Introduction to Bulk and Surface Acoustic Wave Frequency Control Products

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St. John’s University

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TXC Corporation
TXC Brief

What is a Wave?

Bulk and Surface Acoustic Wave (BAW and SAW)

Earthquakes

Why Quartz?

BAW Technology

SAW Technology

Some Interesting SAW Applications
Locations in Taiwan and Mainland China

Peitou Headquarters
Taipei, Taiwan
1,568 Sq. M.
(16,900 Sq. Ft.)

Ping Cheng Factory
Taoyuan, Taiwan
10,800 Sq. M.
(116,000 Sq. Ft.)

Ningbo Factory
Zhejiang, China
56,000 Sq. M.
(603,000 Sq. Ft.)

Ping Cheng New Building
Worldwide Locations

~1,300 Employees
Established SMD Production Lines in 1997

<table>
<thead>
<tr>
<th>Item / Year</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006 (forecast)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Revenues</td>
<td>$32.602</td>
<td>$63.547</td>
<td>$56.725</td>
<td>$51.259</td>
<td>$63.909</td>
<td>$86.414</td>
<td>$106.884</td>
<td>$138.240</td>
</tr>
<tr>
<td>Production DIP (M Pcs)</td>
<td>82.1</td>
<td>127.0</td>
<td>145.5</td>
<td>167.8</td>
<td>213.9</td>
<td>253.1</td>
<td>284.8</td>
<td>376.9</td>
</tr>
<tr>
<td>Production SMD (M Pcs)</td>
<td>17.7</td>
<td>69.7</td>
<td>73.4</td>
<td>96.4</td>
<td>189.5</td>
<td>223.8</td>
<td>328.7</td>
<td>466.8</td>
</tr>
<tr>
<td>Total Production (M Pcs)</td>
<td>99.8</td>
<td>196.7</td>
<td>218.9</td>
<td>264.2</td>
<td>403.4</td>
<td>476.9</td>
<td>613.5</td>
<td>843.7</td>
</tr>
</tbody>
</table>

* Consolidated Revenues- Incl. Taiwan and China Factories
2006 Ranking

<table>
<thead>
<tr>
<th>2006 Rank</th>
<th>Company Name</th>
<th>Country</th>
<th>2004 Revenue In US Million$</th>
<th>% Change from 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Epson-Toyocom</td>
<td>Japan</td>
<td>570</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>NDK</td>
<td>Japan</td>
<td>478</td>
<td>18.3%</td>
</tr>
<tr>
<td>3</td>
<td>KED</td>
<td>Japan</td>
<td>334</td>
<td>1.6%</td>
</tr>
<tr>
<td>4</td>
<td>KDS</td>
<td>Japan</td>
<td>253</td>
<td>29.2%</td>
</tr>
<tr>
<td>5</td>
<td>Vectron</td>
<td>USA</td>
<td>183</td>
<td>10.5%</td>
</tr>
<tr>
<td>6</td>
<td>TXC</td>
<td>Taiwan</td>
<td>92</td>
<td>38.5%</td>
</tr>
<tr>
<td>7</td>
<td>TEW</td>
<td>Japan</td>
<td>85</td>
<td>53.8%</td>
</tr>
<tr>
<td>8</td>
<td>River</td>
<td>Japan</td>
<td>60</td>
<td>18.1%</td>
</tr>
<tr>
<td>9</td>
<td>Rakon</td>
<td>New Zealand</td>
<td>55</td>
<td>10.0%</td>
</tr>
<tr>
<td>10</td>
<td>Microcrystal</td>
<td>Switzerland</td>
<td>51</td>
<td>15.9%</td>
</tr>
</tbody>
</table>

* Source- iSuppli 2004 (Excluding Dedicated IF and RF SAW Companies)

Los Angeles, CA (PRWEB) May 18, 2006 -- Frequency Control Insights (FCI) has released its findings on the crystal and oscillator market which show the market grew 6.5% in 2005 to $3.1 billion. Growth in 2005 was lower versus the 12.6% growth in 2004, which can be attributed to lower electronic equipment growth. However, FCI is forecasting solid market growth for crystals and oscillators with the market reaching $4.6 billion in 2010. Growth will be driven by a number of different application areas.
Applications of Crystals and Crystal Oscillators in Taiwan

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Consumer Products</strong></td>
<td><img src="image1" alt="Consumer Products" /></td>
</tr>
<tr>
<td><strong>IT Products</strong></td>
<td><img src="image2" alt="IT Products" /></td>
</tr>
<tr>
<td><strong>Telecom Products</strong></td>
<td><img src="image3" alt="Telecom Products" /></td>
</tr>
<tr>
<td><strong>Network Products</strong></td>
<td><img src="image4" alt="Network Products" /></td>
</tr>
</tbody>
</table>
Nokia 3310 GSM Handset- Piezoelectric Components

1. Panasonic GP6 Dual SAW Filter-
   Fc1 = 942.5 MHz, Bandwidth 35 MHz
   Fc2 = 1842.5 MHz, Bandwidth 75 MHz

2. See 1

3. SAW Filter- Fc = 897.5 MHz, ±17.5 MHz

4. Crystal (Tuning Fork)- 32.768 kHz

5. VCTCXO- 26 MHz

No IF SAW Filters- Direct Conversion

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Directions

Current

IT
- Desktop/Laptop
- Peripherals
- Multimedia Devices
- Digital Imaging
- Others
  - Size ↓
  - Supply Voltage ↓
  - Reliability ↑

Wireless Communication
- Mobile
- WLAN
- Bluetooth
- Others
  - Reliability ↑

Networking
- WAN
- Others
  - PECL/LVDS
  - Jitter ↓
  - Reliability ↑

Advanced Oscillators and Modules (AOM)
- Networking
- MAN
- Others
  - PECL/LVDS
  - Jitter ↓↓
  - Reliability ↑↑↑

- Long Haul

Automotive
- Non-Safety
- Safety
  - Automotive Crystal Application Program (ACAP)
## Some Terms

<table>
<thead>
<tr>
<th>Chinese</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>體聲波</td>
<td>Bulk Acoustic Wave (BAW) = Crystal</td>
</tr>
<tr>
<td>表面聲波</td>
<td>Surface Acoustic Wave (SAW)</td>
</tr>
<tr>
<td>頻率控制產品</td>
<td>Frequency Control Products (FCPs)</td>
</tr>
</tbody>
</table>
Definition of a Wave

Webster's dictionary defines a wave as "a disturbance or variation that transfers energy progressively from point to point in a medium and that may take the form of an elastic deformation or of a variation of pressure, electric or magnetic intensity, electric potential, or temperature."

The most important part of this definition is that a wave is a disturbance or variation which travels through a medium. The medium through which the wave travels may experience some local oscillations as the wave passes, but the particles in the medium do not travel with the wave.
Body Waves and Surface Waves

*Body Waves* travel through the interior of the Earth.

*P, Primary, or Compressional waves* travel the fastest (~6 km/sec in the upper crust)....

\[ v_t = \sqrt{\frac{\lambda + 2\mu}{\rho}} \]

*S, Secondary, or Shear waves* are somewhat slower (~3.5 km/sec in the upper crust)....

\[ v_t = \sqrt{\frac{\mu}{\rho}} \]

\(\rho\) is the density, and \(\mu\) and \(\lambda\) are the Lamé constants.

\[ \text{Wavelength}(\lambda) = \frac{\text{Velocity}(v)}{\text{Frequency}(f)} \]
Body Waves and Surface Waves

*Surface Waves* travel along the Earth's surface. Slower than body waves. Do the most damages.

*Love waves* shake the ground side-to-side like an S wave.

*Rayleigh waves* displace the ground like rolling ocean waves. The ground rolls forward and up and then down and backwards.

![Graph showing P-wave and S-wave arrival times and travel times.](image)

For \( \frac{V_p V_S}{V_p - V_S} = 8.7 \text{ km sec}^{-1} \), distance = 87 km
8/17/1999, Turkey Earthquake  (18,000 persons killed about 40,000 injured)

Origin time 00:01:38 UTC/GMT, Latitude 40.64 degrees N, Longitude 29.83 degrees E
Magnitude: MW 7.8 based on 4 mm 100 sec Rayleigh waves near Leonard, OK
Depth 10 kilometers
地震

不考虑地震波动的衰减与几何扩散特性，那么在地表所感受到的振动是先P波引起的短周期上下振动，随后为由S波引起的短周期水平振动，最后是由表面波引起的长周期振动。

地震站 A, B, C
The Quartz We Know
Music Tuning Fork and Quartz Watch Tuning Fork

Note E 659 Hz

32,768 Hz = 2**15 Cycles/sec.

How an analog quartz watch works: the battery (1) supplies power to the integrated circuit (2) which sends it to the quartz oscillator (3), causing it to vibrate. The trimmer (4) regulates the vibrations. The integrated circuit reduces the vibrations to 1 per second. The 1-second pulses are sent to the stepping motor (5). The stepping motor turns the electrical pulses into mechanical ones and passes them along to the gear train (6), which drives the watch hands (7).
Key Materials- Quartz

![Quartz crystal image]
Why Quartz?

Piezoelectricity （壓電特性）

Quartz is a mineral made of silicon dioxide (SiO₂) that forms hexagonal (six-sided) crystals or masses of crystals. The Curie brothers, Jacques and Pierre, discovered an electrical effect in quartz in 1880. They called this phenomenon piezoelectricity, derived from the Greek word piezein, meaning to press.

\[
T_{ij} = e_{ijkl} S_{kl} - e_{kij} E_k \\
D_i = e_{ijk} S_{jk} + \varepsilon_{ij} E_j
\]

http://www.piezo.com/tech4history.html
Why Quartz?

The SiO$_2$ is always in the static state of electric neutral.

An electric field is applied, the induced electric field is generated and force the Oxygen atoms move outward.

An opposite electric field is applied, the induced electric field is generated and force the Oxygen atoms move closer.
Different Cuts of Quartz
Accurate, Precise and Stable?

<table>
<thead>
<tr>
<th>Precise but not accurate</th>
<th>Not accurate and not precise</th>
<th>Accurate but not precise</th>
<th>Accurate and precise</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td><img src="image3.png" alt="Diagram" /></td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Stable but not accurate</td>
<td>Not stable and not accurate</td>
<td>Accurate but not stable</td>
<td>Stable and accurate</td>
</tr>
</tbody>
</table>

SINU 5/24/06
## Frequency Control Products (FCPs)

<table>
<thead>
<tr>
<th><strong>BAW-based (&lt;MHz ~ 200 MHz)</strong></th>
<th><strong>SAW-based (&lt;50 MHz ~ 5 GHz)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuning Forks</td>
<td>SAWR</td>
</tr>
<tr>
<td>MCF</td>
<td>SAWF</td>
</tr>
<tr>
<td>XO</td>
<td>SO</td>
</tr>
<tr>
<td>VCXO</td>
<td>VCSO</td>
</tr>
<tr>
<td>TCXO</td>
<td>TCSO</td>
</tr>
<tr>
<td>OCXO</td>
<td>OCSO</td>
</tr>
<tr>
<td>Clock Data Recovery (CDR)</td>
<td>Clock Data Recovery (CDR)</td>
</tr>
<tr>
<td>Clock Smoother (CS)</td>
<td>Clock Smoother (CS)</td>
</tr>
<tr>
<td>Frequency Translator (FX)</td>
<td>Frequency Translator (FX)</td>
</tr>
<tr>
<td>Timing Module (TM)</td>
<td>Timing Module (TM)</td>
</tr>
<tr>
<td>....</td>
<td>....</td>
</tr>
</tbody>
</table>
Crystals

DIP type

- 49U
- 49S
- 49S/SMD
- UM-1

SMD type

- 7x5
- 6x3.5
- 5x3.2
- 4x2
- 3.2x2.5
- 2.5x2
- 8x4.5
- 5x3.2

Tuning Fork type

- 32.768 KHz
- T 2/3/6/7/8

SMD

- 4.1x1.5
DIP Type Crystal

\[ f_n = \frac{n}{2t} \sqrt{\frac{c}{\rho}} \]

- \( f_n \): resonance frequency
- \( n \): odd integers
- \( c \): stiffness coefficient
- \( \rho \): density
- \( t \): thickness
SMD Type Crystal

Diagram showing the components of a SMD Type Crystal:
- Top surface electrode
- Rectangular quartz blank
- Conductive glue
- Supporting blocks
- Bottom surface electrode
- Ceramic package

Images of a SMD Type Crystal component and the final assembly.
Round and Rectangular Quartz Resonators

Parameters of round and rectangular crystals at 20 MHz

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HC49U</th>
<th>HC49S</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0</td>
<td>5.5 pF</td>
<td>3.7 pF</td>
</tr>
<tr>
<td>C1</td>
<td>20.8 fF</td>
<td>14.2 fF</td>
</tr>
<tr>
<td>L1</td>
<td>3.1 mH</td>
<td>4.5 mH</td>
</tr>
<tr>
<td>R1</td>
<td>6.1 Ω</td>
<td>8.7 Ω</td>
</tr>
<tr>
<td>Q</td>
<td>65.6 K</td>
<td>66.2 K</td>
</tr>
</tbody>
</table>
High Frequency Fundamental (HFF) Crystal Resonator

100~200 MHz and higher
Crystal- and SAW-based Oscillators
## Crystal Oscillators

<table>
<thead>
<tr>
<th>Type</th>
<th>14x9</th>
<th>7x5</th>
<th>5x3.2</th>
<th>3.2x2.5</th>
<th>2.5x2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CXO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCXO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCXO</td>
<td></td>
<td></td>
<td>5x3.2</td>
<td>3.2x2.5</td>
<td></td>
</tr>
<tr>
<td>OCXO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(AT-Cut / SC-Cut)</td>
</tr>
</tbody>
</table>

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**XO/TCXO/OCXO**

- **Crystal Oscillator (XO)**
  - Voltage
  - Temperature Sensor
  - Compensation Network or Computer
  - Output

- **Temperature Compensated (TCXO)**
  - Temperature Sensor
  - Compensation Network or Computer
  - Output

- **Oven Controlled (OCXO)**
  - Oven
  - Temperature Sensor
  - Output

**Graphs:**
- Frequency deviation ($\Delta f/f$) over temperature range (from $-45^\circ C$ to $+100^\circ C$).
  - **XO:**
    - $+10$ ppm
    - $-10$ ppm
  - **TCXO:**
    - $+1$ ppm
    - $-1$ ppm
  - **OCXO:**
    - $+1 \times 10^{-8}$
    - $-1 \times 10^{-8}$
## Hierachy of Oscillators

<table>
<thead>
<tr>
<th>Oscillator Type</th>
<th>Abbre.</th>
<th>Accuracy (ppm)</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal oscillator</td>
<td>XO</td>
<td>10⁻⁵ to 10⁻⁴</td>
<td>Computer timing, etc.</td>
</tr>
<tr>
<td>Temperature compensated crystal oscillator</td>
<td>TCXO</td>
<td>10⁻⁶</td>
<td>Mobile phones, tactical radios, etc.</td>
</tr>
<tr>
<td>Microcomputer compensated crystal oscillator</td>
<td>MCXO</td>
<td>10⁻⁸ to 10⁻⁷</td>
<td>Spread spectrum system clock, etc.</td>
</tr>
<tr>
<td>Oven controlled crystal oscillator</td>
<td>OCXO</td>
<td>10⁻⁸</td>
<td>Navigation system clock &amp; frequency standard, radar, basestations, etc.</td>
</tr>
<tr>
<td>Small atomic frequency standard</td>
<td>Rb</td>
<td>10⁻⁹</td>
<td>Satellite terminals, radar, etc.</td>
</tr>
<tr>
<td>High performance atomic standard</td>
<td>Cs</td>
<td>10⁻¹² to 10⁻¹¹</td>
<td>Strategic equipment, EW, etc.</td>
</tr>
</tbody>
</table>
## Crystal Oscillator and Homo Sapien (Modern Man)

<table>
<thead>
<tr>
<th>Crystal Oscillator (XO)</th>
<th>Homo Sapien (HS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>Blood</td>
</tr>
<tr>
<td>Voltage</td>
<td>Blood Pressure</td>
</tr>
<tr>
<td><strong>Crystal- pumps and regulates current flow</strong></td>
<td><strong>Heart- pumps and regulates blood flow</strong></td>
</tr>
<tr>
<td><strong>ASIC</strong></td>
<td><strong>Brain</strong></td>
</tr>
<tr>
<td>Package</td>
<td>Body</td>
</tr>
<tr>
<td>Other active/passive components</td>
<td>Other organs</td>
</tr>
<tr>
<td><strong>Input- supply current</strong></td>
<td><strong>Input- food</strong></td>
</tr>
<tr>
<td>Frequency- sub-KHz to MHz and above</td>
<td>Frequency- 1 Hz per 24 hours</td>
</tr>
<tr>
<td>Pullability</td>
<td>Can work long hours if needed</td>
</tr>
<tr>
<td>Jitter- short term instability</td>
<td>Anger- short term instability</td>
</tr>
<tr>
<td>Aging- long term stability</td>
<td>Aging- long term stability</td>
</tr>
<tr>
<td>TCXO, OCXO, etc.</td>
<td>Person with more stable emotions</td>
</tr>
<tr>
<td>Stop oscillation</td>
<td>Death</td>
</tr>
</tbody>
</table>
Water Wave and Surface Acoustic Wave

http://www.kettering.edu/~drussell/Demos/waves/water.gif

http://www.kettering.edu/~drussell/Demos/waves/rayleigh.gif
Many Types of SAW

SAW
Rayleigh Wave
Lamb Wave
Love Wave
SSBW
STW
LSAW
PSAW
HVPSAW
BGS Wave
Stoneley Wave
Sezawa Wave
......
SAW and Heavy Motor Cycles? 表面聲波與重型機車？

Bleustein-Gulyaev-Shimizu (BGS) Wave (Piezoelectric SH-Wave)

Dr. Jeffrey Bleustein, Former CEO of Harley Davidson
Interdigital Transducer (IDT)

Fig 1: Interdigital transducer
SAW Filter (Transversal)

(Electrical/Mechanical/Electrical Conversions)
\[ V = f \lambda \]

Of the same \( \lambda \), higher \( V \) substrates give higher \( f \)

\[ = \text{Achieving higher } f \text{ with the same } \lambda \]

Of the same \( f \), lower \( V \) substrates give lower \( \lambda \)

\[ = \text{Achieving smaller chip size of the same } f \]
## Selecting SAW Substrates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_f$ (m/s)</td>
<td>SAW Velocity</td>
</tr>
<tr>
<td>$\Delta v/v$</td>
<td>Electromechanical Coupling Constant $k^2 = -(\Delta v/v)$</td>
</tr>
<tr>
<td>TCD (ppm/C)</td>
<td>Temp. Coefficient of Delay</td>
</tr>
<tr>
<td>Leakage</td>
<td>For LSAW and HVPSAW</td>
</tr>
</tbody>
</table>
SAW Substrates

*Established (3”~4”)*

Quartz (SiO₂)
Lithium Niobate (LiNbO₃)
Lithium Tantalate (LiTaO₃)
Lithium Tetraborate (Li₂B₄O₇)
ZnO/Glass

*Available but Limited Supply (2~4”)*

Bismuth Germanium Oxide (Bi₁₂GeO₂₀)
Langasite (La₃Ga₅SiO₁₄)
ZnO/Diamond
Gallium Phosphate (GaPO₄)

*At R&D Stage*

Potassium Niobate (K NbO₃)
ZnO/Sapphire
AlN/Sapphire
SiO₂/LiNbO₃

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**FBAR with Polycrystalline AlN Film (Agilent)**

![Diagram of FBAR with Polycrystalline AlN Film](image)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Ceramic (675 mm²)</th>
<th>SAW (140 mm³; cellular band)</th>
<th>FBAR (98 mm³; going to 46 mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical (L.L., roll-off)</td>
<td>excellent</td>
<td>good</td>
<td>excellent</td>
</tr>
<tr>
<td>Power handling</td>
<td>best (&gt;35 dBm @ 2 GHz)</td>
<td>fair (31 dBm @ 900 MHz)</td>
<td>good (&gt;32 dBm @ 2 GHz)</td>
</tr>
<tr>
<td>Temperature coefficient</td>
<td>0 to -5 ppm/C</td>
<td>-23 to -94 ppm/C</td>
<td>-20 to -30 ppm/C</td>
</tr>
<tr>
<td>Frequency range filters: duplexers:</td>
<td>cellular/PCS</td>
<td>IF-cellular-PCS</td>
<td>cellular-PCS-mw</td>
</tr>
<tr>
<td>Integration</td>
<td>no</td>
<td>Multi-Chip Module (MCM)</td>
<td>MCM; future full integration</td>
</tr>
</tbody>
</table>

**5.6 mm x 11.9 mm footprint**

*SJU 5/24/06*
What the FCP Market Wants?

<table>
<thead>
<tr>
<th>What?</th>
<th>Level?</th>
<th>How to Achieve?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Higher</td>
<td>SAW, high frequency fundamental (HFF) blank, analog multiplier, phase lock loop (PLL), film bulk acoustic resonator (FBAR), ....</td>
</tr>
<tr>
<td>Activity Dip</td>
<td>Absence</td>
<td>Better crystal design tools.</td>
</tr>
<tr>
<td>Drive Level Dependence</td>
<td>Low</td>
<td>Cleaner process.</td>
</tr>
<tr>
<td>Stability (Long &amp; Short Term)</td>
<td>Better</td>
<td>HFF, new BAW/SAW cuts and materials, compensated, cleaner processes, ....</td>
</tr>
<tr>
<td>Functions</td>
<td>More</td>
<td>PLL, multipliers, dividers, programmable, ....</td>
</tr>
<tr>
<td>Power</td>
<td>Lower</td>
<td>LVPECL, LVDS, 3.3V, 2.5V and lower....</td>
</tr>
<tr>
<td>Cost</td>
<td>Lower</td>
<td>Lower materials &amp; labor cost, better yield, ....</td>
</tr>
<tr>
<td>Size</td>
<td>Smaller</td>
<td>ASIC, innovative packaging techniques-low temperature co-fired ceramic (LTCC), chip scale package (CSP), flipchip, ....</td>
</tr>
</tbody>
</table>
Some Interesting SAW Applications

- SAW Touch Screen
- AOTF
- SAW RFID Tags
- SAW Sensors
SAW Touch Screen
DWDM  Dense Wavelength Division Multiplexing 高密度波分复用系统

OADM  Optical Add/Drop Multiplexer 光选多工器/光分插复用器
Acousto-Optical Interactions
Acousto-Optical Tunable Filter

Configuration of AOTF

- Tilted thin-film SAW guide
- λ1, λ2, λ3, λ4, λ5 Optical signal input
- PBS (Polarization beam splitter)
- IDT (Inter-digital transducer)
- Control signal (RF) (170-180 MHz)
- SAW: Surface acoustic wave
- λ2, λ4, λ5 Optical signal output
- Drop signal λ1, λ3

Sparameter
Dropping Wavelengths with AOTFs

Fujitsu 2000
SAW RFID Tags

Radio Waves

Tag Antenna

IDT Surface Acoustic Wave Pulses Wave Reflectors

SAW RFID Chip

Reader

Request Impulse

RF Response

Environmental Echoes Sensor Echoes

Typical Readout Signal at 60 feet
Photomicrograph of a monolithically integrated GaAs SAW sensor showing the SAW device and oscillator amplifier. This sensor operates at 470 MHz. Changes in the SAW velocity produce changes in the oscillator frequency (Sandia Labs).