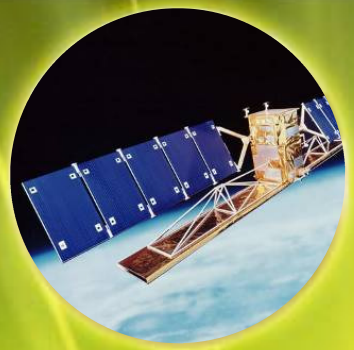
VECTRON INTERNATIONAL
A DOVER COMPANY

Helping Customers Innovate, Improve & Grow

Black



Manned

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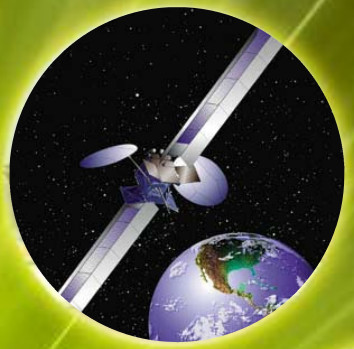
Comms



Military

Microacoustic Space-Grade Filters and Oscillators

Nov 2012

Richard Gruenwald
Director Engineering

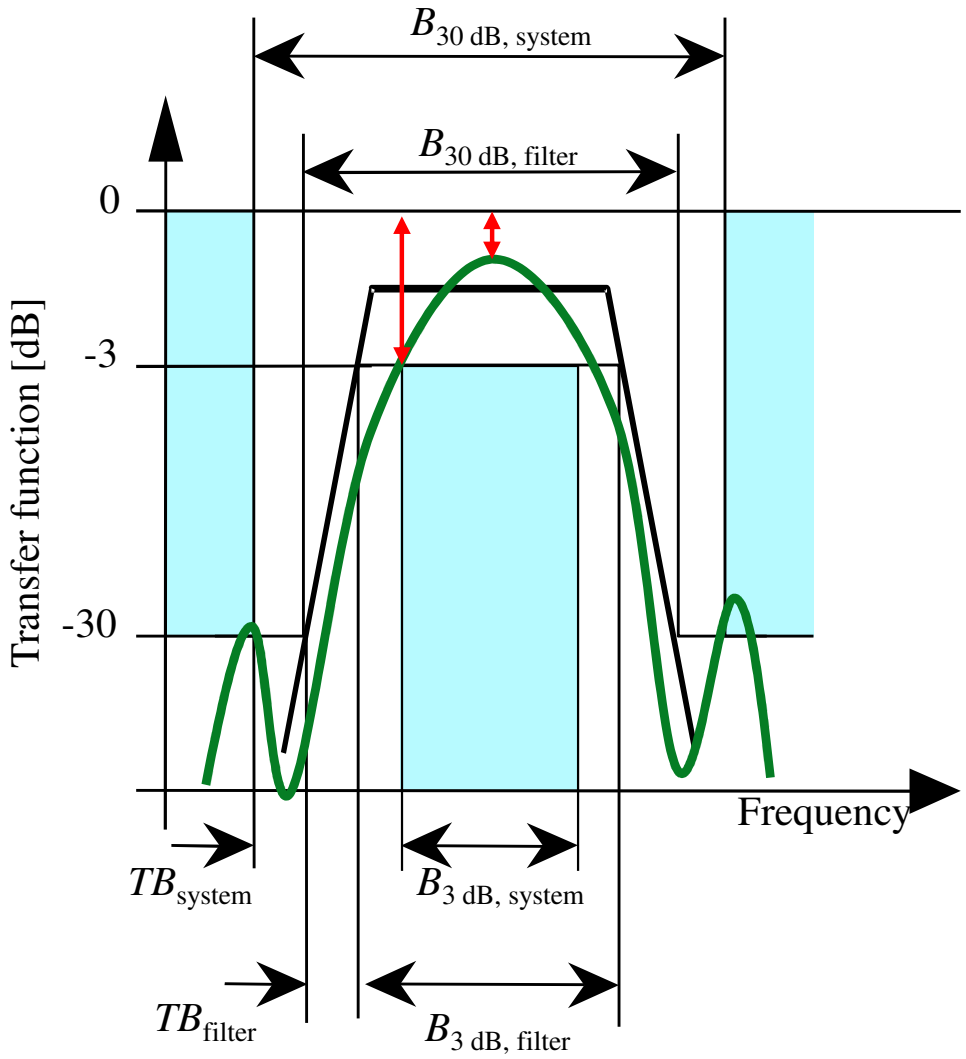
Launch Vehicles

Agenda

- SAW Filters
  - Products and Roadmaps
  - Space Solutions
- Crystal Filters
  - Products
  - Space Solutions
- SAW-based Oscillators

Property of Vectron International

Generic Filter Specifications



Major spec requirements, e.g.

- Center frequency
- Insertion attenuation
  - IL_{min}: maximum of S_{21} (transfer function)
  - IL_{max}: minimum of S_{21} within passband
- Absolute / relative bandwidth:

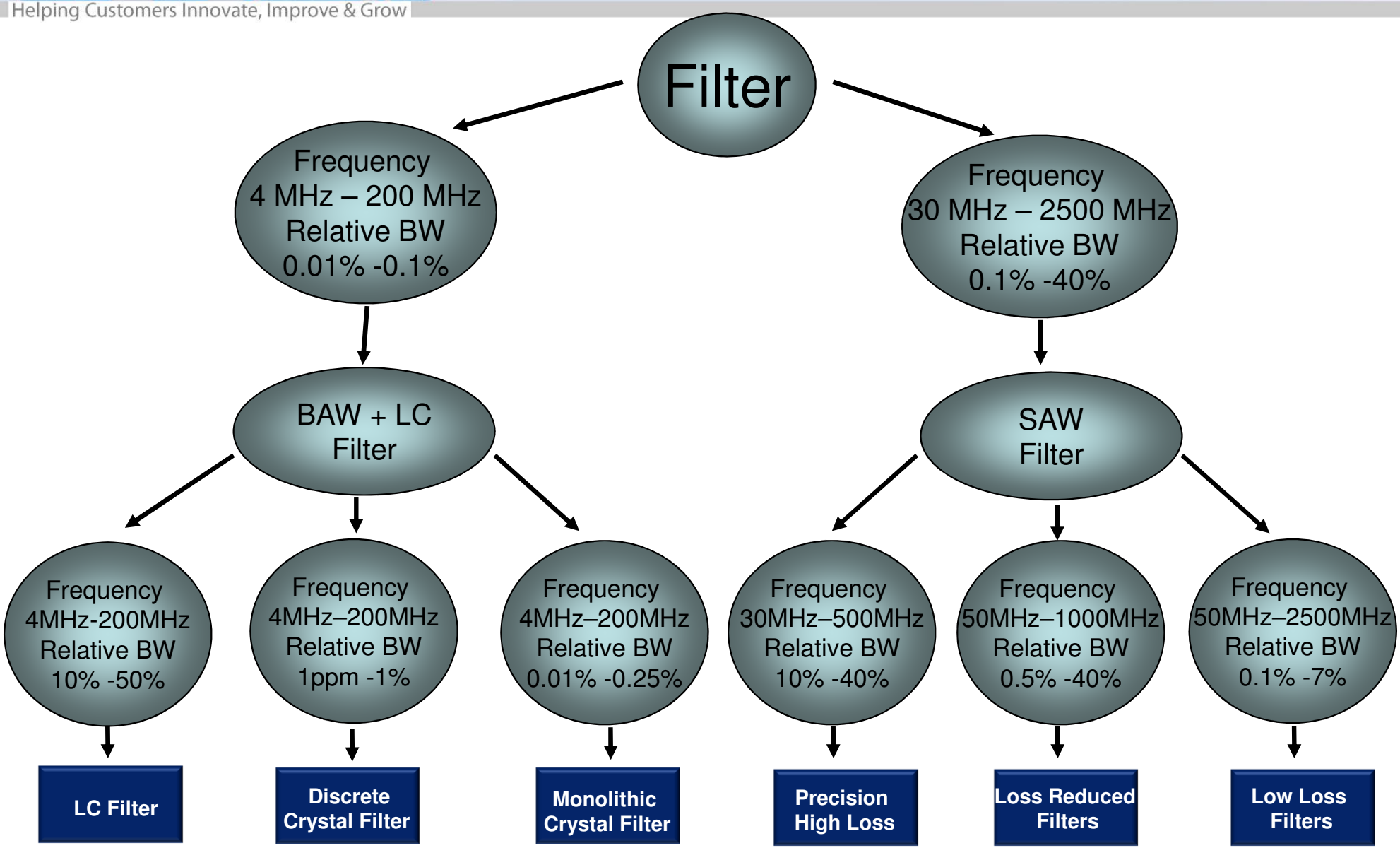
  $B_{rel} = B_{abs} / f_c$
- Amplitude / phase / group delay linearity (ripple / variation)
- Transition bandwidth TB_{system}
  - = Filter skirts TB_{filter}
  - \+ Temperature tolerance
  - \+ Production tolerance
- Input / output impedance
- Power durability

… determine applicable

- Piezoelectric substrate
- Filter design technique
- Rule of thumb:

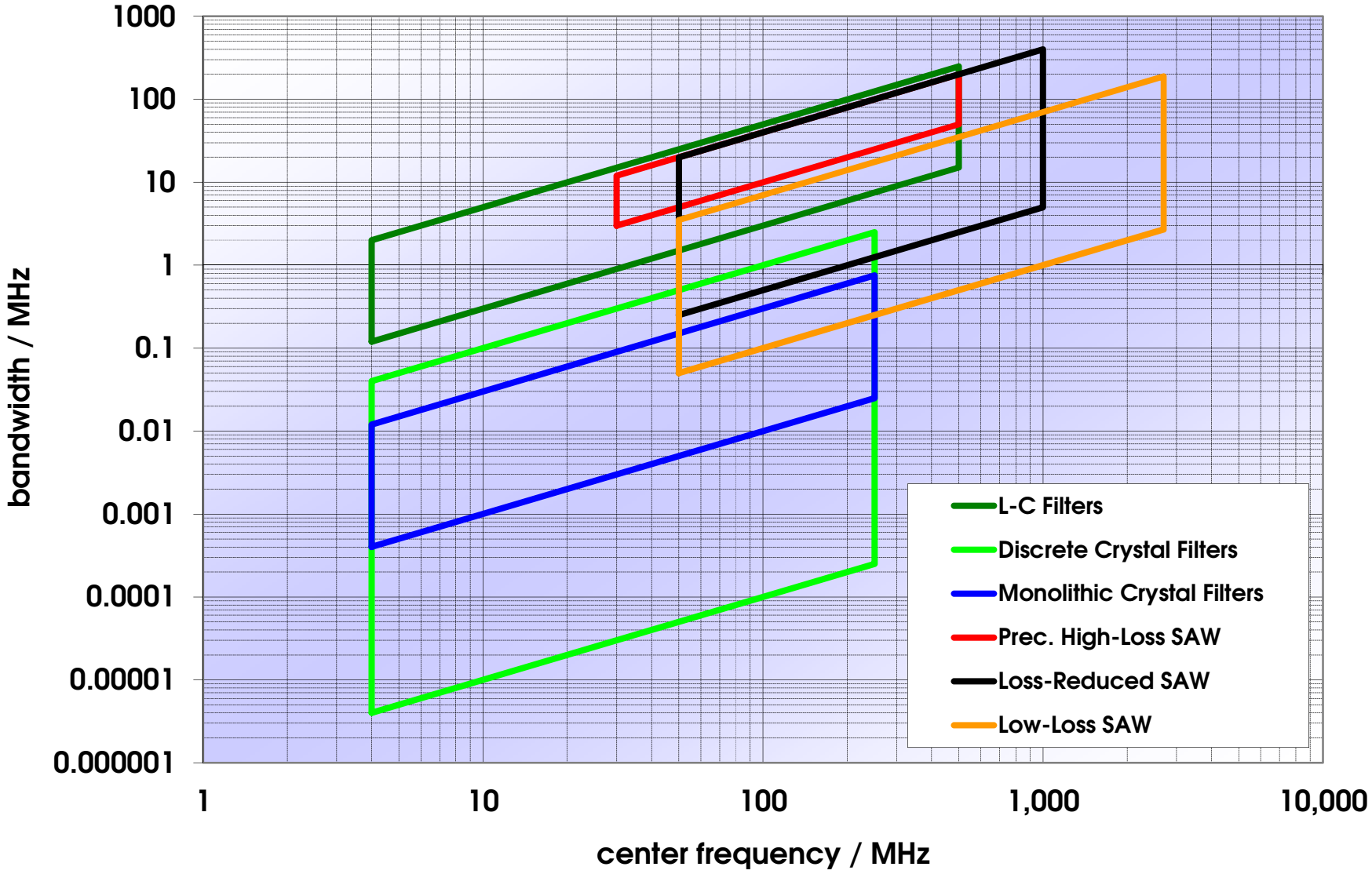
  „More rectangular“ ⇔ higher cost

Filter – Decision Tree



Property of Vectron International

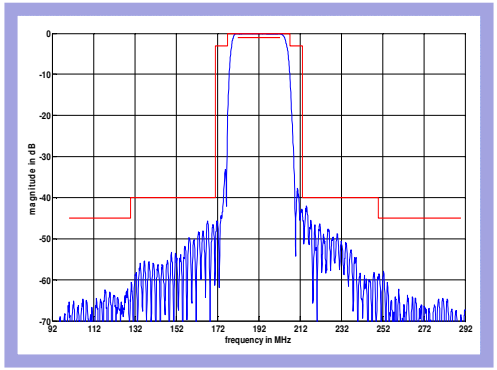
Overview - Filters

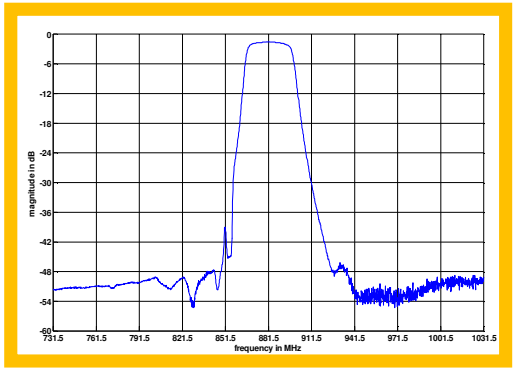


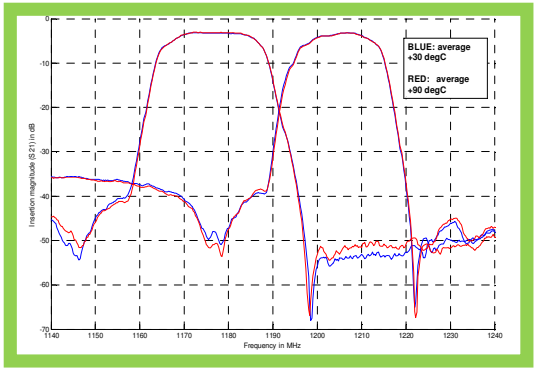
VECTRON - Complete Filter Solutions

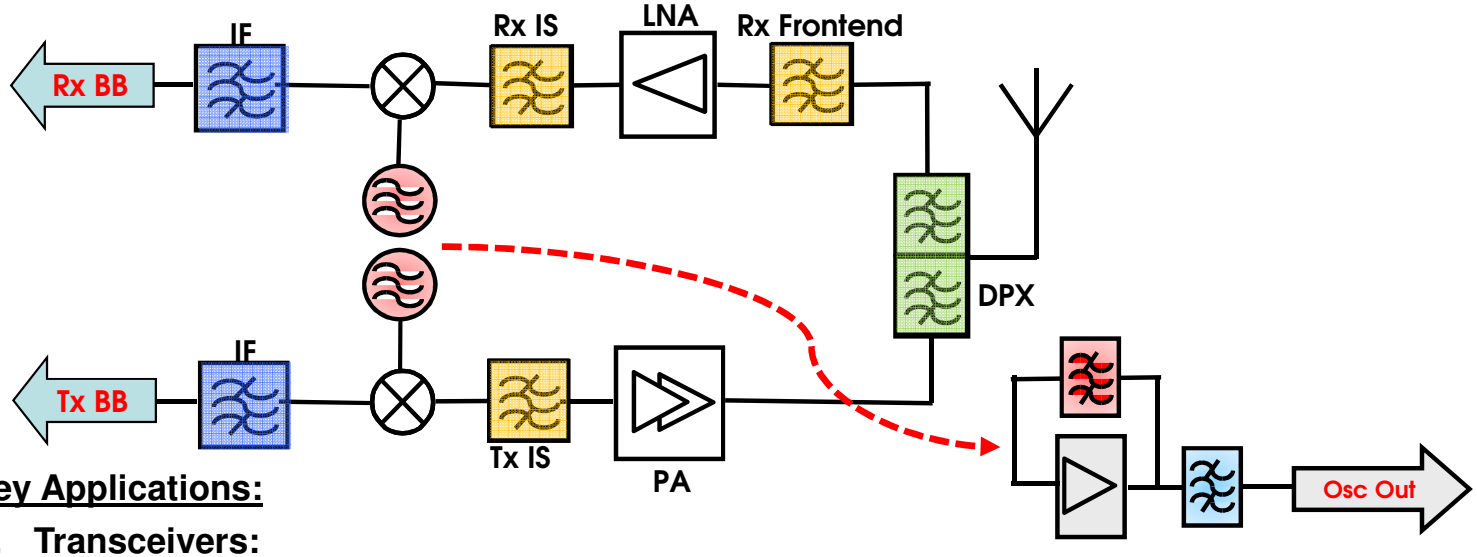
Property of Vectron International

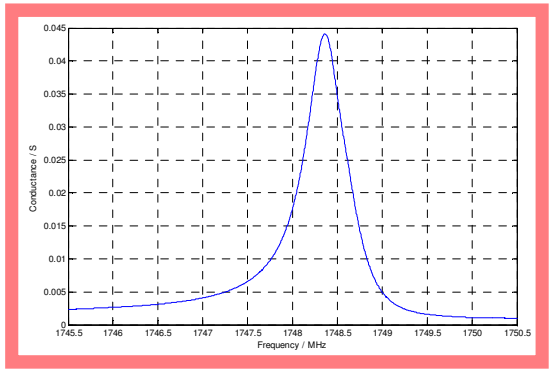
VECTRON SAW Applications

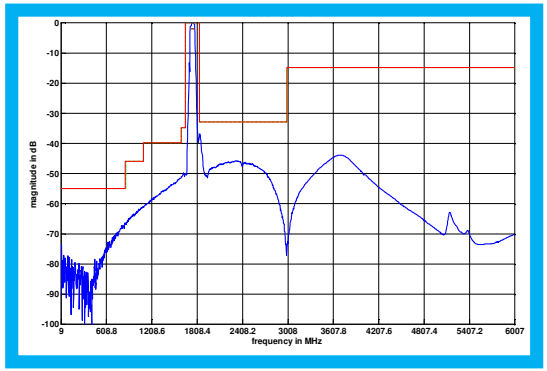












Key Applications:

A. Transceivers:

- Filtering of receive signal in RF (frontend and interstage) and IF
- Suppression of spurious signals in transmit path
- Separation of receive and transmit signal at antenna port - duplexer

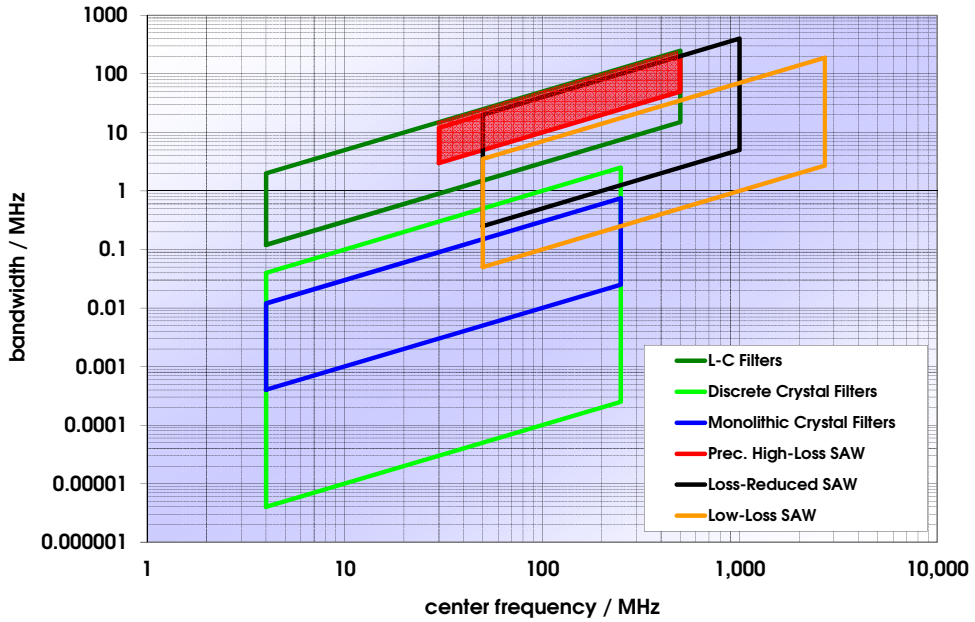
B. Oscillators:

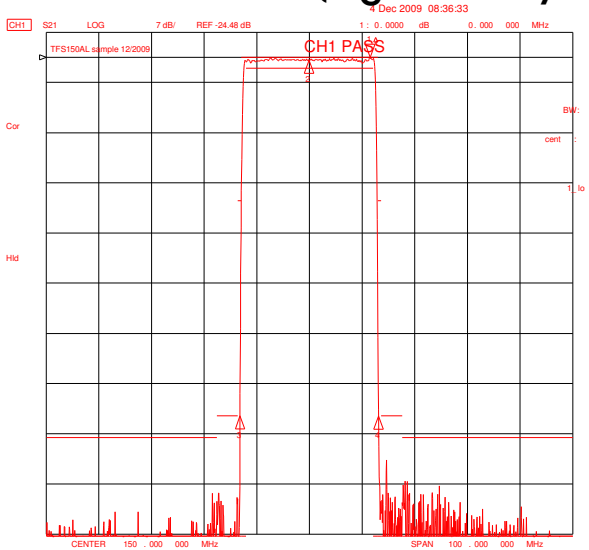
- Signal generation (VCSO) – 1- or 2-port SAW resonator
- Output (clean-up) filtering

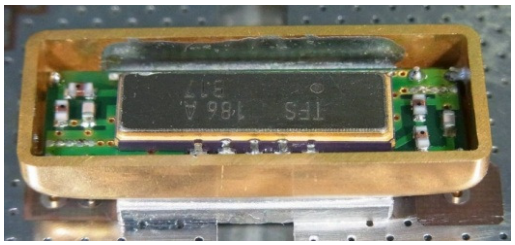
Property of Vectron International

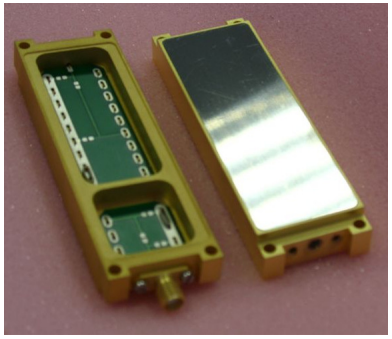
Precision High-Loss SAW Filters

- Features / Performance
  - Excellent skirt steepness
  - Lowest Shape factor: $BW_{stopband}$ / $BW_{passband}$ ≥ 1.03
  - Insertion attenuation: IL ≈ 12dB…35dB
  - Matching network required
  - Ceramic or (custom) metal can packages
- Filter types
  - Bandpass Filters
  - Delay lines
  - Correlators / Pulse compression filters
- Application
  - High-Rel Mil/Space applications
  - Wireless Base Stations / Repeaters
  - Test and Measurement Equipment
  - Customized (e.g. internally matched) solutions









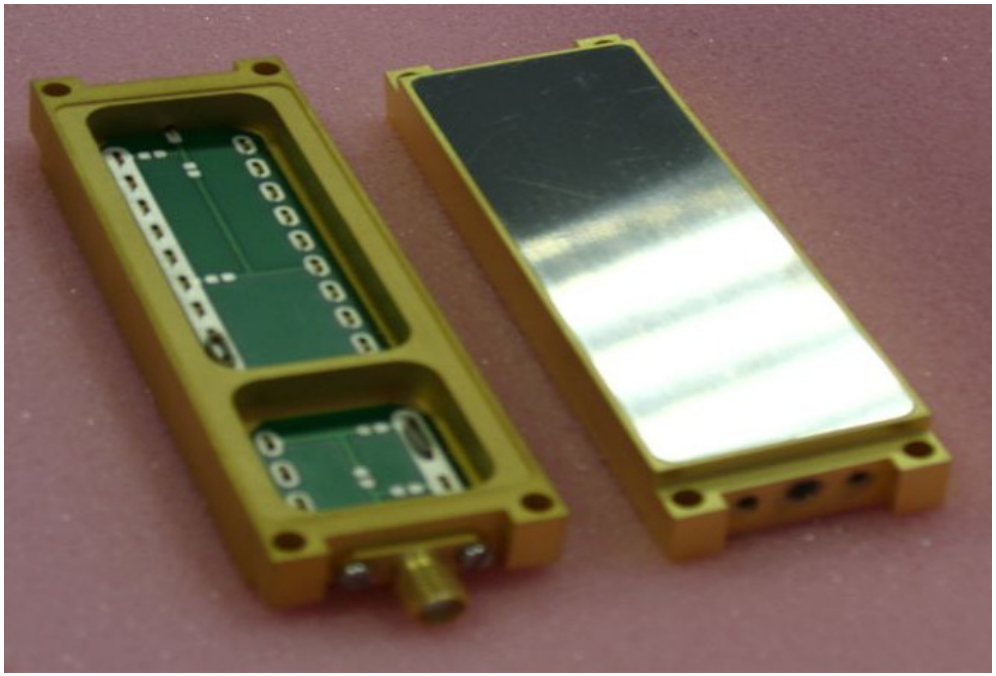
Property of Vectron International

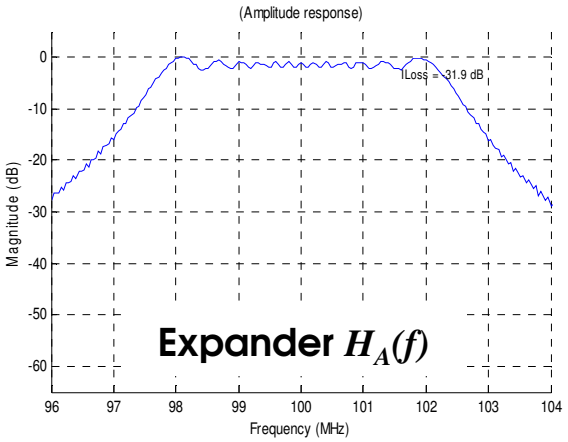
Integrated SAW IF Modules

- High-reliability Filter Modules with Integrated Matching
- Matched Filter Solutions, e.g.
  - Analogue pulse compression (radar application, paired)

$$h_{corr}(t) = \int_{\tau} h_A(\tau) \cdot h_B(t-\tau) d\tau$$

- Integrated Matching
- Hermetic and high-reliability





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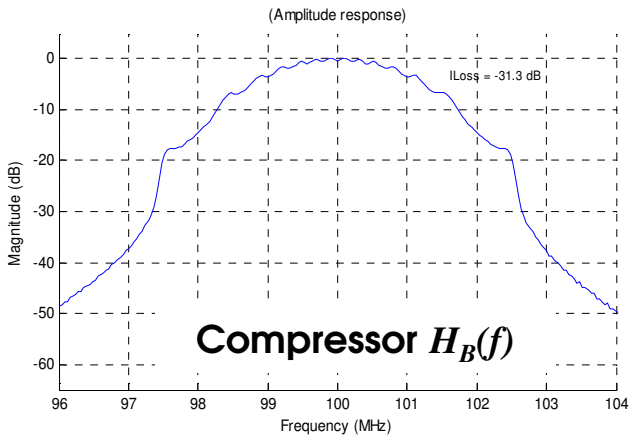
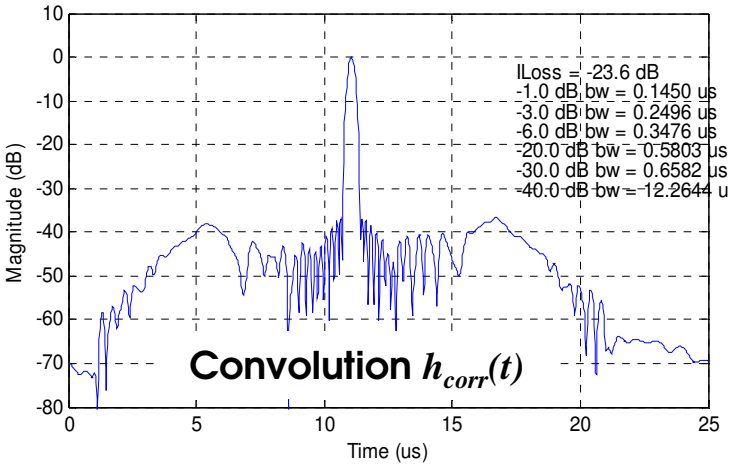
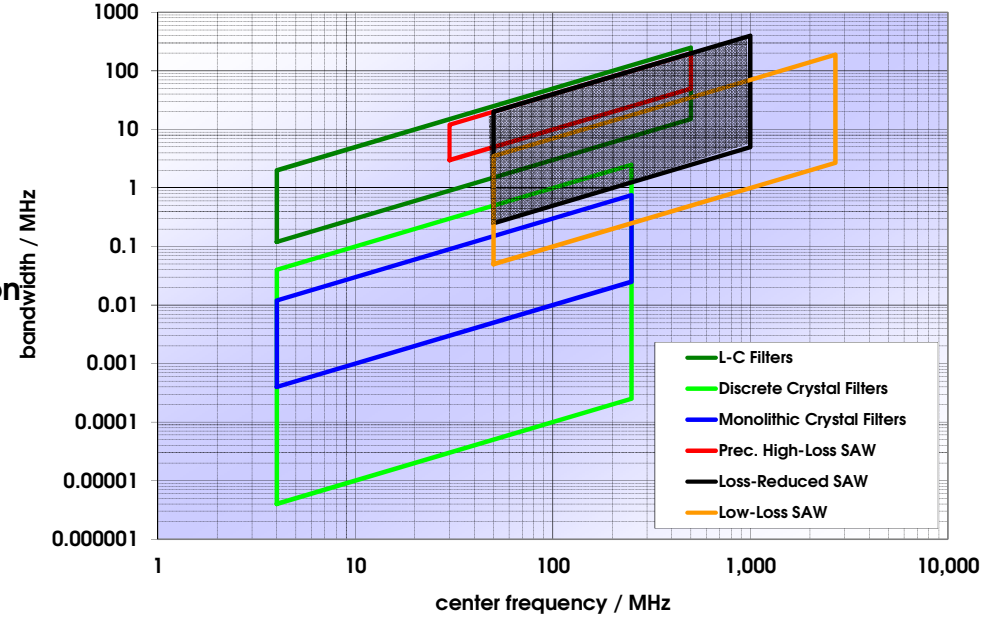


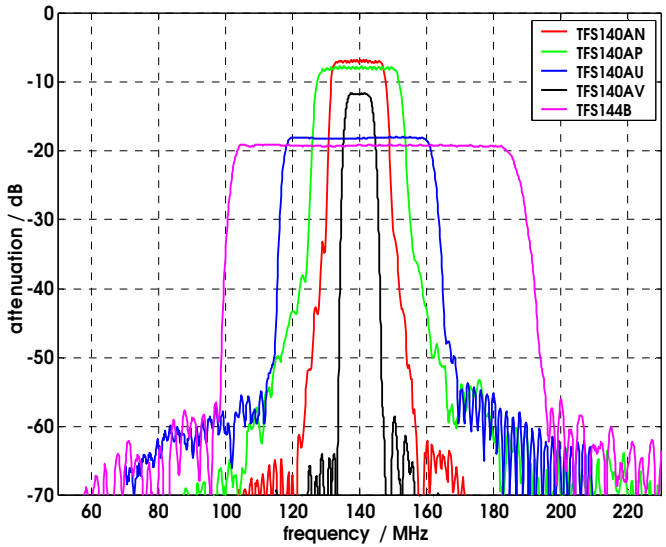


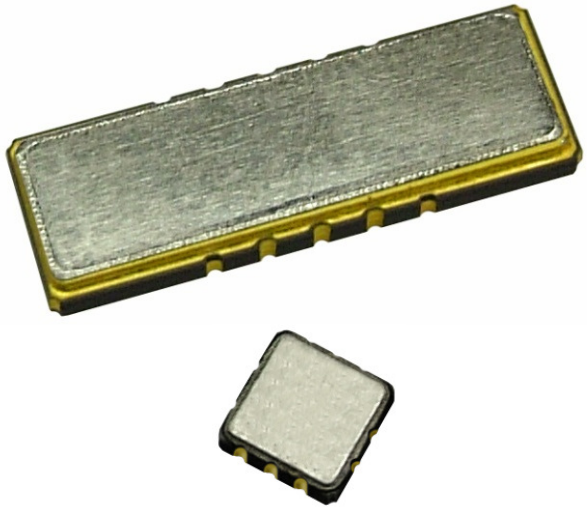
Property of Vectron International

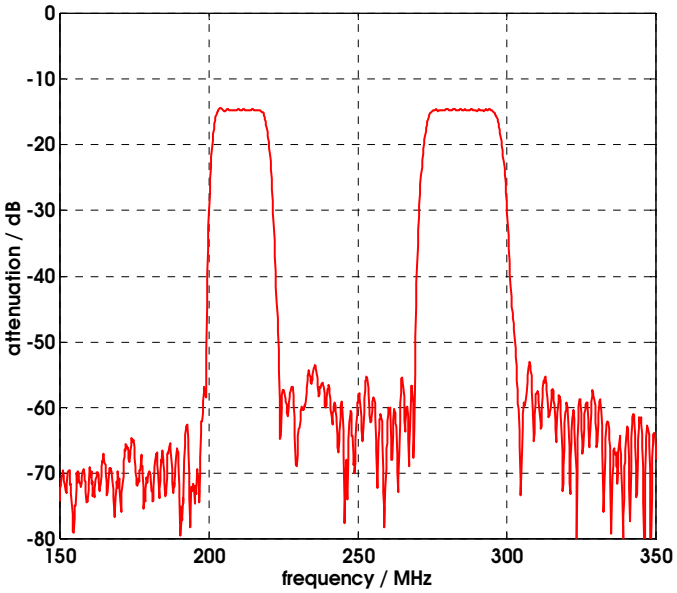
Loss-Reduced SAW IF Filters

- Features / Performance
  - Customized narrow-band and wide-band solutions
  - Medium insertion attenuation: 5…15dB
  - High-reliability ceramic package
  - Small size down to 3x3mm² (frequency-dependent)
  - IF stage in all communication systems
  - Low shape factor BW_{30dB}/BW_{3dB} and high stopband rejection
  - Wider fractional bandwidth → wide band systems, e.g. LTE
  - BUT: Little standardization of IF filters → individual design of transceiver frequency plan
- Application
  - High-rel solutions
  - LTE / 4G transceiver designs
  - Custom solutions, e.g. dual-passband filter
  - Low-spurious / high-CMRR / high-IP3 versions under development





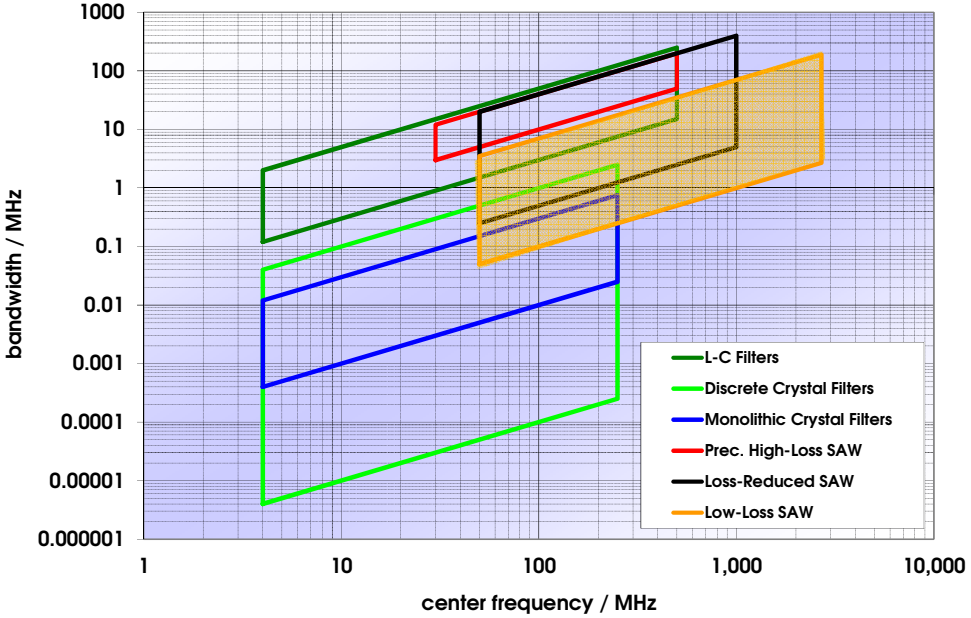


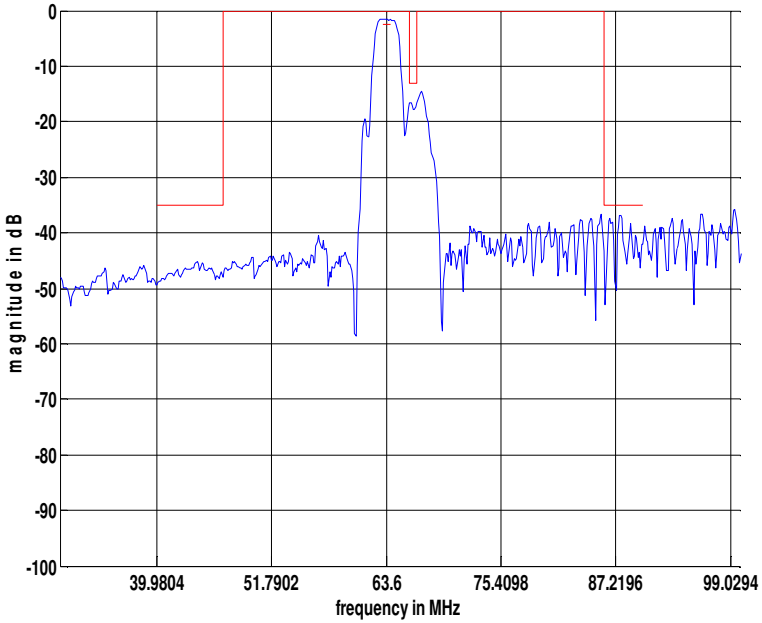


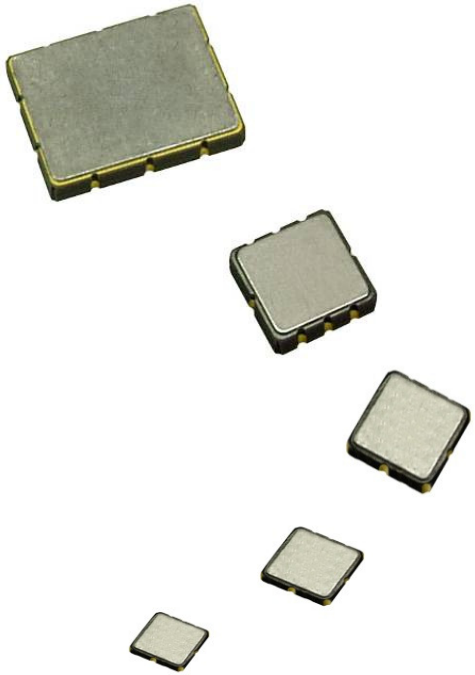
Property of Vectron International

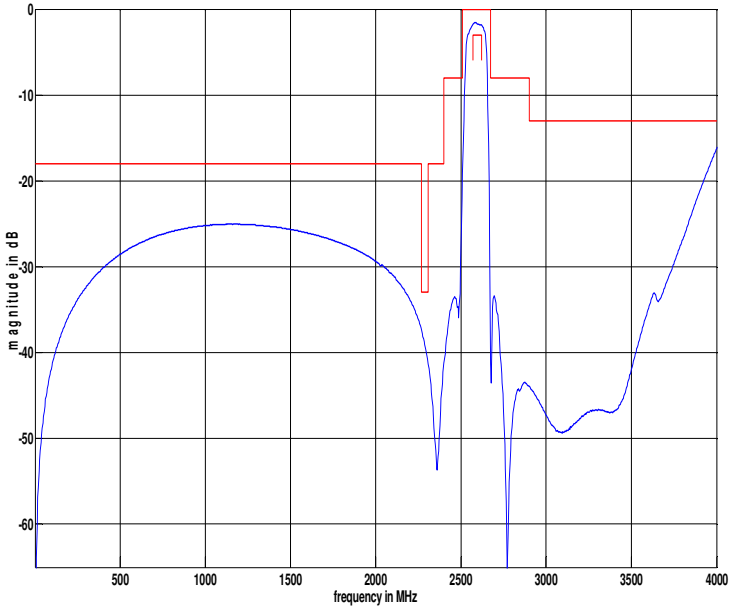
SAW RF / Low-Loss Filters

- **Application**
  - Frontend and Interstage Filters for all Communication Systems
  - Higher degree of standardization (center frequency / bandwidth) than IF filters, e.g. due to 3GPP regulations
  - Solutions 60MHz…2.6GHz center frequency
- **Packaging:**
  - Package sizes down to 2x2.5mm² available (frequency-dependent)
  - Smaller solutions under development
  - High power solutions (P > 25dBm) under development







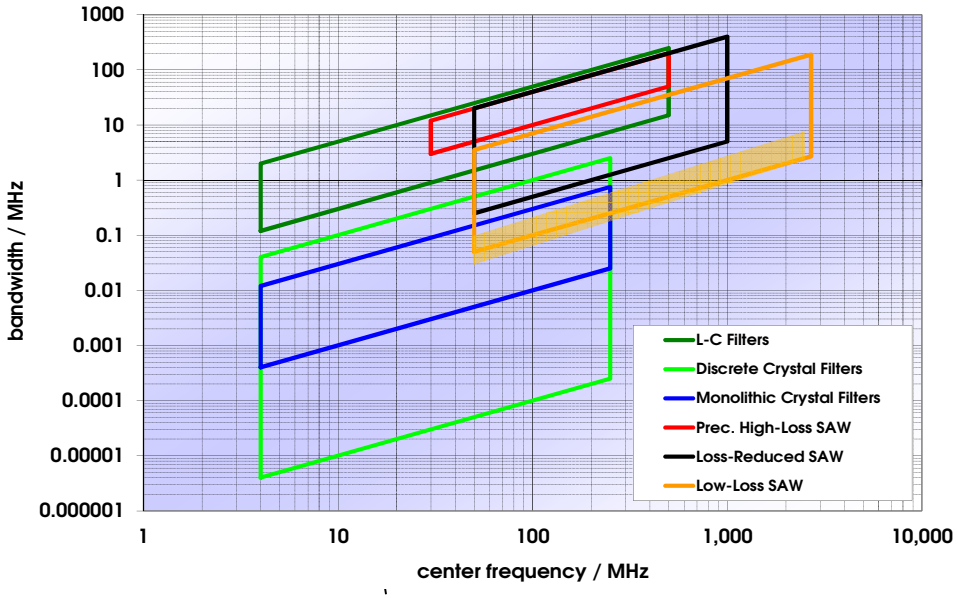


Property of Vectron International

Quartz RF Devices

Quartz as SAW substrate material:

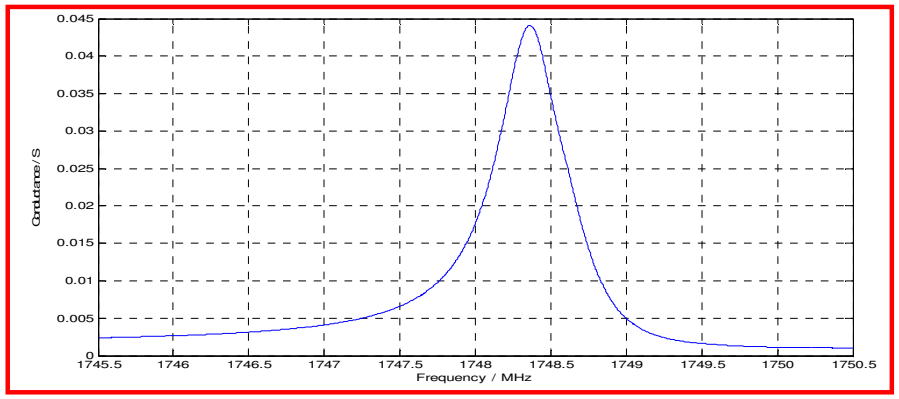
- Low coupling → low bandwidth
- Excellent temperature stability

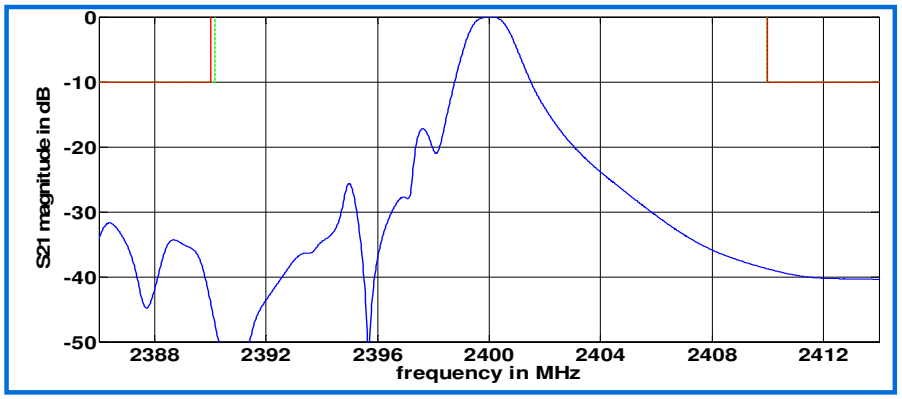


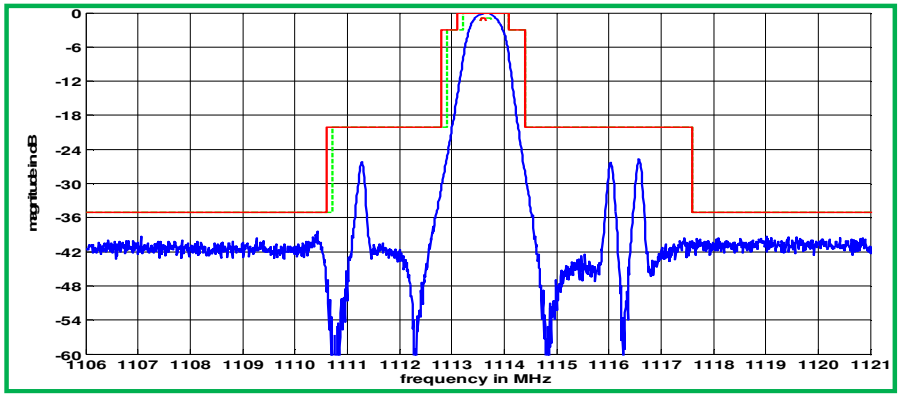
- Precision manufacturing processes required to utilize low TC_f at f≥1GHz
- Preferred technology for narrow-band filtering >1GHz

Success stories, e.g.

- Resonators 800...1800MHz inside Vectron VS-401/VS-501
- 2.4GHz 2-port resonator in T&M VCSOs
- Narrow-band filters in MIL radio platforms

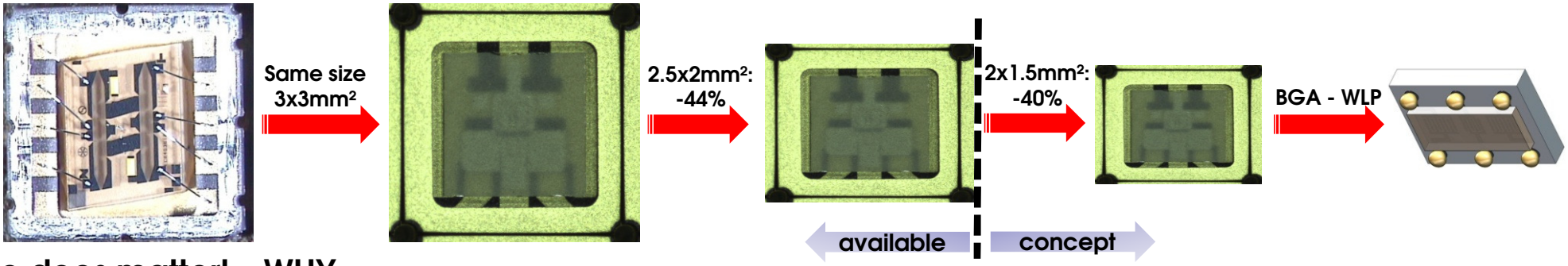






Property of Vectron International

Key technologies: Miniaturization / Passive Integration

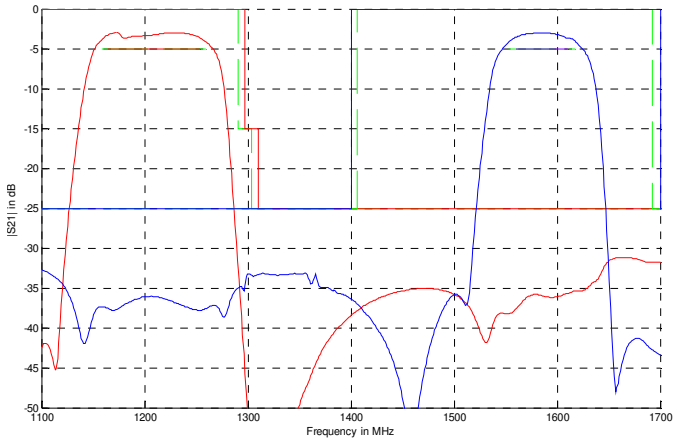


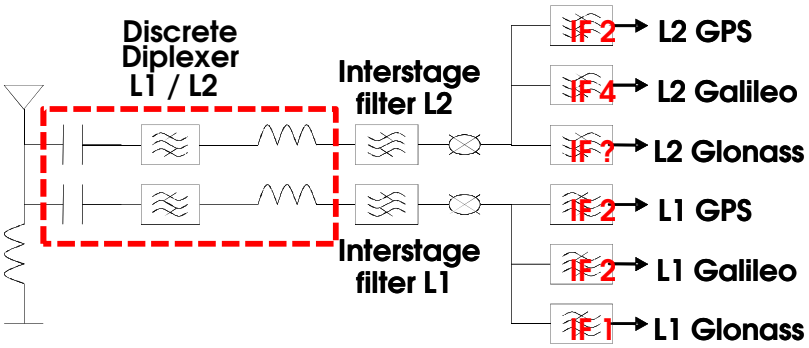
Size does matter! – WHY:

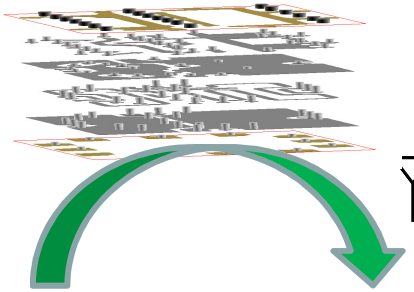
- Size-sensitive applications, e.g. Handheld or implantable
- BUT: typically standard sizes in COM systems (focus: 3x3mm²)

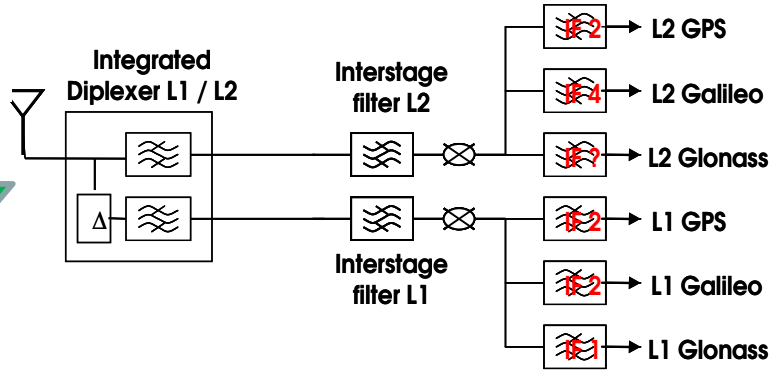
Passive Integration LTCC - WHY:

- Reduction of design complexity for customer in multiband systems
- Miniaturization / Elimination of components
- Status: „discrete → integrated“







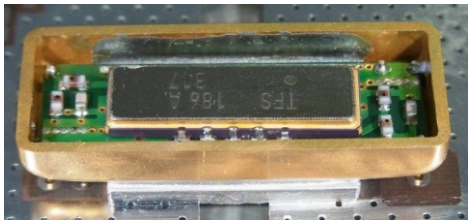


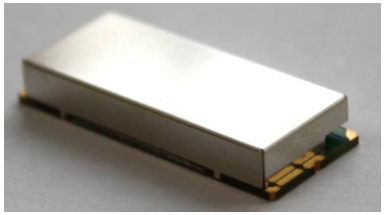
Property of Vectron International

Vectron Filters for Space Applications

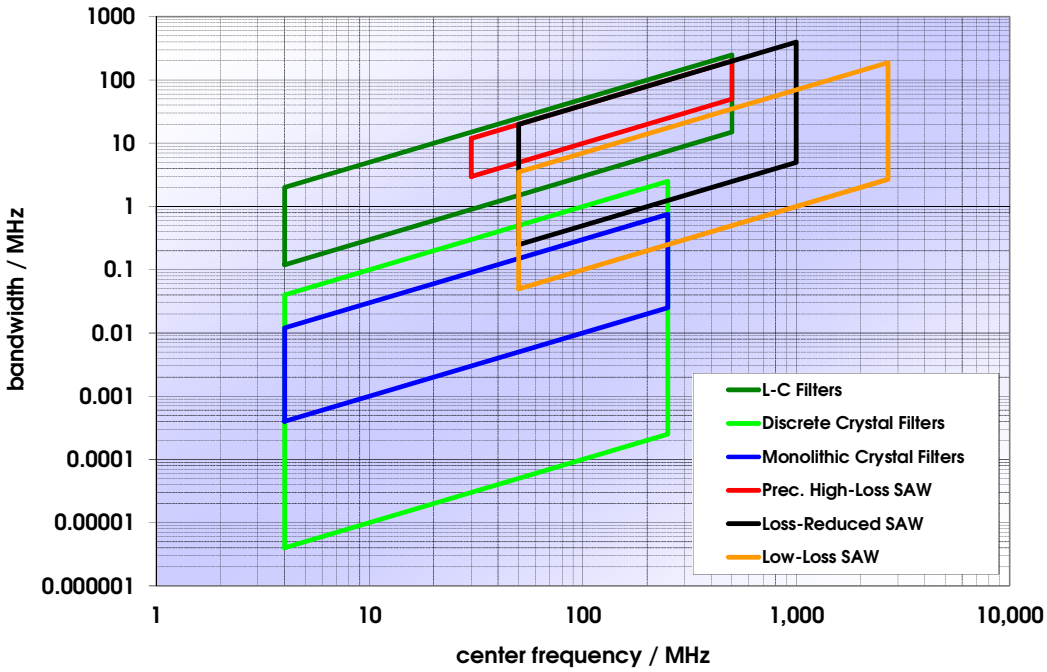
Capabilities:

- Frequency Range:
  - SAW: 30...2600MHz
  - Crystal Filters: 4...250MHz
- Package Solutions:
  - Ceramic Multi-layer
  - Standard Metal Can
  - Double packaged custom solutions (integrated matching)

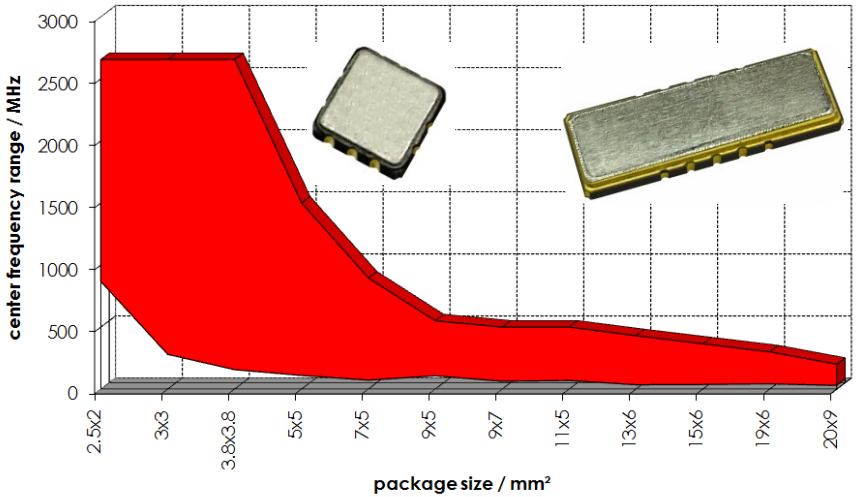


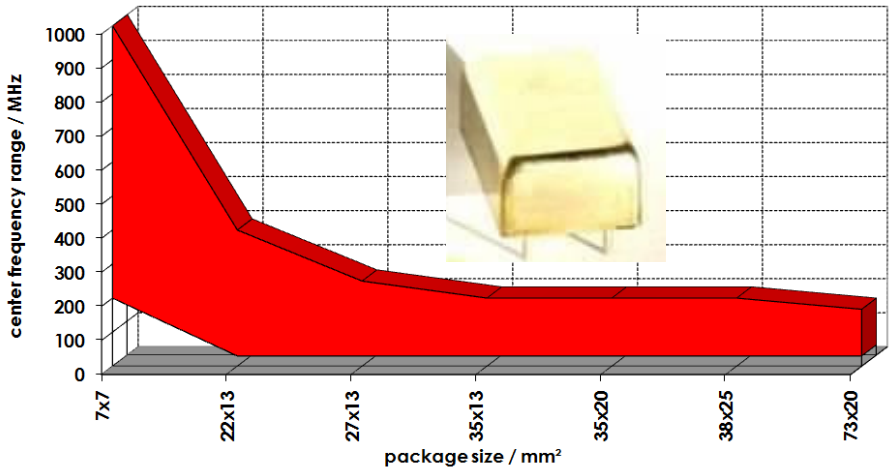


Typical center frequencies for VECTRON LCC SAW Filters



Typical center frequencies for VECTRON Metal Package SAW Filters





Hi-Rel SAW Filter Standard Document

General specification (VA 03-010) for Hi-Reliability products to be used in absence of customer generated Specification Controlled Document (SCD). The procedure defines design, assembly and functional evaluation for micro-acoustic filters.

Key elements include the following:

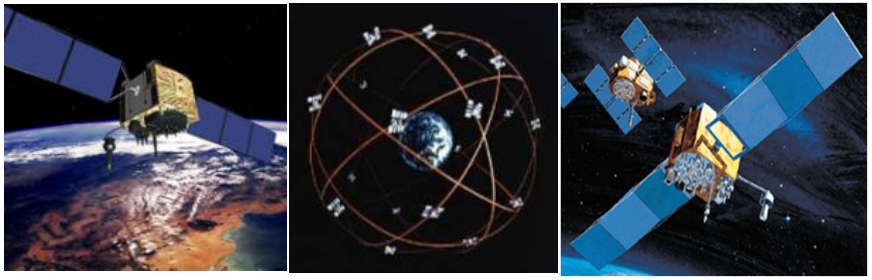
- **System: VI uses ISO/TS16949-certified quality system**
- **Highly Automated Assembly and Test operations:**
  - **Specially controlled and documented processes**
  - **Highly accurate test procedures incl. full traceability**
- **Qualification:**
  - **Standard qualification plan for product families**
  - **Wide range of available special qualification plans**
- **Documentation:**
  - **Standard – production data and lot travelers**
  - **Extended – additional failure analysis data and status**
- **Customized ordering code system**

Property of Vectron International

Hi-Rel SAW Filter Standard Document

Why special standard?

- **No Customer SCD**
- **No Additional Qualification Required**
- **Quicker Delivery**
- **Lower Overall Cost**
- **Multiple Screening Choices**



Based on following standards:

- **MIL-STD-202 - Test Method Standard, Electronic and Electrical Component Parts**
- **MIL-STD-883H - Test Method and Procedures for Microelectronics**
- **MIL-STD-1686C - Electrostatic Discharge Control Program for Protection of Electrical and Electronics Parts, Assemblies and Equipment**
- **ESCC 3502 - Generic Specification for Space SAW Filters**

Property of Vectron International

SPACE-Grade Filter Qual. Options

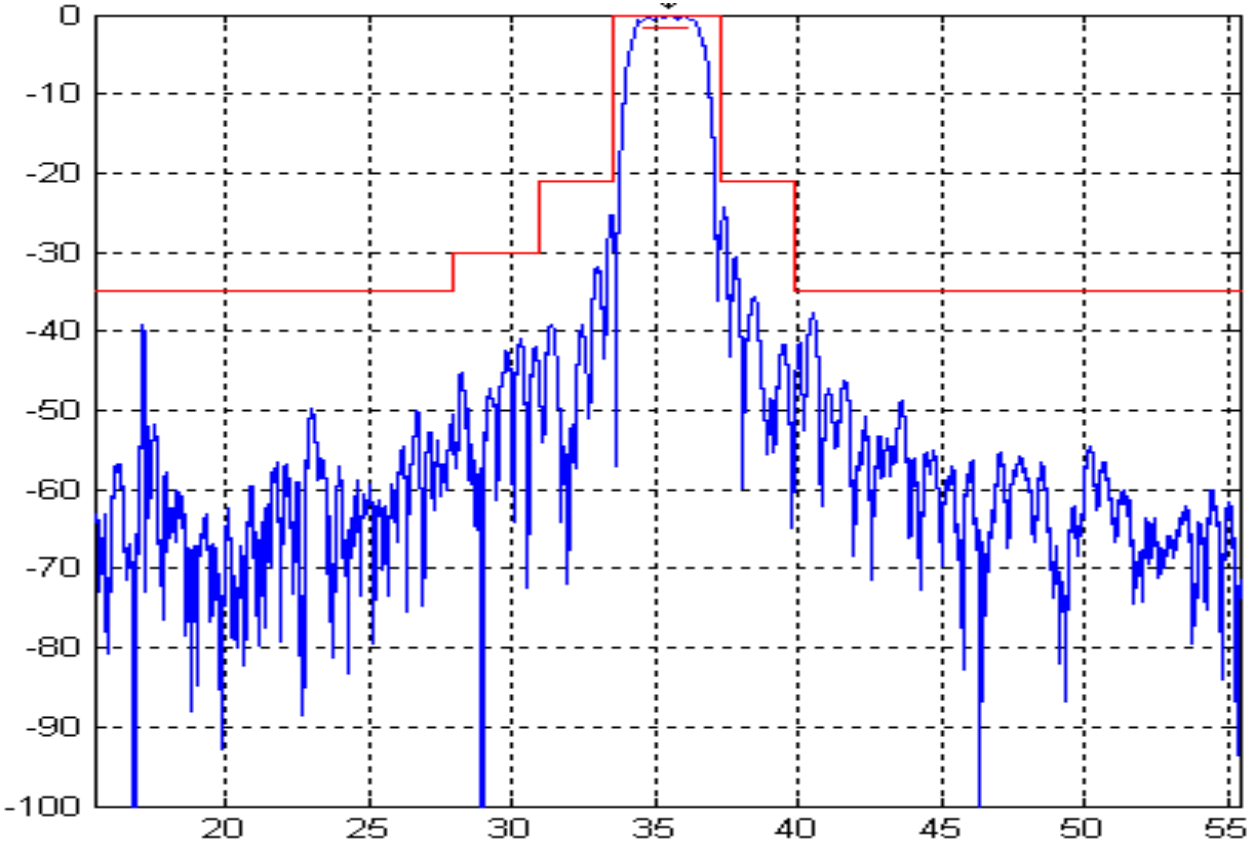
OPN. No.	Screening	Description	Q-A	Q-B	Q-C	Q-D	Q-E	Q-F	Q-G
1	Internal Visual	MIL-STD-883, Meth. 2032 Class K	X	X_1	X_1	X_1	X_1	X_1	X_1
2	Stabilization (Vacuum) Bake	MIL-STD-883, Meth. 1008 Cond B	X	X	X	X	X	X	X
3	Thermal Shock	MIL-STD-883, Meth. 1011 Cond A						X	Customer defined
4	Temperature Cycle	MIL-STD-883, Meth. 1010 Cond B		X	X	X	X		
5	Constant Acceleration	MIL-STD-883, Meth. 2001 Cond A Y1 plant only, 5000g's			X	X	X	X	
6	Particle Impact Noise Detection	MIL-STD-883, Meth. 2020 Cond B				X	X	X	
7	Burn In	MIL-STD-883, Meth. 1015 Cond B	X	X	X	X	X	X	
8	Seal: Fine Leak	MIL-STD-883, Meth. 1014 Cond A2 5x E-8 mbar*l/s	X	X	X	X	X	X	
9	Seal: Gross Leak	MIL-STD-202, Meth. 112 Cond D	X	X	X	X	X	X	
10	Radiographic Inspection	MIL-STD-883, Meth. 2012					X	X	
11	Solderability (lot acceptance test)	MIL-STD-883, Meth. 2003		X	X	X	X	X	
12	External Visual & Mechanical	MIL-STD-883, Meth. 2009	X	X_1	X_1	X_1	X_1	X_1	
13	Aging	30 days at 125°C					X		
14	Operating life (LAT)	MIL-STD-202 /Meth.108/ 6V						X	
15	Mechanical Shock	MIL-STD-883, Test Method 2002 Cond. B				X	X	X	

Property of Vectron International

SPACE-Grade: Radiation Tests

Radiation Test:

- according to "Total Dose Steady State Irradiation Test Method" ESCC No. 22900
- 100krad; dose power – 300 rad/min
- Gamma-cell I radiation chamber (Co60, 335min)



Example TFS35A: Continuous measurement – 1429 sweeps
→ no measureable changes

Property of Vectron International

Vectron SAW - Space Heritage

Vectron Filter Space Heritage, e.g.

Part Desc	End user	Year	Country	Program name
TFS70BA, TFS465G, TFS70BC	Inta	2006	Spain	Nanosat1B LEO
TFS35A	EADS	2006	Germany	GPS Receiver
TFS140BA	Carlo Gavazzi Space	2008	Italy	Mini satellite GPS (OBDH)
TFS1575W	Carlo Gavazzi Space	2008	Italy	Mini satellite GPS (OBDH)
TFS35A	EADS	2008	Germany	GPS Receiver
TFS35S01	NASA	2010	USA	MMS/GPM
TFS70BH	TESAT	2010	Germany	GPS Receiver
TFS35AS02	EADS	2010	Germany	GPS Receiver
TFS150AU, TFS150AV, TFS150AW, LC0-64.0/06, LC0-165.0/06	Fraunhofer Institut	2011	Germany	H2SAT
TFS1176, TFS1227, TFS1575D	EADS Astrium	2012	Germany	GPS Receiver
TFS84	Bilkent / Aselsan	2011	Turkey	Satellite Transceiver

Property of Vectron International

Agenda

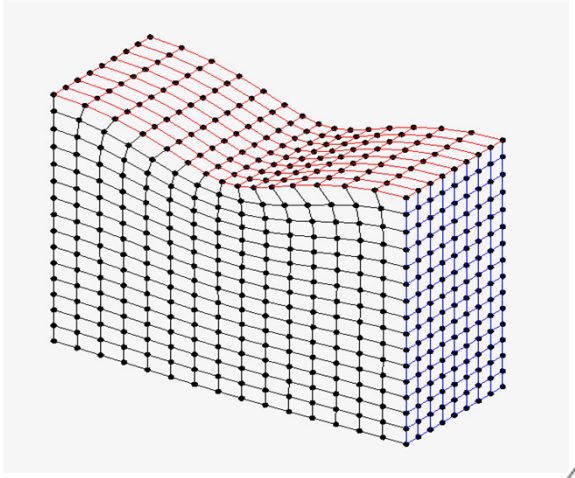
- SAW Filters
  - Products and Roadmaps
  - Space Solutions
- Crystal Filters
  - Products
  - Space Solutions
- SAW-based Oscillators

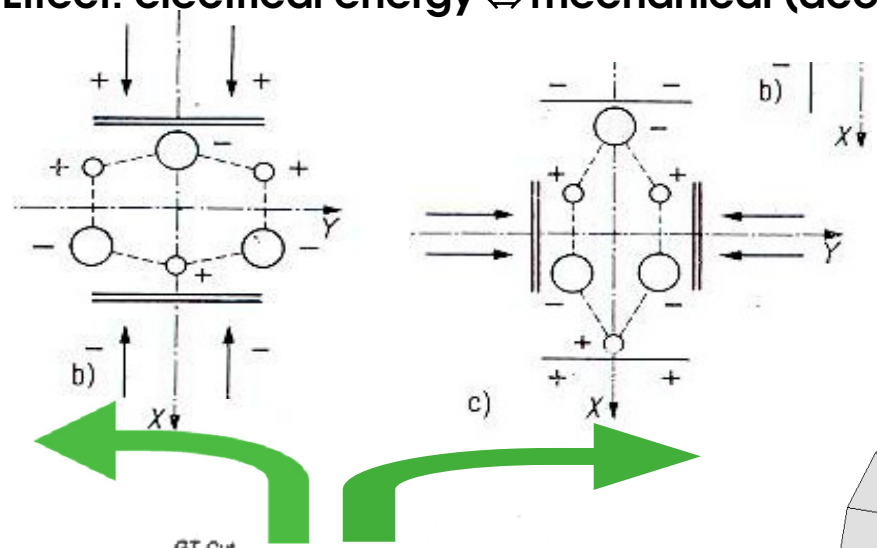
Property of Vectron International

Micro-Acoustics: SAW vs. BAW

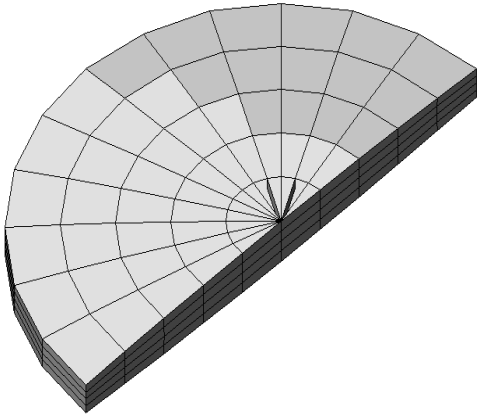
Piezo-Electric Effect: electrical energy ⇔ mechanical (acoustic) energy

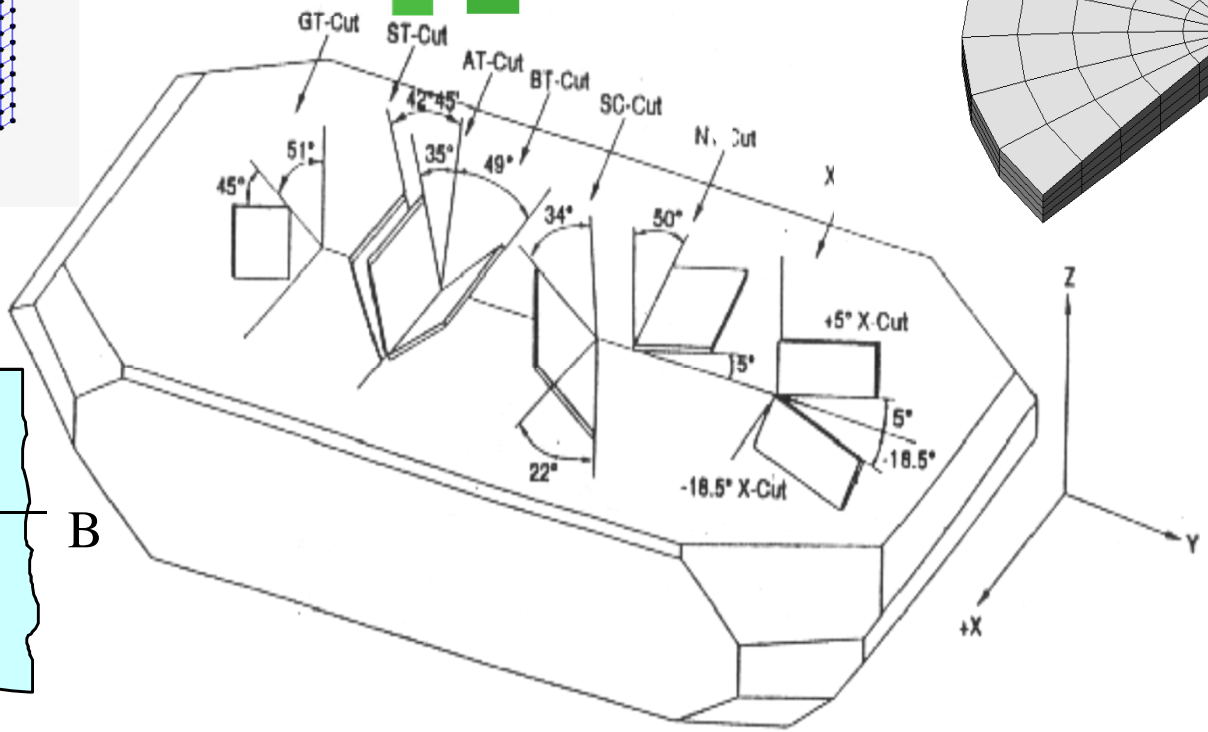
Surface Acoustic Waves:
- Filters
- Resonators

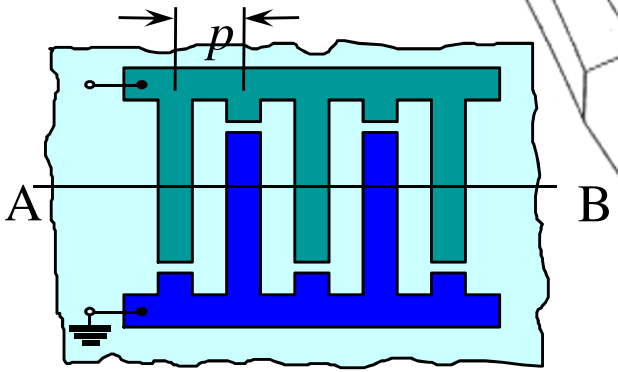




Bulk Acoustic Waves:
- Crystals
- Monolithic Crystal Filters

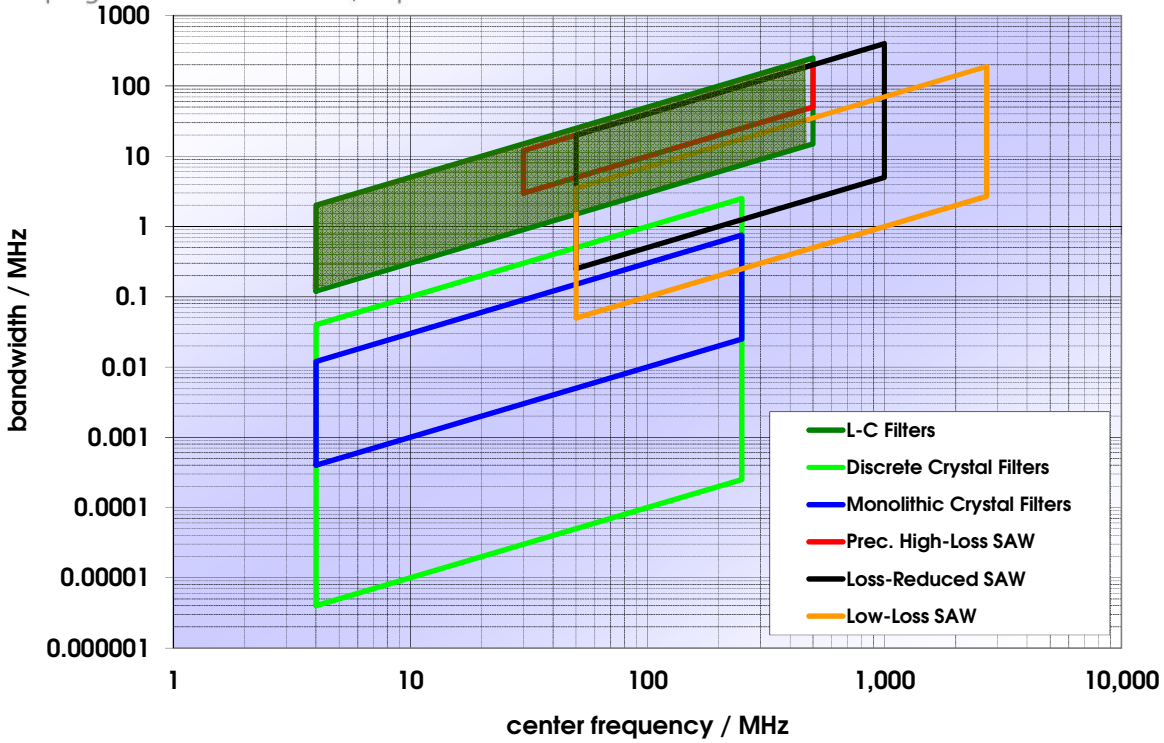




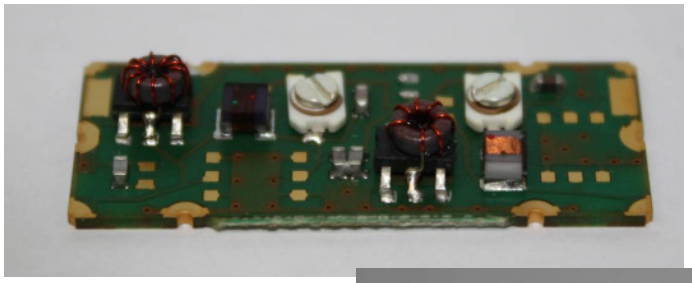


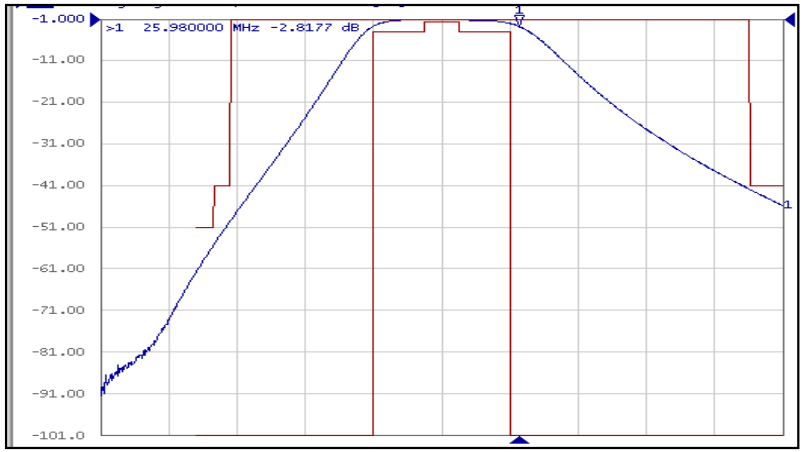
Property of Vectron International

LC-Filters



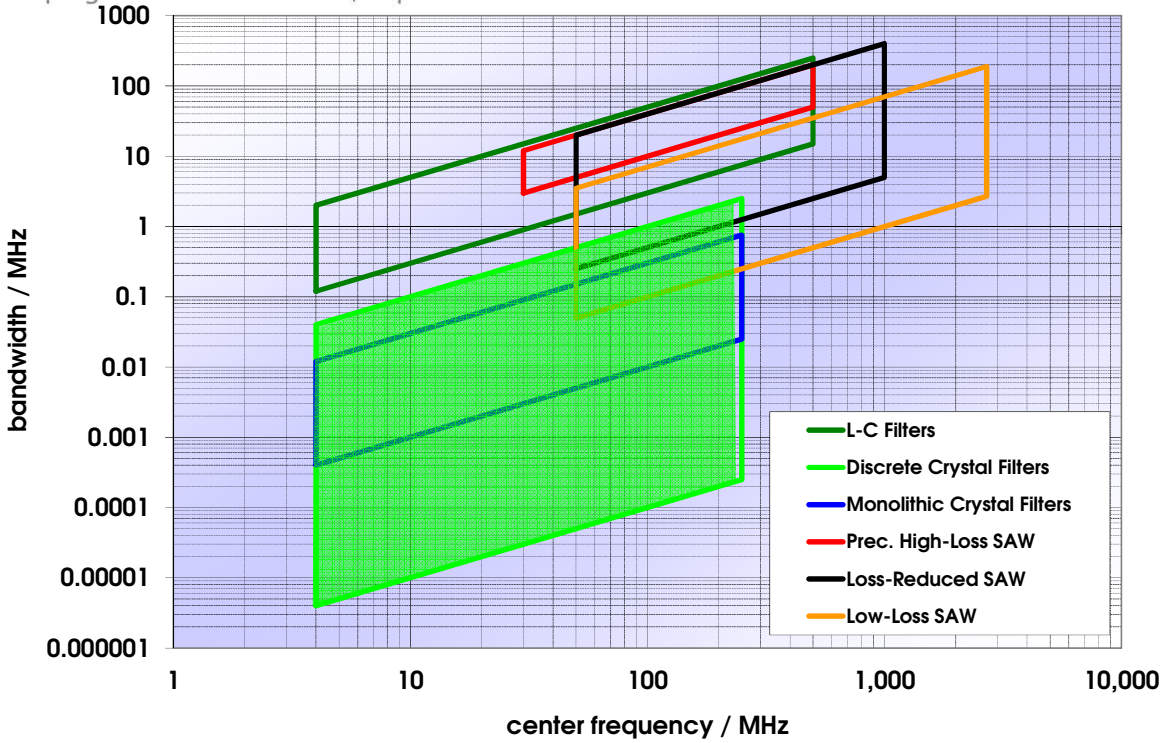
- **Key Parameters:**
  - **Center frequency 4…500MHz**
  - **Fractional bandwidth 10…50%**
  - **Input power level →50dBm**
  - **Shape Factor ≥ 2.8**
- **Qualification Levels**
  - **Military (MIL STD)**
  - **Commercial**
- **Package Technology**
  - **Metal cap with PCB base (SMD)**
  - **Metal package (THT)**



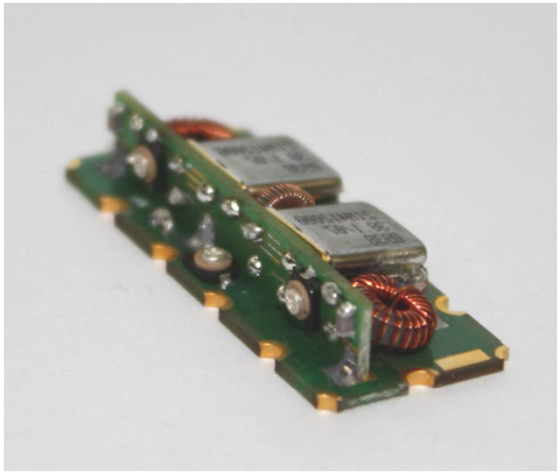


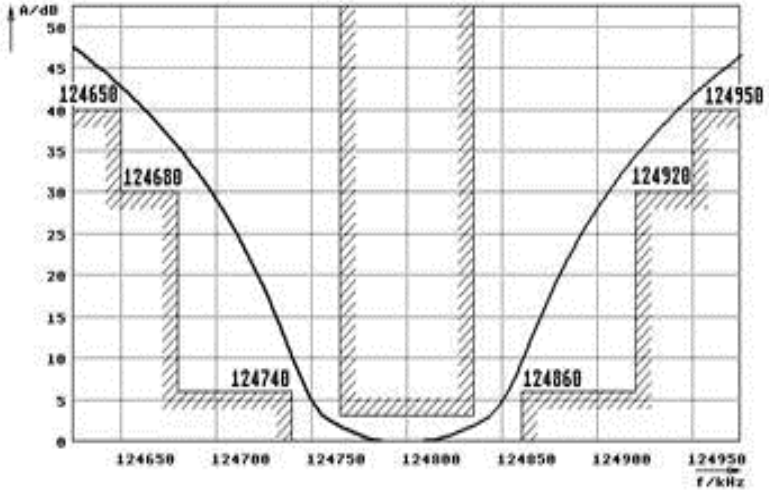
Property of Vectron International

Discrete Crystal Filters



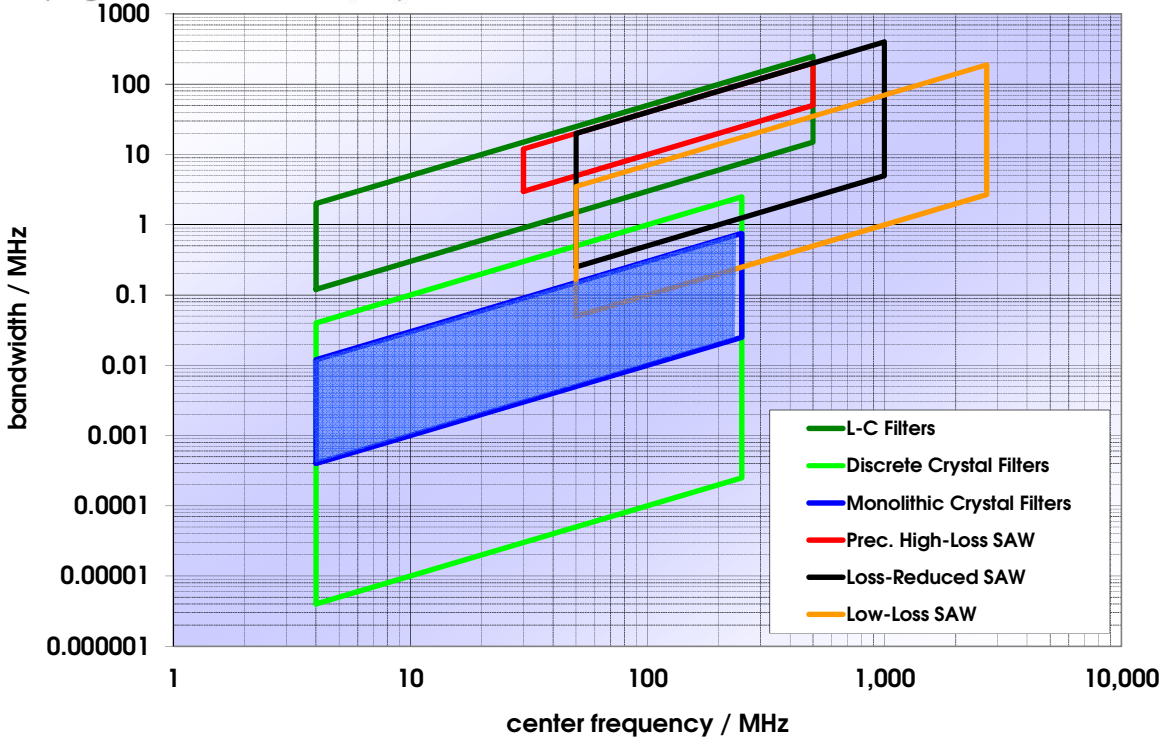
- **Key parameters:**
  - Bandwidth 1ppm…1%
  - Low Passband Ripple
  - Shape Factor ≥ 1.5
  - Excellent Return loss
  - Good Intermodulation
- **Qualification Levels**
  - Military (MIL STD)
  - Commercial
- **Package Technology**
  - Metal cap and PCB base (SMD)
  - Metal package (THT)

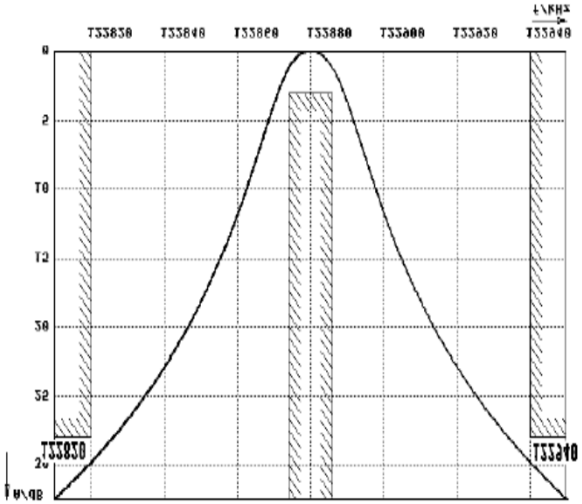


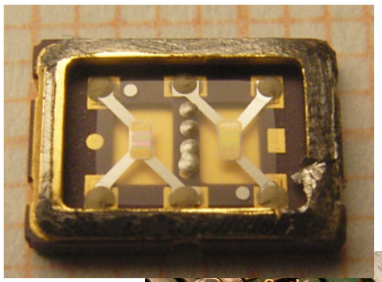


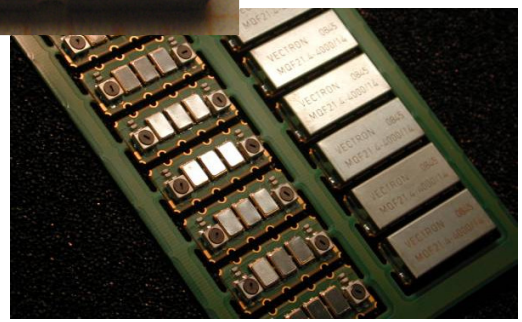
Property of Vectron International

Monolithic Crystal Filters







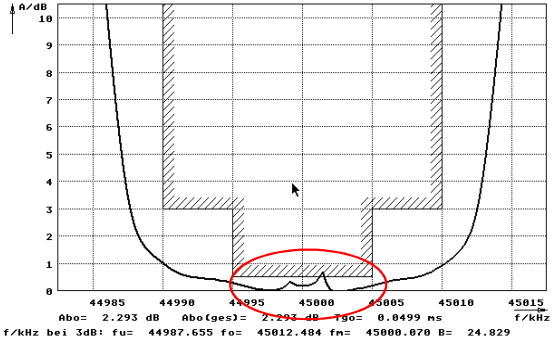


- **Features / Performance**
  - 2-/ 4-pole filters in 5x7mm² package
  - Compact custom filters up to ≥12 poles with internal matching network to 50 Ω
- **Technical aspect**
  - Quartz dual resonators with two electrode pairs on one crystal blank
  - Mechanical coupling of two resonance regions
- **Application**
  - Wireless – Base Station / Repeaters
  - Military/Commercial Mobile Radio Communications Military / Aerospace
  - Test and Measurement Equipment
  - Medical applications

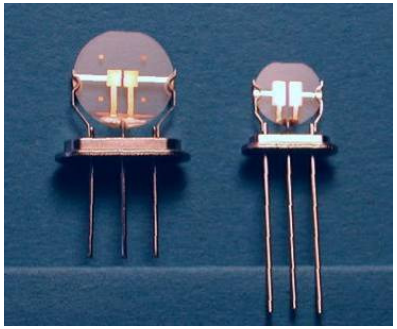
Property of Vectron International

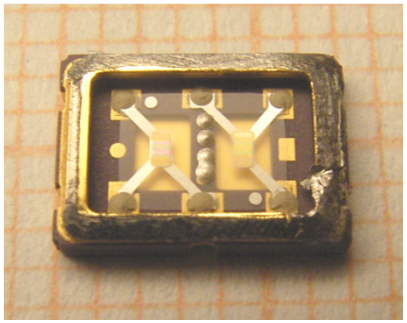
Monolithic Crystal Filters - Roadmap

- Improvement of power durability (in-band Intermodulation)

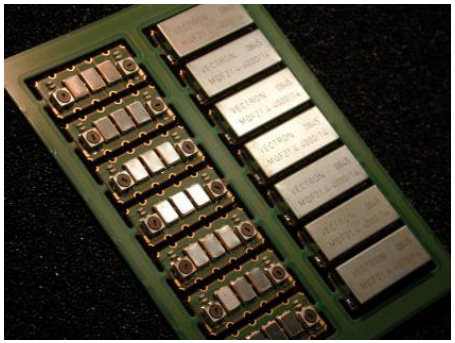


- Focus on SMD 2-pole and 4-pole filters
- Reduced „mm²/pole“



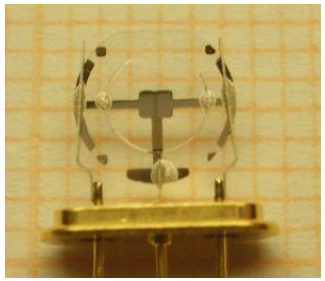


- Migration from through-hole to surface-mount technology



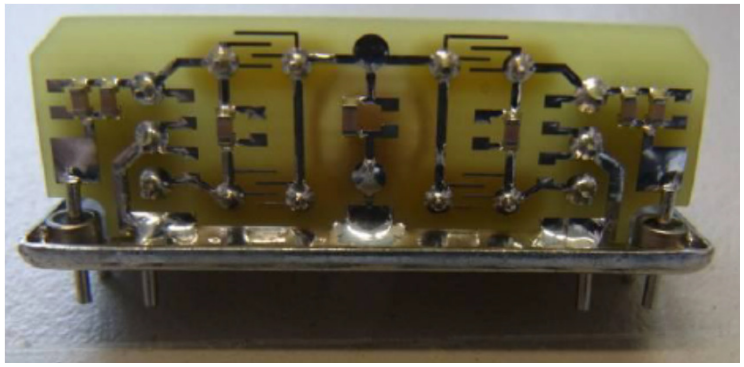
- Inverted Mesa Crystals

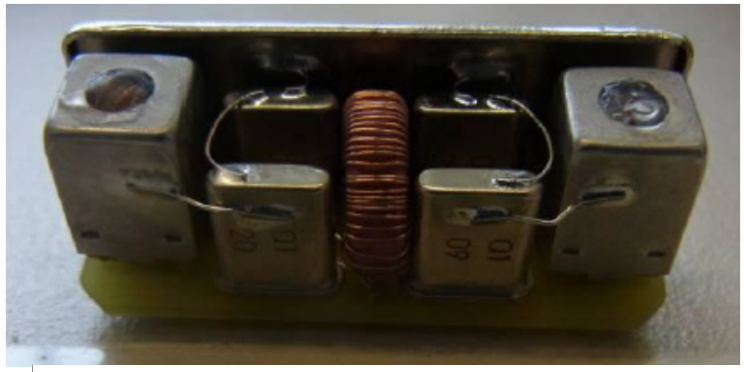
Fundamental Mode >200MHz
Large relative bandwidth



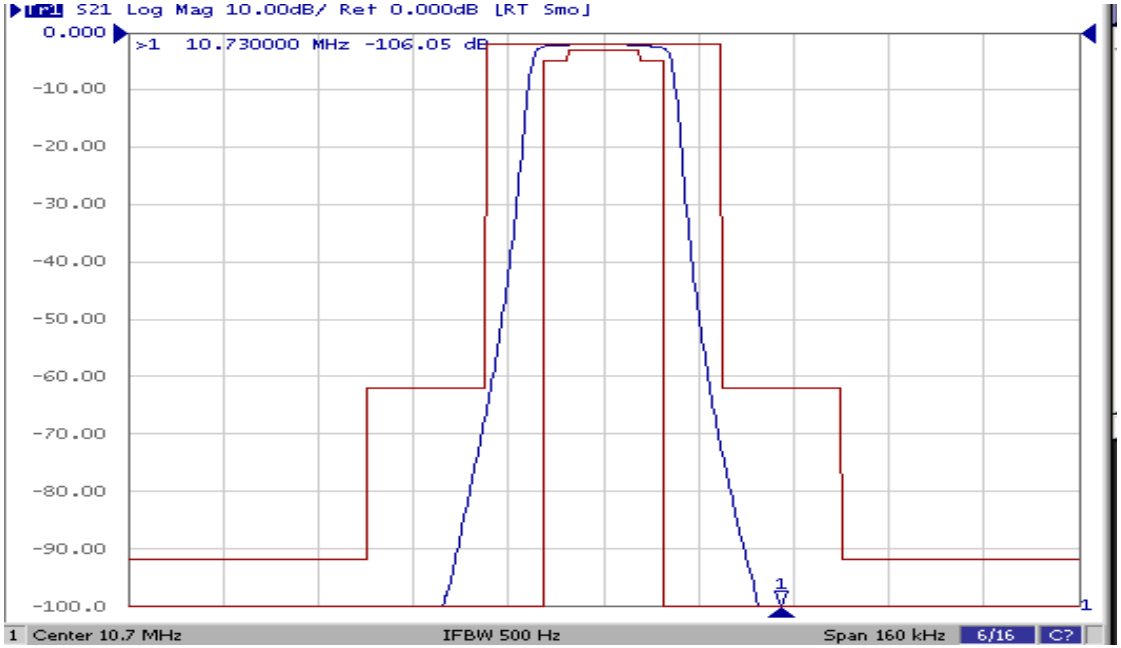
Property of Vectron International

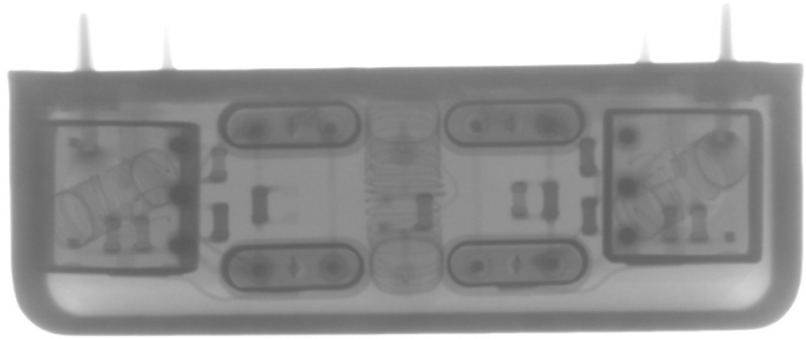
Discrete / Monolithic Crystal Filters for Space Applications

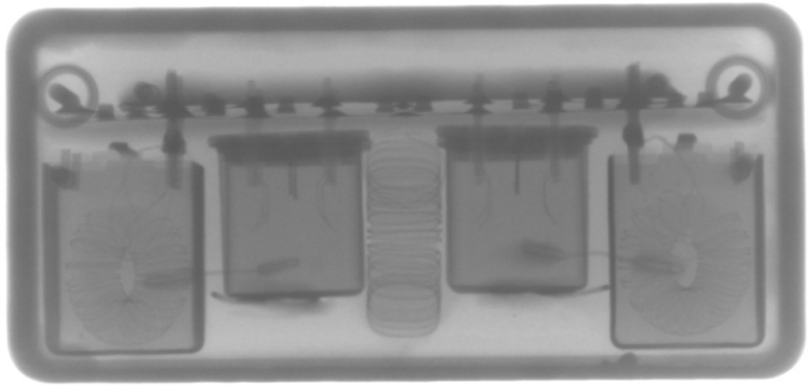




- Discrete construction with fully Space-qualified processes and materials
- Full screening and qualification capabilities







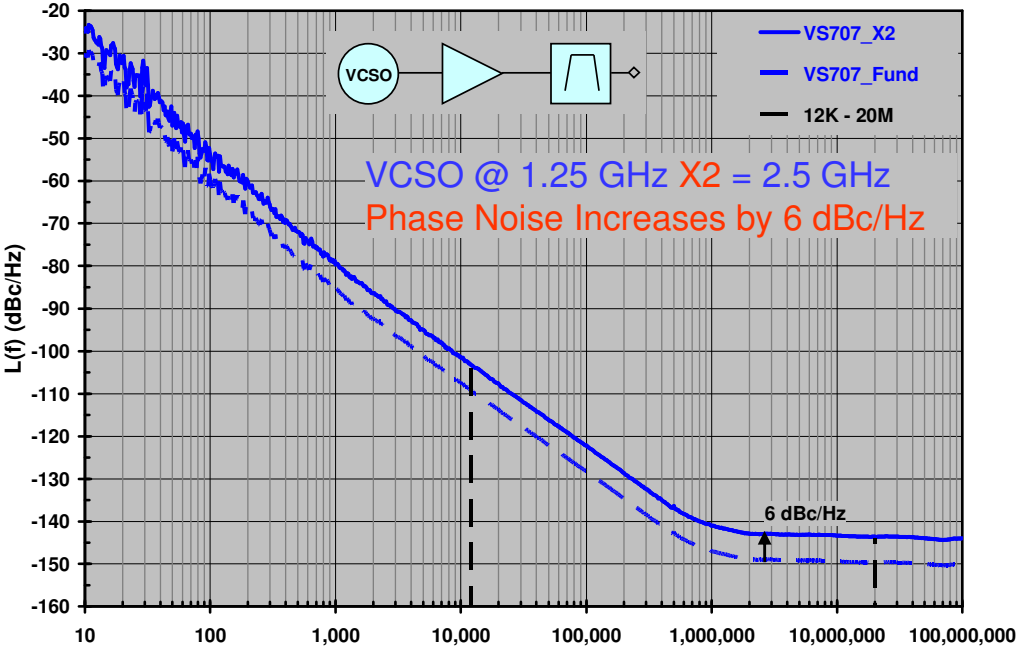
Property of Vectron International

Agenda

- SAW Filters
  - Products and Roadmaps
  - Space Solutions
- Crystal Filters
  - Products
  - Space Solutions
- SAW-based Oscillators

Property of Vectron International

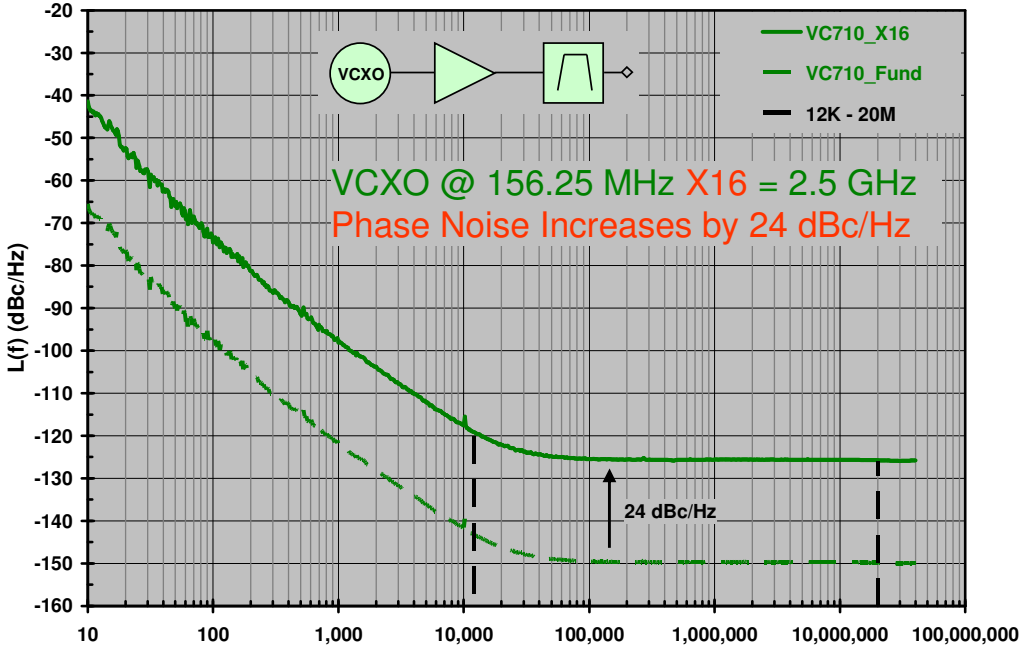
Harmonic Multiplication – XO vs. SO



VCSO @ 2.5 GHz (X2)
Sub-Harmonic Spectrum
@ Multiples of 1.25 GHz

Easier to Filter A Single SubHarmonic

Why VCSO's? → Multiply Less



VCXO @ 2.5 GHz (X16)
Sub-Harmonic Spectrum
@ Multiples of 156.25 MHz

Difficult to Filter Entire Spectrum
Is An Issue When Mixing Signals
(Up & Down Conversion)

Property of Vectron International

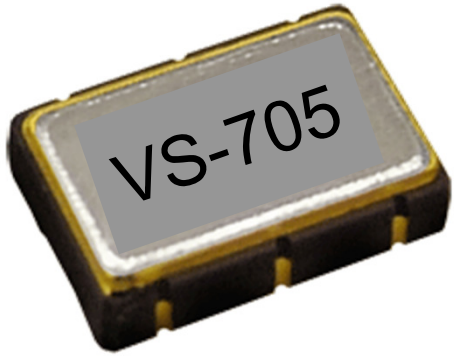
High Frequency VCSO's - Key Parameters

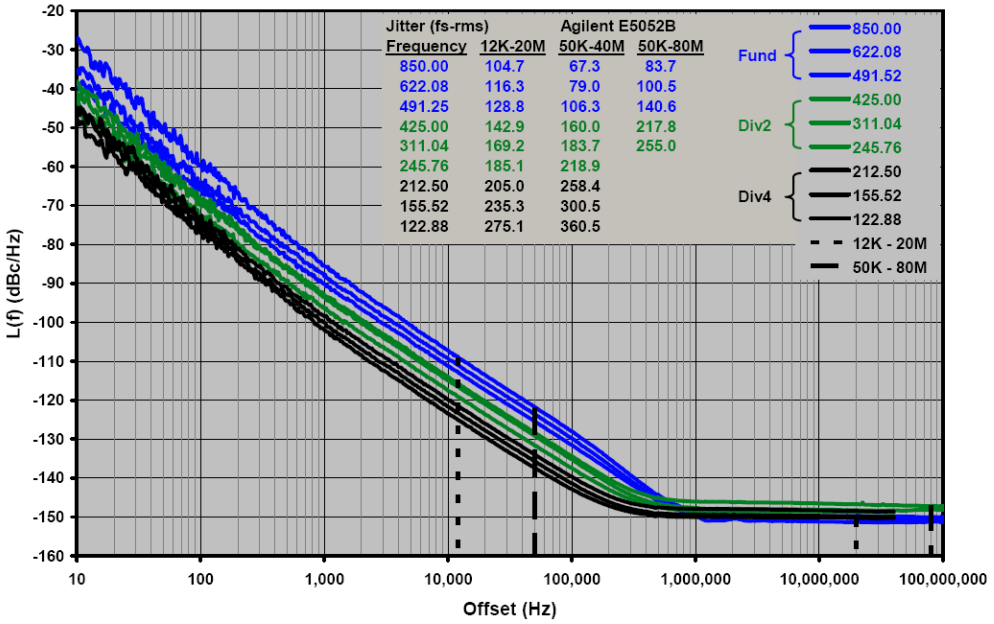
Product	Size (mm)	Frequency Range (GHz)	Supply Voltage (V)	Power Consumption (mW)	Output Configuration	Operating Temperature (DegC)	APR (ppm)	Typ Jitter 12K-20M (fs-rms)	Sub Harmonic (dBc)	Samples	Production
VS-401	13 x 20 x 5.9	1.3 to 2.0	5 / 3.3	300	SE / BAL	-5 to +85	±20	12	-30	Now	Now
VS-501	9 x 14 x 4.9	1.3 to 2.5	5 / 3.3	300	SE / BAL / LVPECL	-5 to +85	±20	12	-25	Now	Q4-12
VS-707	5 x 7 x 1.8	0.15 to 1.5	3.3 / 2.5	250	LVPECL / LVDS	-40 to +85	±100	100	-90	Q4-12	Q1-13
VS-703	5 x 7 x 1.8	1.3 to 2.5	3.3	265	CML	-40 to +85	±100	100	-25	Q4-12	Q2-13
VS-704	5 x 7 x 1.8	0.8 to 3.1	3.3	250	BAL	-40 to +85	±20	10	-30	Q1-14	Q2-14

Property of Vectron International

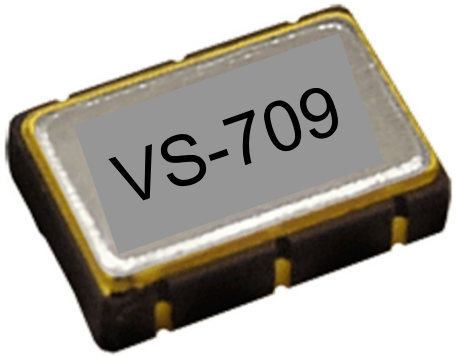
VS-705 / 709: Single/Dual Frequency VCSO

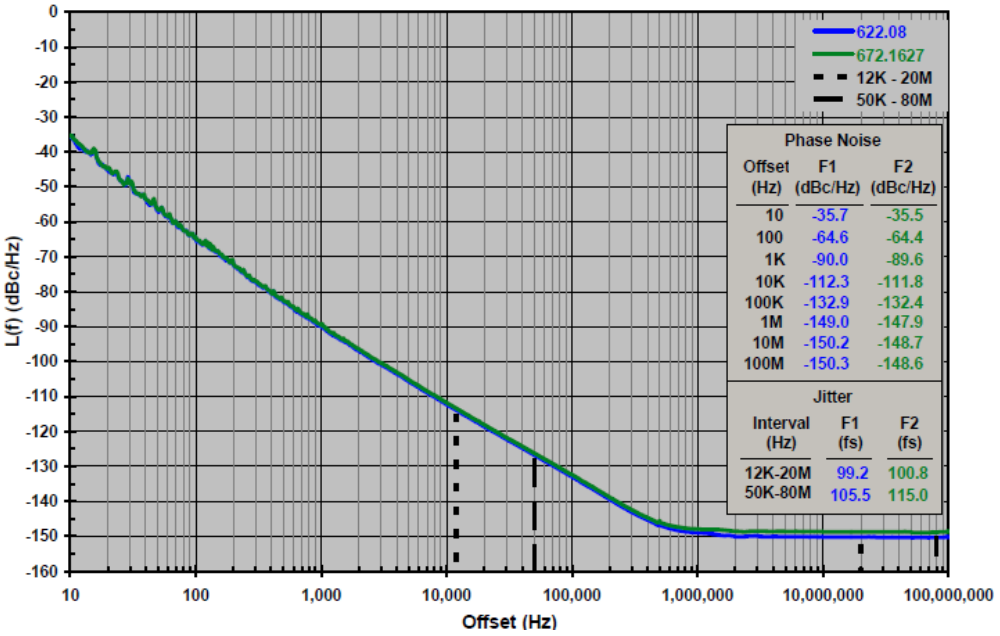
Size: 5.0 x 7.5 x 2.5 mm
Frequency Range: 125 MHz to 1.45 GHz
Output Configuration:
LVPECL/LVDS
Typical Jitter:
12K-20M: 120 fs-rms
50k-80M: 105 fs-rms
Typical Phase Noise:
10K = -115 dBc/Hz
100K = -135 dBc/Hz
Floor = -149 dBc/Hz
Samples = Now
Production = Now





Size: 5.0 x 7.0 x 1.8 mm
Frequency Range: 150 MHz to 1.0 GHz
Output Configuration:
LVPECL/LVDS
Typical Jitter:
12K-20M: 120 fs-rms
50k-80M: 75 fs-rms
Typical Phase Noise:
10K = -112 dBc/Hz
100K = -132 dBc/Hz
Floor = -149 dBc/Hz
Samples = Now
Production = Now

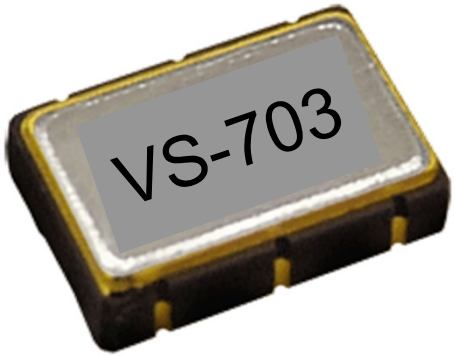


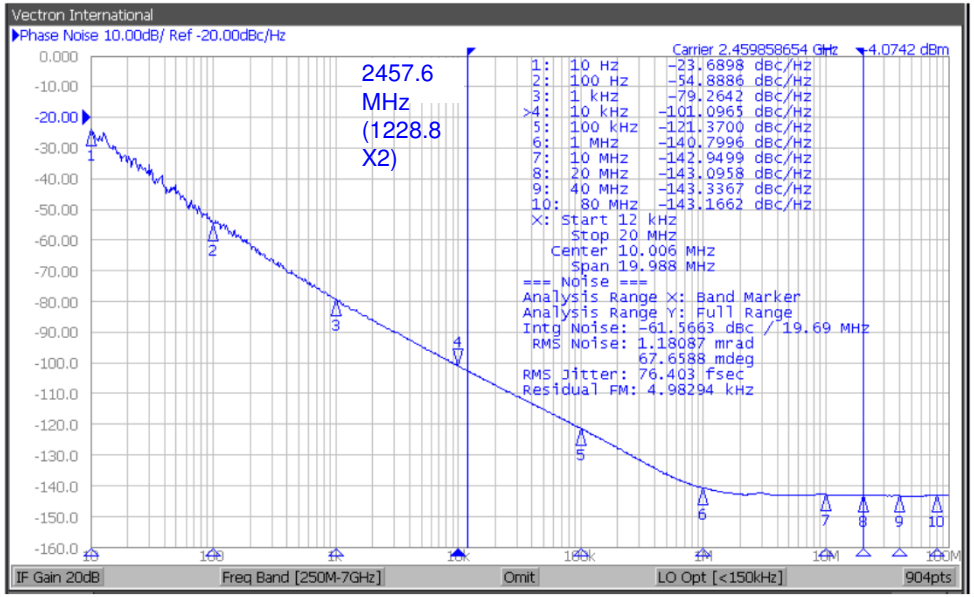


Property of Vectron International

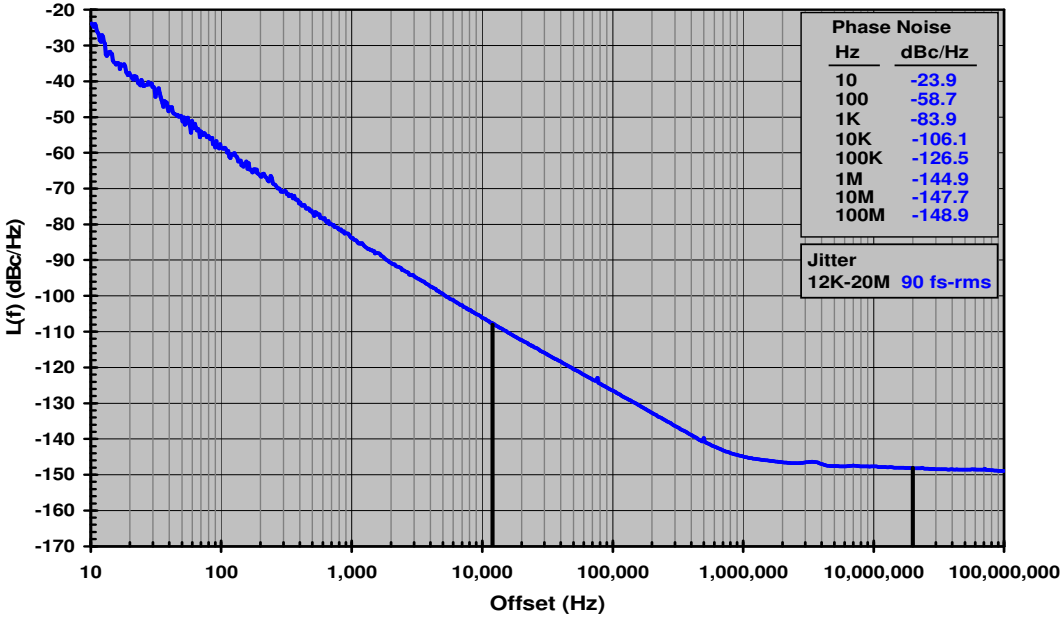
Lead Products VS-703 / VS-707

Size: 5.0 x 7.0 x 1.8 mm
Frequency Range: 1.3 GHz to 2.5 GHz
X2 = 1.3 GHz to 2.5 GHz
Output Configuration:
CML (Current Mode Logic)
Typical Jitter:
12K-20M: 100 fs-rms
Typical Phase Noise:
10K = -101 dBc/Hz
100K = -121 dBc/Hz
Floor = -143 dBc/Hz
Samples = Q4-12
Production = Q2-13





Size: 5.0 x 7.0 x 1.8 mm
Frequency Range: 150 MHz to 1.5 GHz
Fund = 0.15 GHz to 1.50 GHz
Output Configuration:
LVPECL or LVDS
Typical Jitter:
12K-20M: 100 fs-rms
Typical Phase Noise:
10K = -107 dBc/Hz
100K = -127 dBc/Hz
Floor = -149 dBc/Hz
Samples = Q4-12
Production = Q1-13



Lead Product 1 VS-501 (Low Jitter)

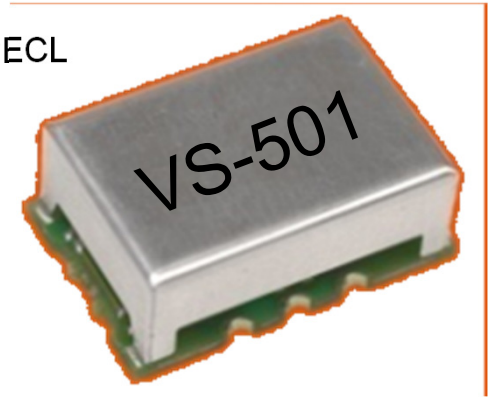
Size: 9.5 x 14.4 x 4.9 mm
Frequency Range: 1.3 GHz to 2.9 GHz
- X2 = 1.81 GHz to 2.9 GHz
- Fund = 1.3 GHz to 1.8 GHz

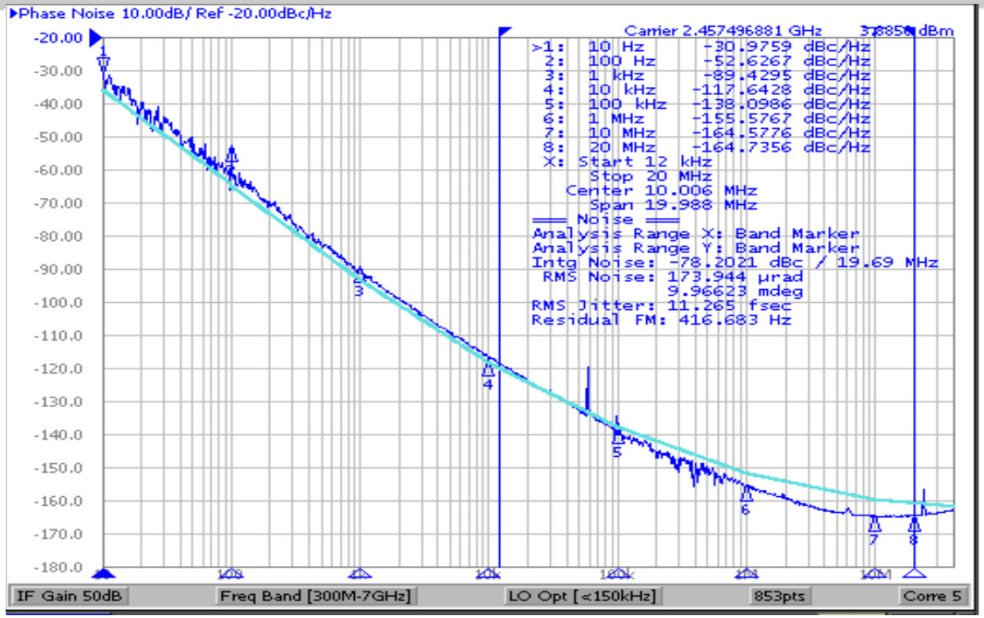
Output Configuration:
- SE or BAL Sinewave, or LVPECL

Typical Jitter:
- 12K-20M: 12 fs-rms

Typical Phase Noise:
- 10K = -117 dBc/Hz
- 100K = -128 dBc/Hz
- Floor = -164 dBc/Hz

Samples = Now
Production = Q4-12





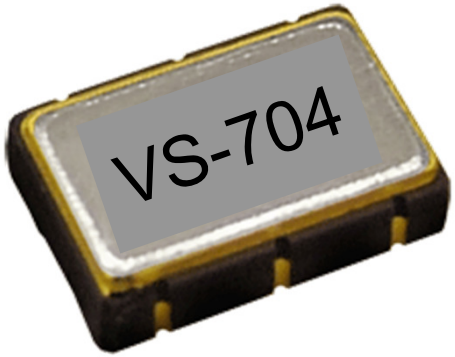
Size: 5.0 x 7.0 x 1.8 mm
Frequency Range: 0.8 GHz to 3.1 GHz
- X2 = 1.61 GHz to 3.1 GHz
- Fund = 0.8 GHz to 1.6 GHz

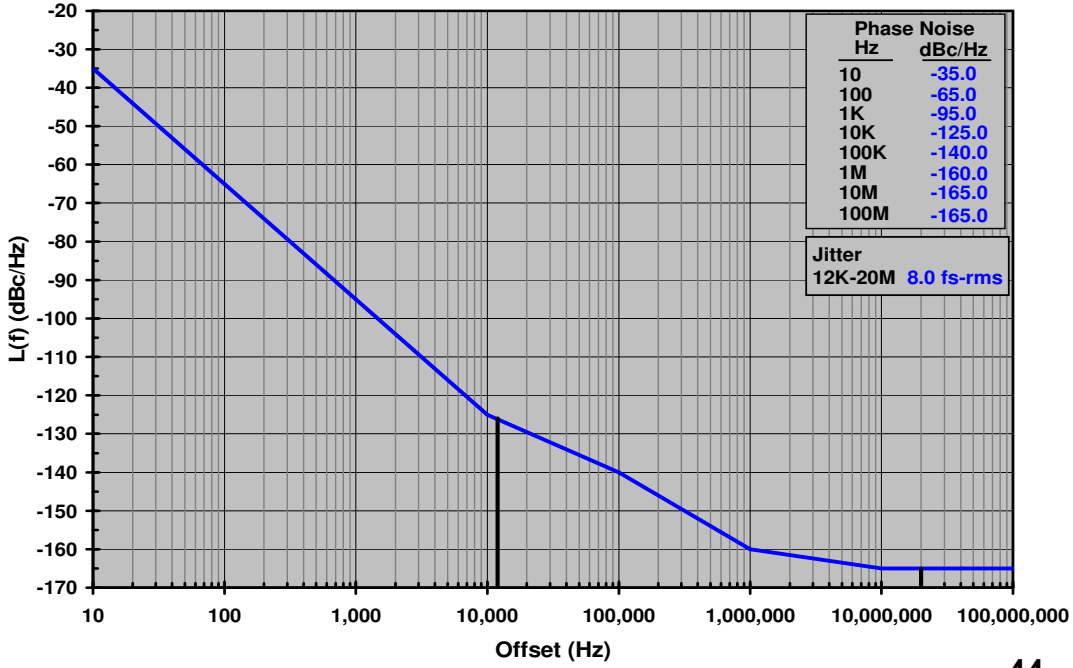
Output Configuration:
- BAL Sinewave

Typical Jitter:
- 12K-20M: 10 fs-rms

Typical Phase Noise:
- 10K = -125 dBc/Hz
- 100K = -140 dBc/Hz
- Floor = -165 dBc/Hz

Samples = Q1-14
Production = Q2-14





Aspects of High-Frequency VCSO Approaches

	Delay Line Based Oscillators			Resonator Based Oscillators		
Column1	**VS-707**	**VS-5xx with VS-707**	VS-703	**VS-401**	**VS-501**	VS-704
Performance	♦♦	♦	♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Size	♦♦♦♦	♦♦♦	♦♦♦♦	♦	♦♦♦	♦♦♦♦
Cost	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦	♦♦♦	♦♦♦♦
Reliability	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦	♦♦♦♦
New Frequencies	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦	♦♦	♦♦
Scalability	♦♦♦♦	♦♦♦	♦♦♦	♦	♦	♦♦♦

♦♦♦♦ Best in Class

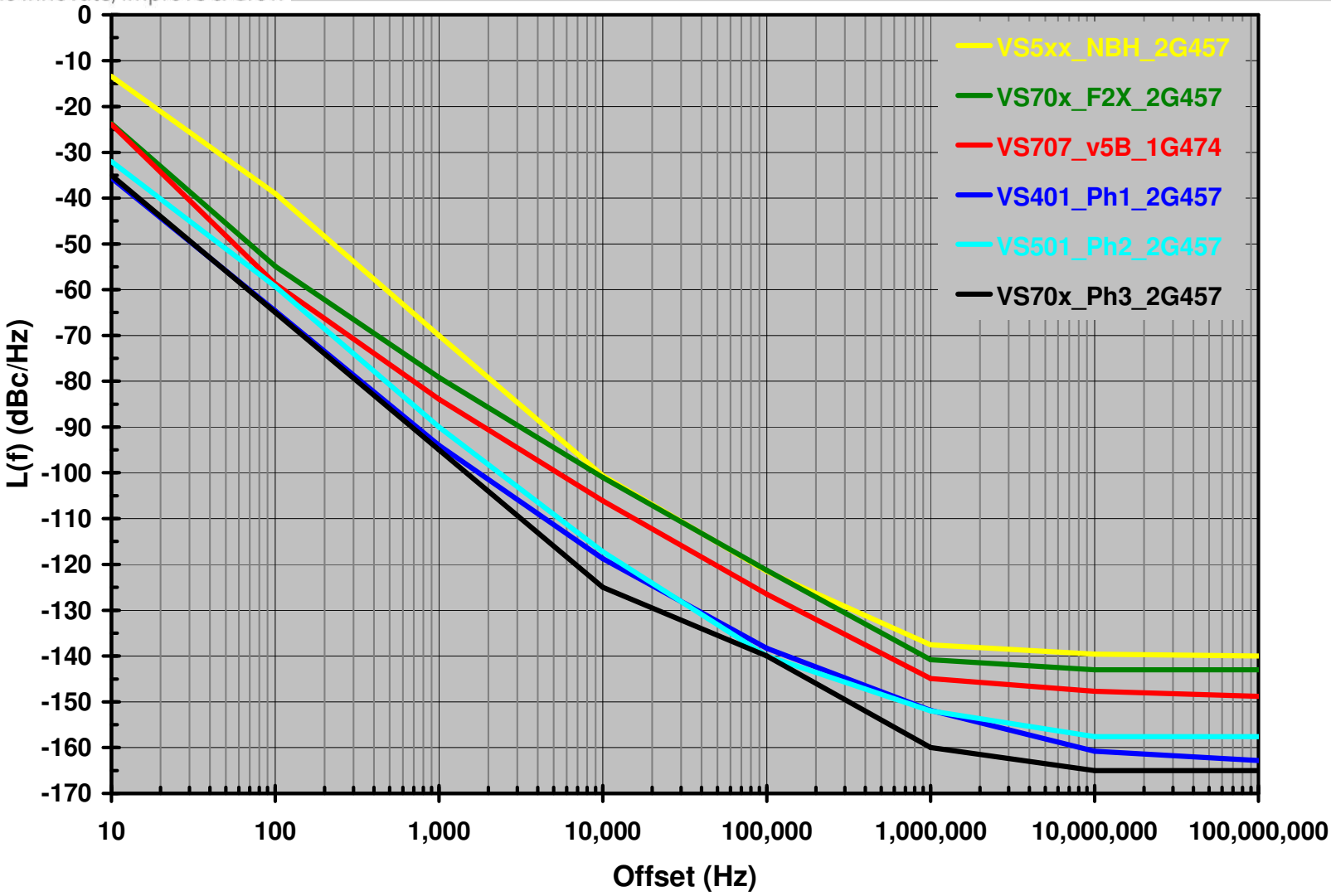
♦♦♦ Better

♦♦ Good

♦ Fair

Property of Vectron International

High Frequency VCSO Phase Noise



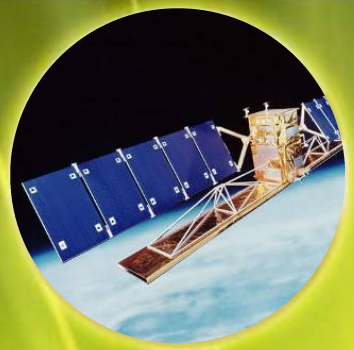
- SAW-based oscillators have not been qualified for Space projects yet
- Materials and manufacturing processes are in use for Space projects in other product platforms

Property of Vectron International

VECTRON INTERNATIONAL
A DOVER COMPANY

Helping Customers Innovate, Improve & Grow

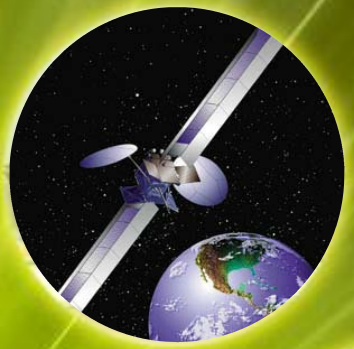
Black



Manned

Scientific

Comms



Military

Thank You!

Launch Vehicles