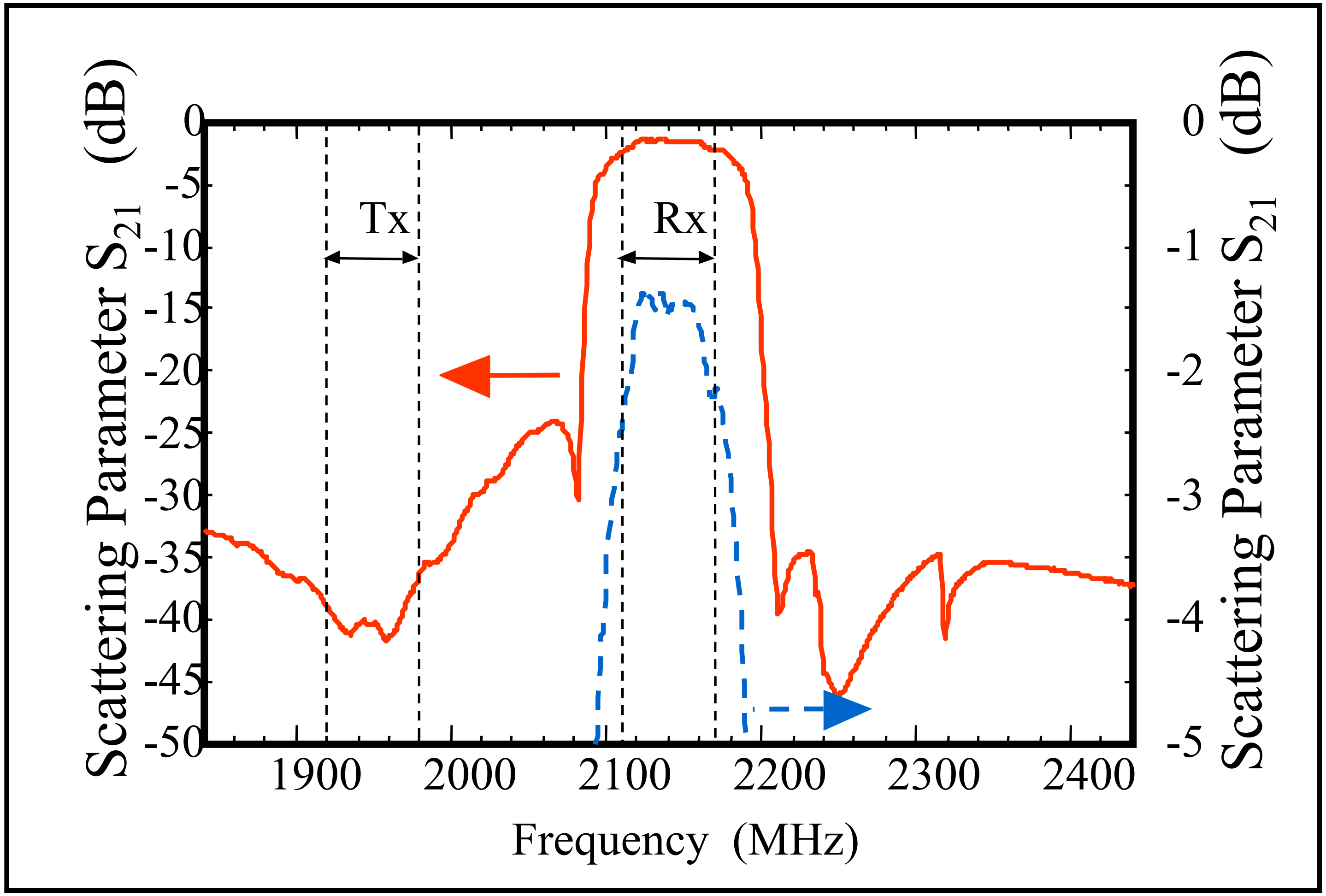






Null Generation at Both Sides

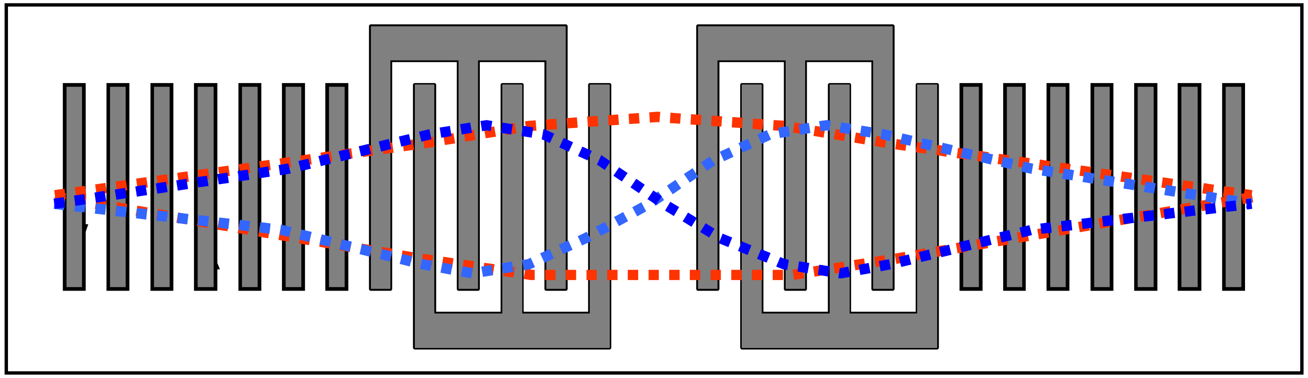
Performance of Ladder-Type SAW Filter



Fujitsu FAR-F6CP-2G1400-L21M

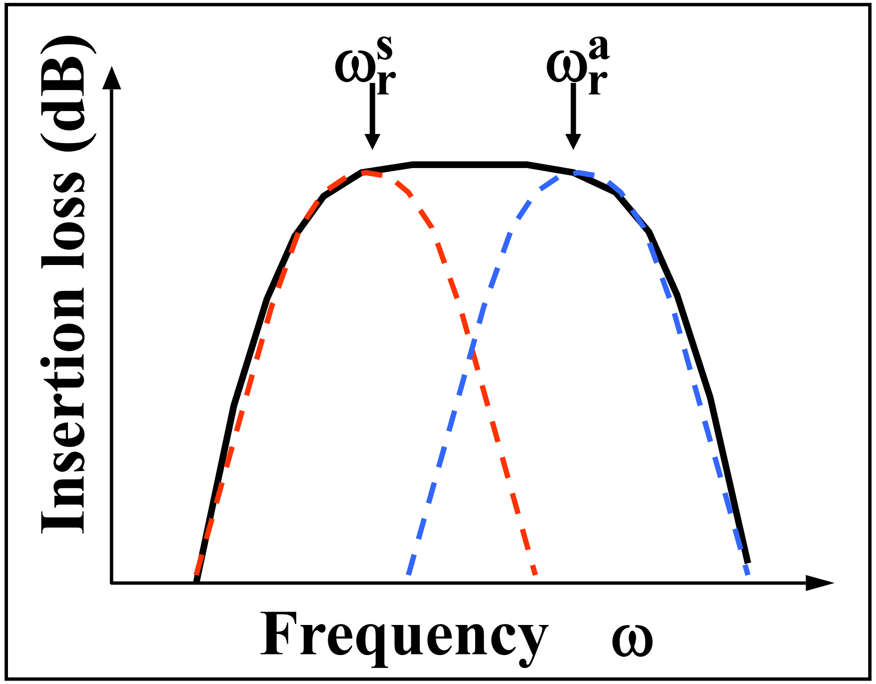
W-CDMA-Rx

Double Mode SAW (DMS) Filter



Symmetrical & Anti-symmetrical Resonances

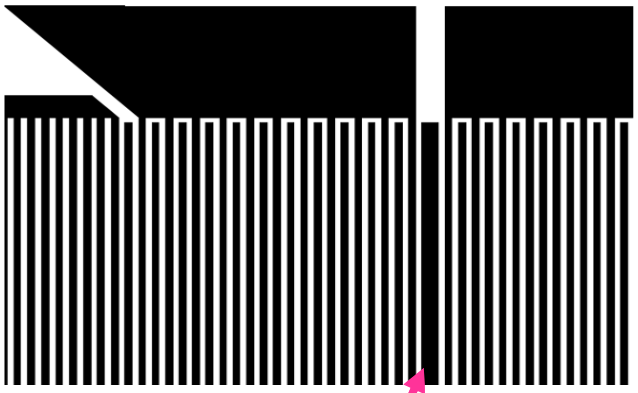
Electrically Isolated I/O



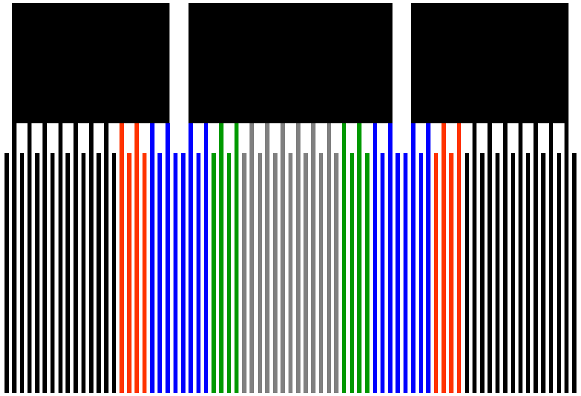
- Good Out-of-Band Rejection
- Balun Function
- Transformer Function
- Low Loss
- Lower Power Durability

Structure of **Pitch-Modulated IDT & Reflector**

Conventional Structure

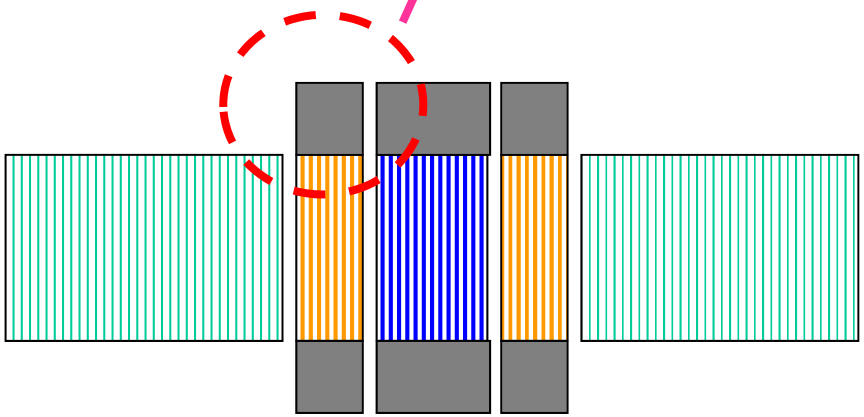


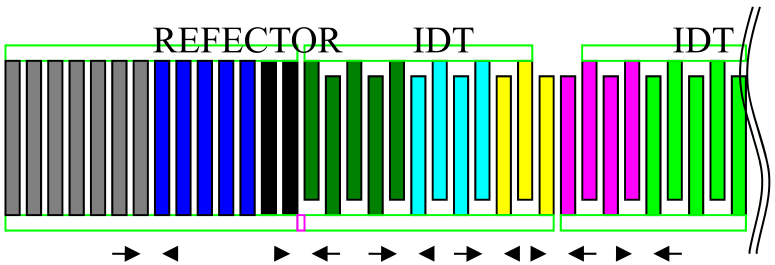
Pitch-Modulated Structure



Gap Controlled

Modulated

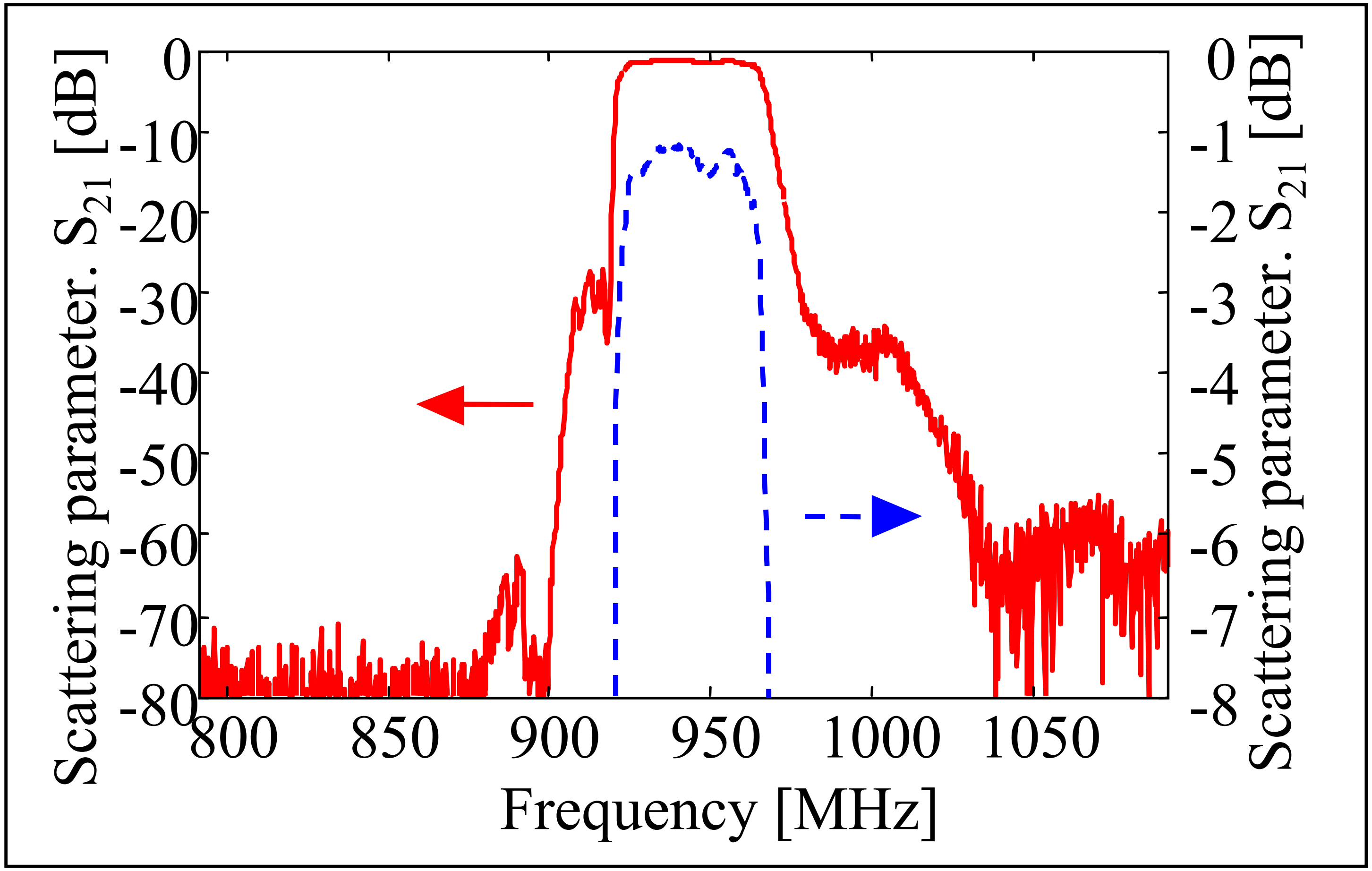




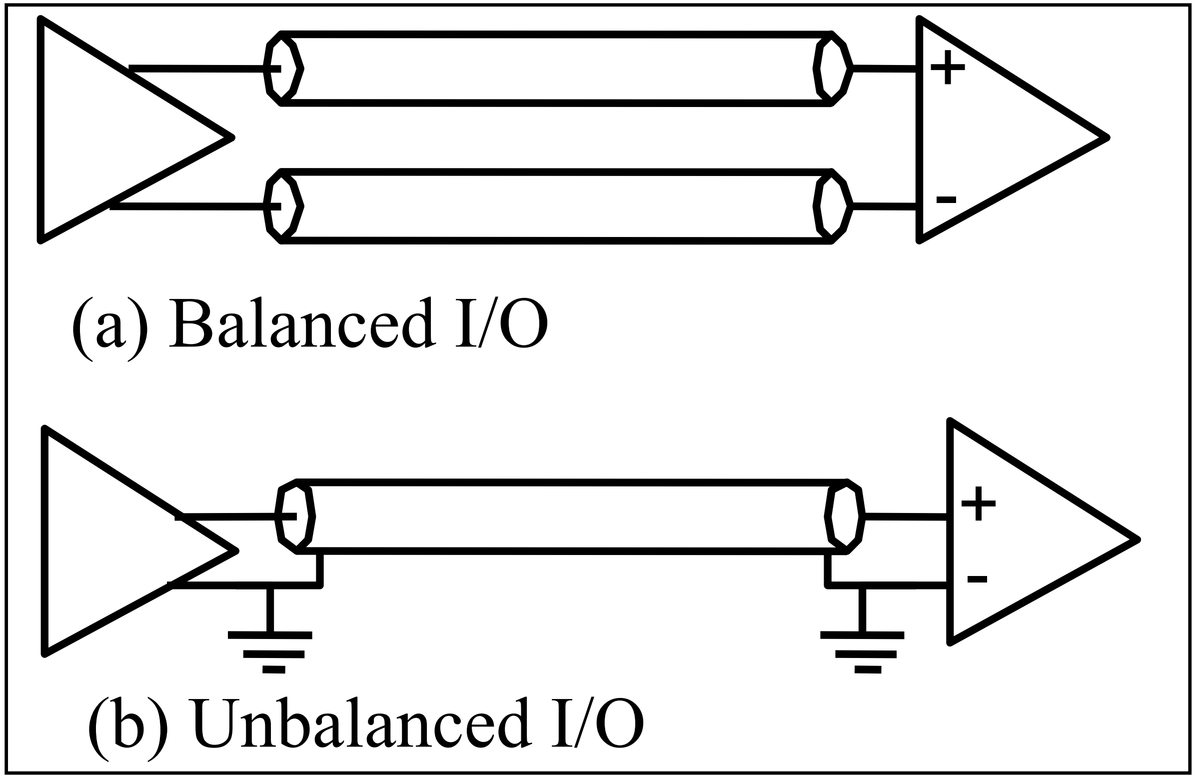
Modulated

Presented at IEEE 2004 UFFC Conf.

DMS Filter with Modulated Structure

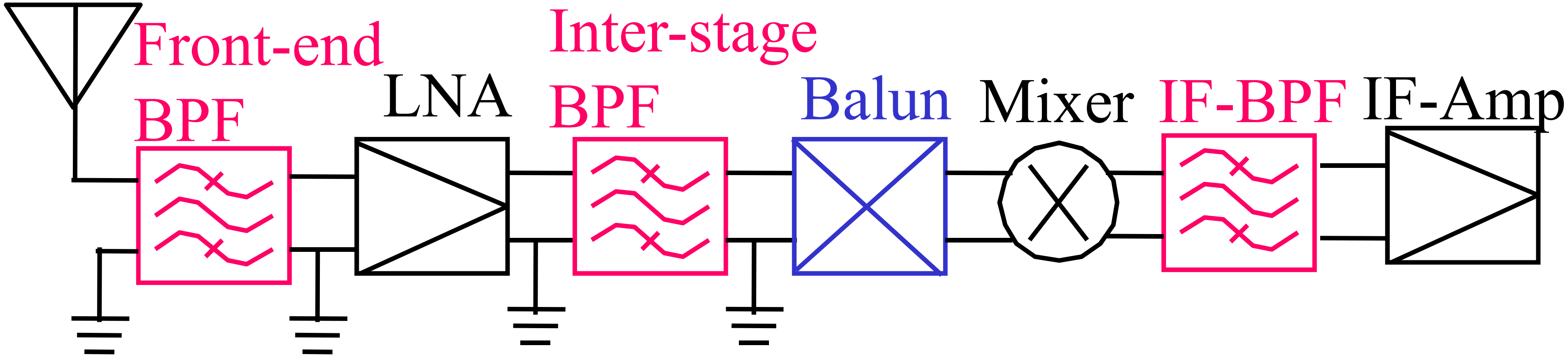


Integrated RF Circuit

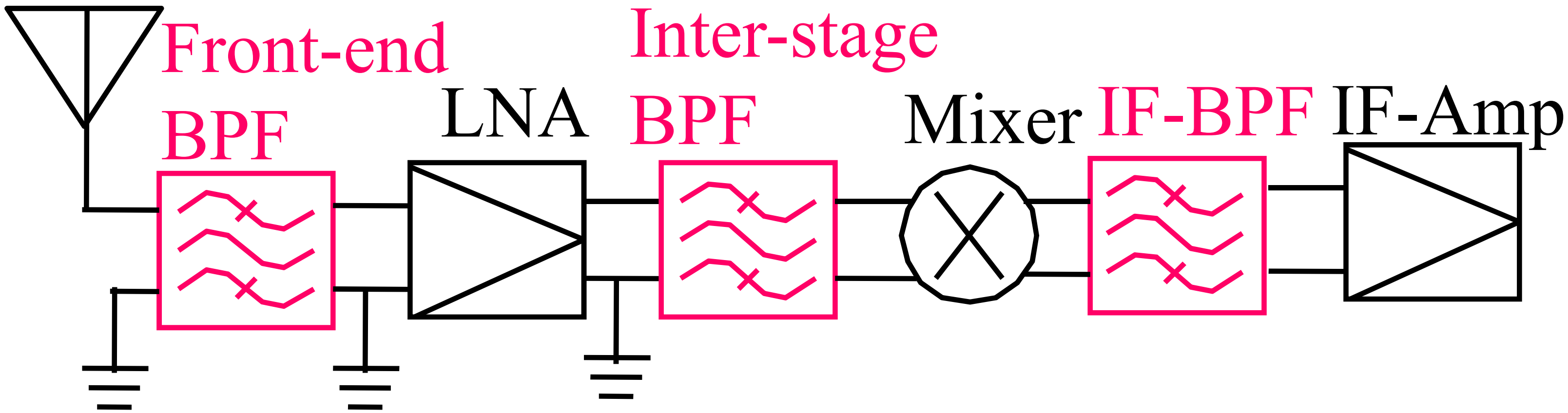


Current Antenna and RF Stage are Unbalanced

Discrete SAW Filter & Balun

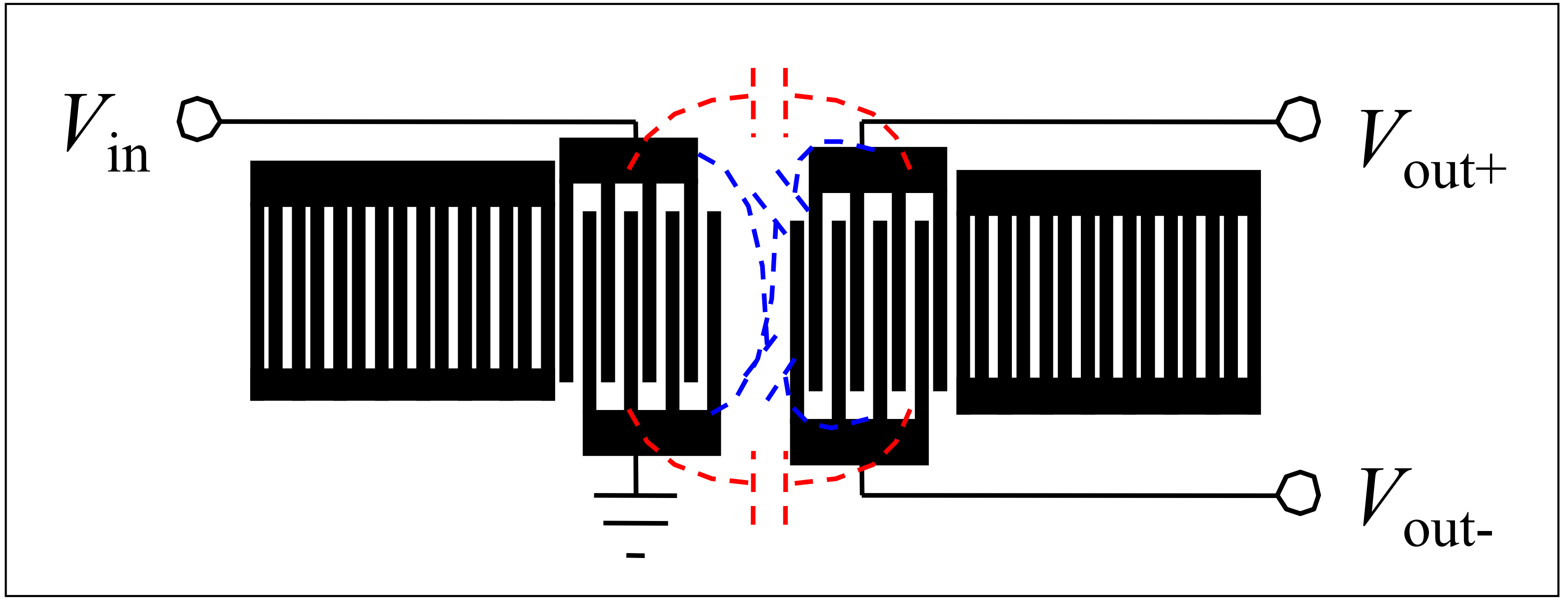


SAW Filter with Balun Function



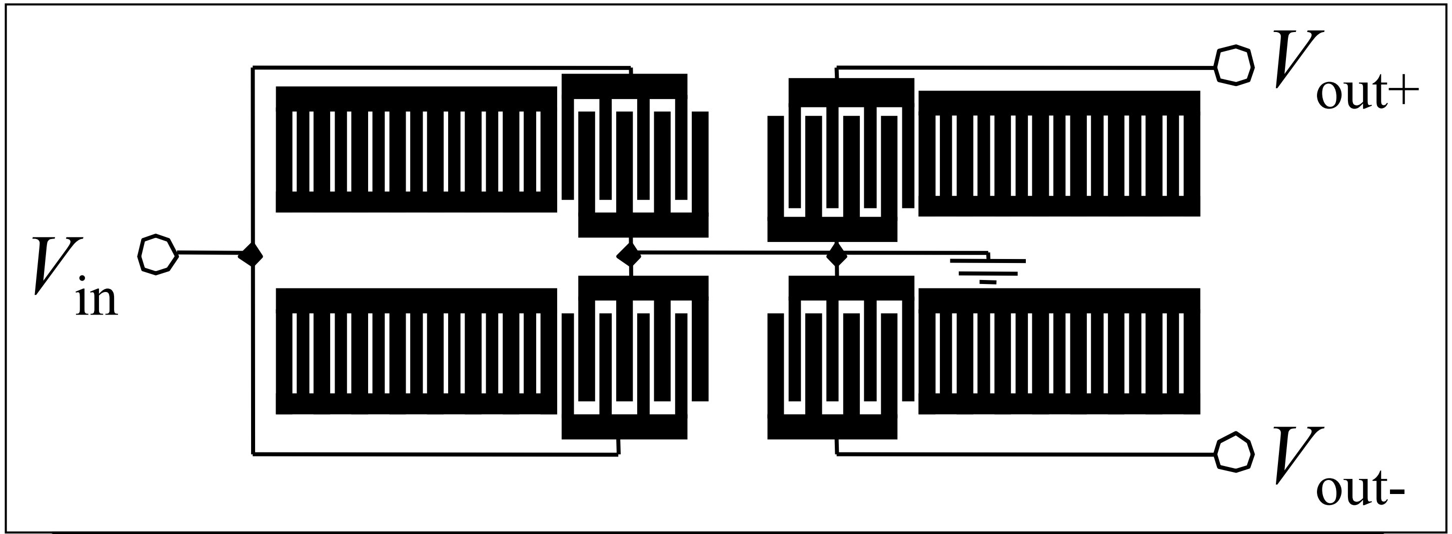
DMS Filter (Ideally No Common Signal)

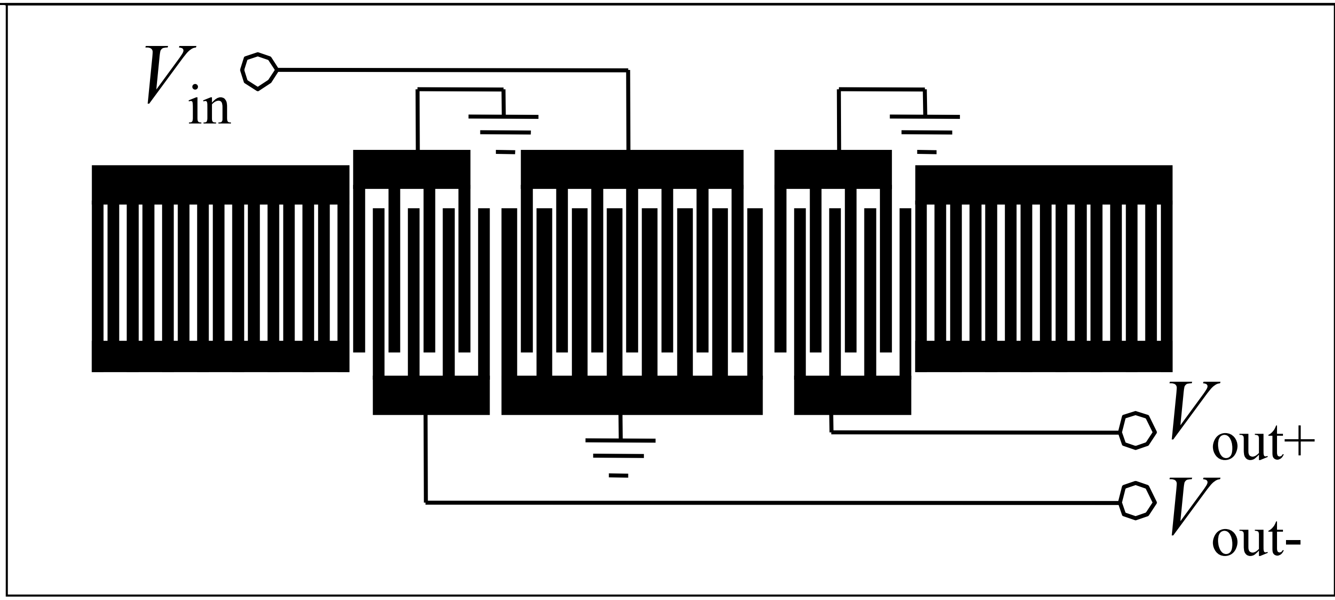
Acoustically Coupled but Electrically Isolated



Common Signal Generation by Parasitics

Z-conversion by DMS Filter

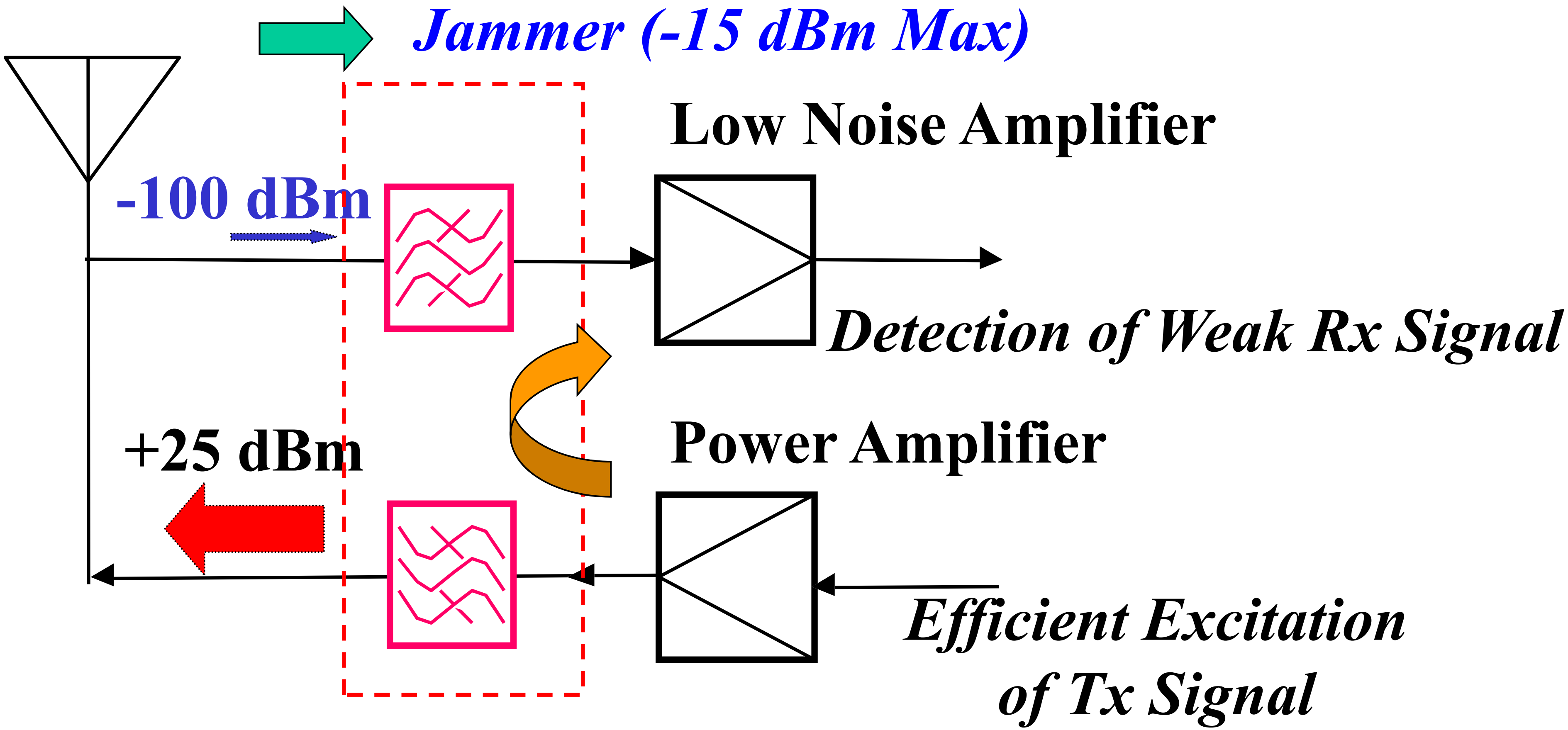




Contents

- Duplexers

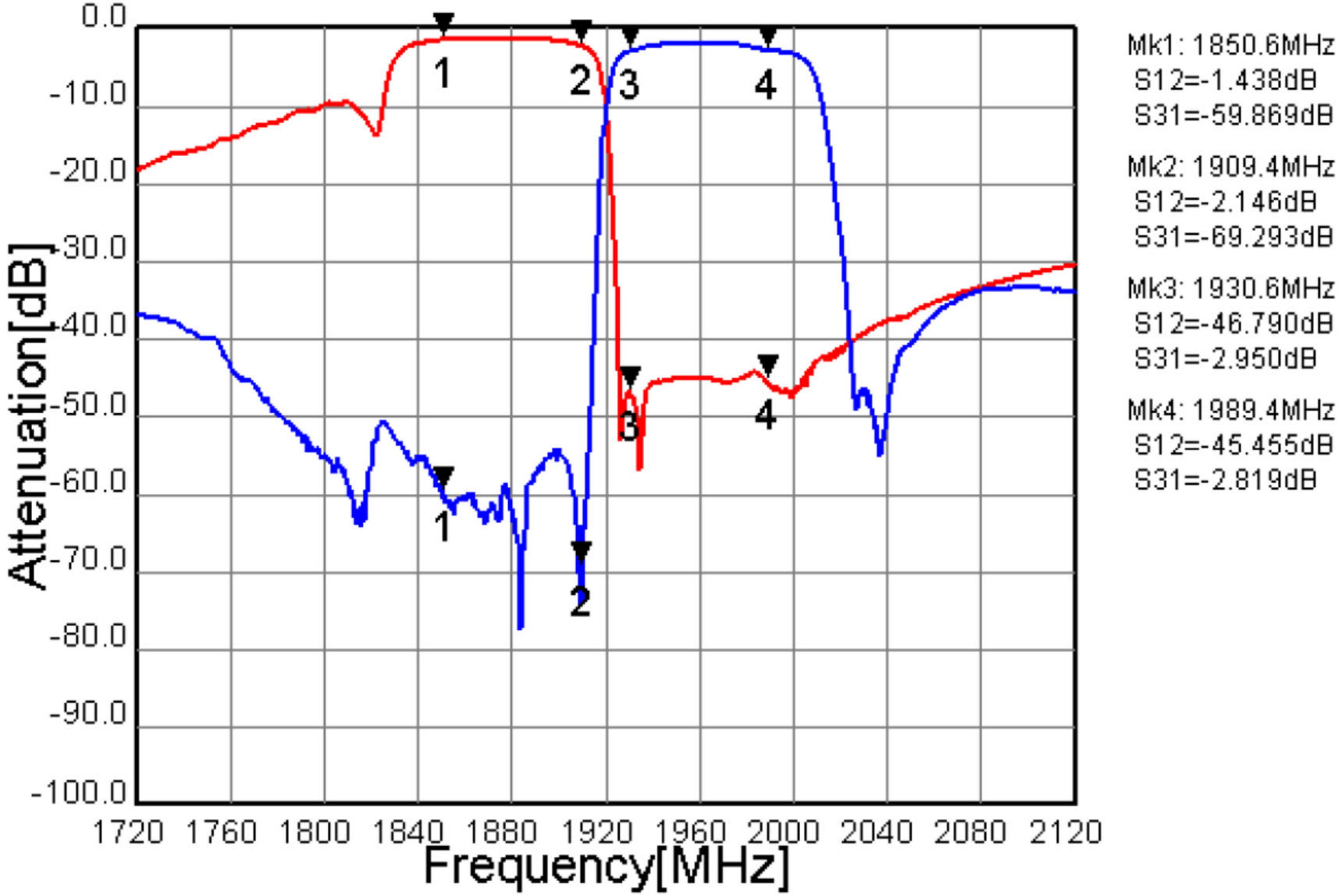
Role of Duplexer in FDD Transceiver



Tx->Rx Leakage Suppression in Tx Band = Duplexer

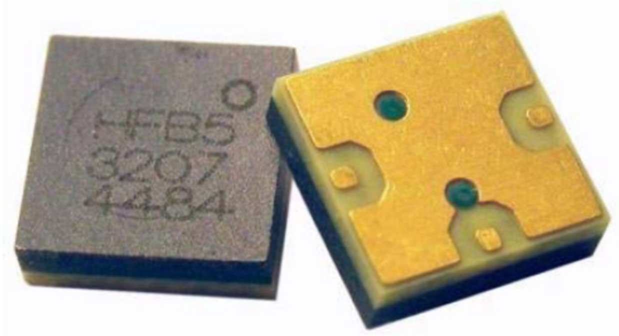
Minimization of RF Power Loss

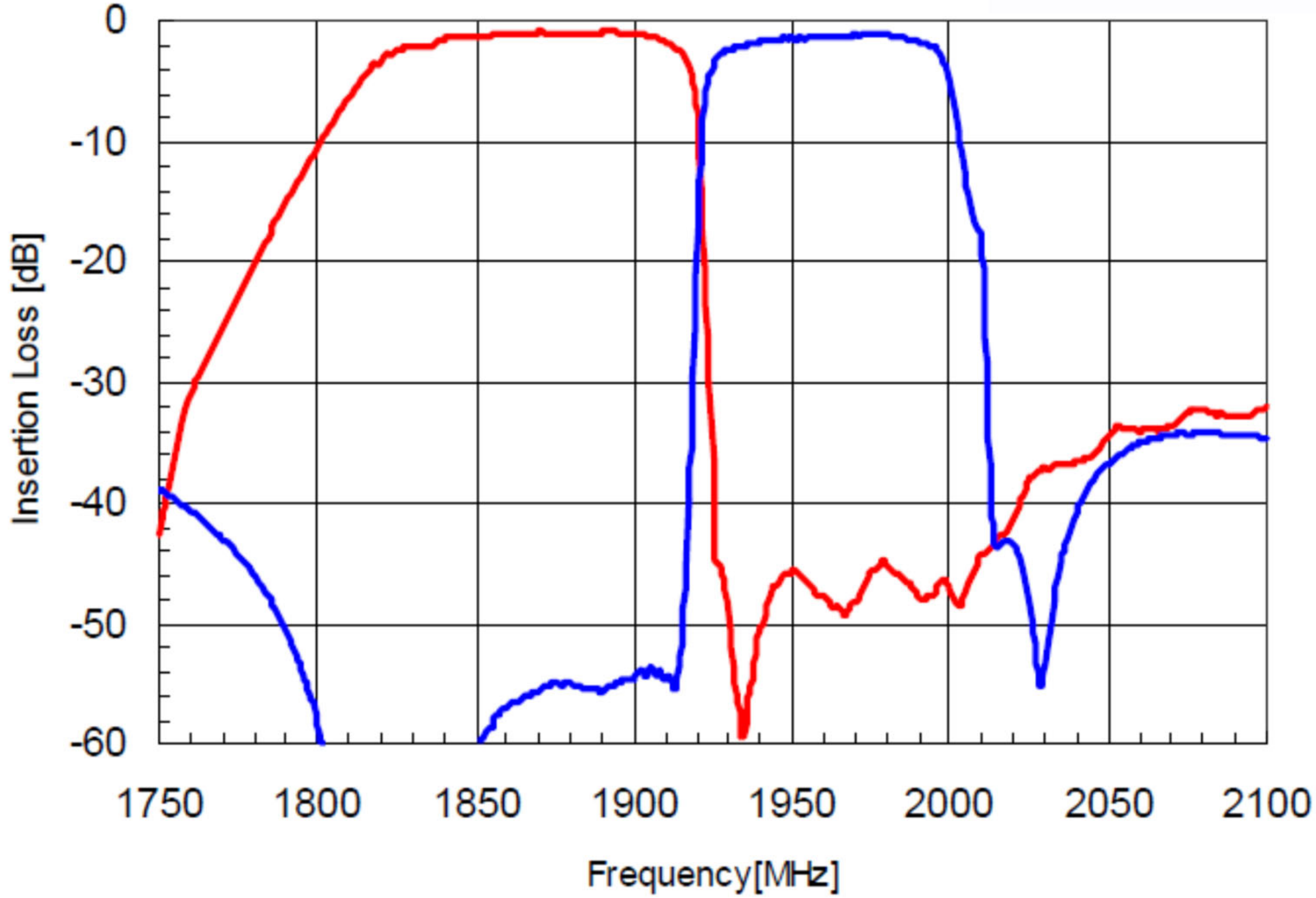
Taiyo Yuden FAR-D6CZ-1G9600-D1XC



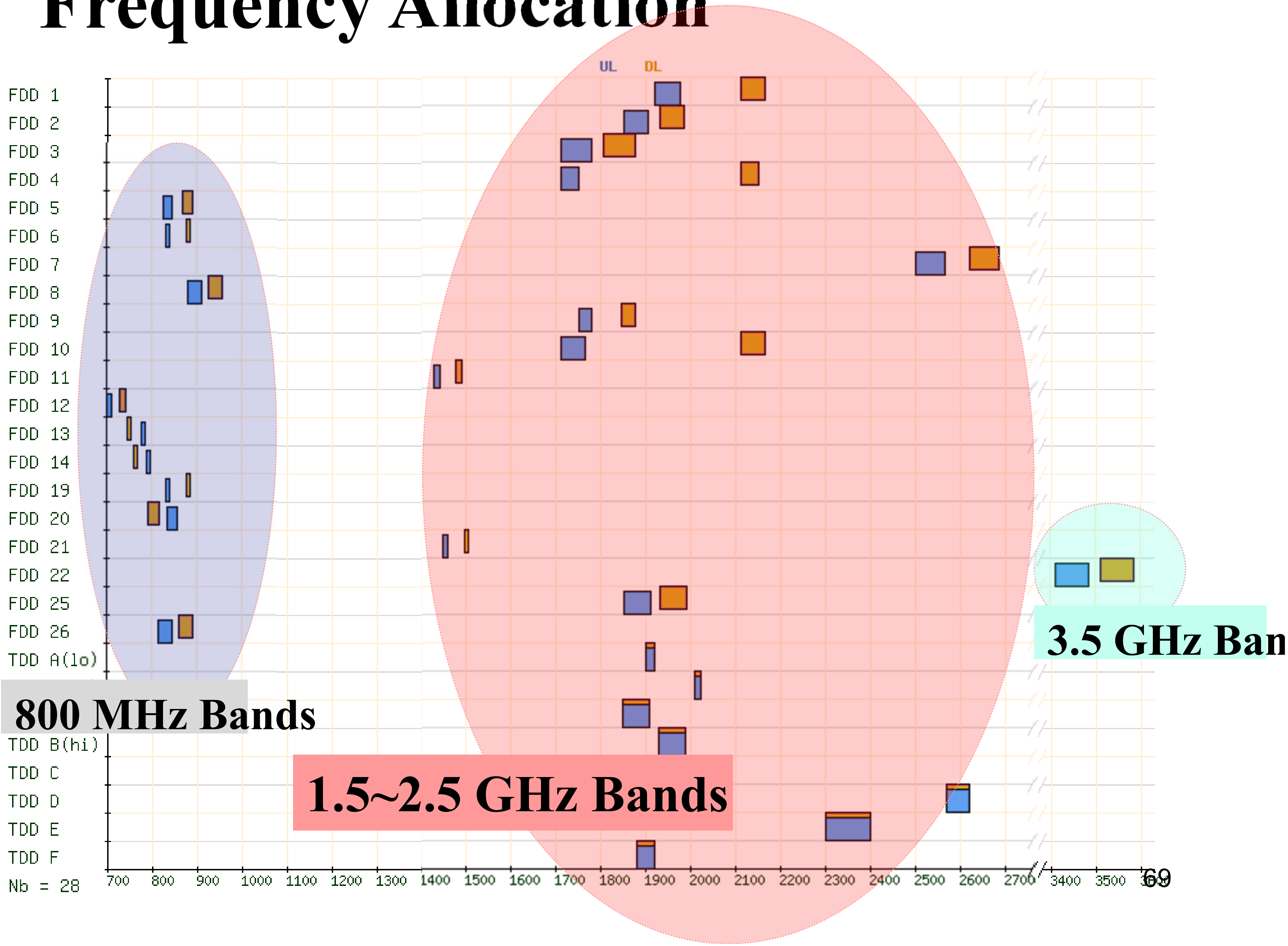
Avago’s FBAR PCS Duplexer

ACMD-7402 (3.8*3.8*1.3mm)

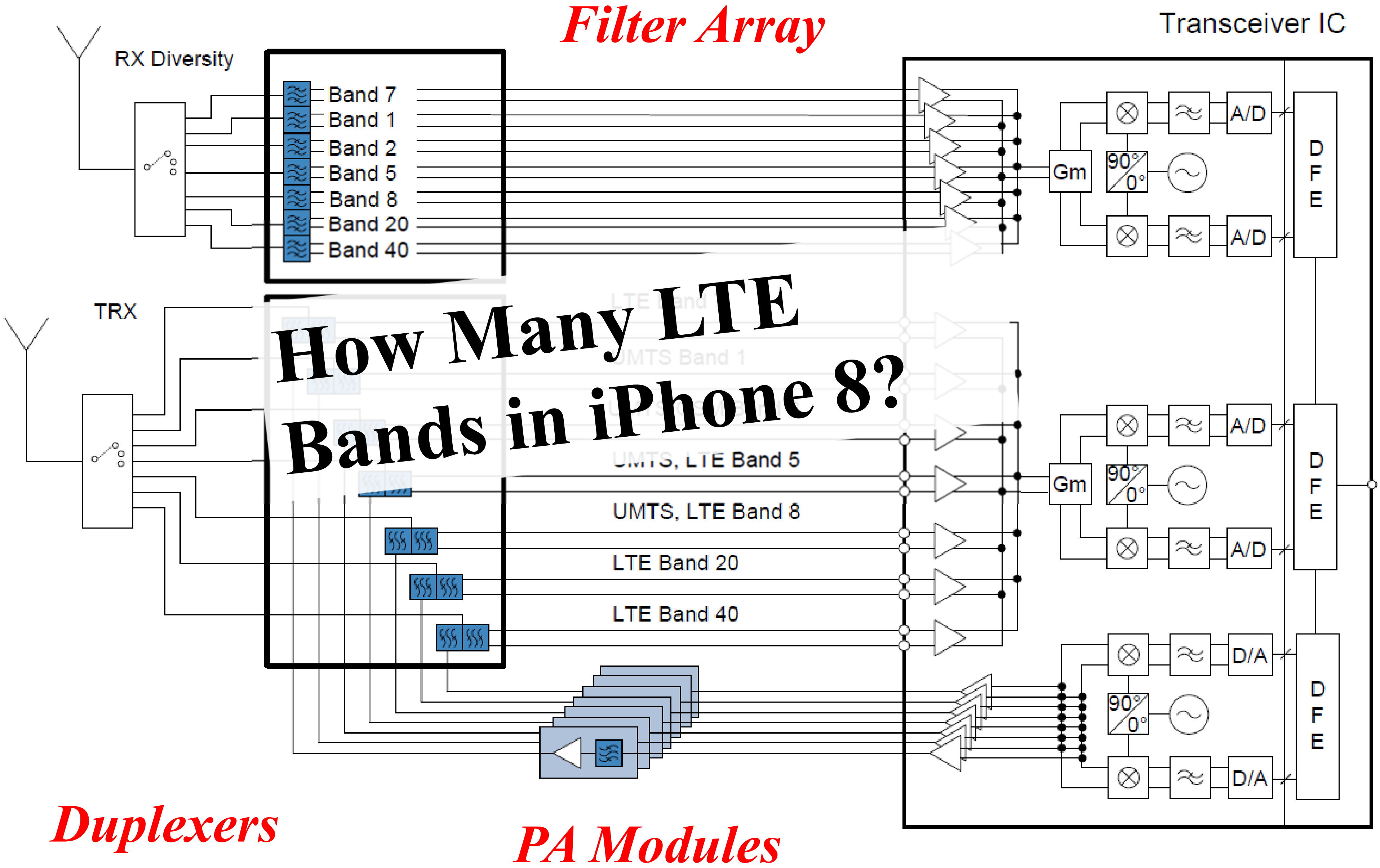




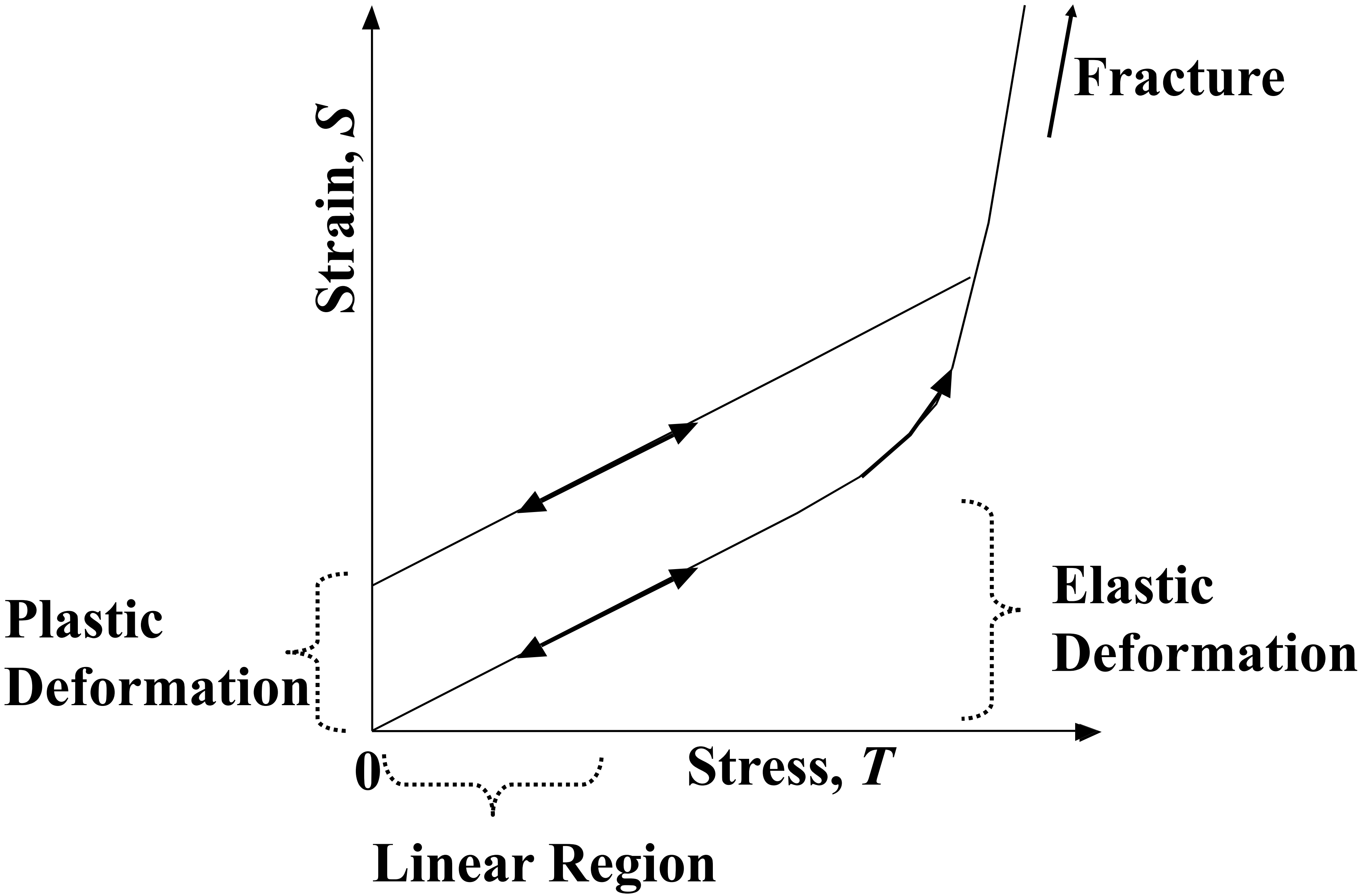
Frequency Allocation



RF Front End of One Generation Before….



Relation Between Stress *T* and Strain *S*



Case 2: When $T=T_a\cos(\omega_a t)+T_b\cos(\omega_b t)$ ($|T_a|>>|T_b|$),

$$S = s^{(1)}(T_a\cos\omega_a t + T_b\cos\omega_2 t) + s^{(2)}(T_a\cos\omega_a t + T_b\cos\omega_b t)^2/2$$

$$+ s^{(3)}(T_a\cos\omega_a t + T_b\cos\omega_b t)^3/3 + \cdots$$

$$\cong T_a\{s^{(1)} + s^{(3)}T_a^2/4\}\cos\omega_a t$$

$$+ T_b\{s^{(1)} + s^{(3)}T_a^2/2\}\cos\omega_b t$$

Linear Vibration +Gain Compression

$$+ s^{(2)}T_a^2\cos(2\omega_a t)/4 + s^{(2)}T_a^2/4$$

H2+DC Generation

$$+ s^{(2)}T_a T_b[\cos\{(\omega_a+\omega_b)t\} + \cos\{(\omega_a-\omega_b)t\}]/2$$

IMD2 Generation

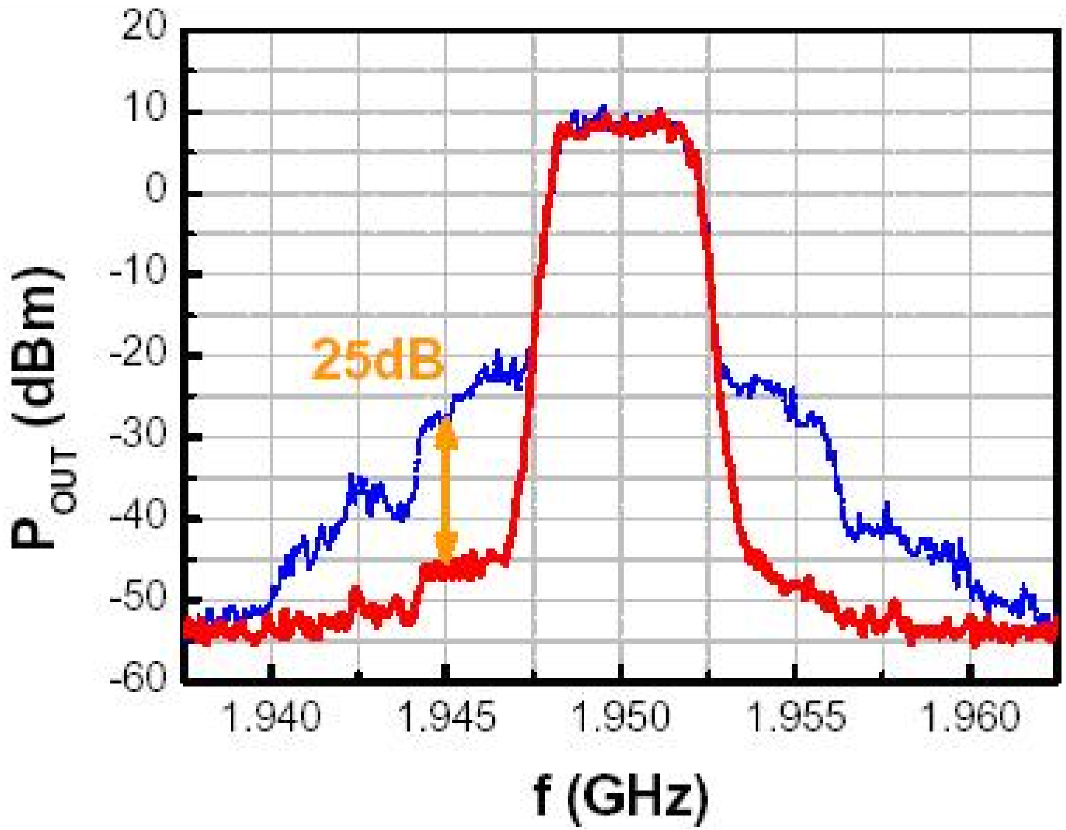
$$+ s^{(3)}T_a^2 T_b[\cos\{(2\omega_a+\omega_b)t\} + \cos\{(2\omega_a-\omega_b)t\}]/4$$

$$+\cdots$$

IMD3 Generation

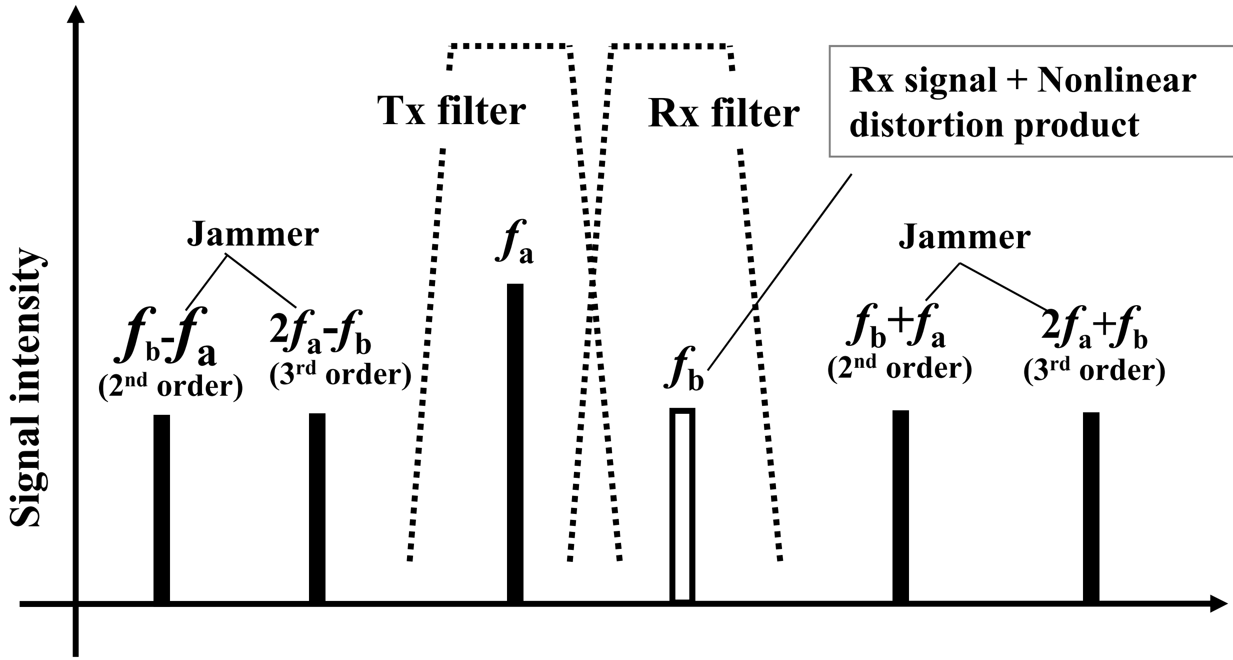
IMD: Inter-Modulation Distortion

Spectrum Regrowth in PA and DPX = Self Mixing of Tx Signals



Jammer Signal Emission Toward Adjacent Channels

Inter Modulation Distortion in Nonlinear Circuit for WCDMA System



Band1

Tx: 1920-1980 MHz

Rx: 2110-2170 MHz

190MHz

1730 - 1790 MHz

4030 – 4150 MHz

5950 – 6010 MHz

Jammer Frequency

Band2

Tx: 1850-1910 MHz

Rx: 1930-1990 MHz

80MHz

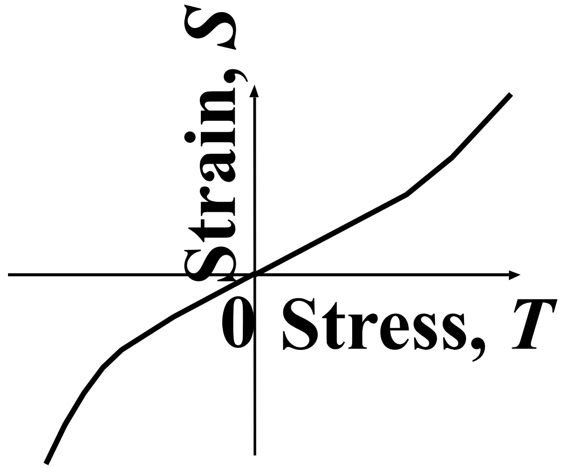
1770 - 1830 MHz

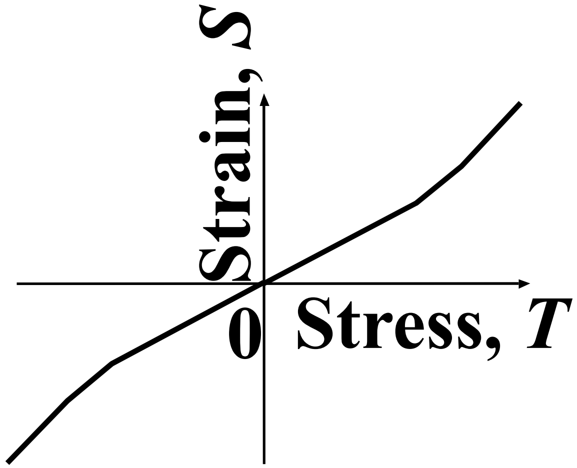
3780 – 3900 MHz

5630 – 5810 MHz

Jammer Frequency

In Elastic Region (w/o Hysteresis)





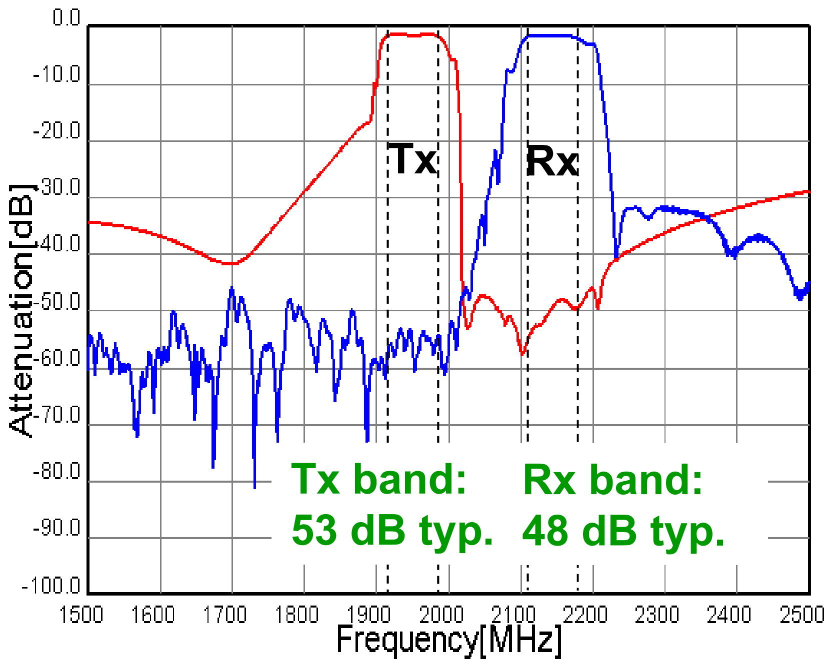
$$S = s^{(1)}T + \frac{1}{2}s^{(2)}T^2 + \frac{1}{3}s^{(3)}T^3 \dots$$

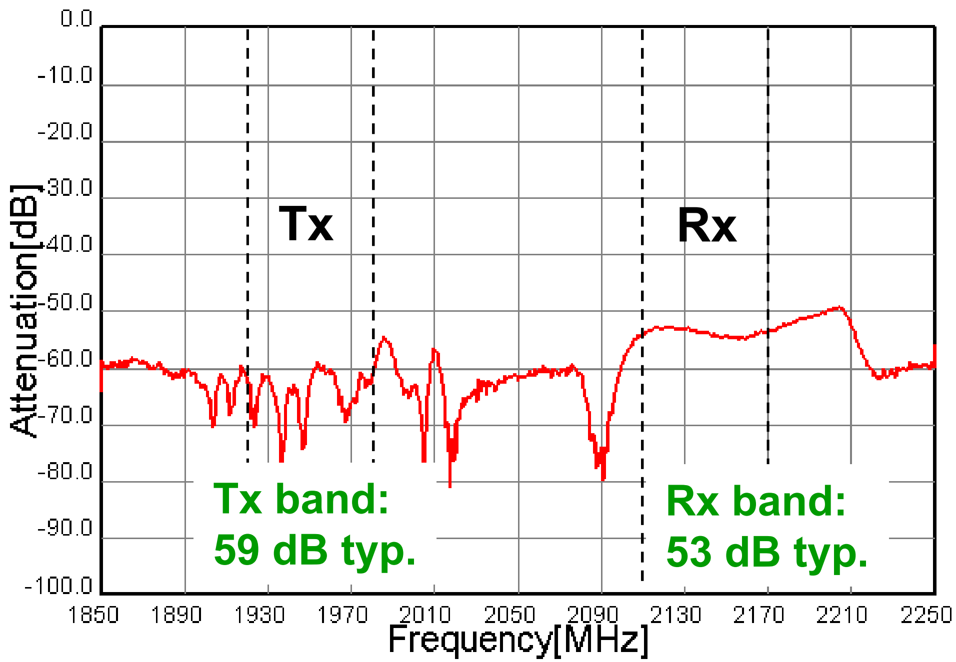
Only True for Asymmetric Cases

$$S = s^{(1)}T + \frac{1}{3}s^{(3)}T^3 \dots$$

For Symmetric Cases, $s^{(2n)}=0$

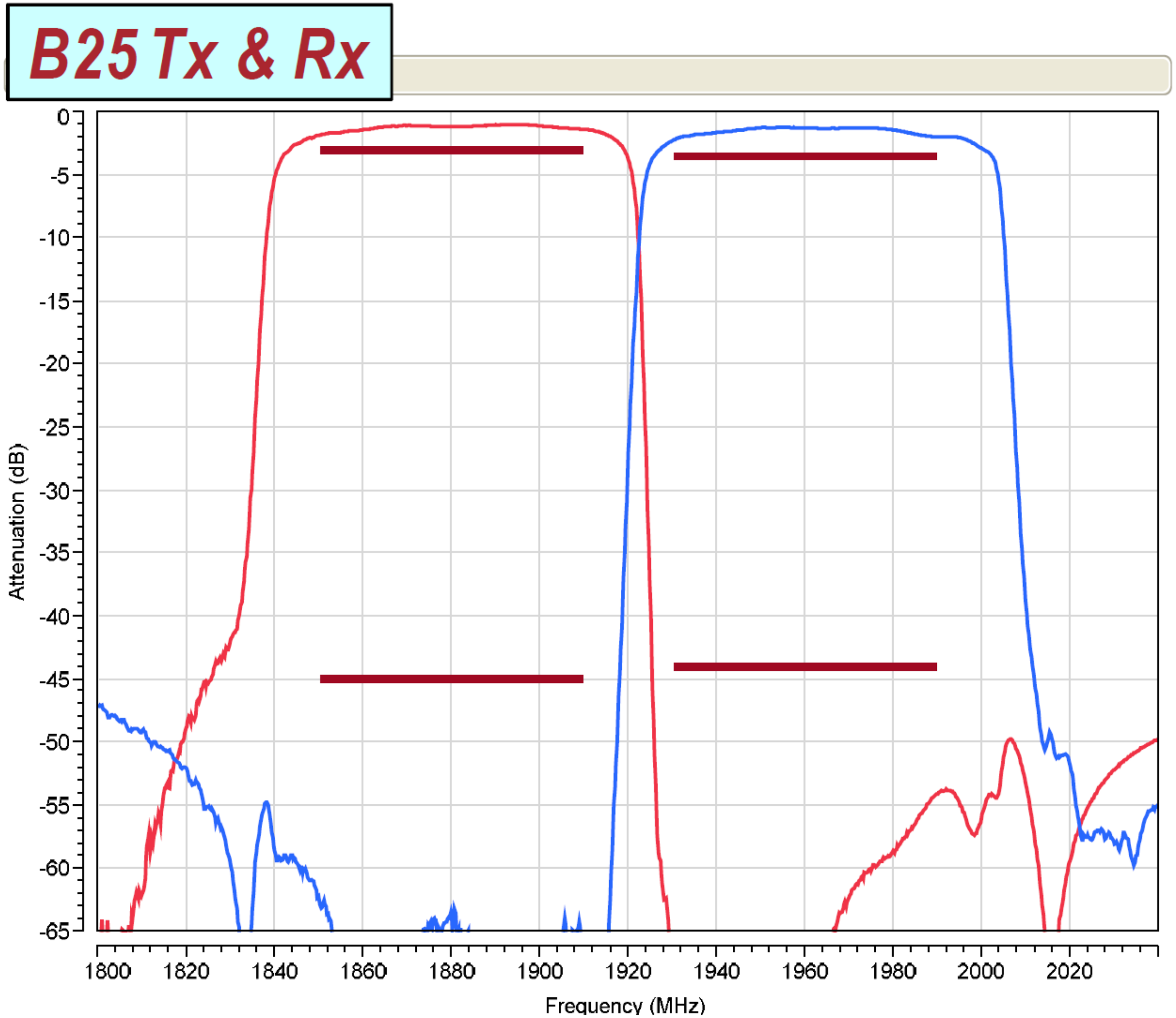
FBAR (Tx) + DMS (Rx) Duplexer





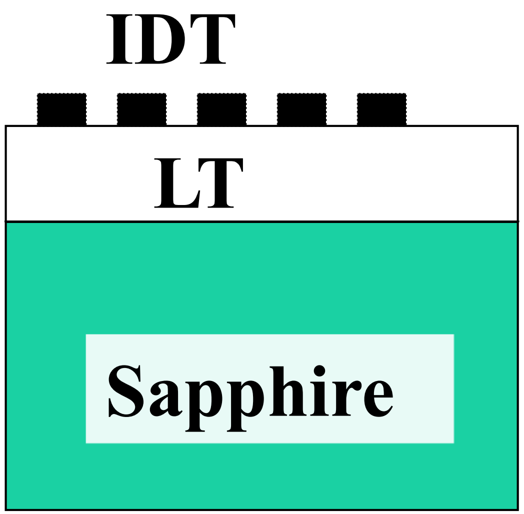
DMS Offers Balanced Output

With Improved Temperature Stability



R.Ruby and M.Gat, "FBAR Filters- 2012," Proc. 2012 International Symposium on Acoustic Wave Devices for Future Mobile Communications) G1 -1~4

LT/Sapphire Wafer Bonding



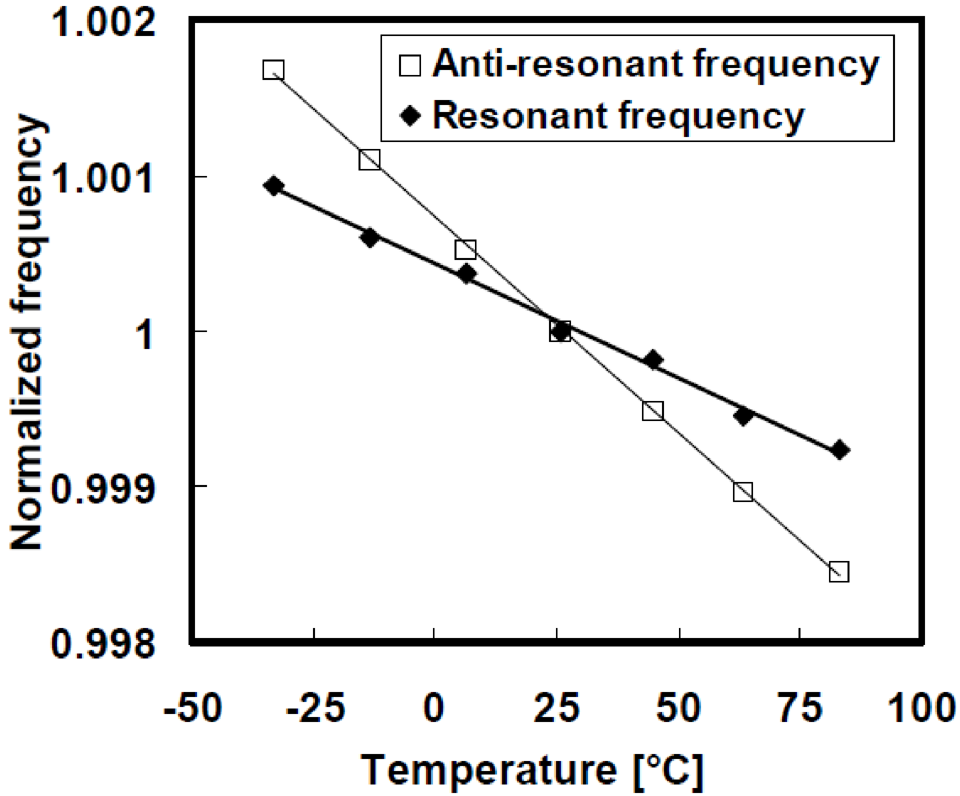


Figure 8: Temperature characteristics of the resonant and anti-resonant frequencies of a one-port SAW resonator using a bonded $LiTaO_3$/sapphire substrate.

M. Miura, T. Matsuda, Y. Satoh、M. Ueda, O. Ikata, Y. Ebata, and H.Takagi, "Temperature Compensated $LiTaO_3$/Sapphire Bonded SAW Substrate with Low Loss and High Coupling Factor Suitable for US-PCS Application," Proc. IEEE Ultrasonics Symposium (2004) pp. 1322-1325

Performance Example

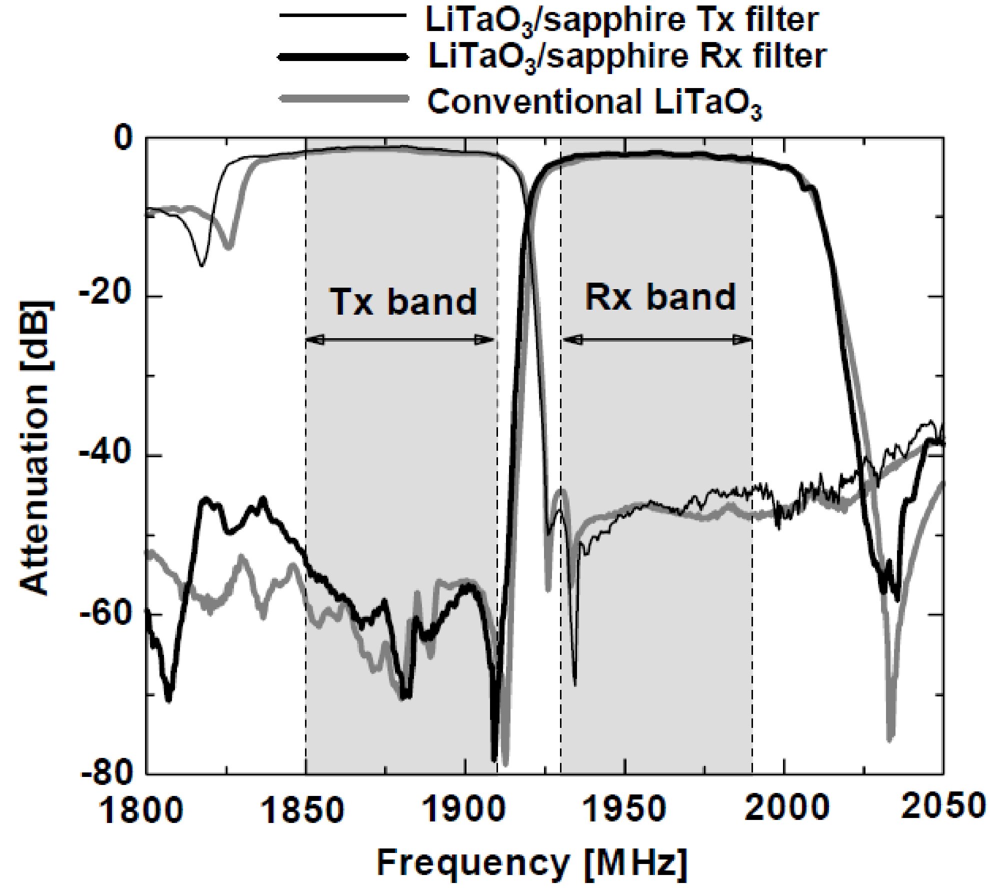
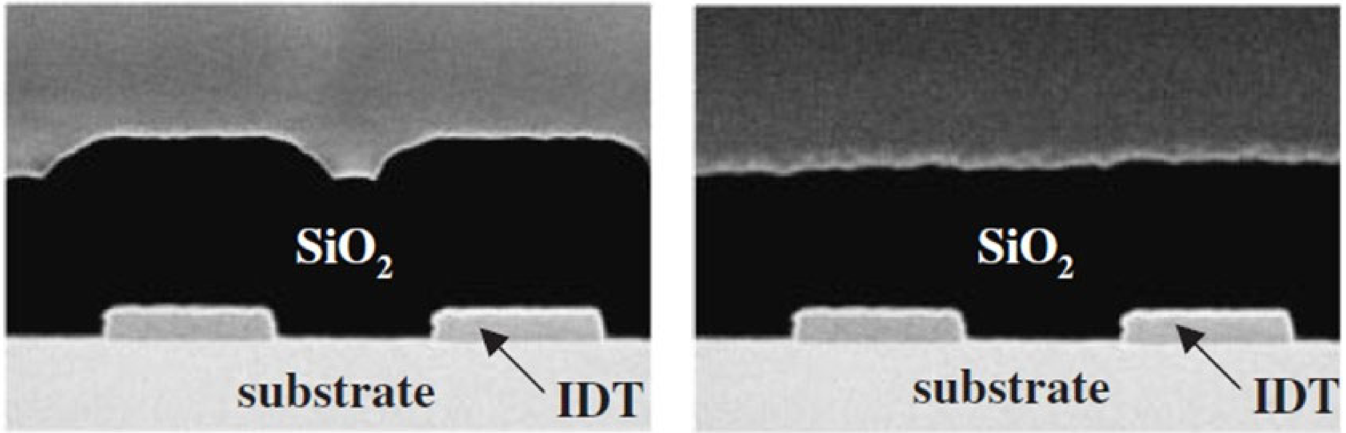


Figure 9: Frequency characteristics of PCS SAW duplexers using a bonded $LiTaO_3$/sapphire substrate and a conventional $LiTaO_3$ substrate.

M. Miura, T. Matsuda, Y. Satoh、M. Ueda, O. Ikata, Y. Ebata, and H.Takagi, "Temperature Compensated LiTaO3/Sapphire Bonded SAW Substrate with Low Loss and High Coupling Factor Suitable for US-PCS Application," Proc. IEEE Ultrasonics Symposium (2004) pp. 1322-1325

SiO_2 On-Top Deposition

SiO_2: Stiffness Increase with Temperature



(a) nonflattened SiO_2 surface

(b) flattened SiO_2 surface

Fig. 5. Side-wall sections of SiO_2/IDT/substrate structure with non-flattened and flattened SiO_2 surface (IDT thickness: 0.048λ).

M Kadota, N.Takaeshi, N.Taniguchi, E.Takata, M.Miura, K.Nishiyama, T.Hada, and T.Komura, "Surface Acoustic Wave Duplexer for US Personal Communication Services with Good Temperature Characteristics," Jpn. J. Appl. Phys., 44 6B (2005) pp. 4527-4531

Performance Example

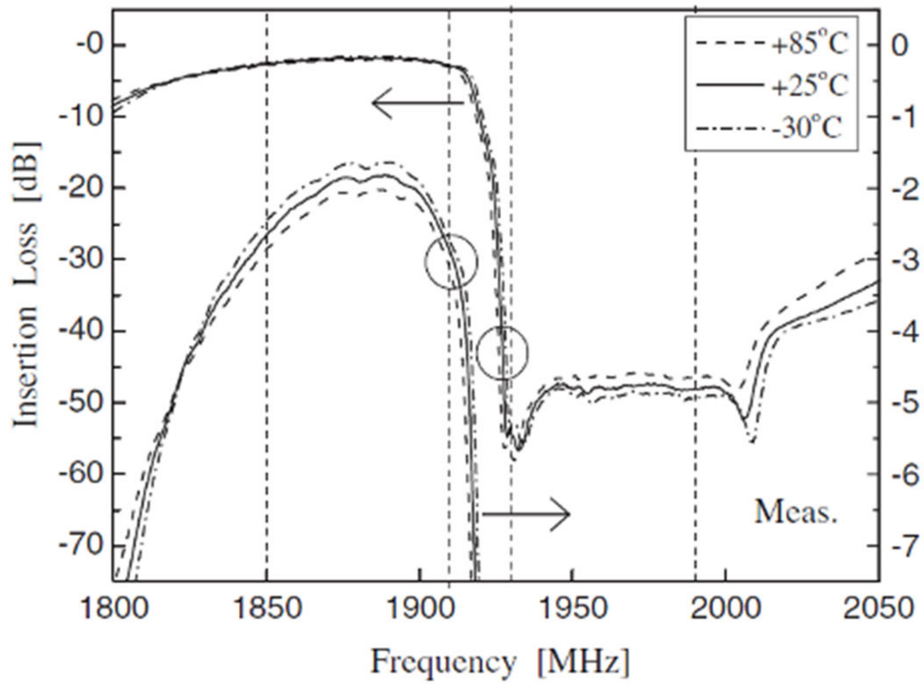
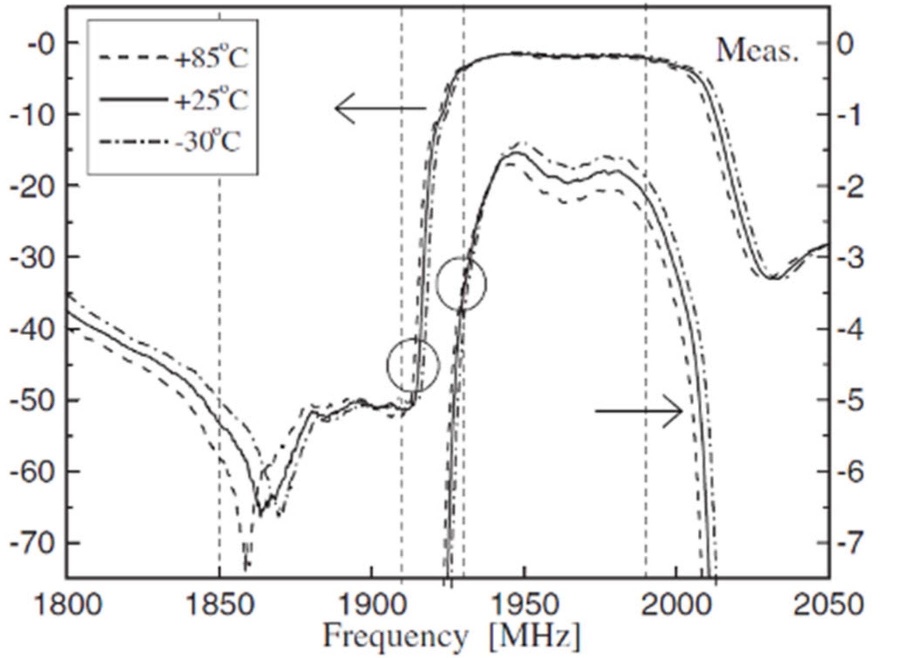


Fig. 8. Frequency characteristics of Tx filter of US-PCS SAW duplexer using flattened $SiO_2/Cu(0.048\lambda)/LiTaO_3$ structure at −30°C, 25°C, and 85°C.



). Frequency characteristics of Rx filter of US-PCS SAW duplexer ng flattened $SiO_2/Cu(0.048\lambda)/LiTaO_3$ structure at −30°C, 25°C, and 'C.

M Kadota, N.Takaeshi, N.Taniguchi, E.Takata, M.Miura, K.Nishiyama, T.Hada, and T.Komura, “Surface Acoustic Wave Duplexer for US Personal Communication Services with Good Temperature Characteristics,” Jpn. J. Appl. Phys., 44 6B (2005) pp. 4527-4531

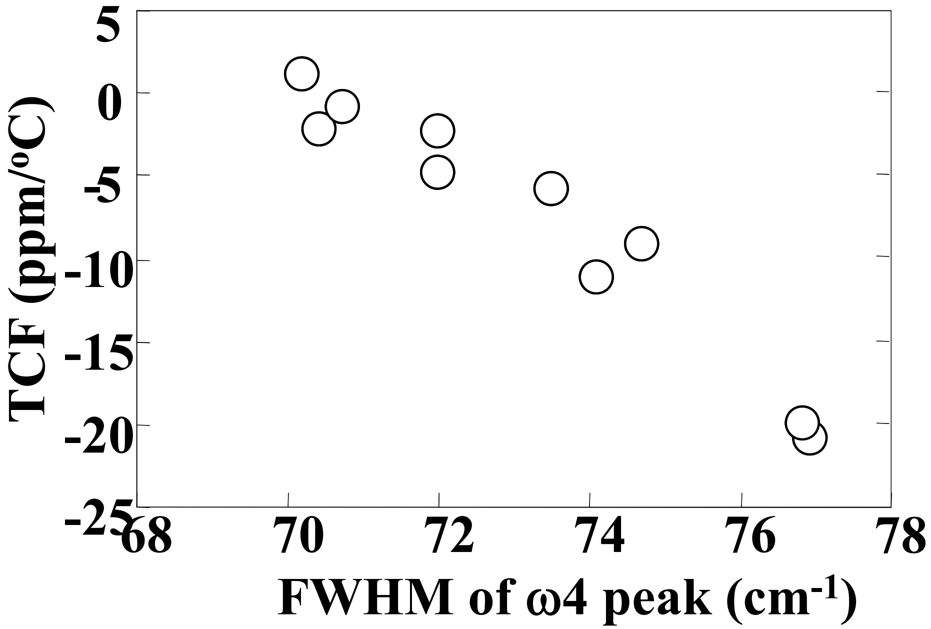
Use of SiO_2 for Temperature Compensation

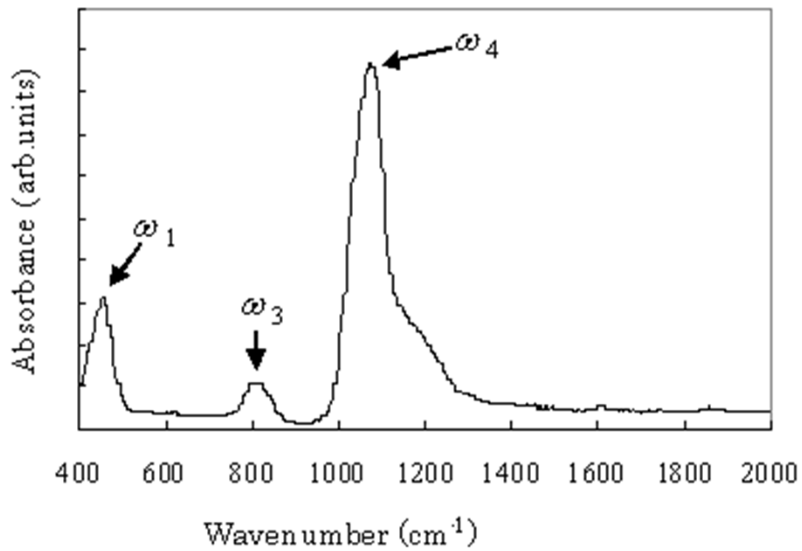
How to Realize Good SiO_2 Films?

What are “Good” SiO_2 Films for Acoustics?

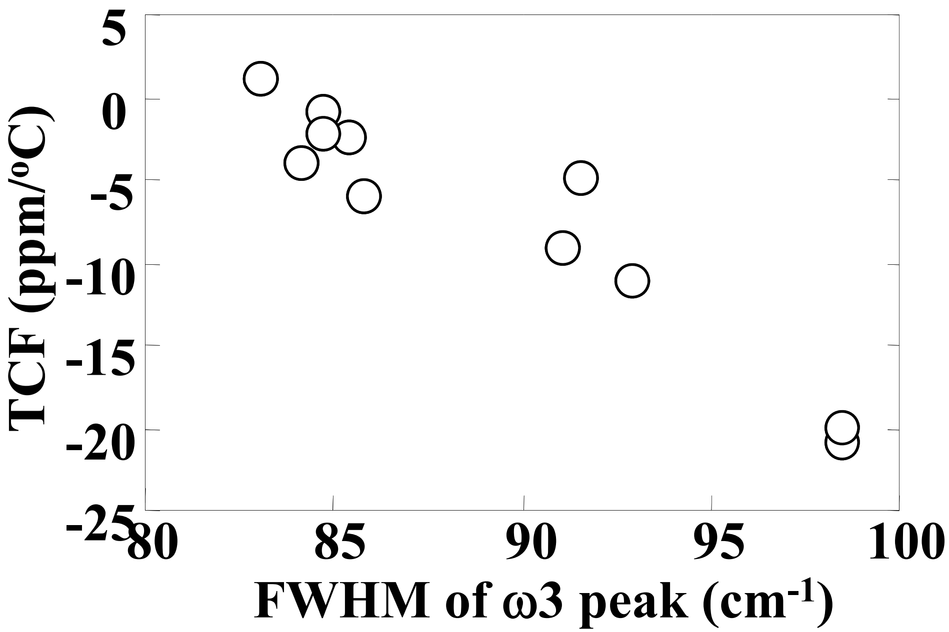
Figure 6. Cross section of a Zero Drift Resonator (ZDR). The edge of the ‘swimming’ pool is shown. The layers are labeled.

Rich Ruby, “A Decade of FBAR Success and What is Needed for Another Successful Decade,” Proc. SPAWDA (2011) pp. 365-369





Relation Between FTIR FWHM and TCF in

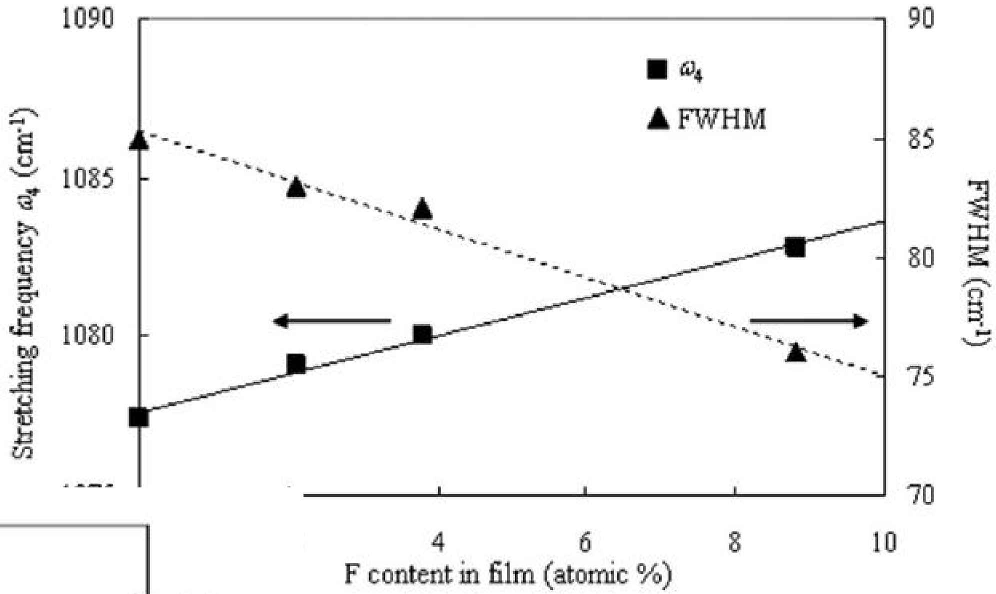


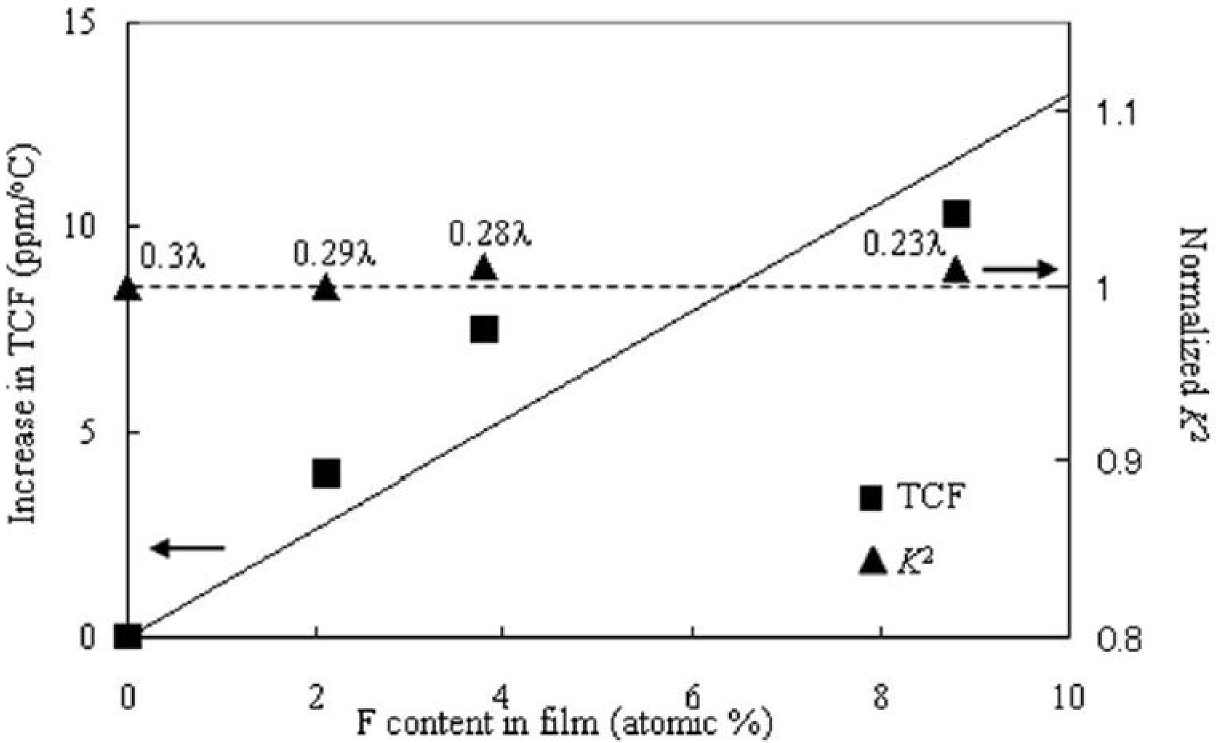
SiO_2 Properties Change with Deposition Condition

Use of SiOF Fims

Anticipated from FTIR Data

⇒ Experimental Verification

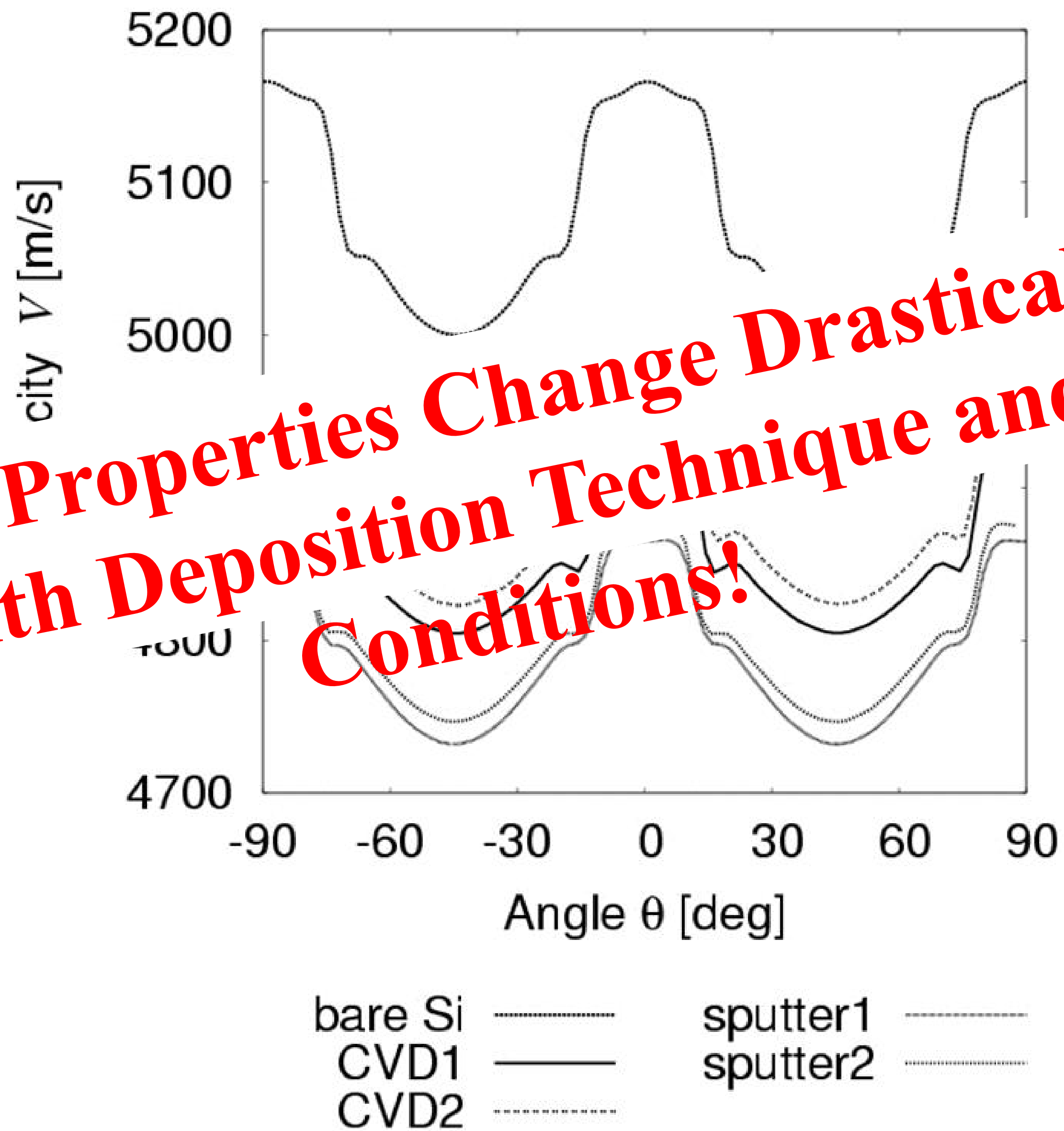




S.Matsuda, M.Hara, M.Miura, T.Matsuda, M.Ueda, Y.Satoh, and K.Hashimoto, "Use of Fluorine Doped Silicon Oxide for Temperature Compensation of Radio Frequency Surface Acoustic Wave Devices," IEEE Trans. Ultrason., Ferroelec., and Freq. Contr., 59, 1 (2012) pp. 135-138

Material Characterization

Quantitative Evaluation of Acoustic Properties of Thin Films with High Accuracy



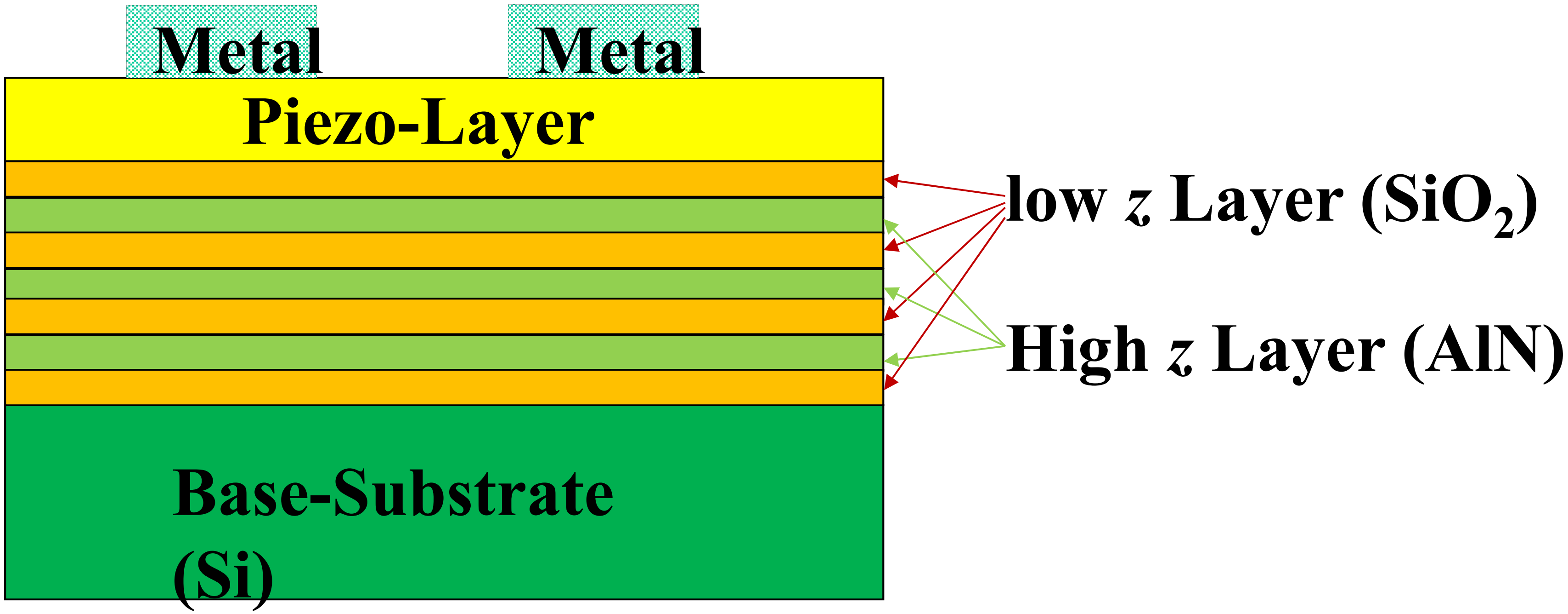
SiO_2 Properties Change Drastically with Deposition Technique and Conditions!

***f*=225 MHz**

θ Dependence of SAW Vel. on SiO_2 (1 μm)/ (001)Si Surface

K.Sakamoto, S.Suzuki, T.Omori, K.Hashimoto, J.Kushibiki, and S.Matsuda, "Characterization of Elastic Properties of SiO_2 Thin Films by Ultrasonic Microscopy," Proc. IEEE Ultrason. Symp. (2014) pp. 893-896

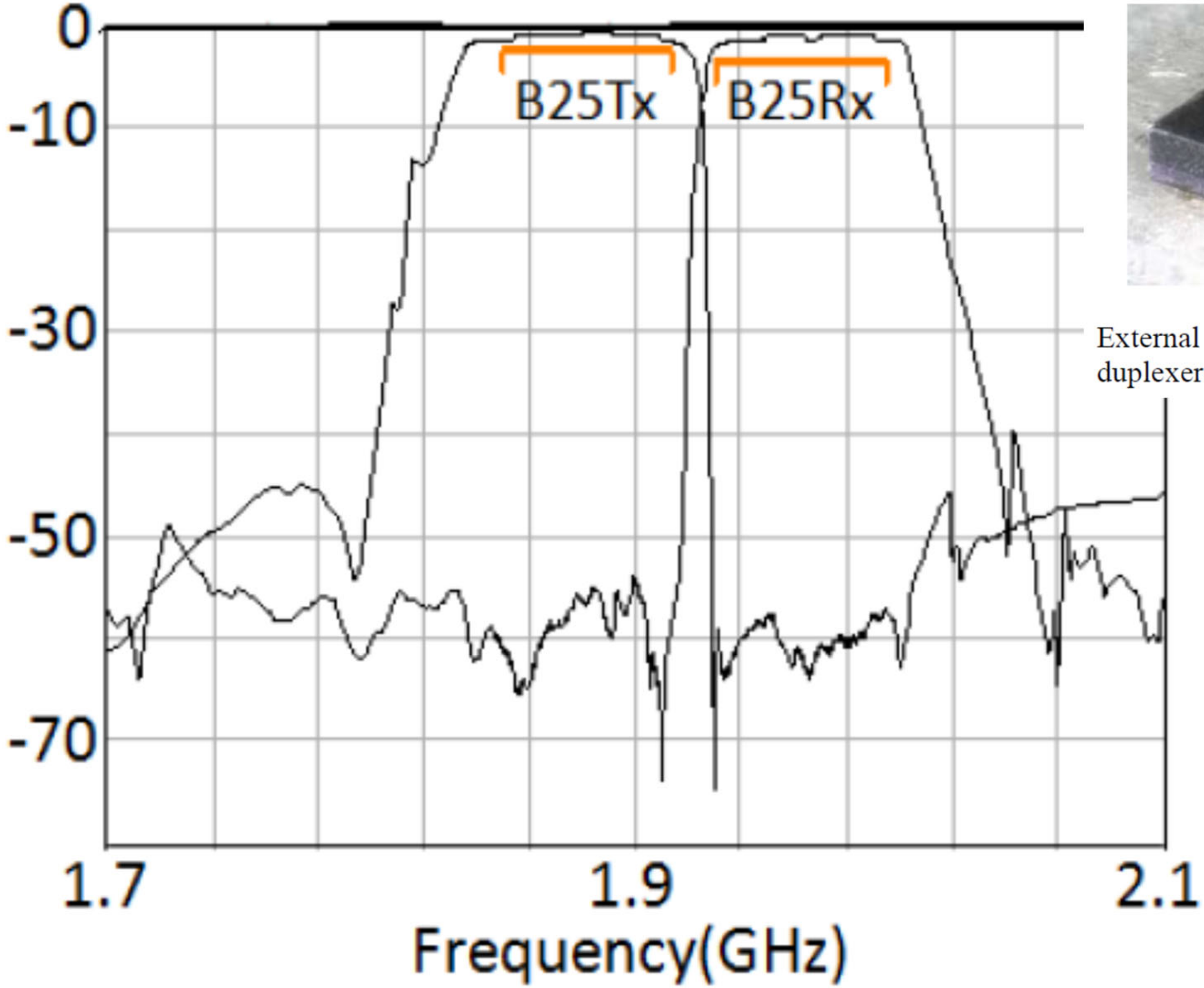
Use of Extremely Thin Piezo-Layer

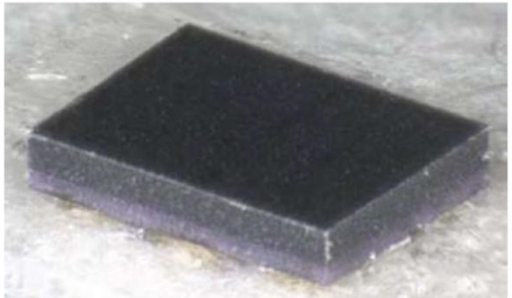


Energy Confinement in Thin Piezo-Layer

➡ K^2 Enhancement
BAW Loss Reduction

Murata's IHP SAW Duplexer





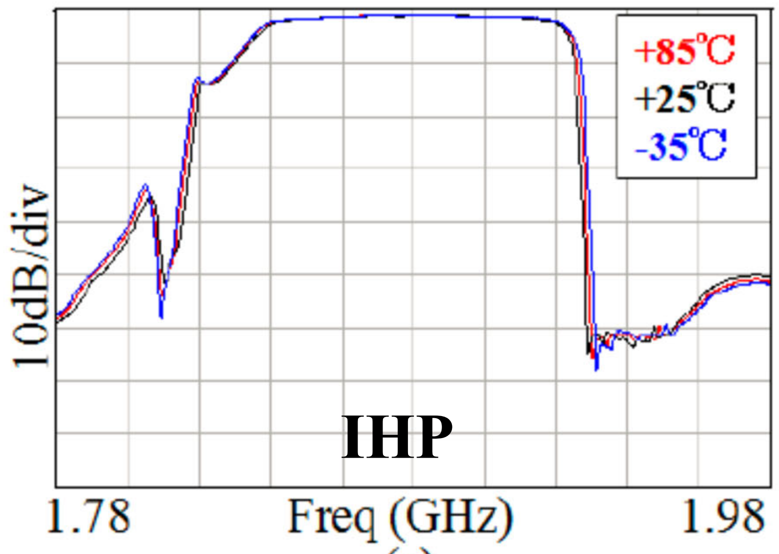
External view of Band25 IHP-SAW duplexer($2.0\times1.6\times0.6mm^3$)

IL TX 1.5 dB, Rx: 1.9 dB

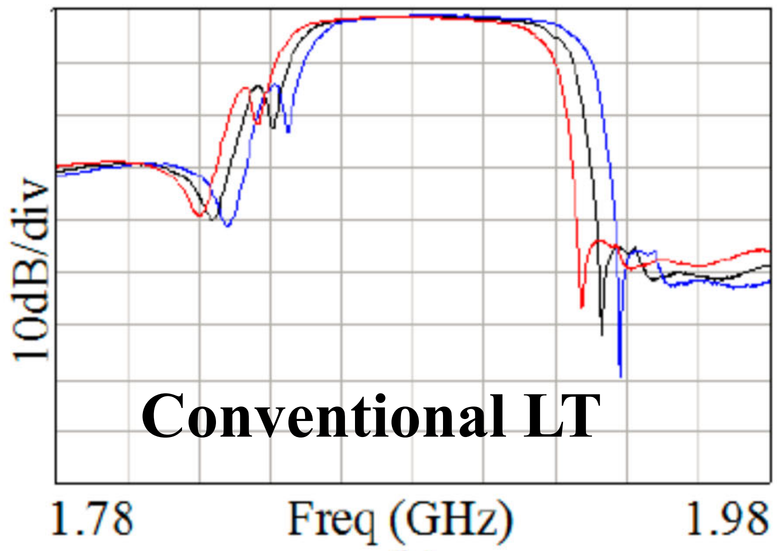
TCF: 8 ppm/^{o}C

Iso.: 56 dB for Tx and 60 for Rx

Temperature Stability



(a)



(b)

T.Takai, H.Iwamoto, Y.Takamine, H.Yamazaki, T.Fuyutsume, H.Kyoya, T.Nakao, H.Kando, M.Hiramoto, T.Toi, M.Koshino and N.Nakajima "Incredible High Performance SAW resonator on Novel Multi-layerd Substrate", Proc. IEEE Ultrason. Symp. (2016)

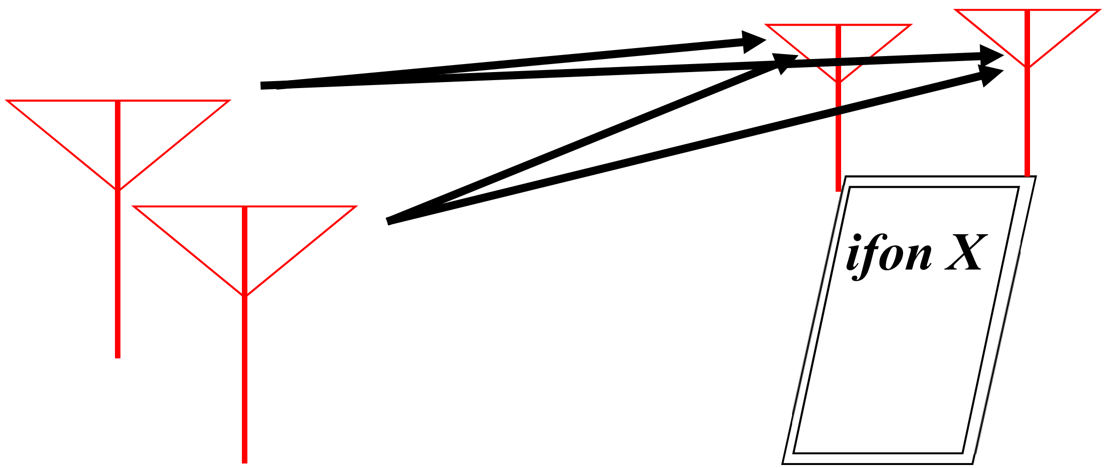
For Further Increase in Channel Capacity

$$C = B\log_2\left(1+\mathrm{SNR}\right)$$

***B*: Bandwidth**

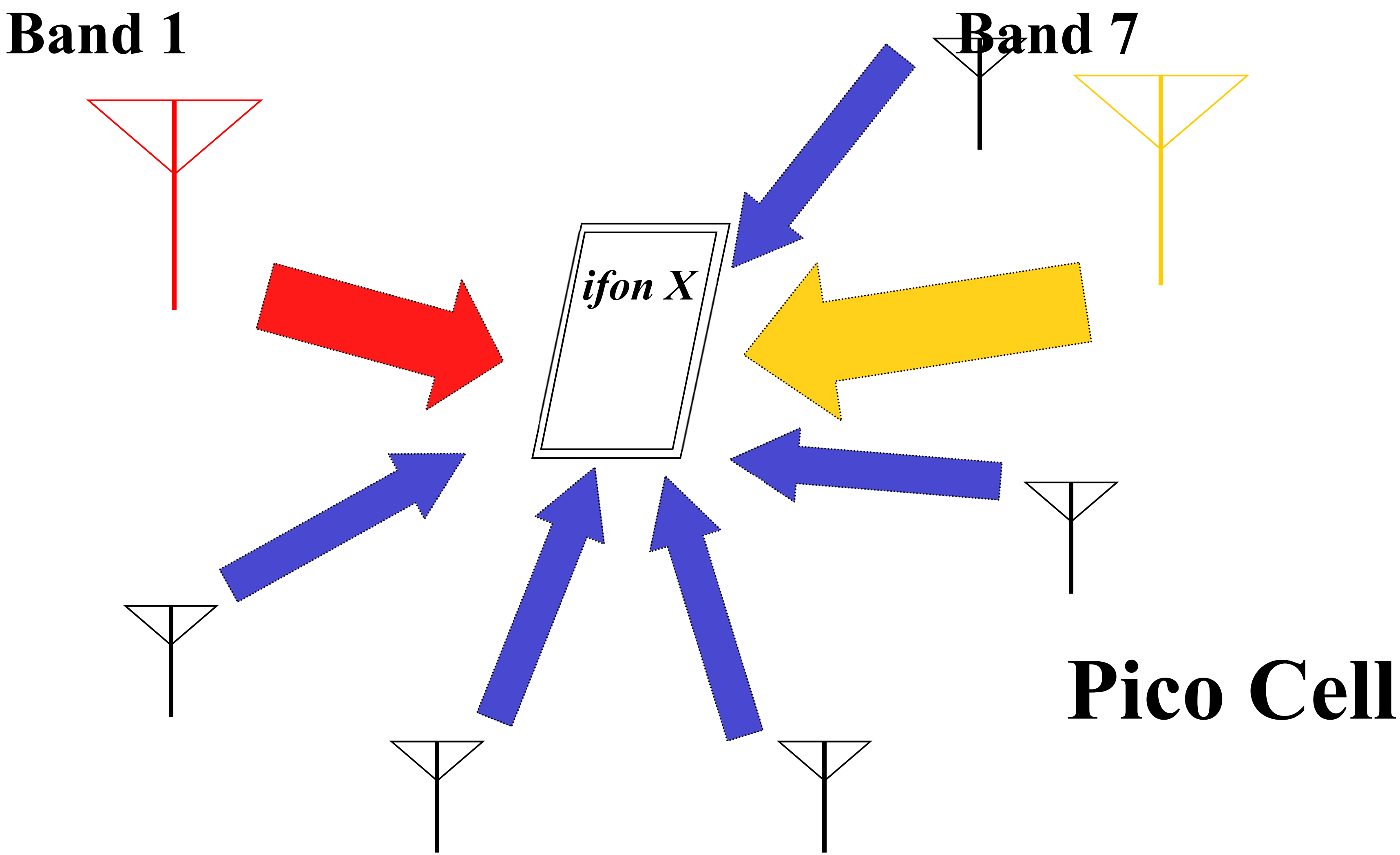
$$C \cong NB\log_2\left(1+\mathrm{SNR}\right)$$

***N*: No. Antenna**



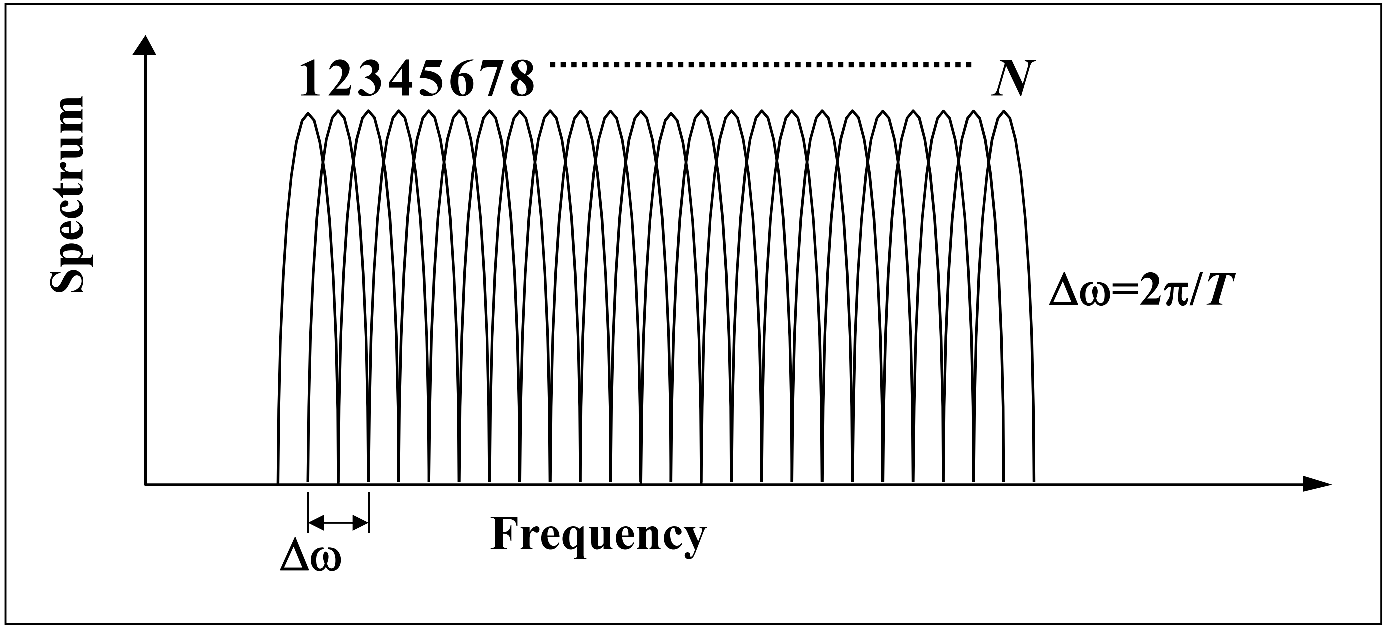
Multi-Input
Multi-Output
(MIMO)

Carrier Aggregation

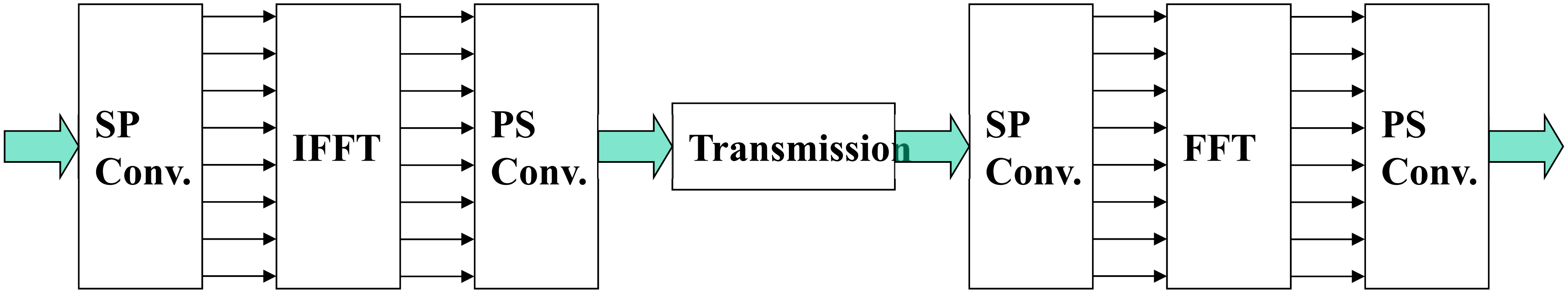


Requirements to Pico Cell Duplexer?

Orthogonal Frequency Division Multiple Access, OFDMA



OFDMA System Setup

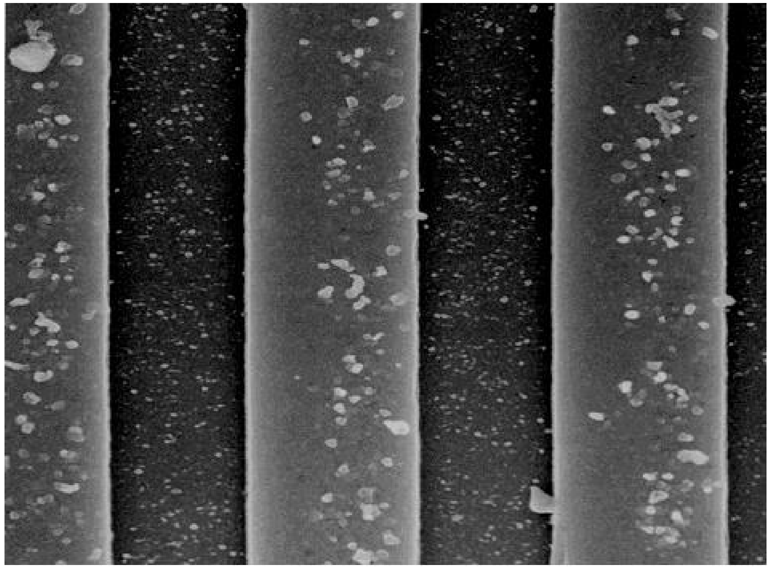


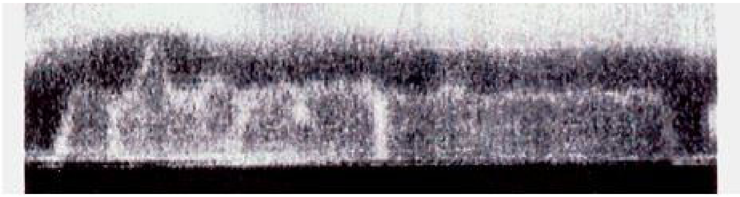
Peak to Average Power Ratio (PAPR)

Use of Effective Coding = Increase of PAPR (Random Variation in time)

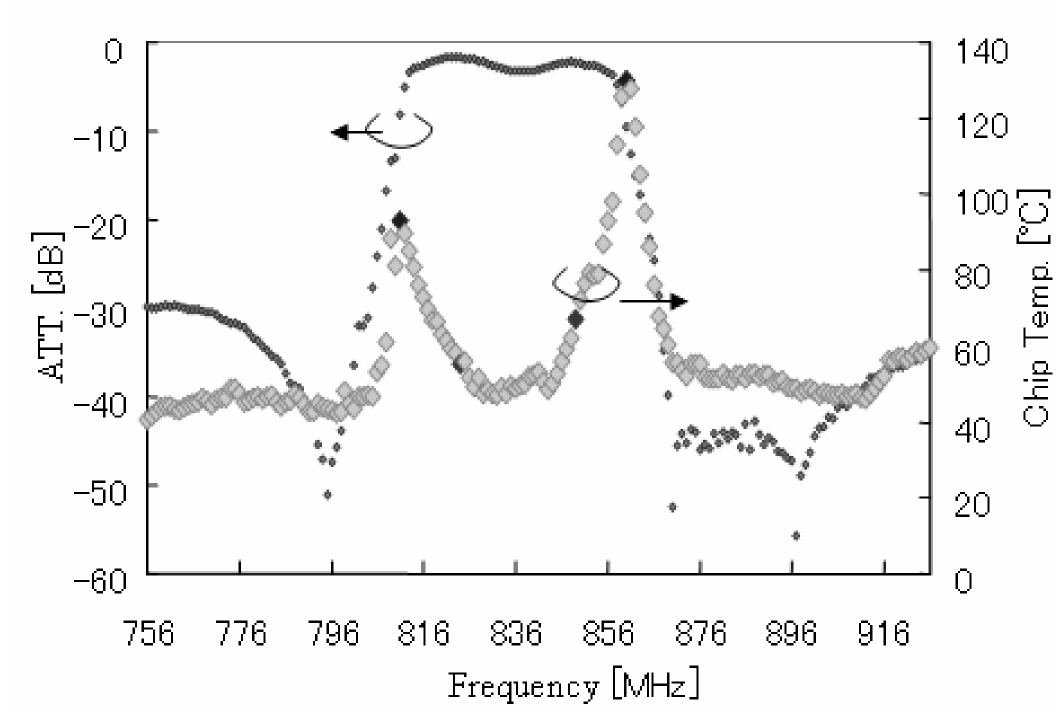
Necessity of Linearity Improvement
Necessity of Durability Improvement for Peak Power

Power Durability





Generation of Voids and Hillocks = Acousto-Migration



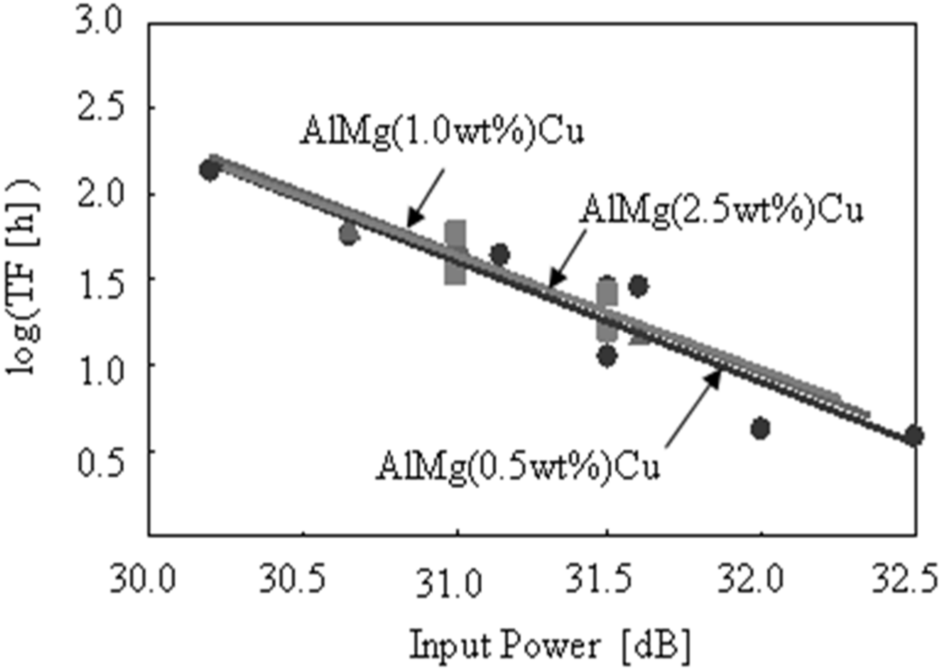
Increase in Substrate Temperature for Given Input Power

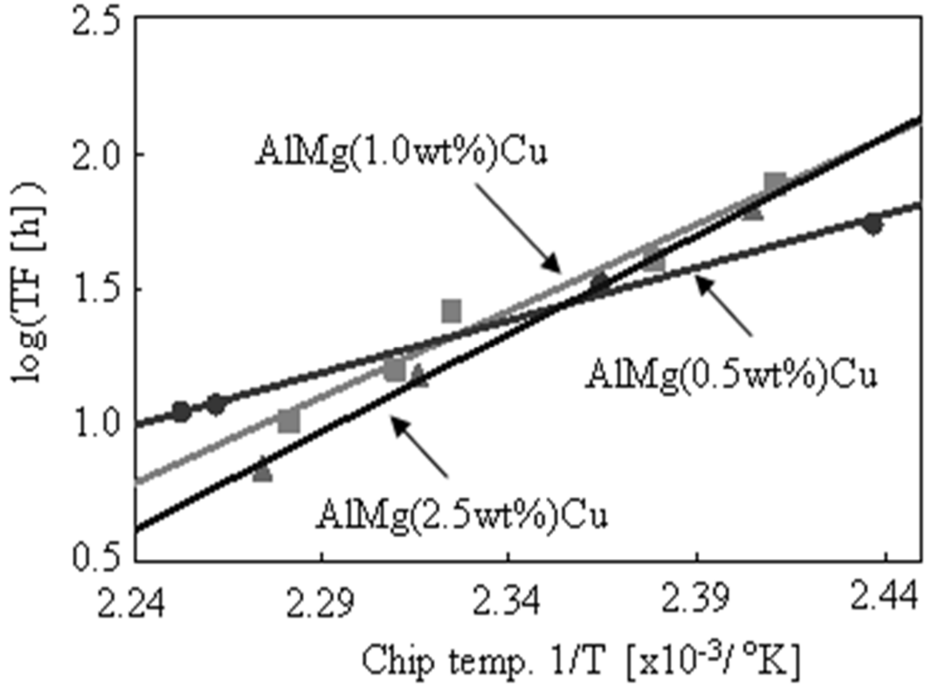
Where is the Weakest?

Life Time Modelling

$$\mathrm{TF} = \alpha P^{-\beta} \exp\left(-E/kT\right)$$

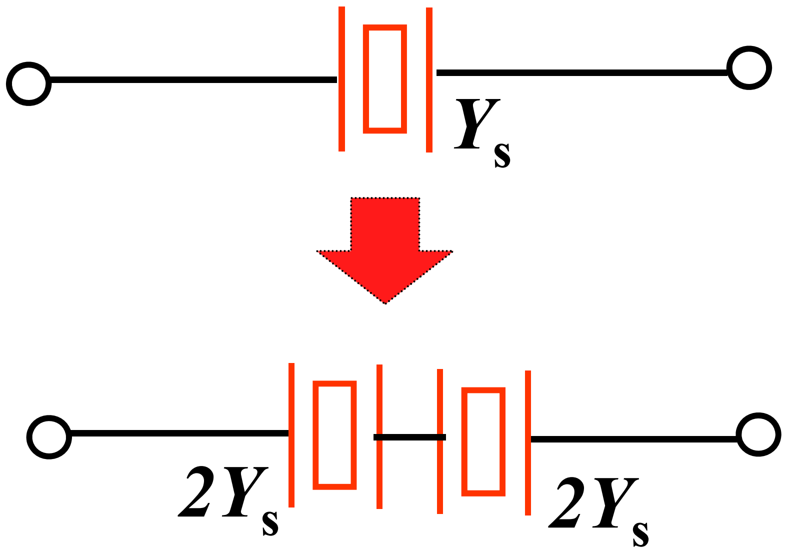
α,β, *E*:constant, *k*: Boltzmann Constant,
T: Absolute Temperature





For High Power?

- Electrode Material and Structure
- Heat Reduction (Loss Reduction)
- Improving Thermal Conductivity: Wafer Bonding, ScAlN?
- Reduction of Power Density

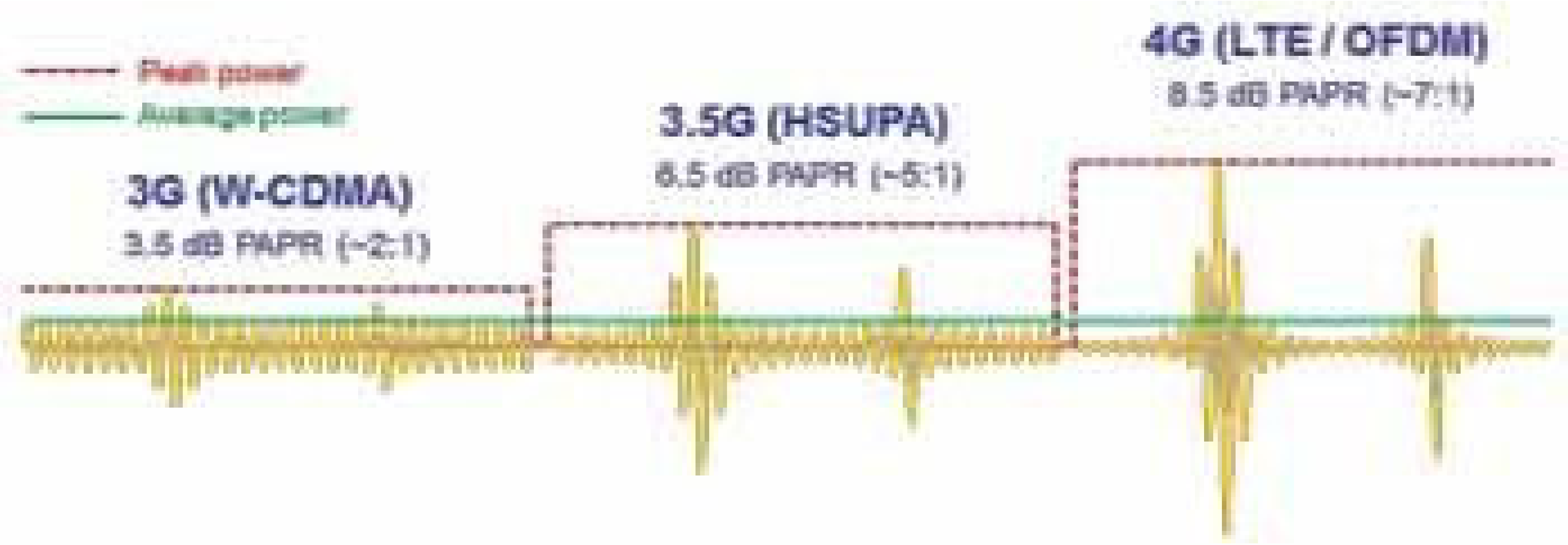


Half Input Voltage

Doubled Electrode Area

Increase in Chip Size…

Peak to Average Power Ratio (PAPR)

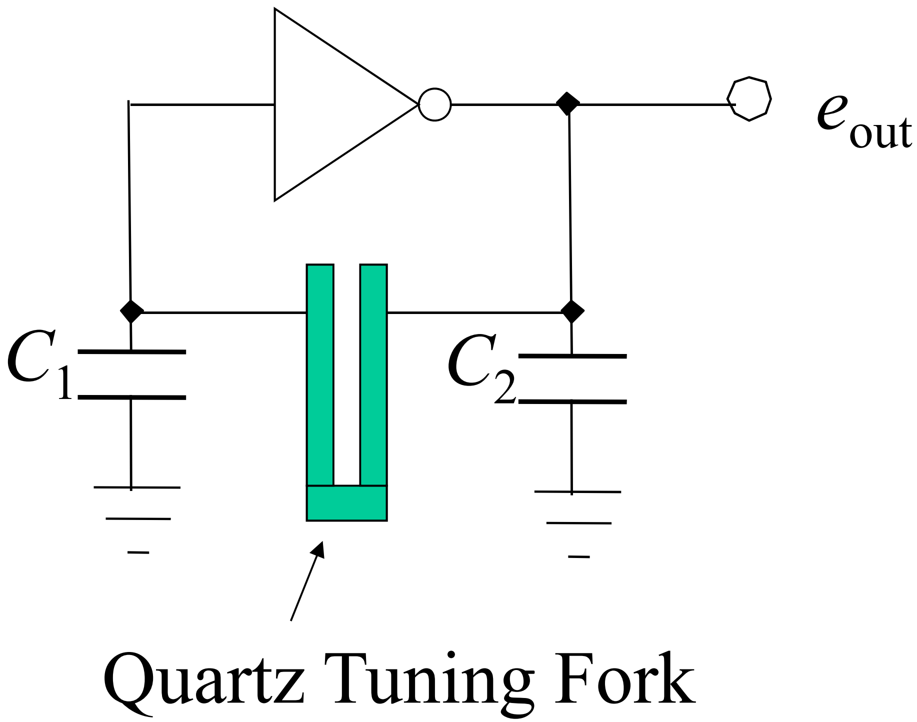


Increase in Peak Power → Cause of Different Failure Mechanism

Contents

- Oscillators

Quartz Oscillation Circuit



Use of Acoustic Vibration

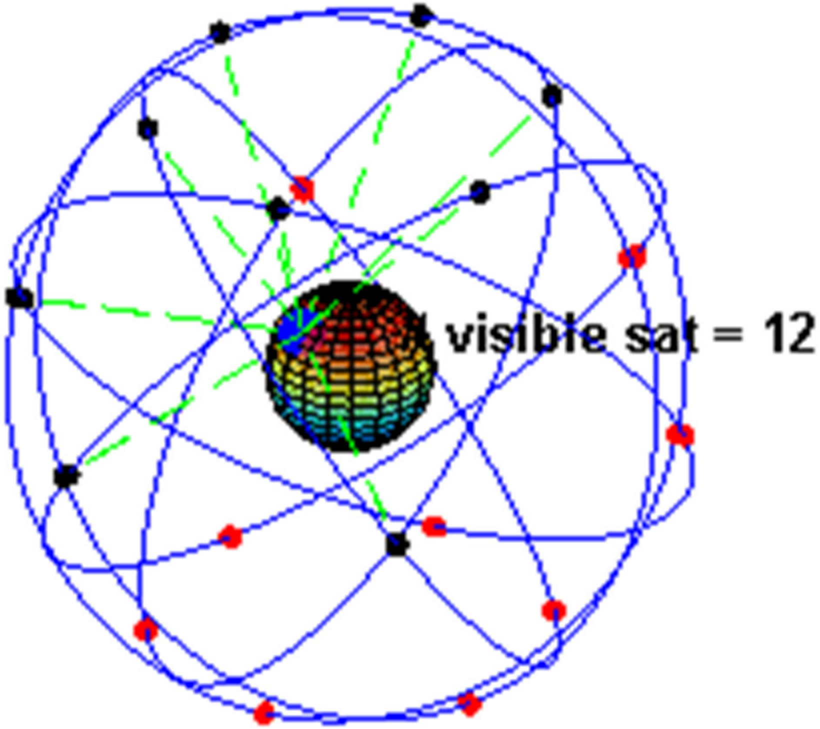
High Quality Factor =
Long Vibration Sustain
$\rightarrow$ Insensitive to Noise

High Temperature Stability

2^{15} =32,768Hz Osc. $\rightarrow$Counting 2^{15} Pulses Gives 1 Sec.

How Accurate? $$\frac{1\,\text{sec.}}{1\,\text{day}} \cong 10\,\text{ppm}$$

Global Positioning System (GPS)



Present position (x, y, z) is given by solving

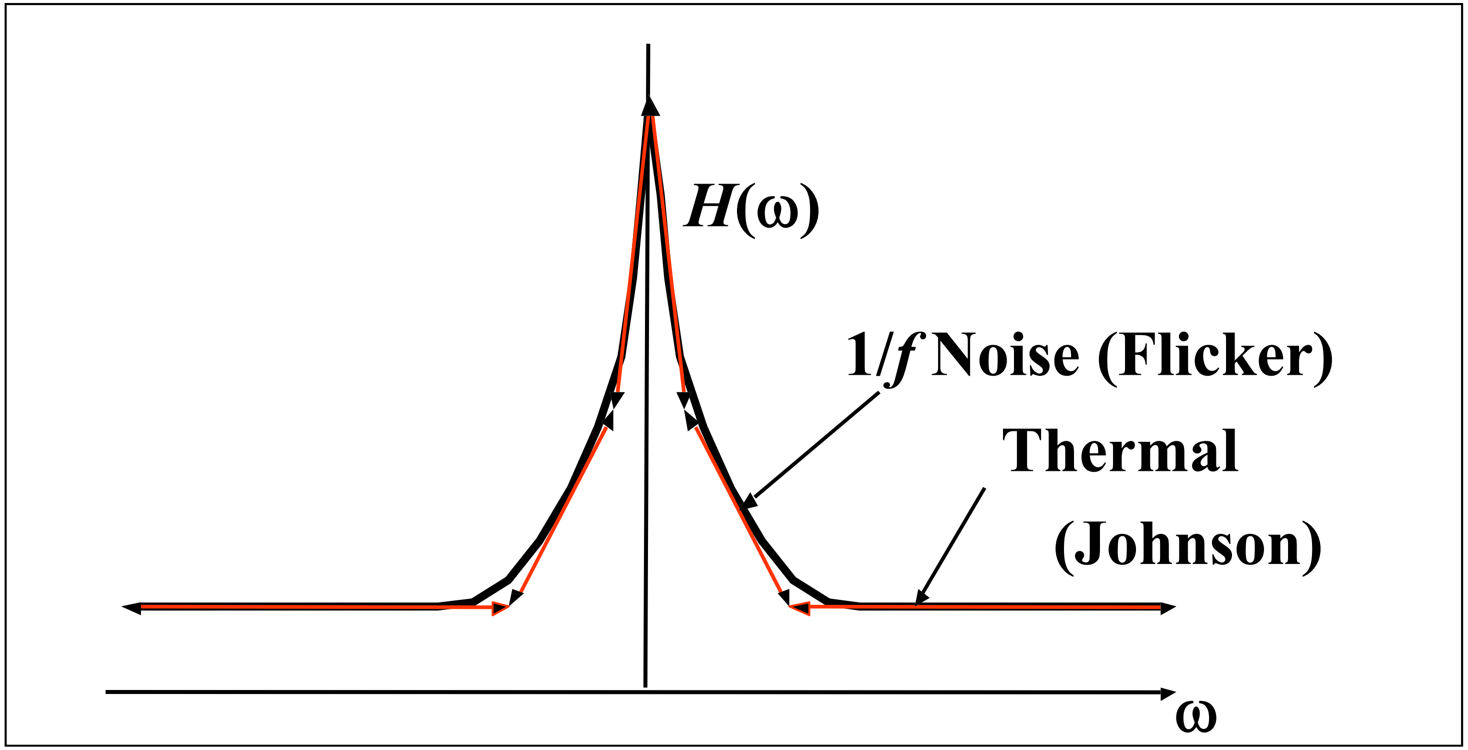
$$d_n^2 = (x - x_n)^2 + (y - y_n)^2 + (z - z_n)^2 \qquad n = 1, 2, \cdots, N$$

x_n, y_n, z_n : position of the n-th satellite

d_n: distance from the n-th satellite

Oscillation Spectrum (Phase Noise)

Conversion of AM Noise to PM Noise via Saturation

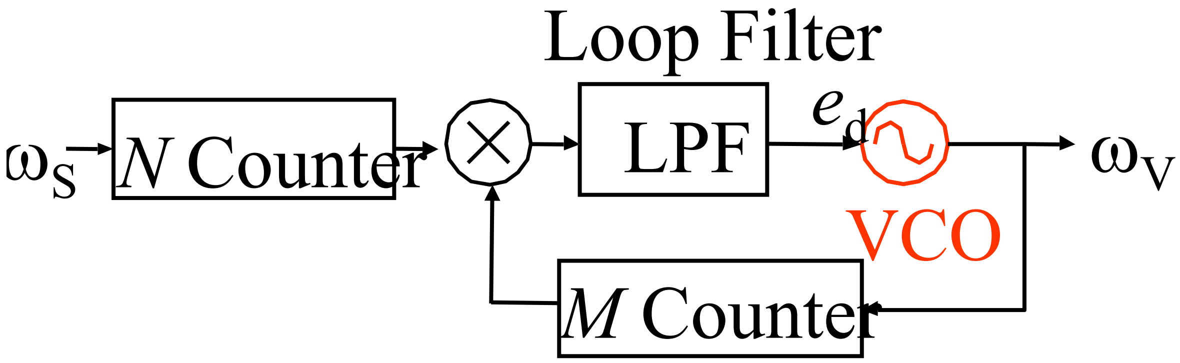


Long Term Stability (Ageing)

Mid Term Stability (Temp. Drift)

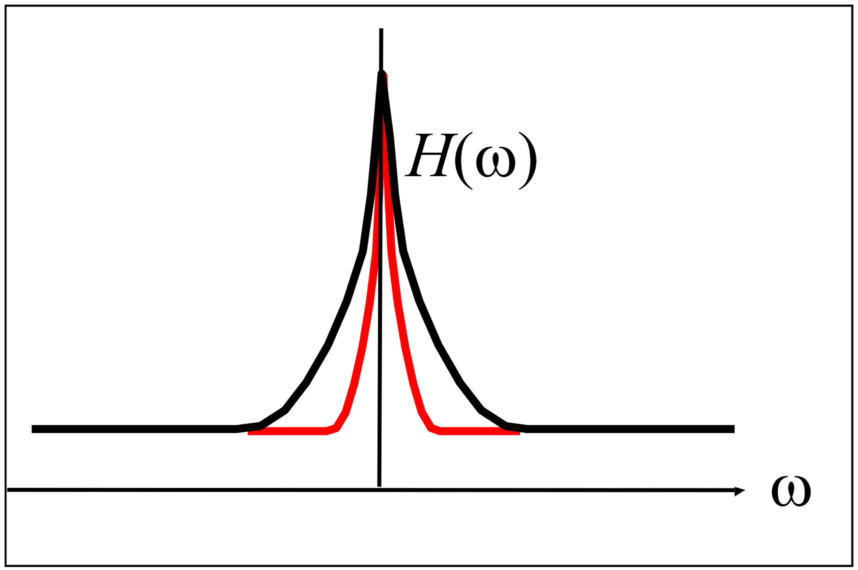
Short Term Stability (Fluctuation)

Frequency Synthesizer ($\omega_v = M\omega_s / N$)



Phase-Locked Loop (PLL)

- Use of Stable ω_s $\Rightarrow$ Accurate & Stable
- Programmable Divider $\Rightarrow$ Tunable

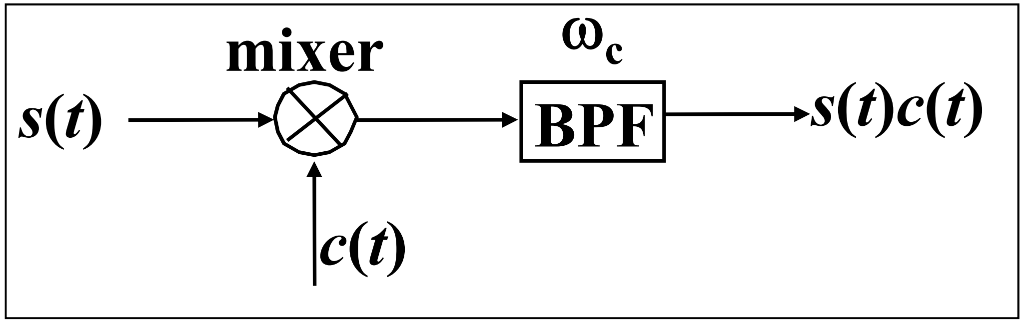


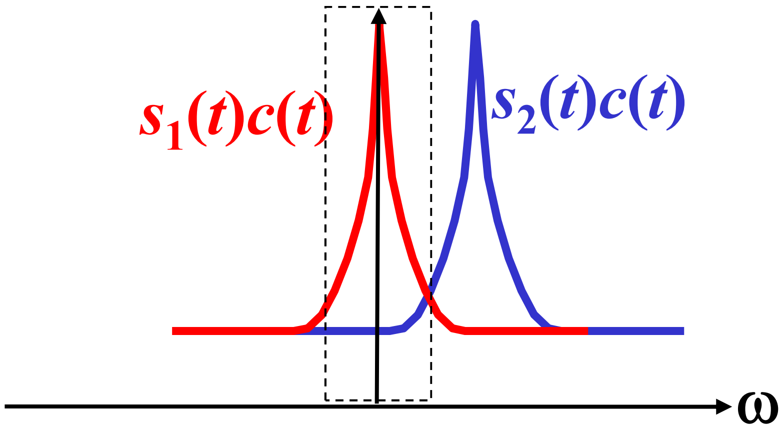
VCO (Voltage Controlled Oscillator) Determines Thermal Noise Level

Phase Noise Deterioration at Counter Change

Influence of Phase Noise

Mixing with Local Oscillation $c(t)$ with Noise

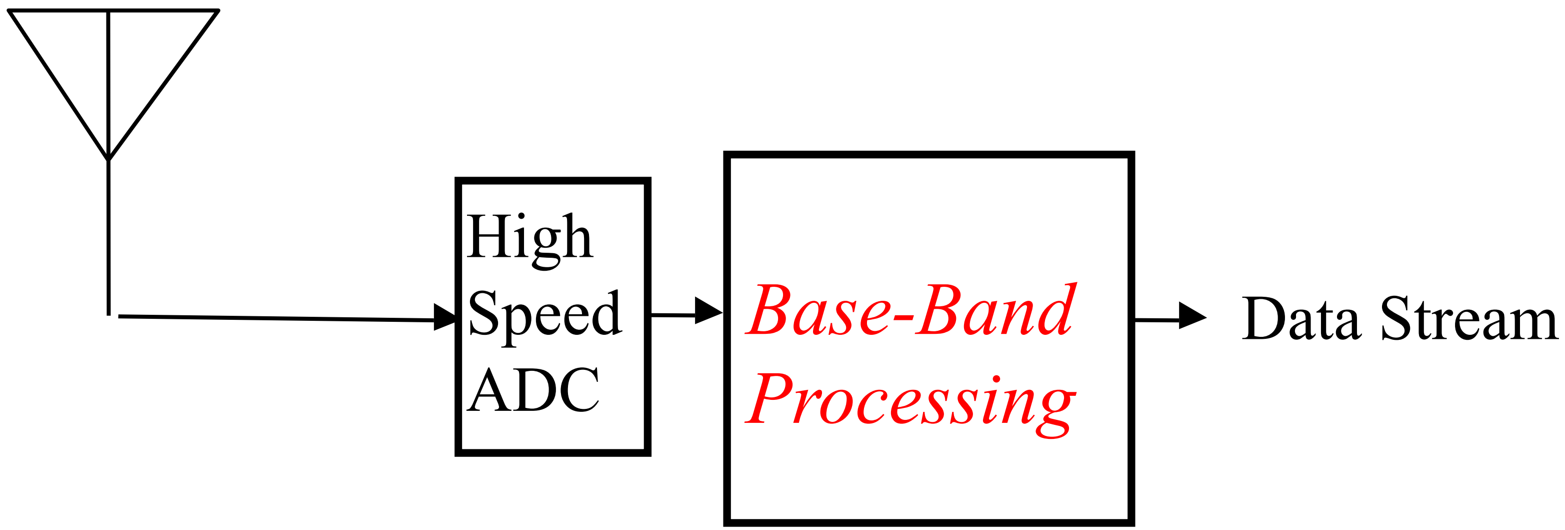




Spectrum After Mixing

Conversion of Thermal and 1/f Noise in Adjacent Channel to Desired Channel

Software Defined Radio (SDR)

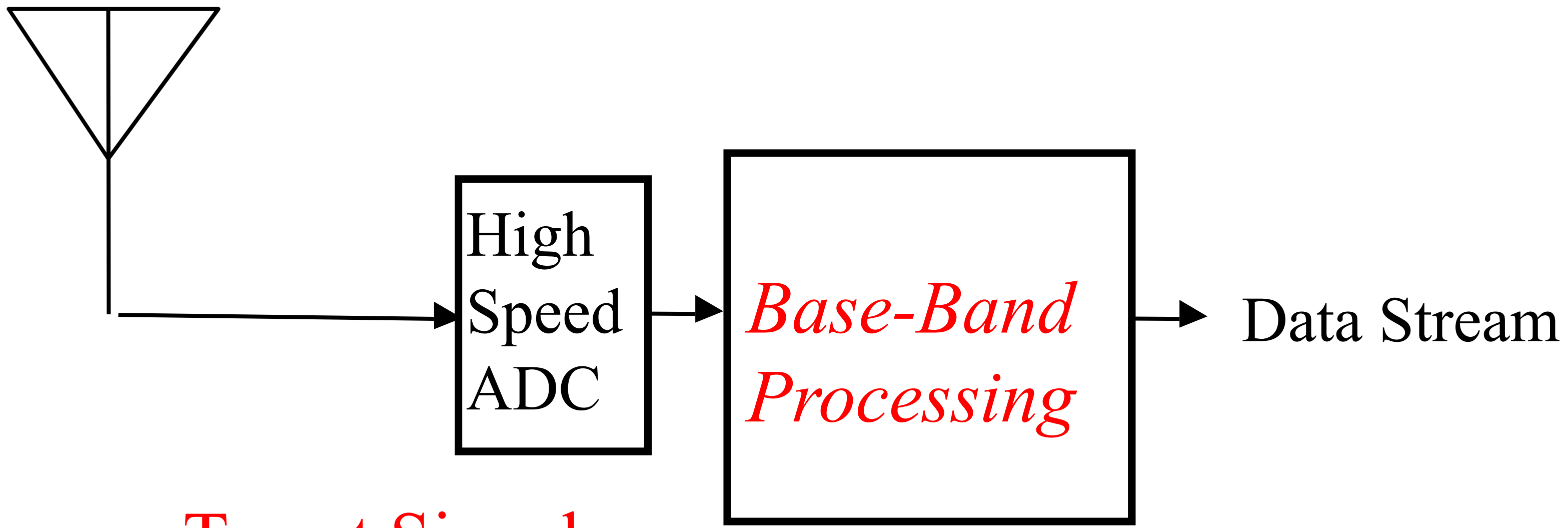


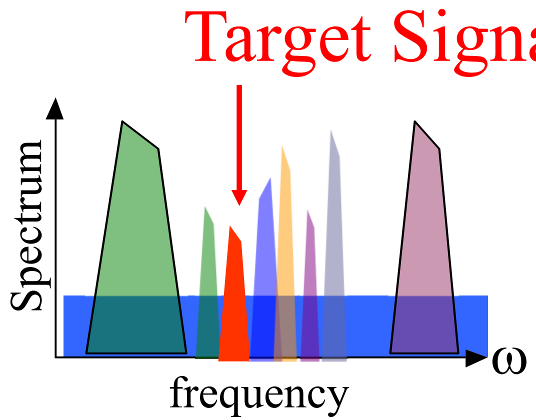
ADC: Analog-to-Digital Converter

Multiple Standard (GSM, UMTS, GPS, etc.)
Support by Software Loading from HDD

System Upgrade by Software Download

For SDR Realization

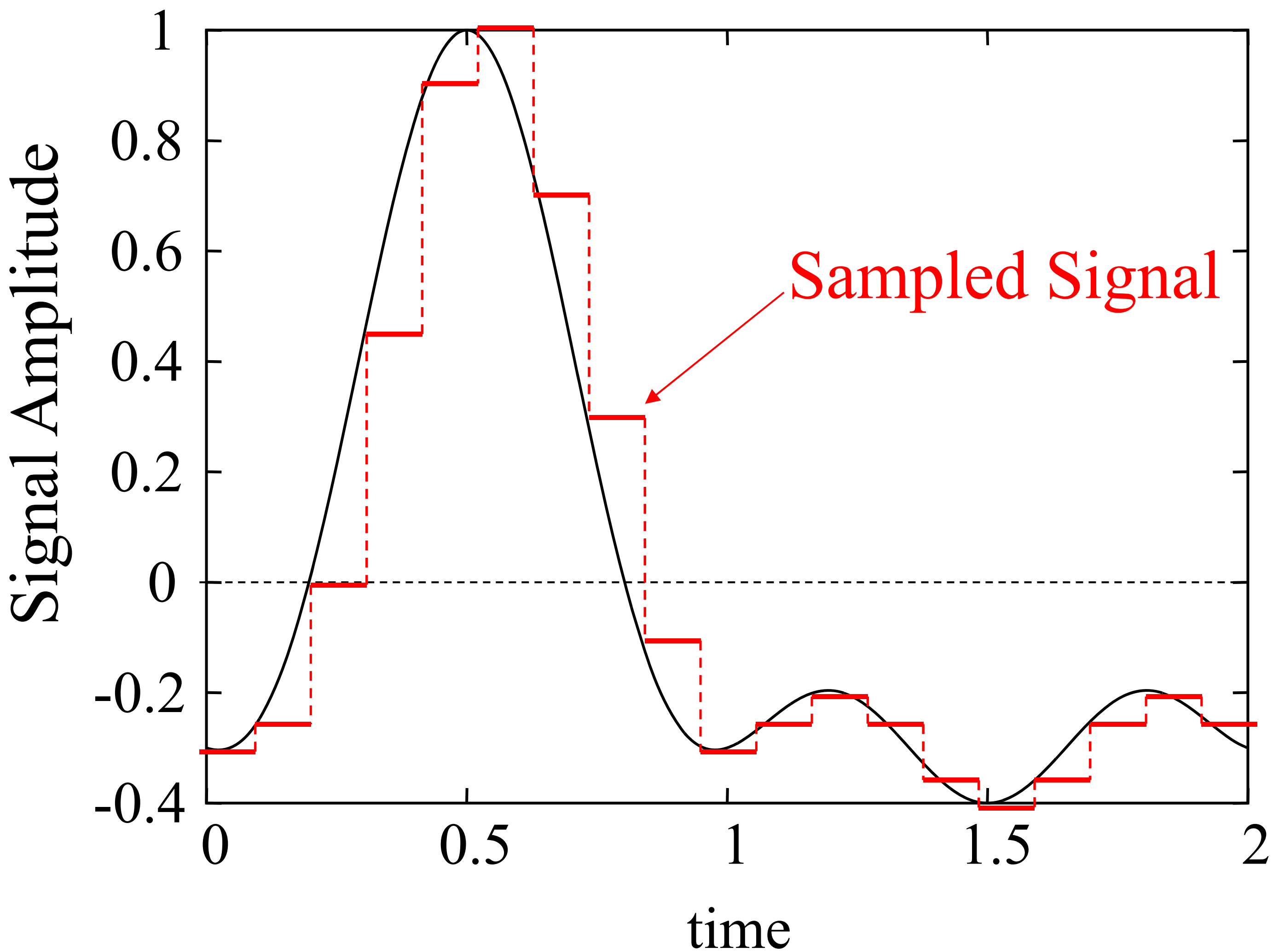




Extremely Large Dynamic Range Necessary

High Speed & Extremely Large Dynamic Range ADC Possible?

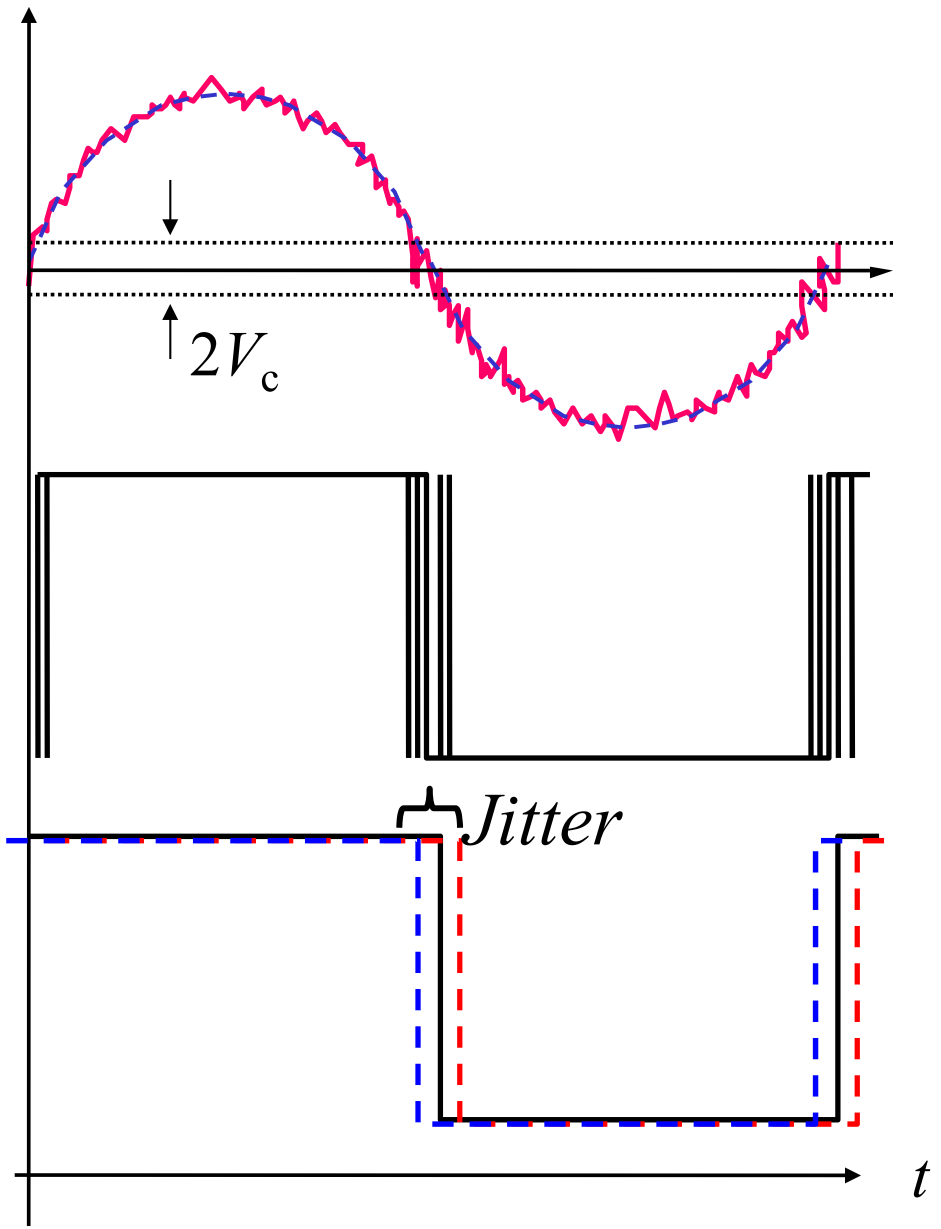
Sampling Theorem



Low Pass Filtering of Periodically Sampled Data

Recovery of Original Signal

Jitter Generation by Thermal Noise



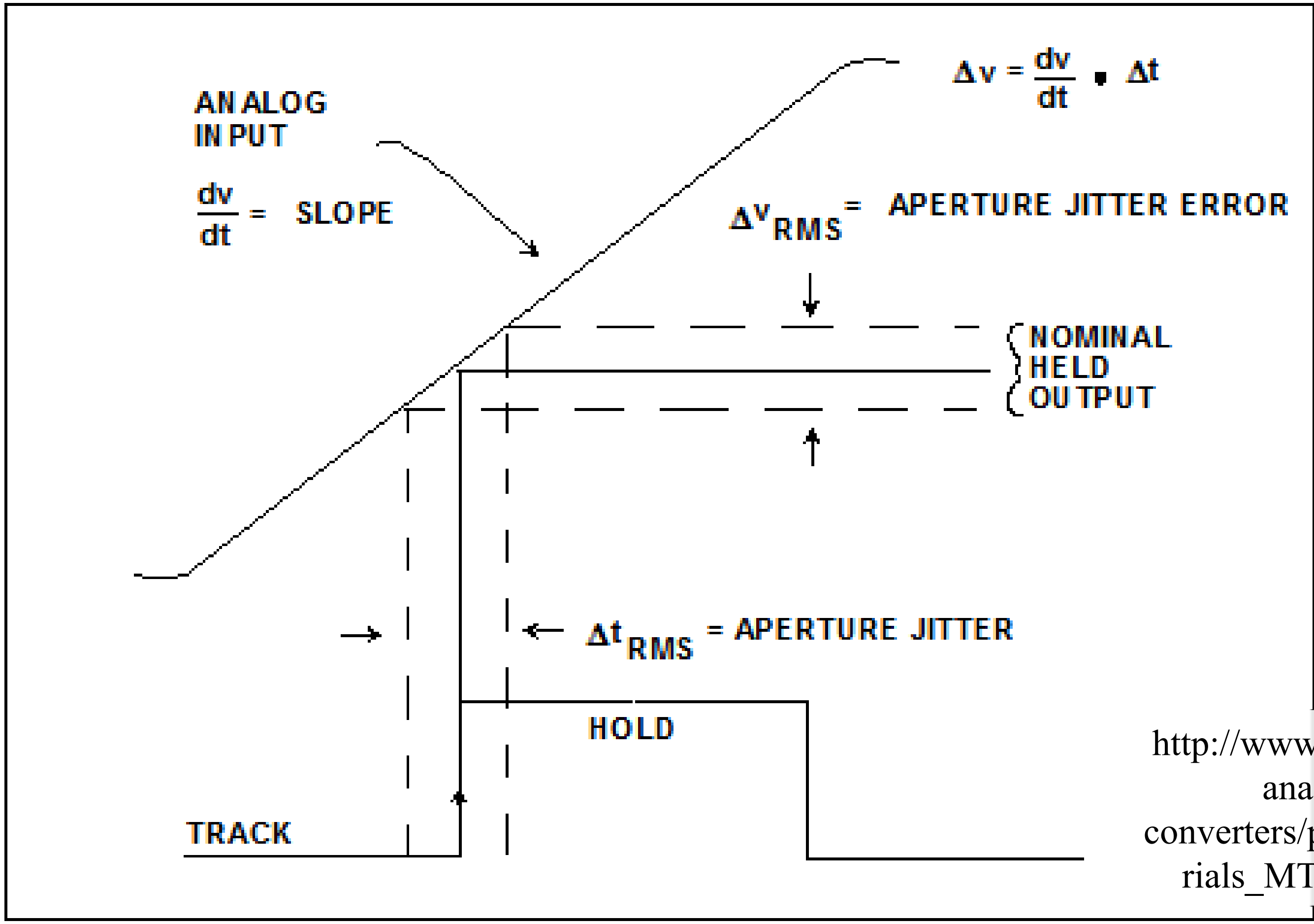
Signal with
Thermal Noise

After Digitization

→ Pulse Miss-Count

After Digitization
with Hysteresis

Influence of Jitter to High Speed ADC

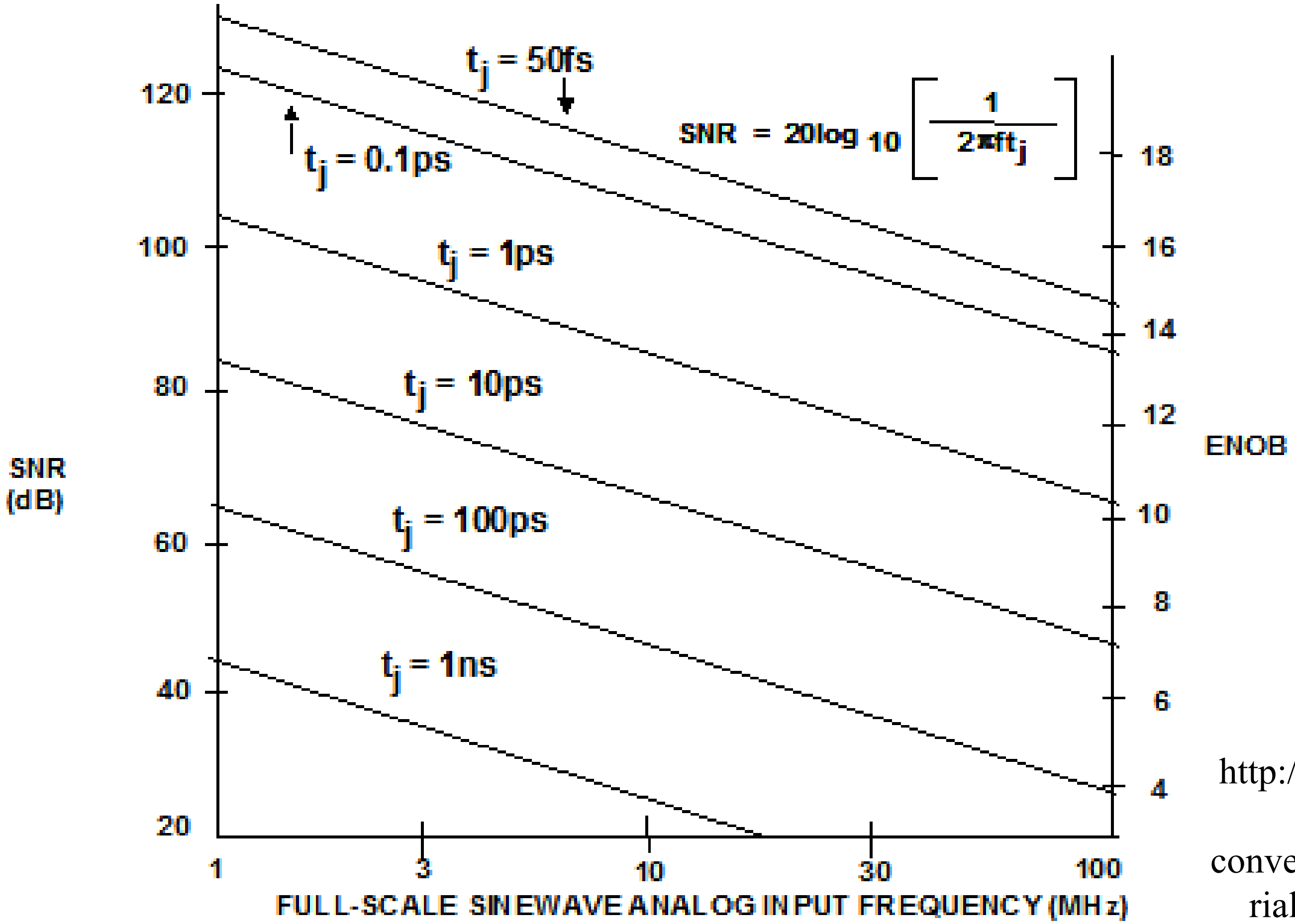


http://www.analog.com/jp/digital-to-analog-converters/da-converters/products/tutorials/CU_tutorials_MT-007/resources/fca.html

Jitter Causes Amplitude Fluctuation (Error)

Influence of Jitter Significant at High Frequency

Influence of Jitter and Freq. to SNR



http://www.analog.com/jp/digital-to-analog-converters/da-converters/products/tutorials/CU_tutorials_MT-007/resources/fca.html

How to Reduce Jitters

- **Low Jitter (Low Noise) Oscillation Using High *Q* Resonators**

cf: Atomic Clock (Very Accurate But Not Precise)

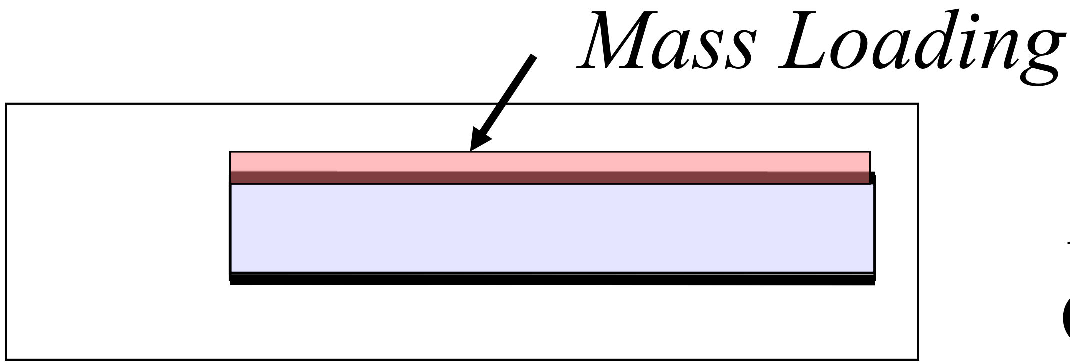
Stabilization by Quartz Oscillator (Very Precise But Not Accurate Enough)

Very Precise and Very Accurate Oscillation

Contents

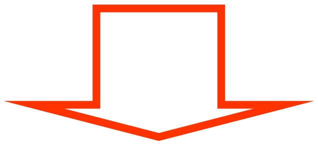
- SAW Wireless Tags and Sensors

Quartz Micro-Balance (QMB)



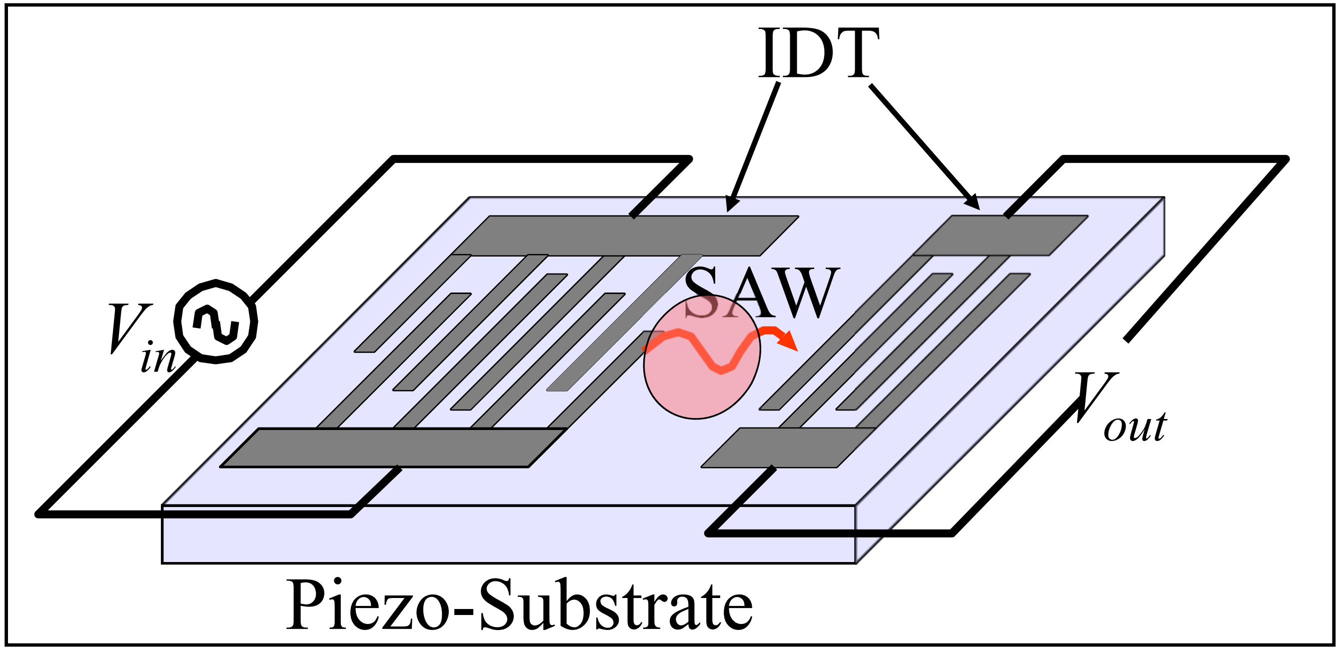
AT-cut Quartz

- **Temperature Stability**
- **Phase (or Frequency) Output $\Rightarrow$ High Resolution**
- **Low Price**



Sensor Applications: Physical (Film Thickness, Pressure), Chemical(Gas, Liquid), Bio

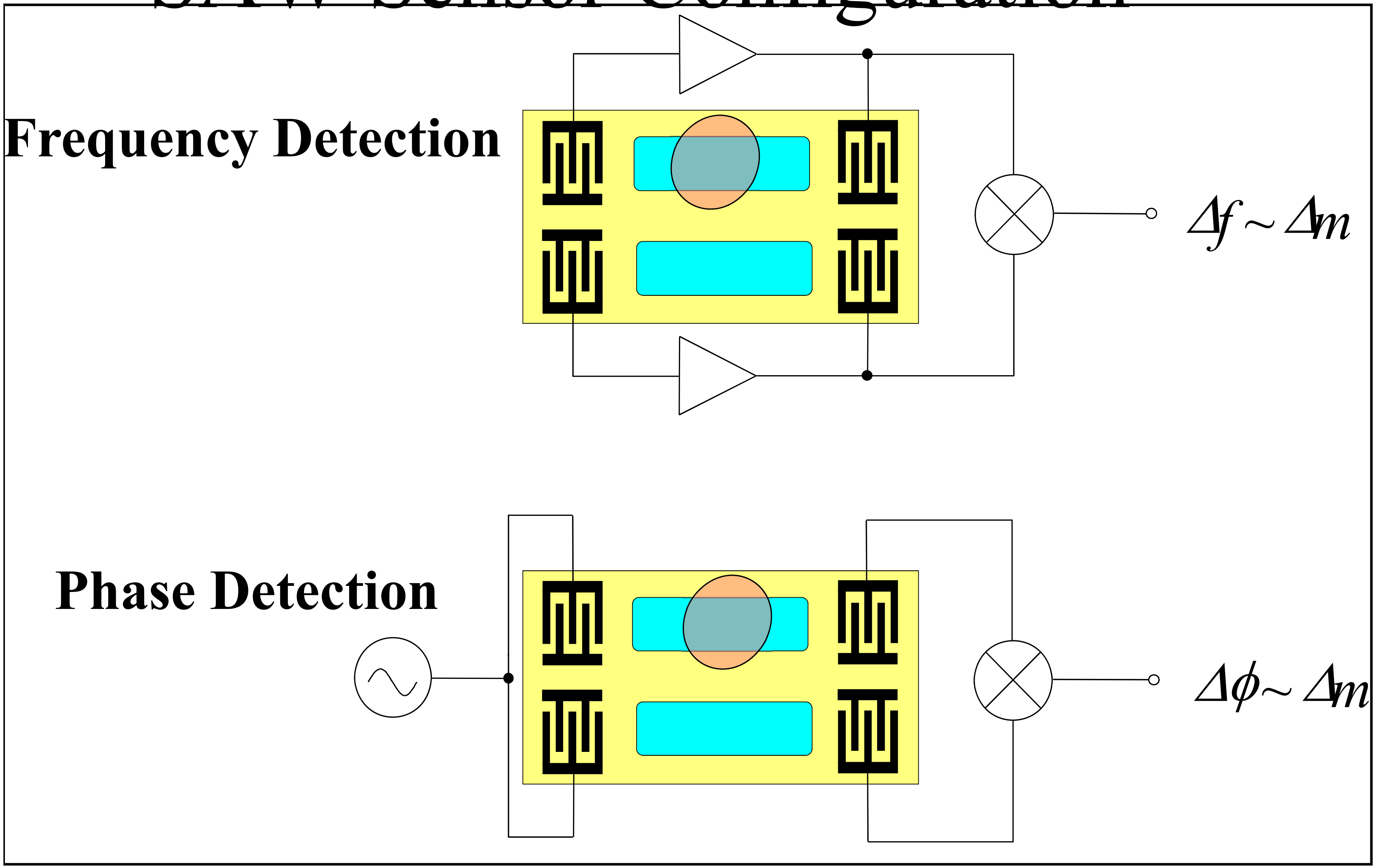
SAW Sensor



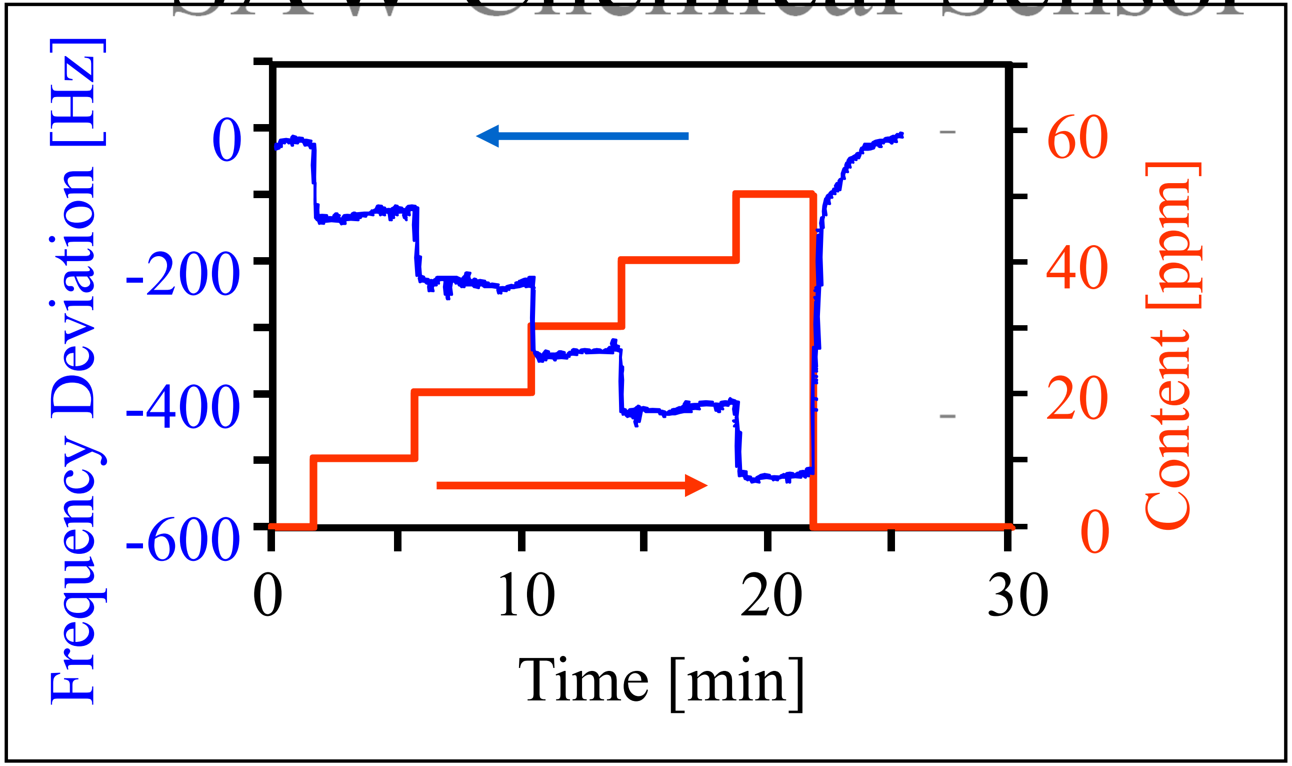
- High f ($\Delta f = -K f_0^2 \Delta m$) $\Rightarrow$ High Sensitivity
- Moderate Temperature Stability
- *Surface Protection (Packaging) ?*

Area 1 mm^2 & f_0=1 GHz give $K f_0 \sim 10^7$ / kg
$\Rightarrow$ 1 ppm of f deviation=Resolution 0.1 pg.

SAW Sensor Configuration

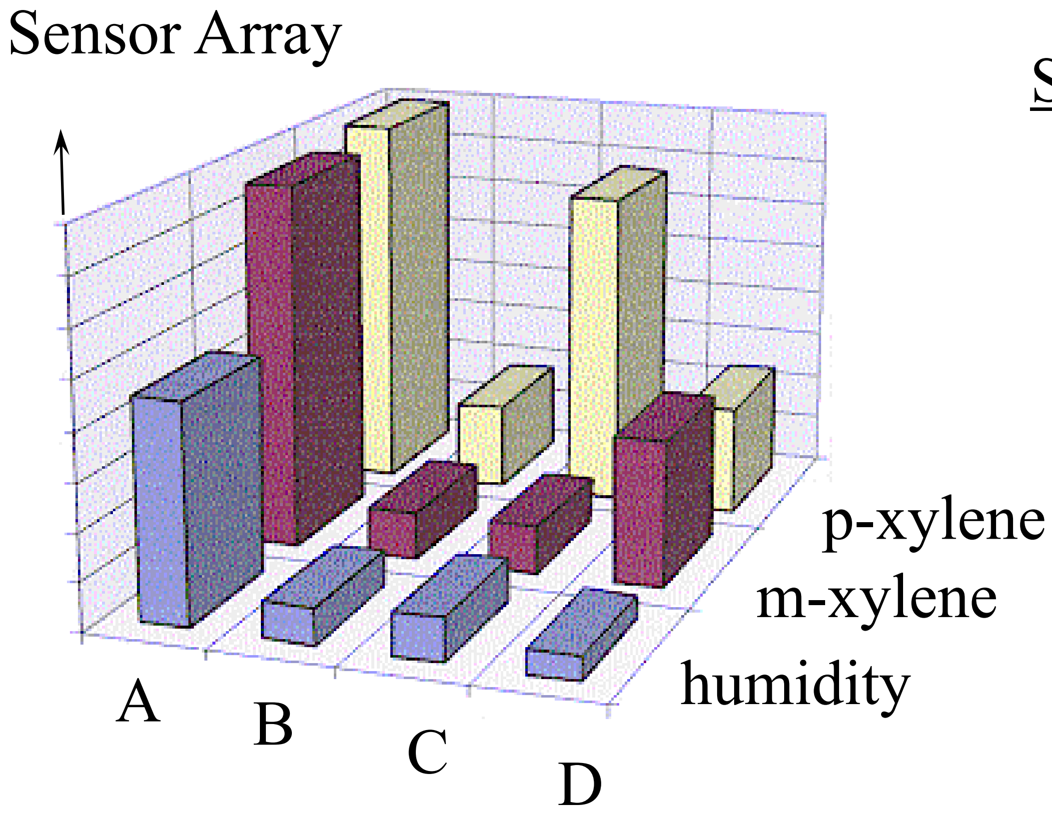


SAW Chemical Sensor



- Sensitive Layer: A calixarene (10 nm)
- Object: tetrachloroethene
- f_0: 434 MHz

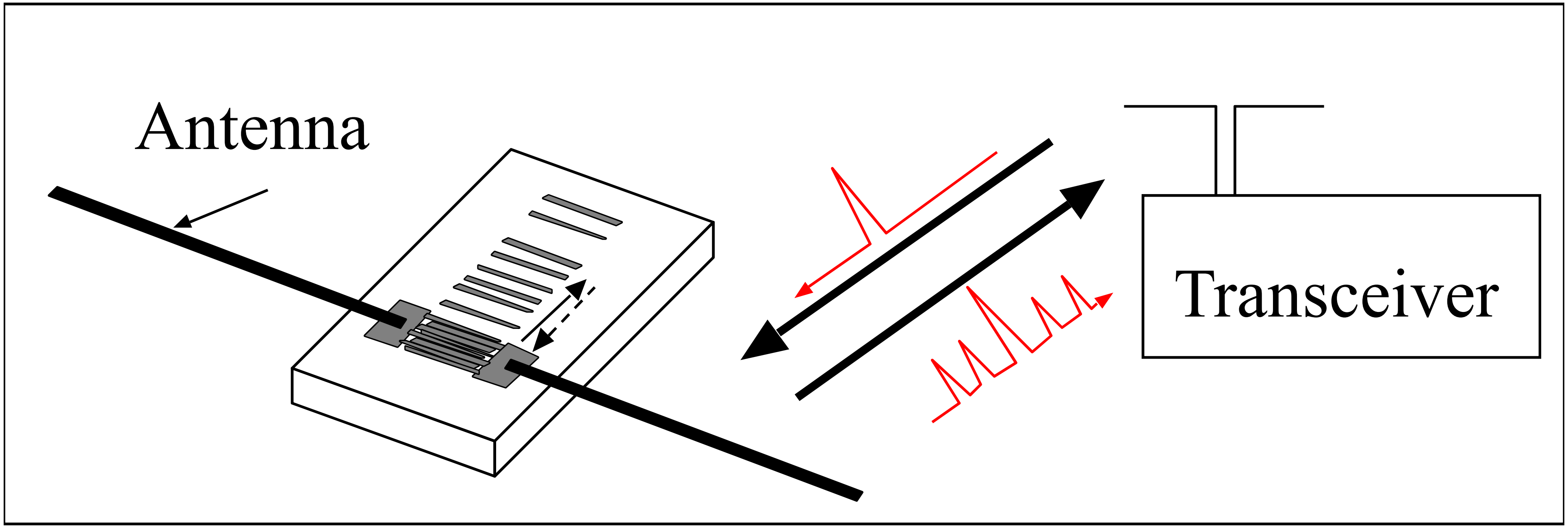
Pattern Recognisition with Sensor Array



<u>Sensor : Sensitive Film</u>

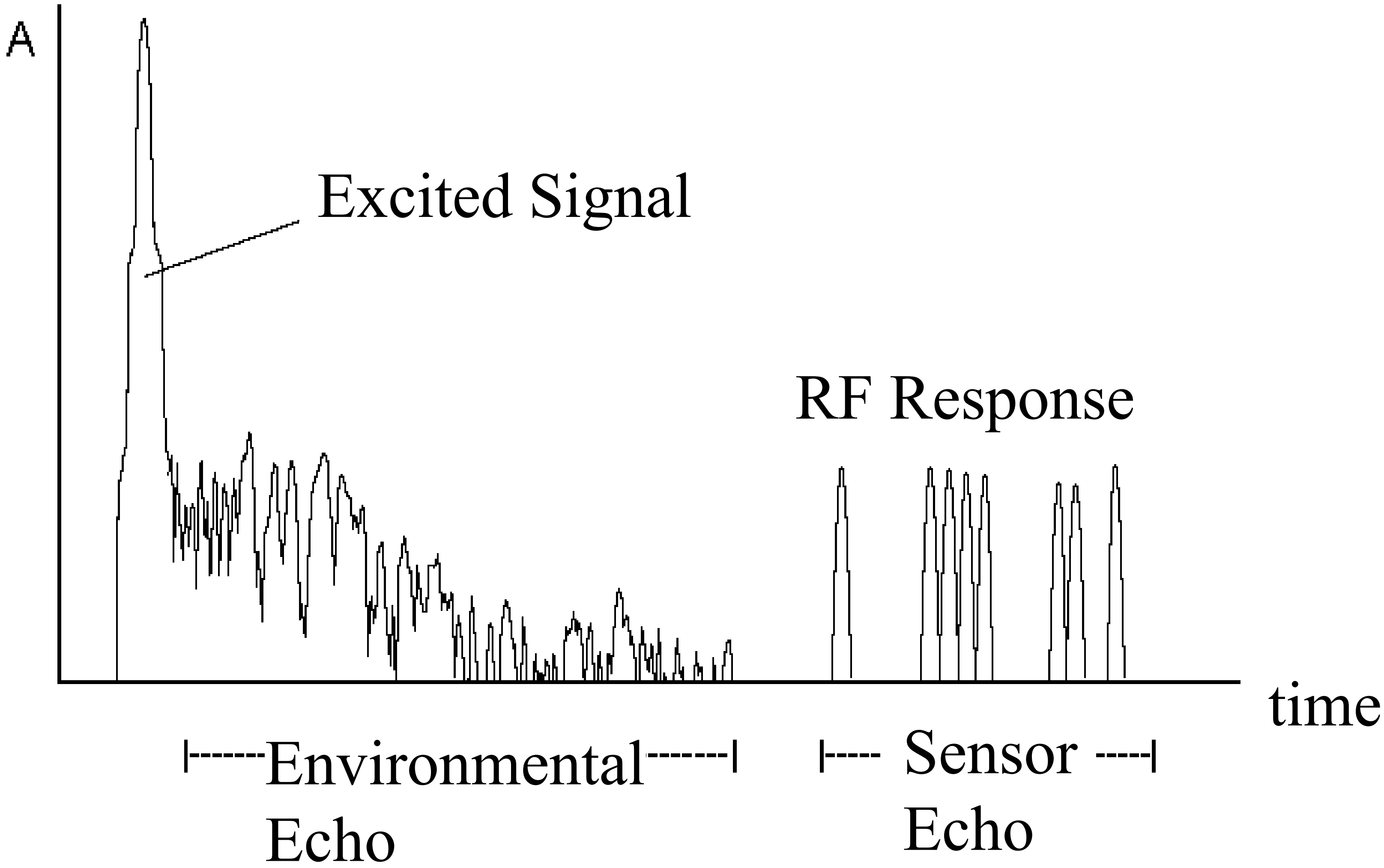
A	Calix[4]resorcinearene 1
B	Calix[4]resorcinearene 2
C	Cyclodextrine-functiona-lized polymer 1
D	Cyclodextrine-functiona-lized polymer 2

What is SAW ID-TAG?



- Wireless, Batteryless
- Large Group Delay (Separation with Environmental Echoes)

Separation of SAW Signal in Time Domain



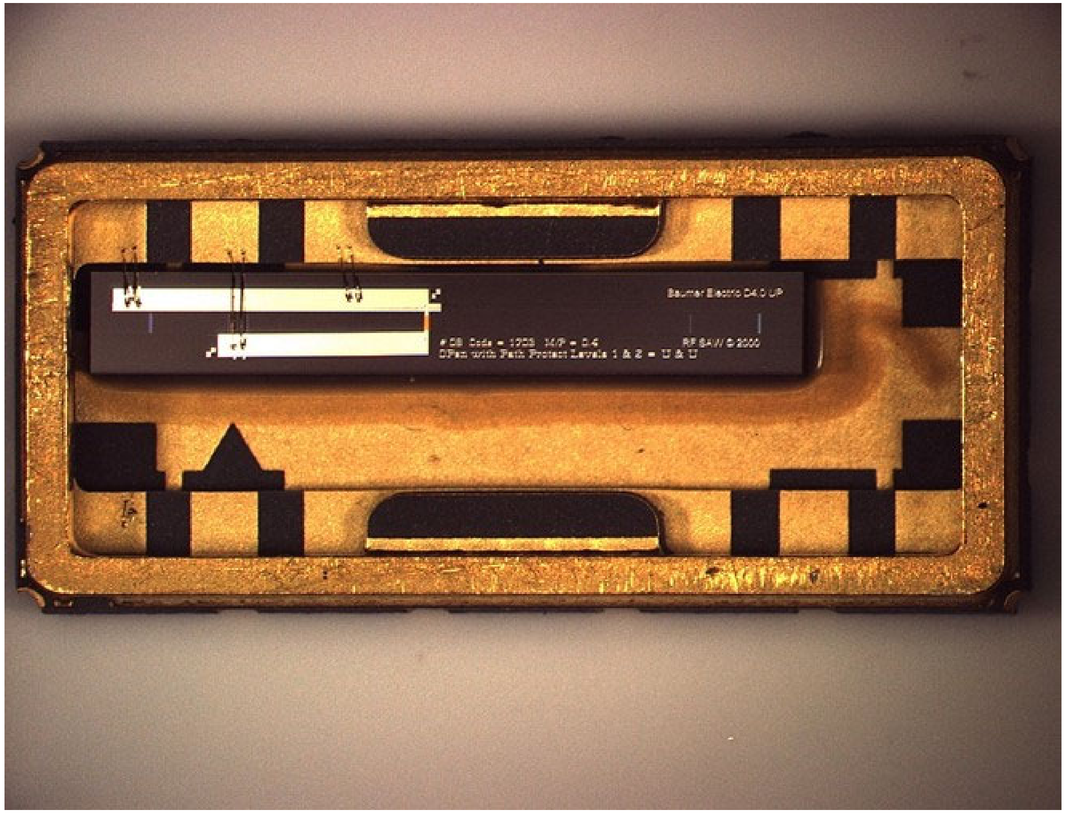
Which Frequency?

•5.2 GHz (ISM Band)
Wideband (100MHz), Short Accessible Distance (<1m), Hard to Realize SAW Devices

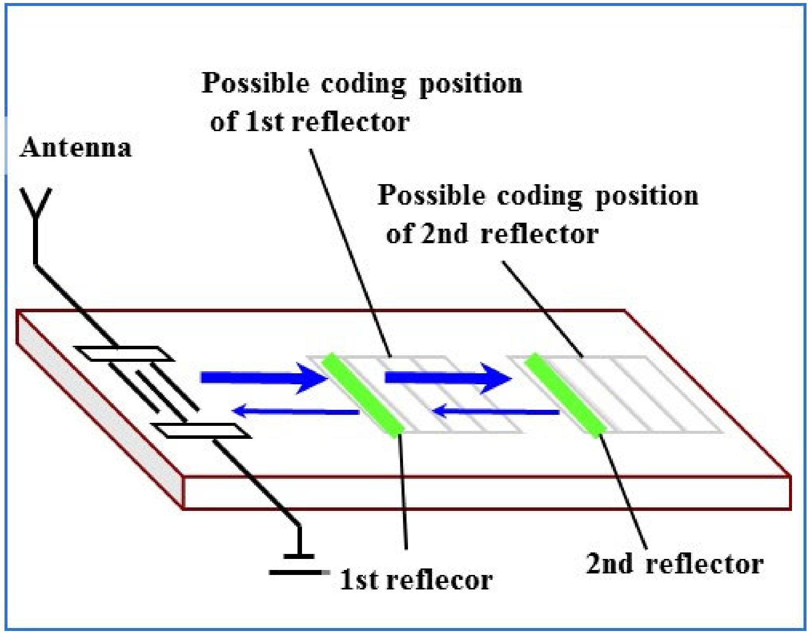
•2.45 GHz (ISM Band) Wideband(22MHz), Short Accessible Distance (2-3m), Price of SAW Devices?

•433.92 MHz (RKE Band)
Narrowband(1.7MHz), Long Accessible Distance (>10m), Low SAW Device Cost

SAW ID Tag with 5 reflectors in one track (f_0 = 2.45 GHz) using pulse position coding



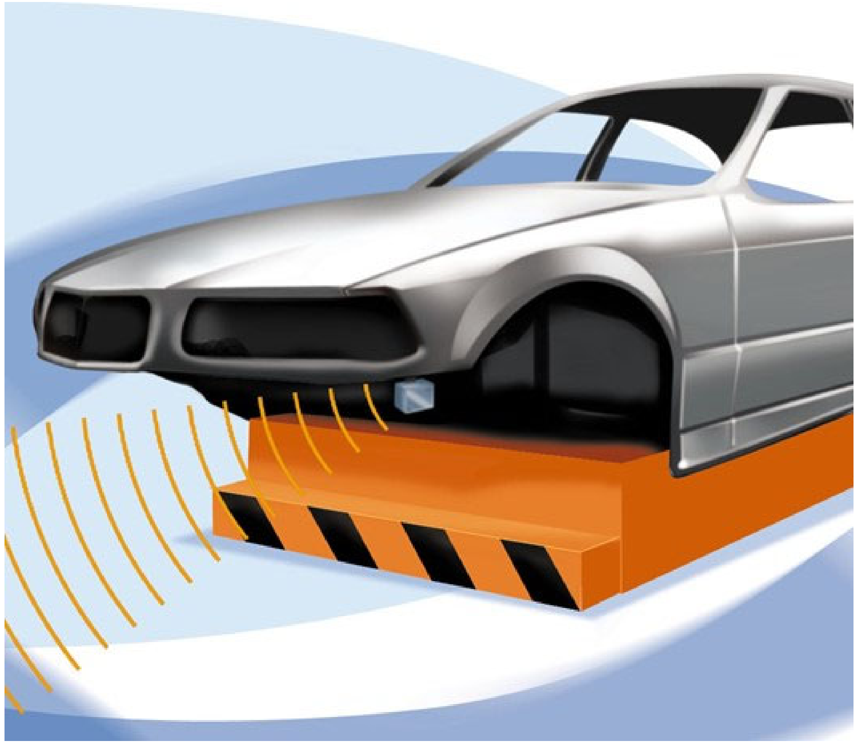
Pulse position coding schema



Baumer IDENT

Baumer Ident (2.45 GHz ISM)

OIS - W

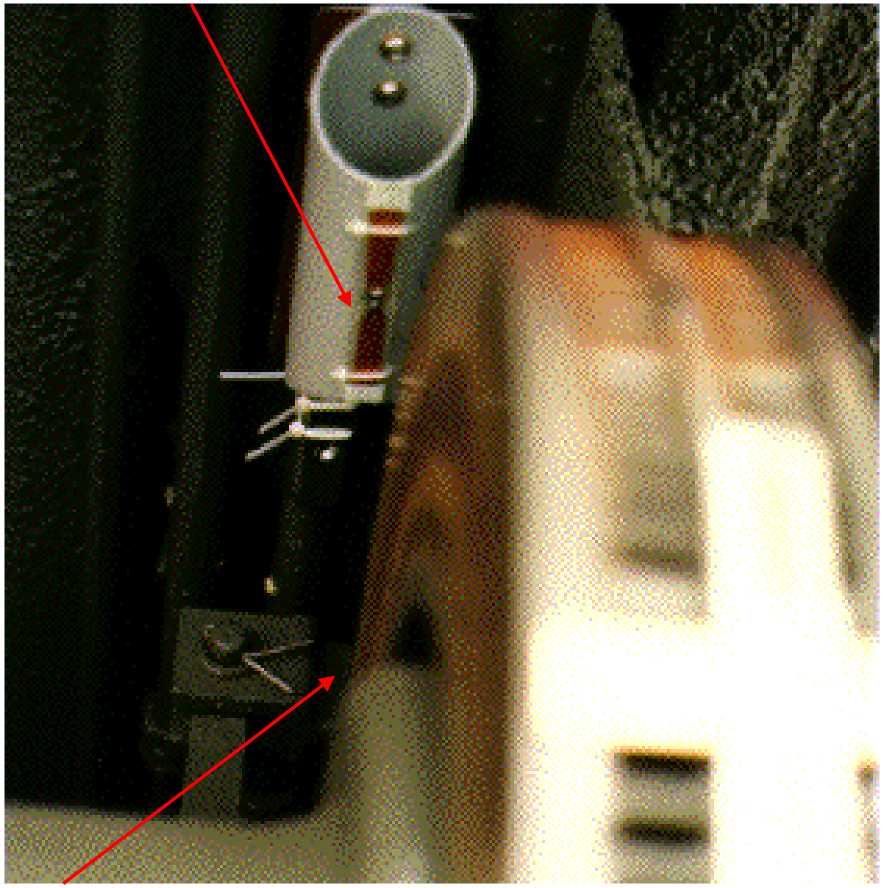


Baumer electric

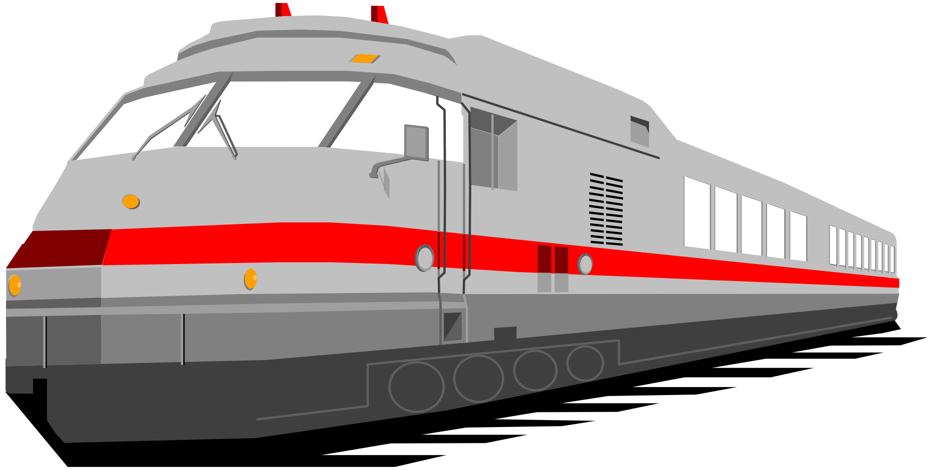
Baumer IDENT

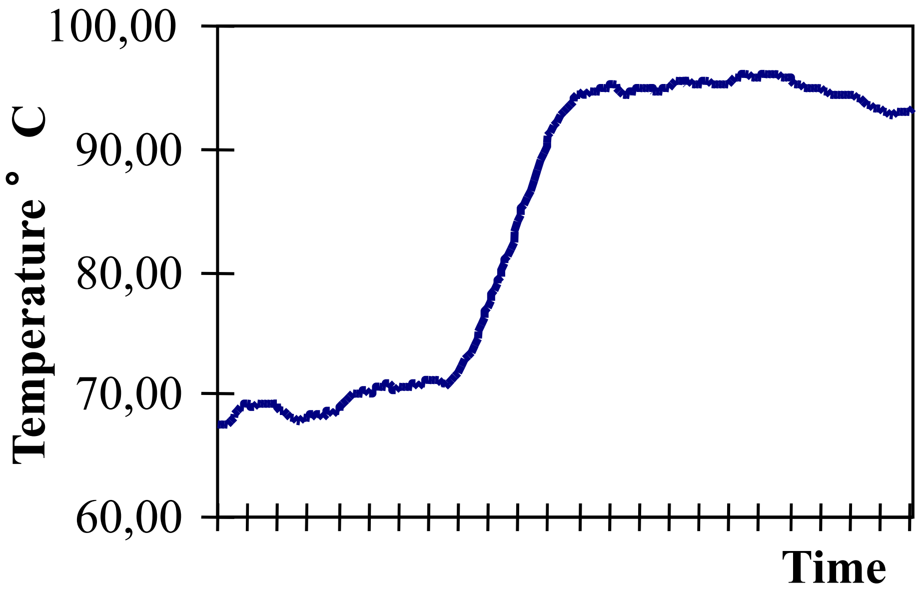
Brake temperature of a train entering a station

reader antenna

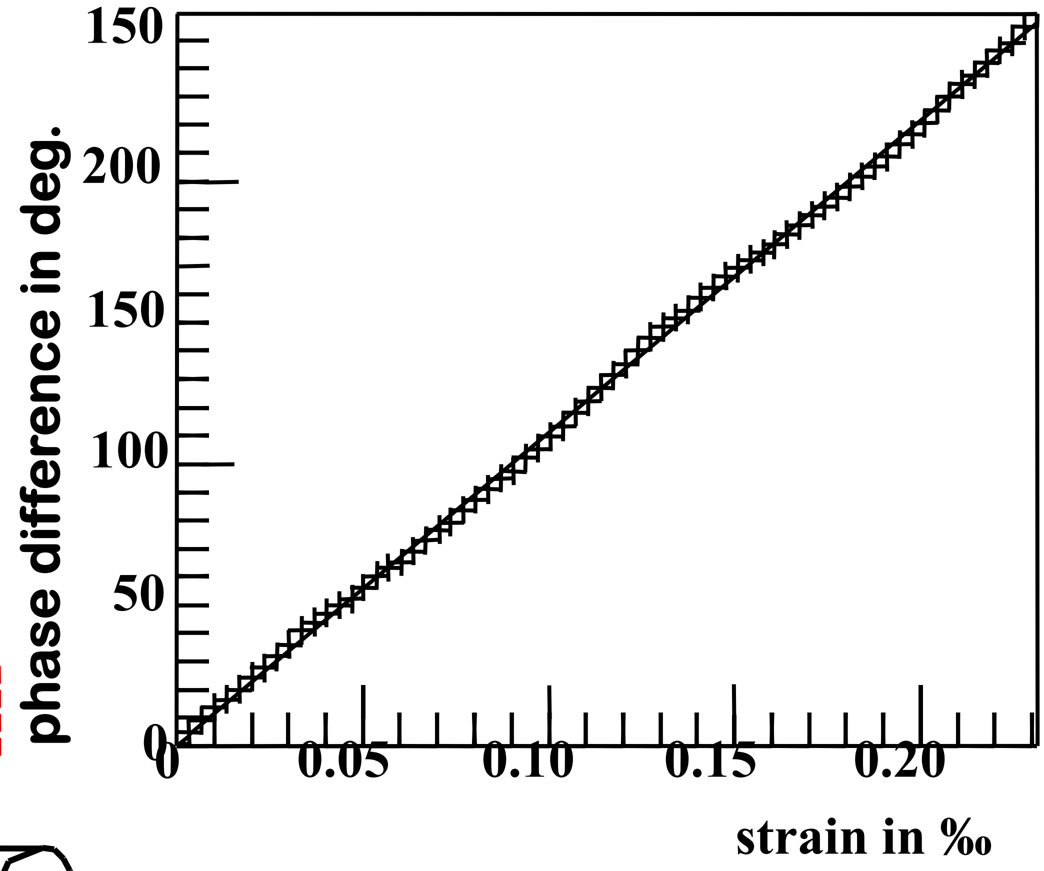


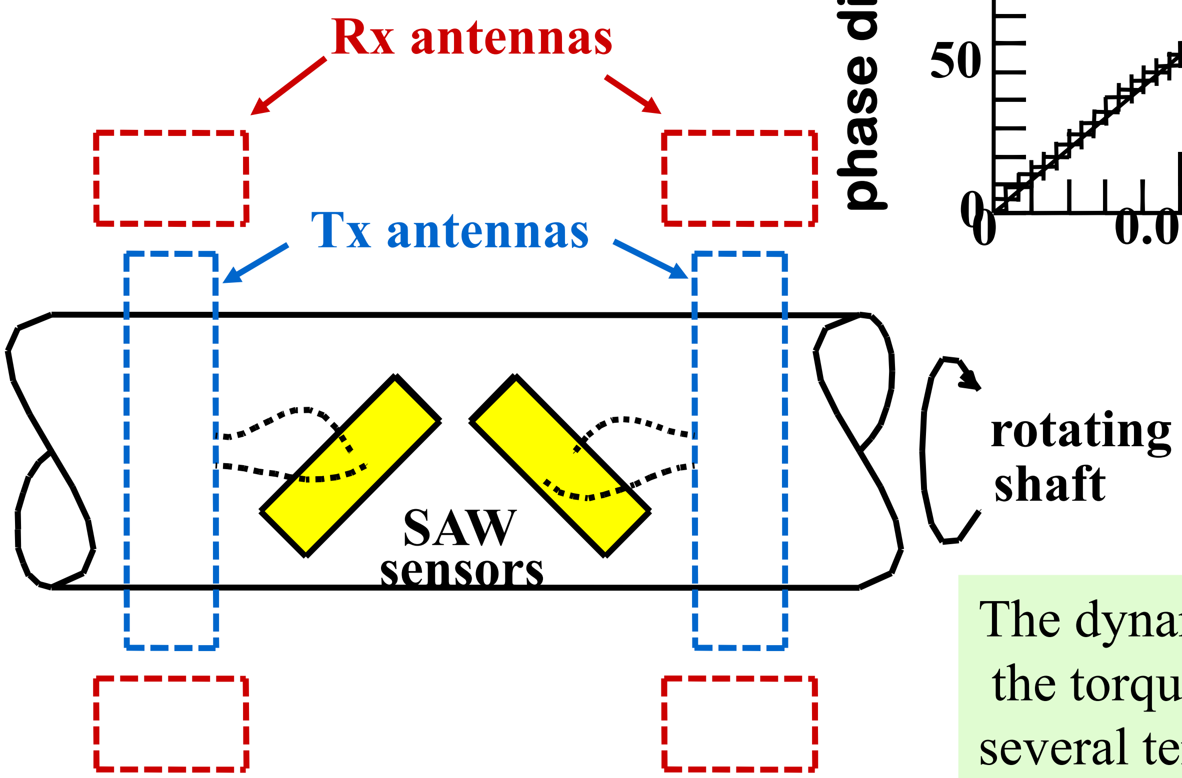
Brake (with attached SAW temperature transponder, not seen)





SAW Torque Sensor





measurement set-up

The dynamic range of monitoring the torque with SAW can be up to several tenths of kHz

SAW pressure sensor