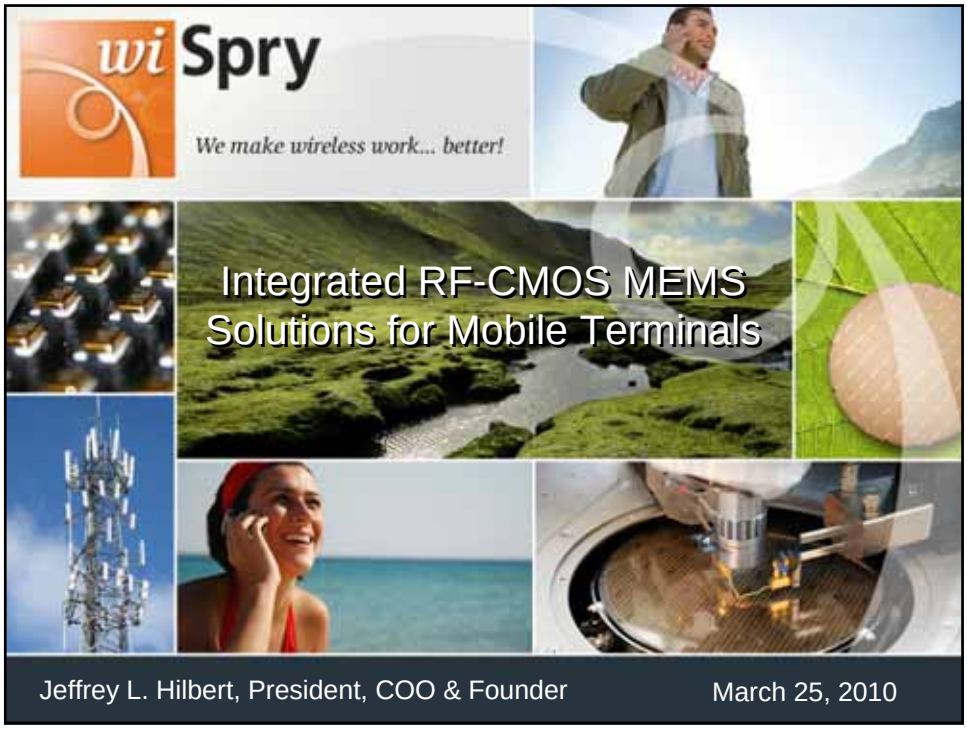
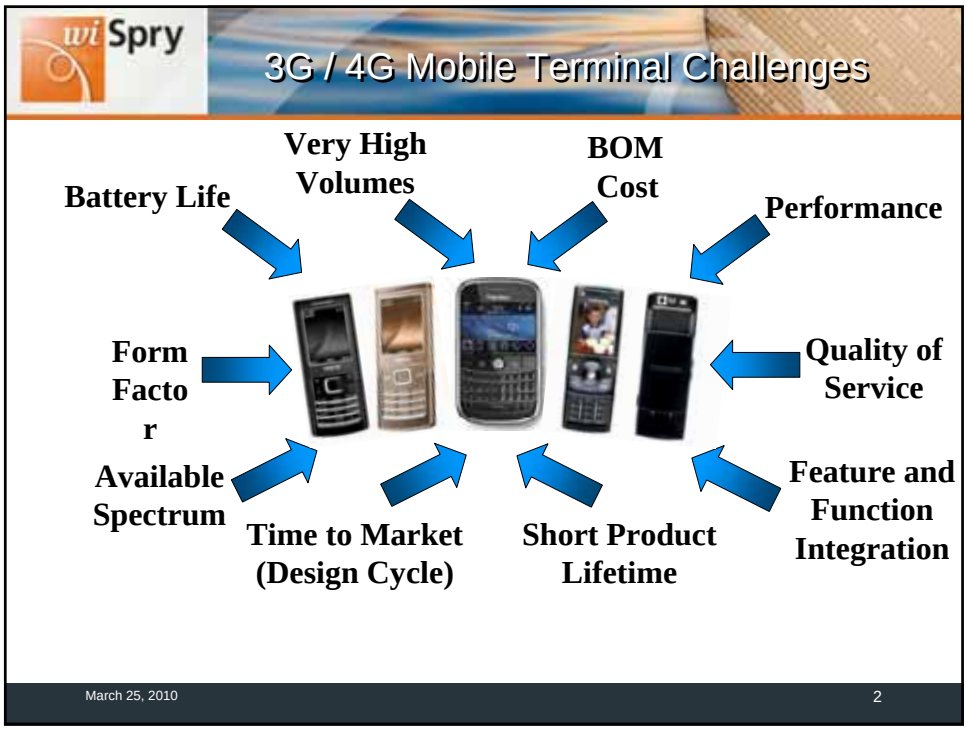

wiSpry
We make wireless work... better!
Integrated RF-CMOS MEMS Solutions for Mobile Terminals
Jeffrey L. Hilbert, President, COO & Founder
March 25, 2010


wiSpry
3G / 4G Mobile Terminal Challenges
Very High Volumes
BOM Cost
Battery Life
Performance
Form Factor
Quality of Service
Available Spectrum
Time to Market (Design Cycle)
Short Product Lifetime
Feature and Function Integration
March 25, 2010
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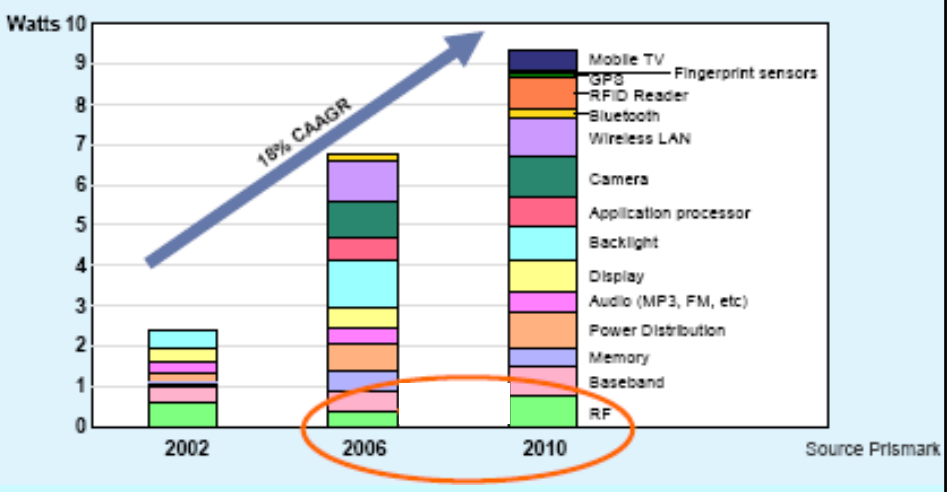
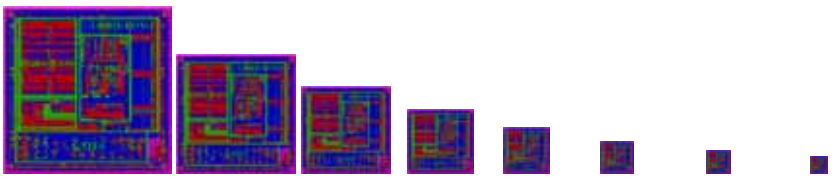
Functions and Features Drive Power Consumption in 3G / 4G Handsets



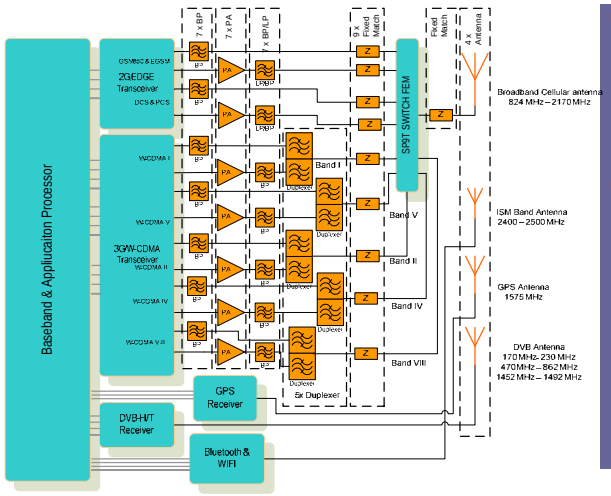
Moore's Law Has Driven Evolution of Digital GSM Basebands



Year	1994	1997	1999	2000	2002	2004	2006	2008
Geometry	500nm	350nm	250nm	180nm	130nm	90nm	65nm	45nm
Wafer Size	6"	8"	8"	8"	12"	12"	12"	12"
Die Size (mm^2)	80.7	46.6	19.2	10.7	6.7	4.2	2.4	1.4
Die per Wafer	310	950	2550	4700	12,200	18,700	26,500	46,500

15000 % increase in DPW Source: TI

But Point Solutions Have Limited RF Integration



- **Compromised RF Performance**
  - Proliferation of Bands and Standards
  - Introduction of Multiple Antennas
- **Platform Design Cycle Too Long**
  - Hand Tuning of Platforms Required
  - Every Platform is a "Custom"
- **Increased Number of RF Paths**
  - Un-integratable "Point" Solutions
  - BOM Cost , Area, Power

Growing Number of Specialized, Static and Expensive RF Components

*. . . And it only gets more difficult with **4G***

Removing RF Integration Limits

- Dynamically Reconfigure Properties / Performance of RF Functions Using Software
- Tunable, Re-Configurable, or Programmable RF Components
- Approaches Include
  - Switching
  - Modifying Material Properties
  - ***Moving Micro-Scale Structures (RF-MEMS)***

RF-MEMS Enabled Tunable Components

- **High Value Solution to Pressing Problem, But**
  - Market Forces Make Adoption of New Disruptive Technology-Based Solutions Risky
  - Little to No High Volume Manufacturing and Field Performance Data to Demonstrate Production Readiness
- **Minimizing the Risk**
  - Thoughtful Selection of Customers and Initial Insertion Opportunities
  - Few to No Changes Required to Existing Customer Designs
  - Deep Integration with Mainstream CMOS Technology
  - Technology Platform Enabling High Level of Proven Silicon Design Re-Use
  - Early Demonstration of Insertion Readiness, Manufacturability, Scalability, and Reliability
  - "MEMS on the Inside"

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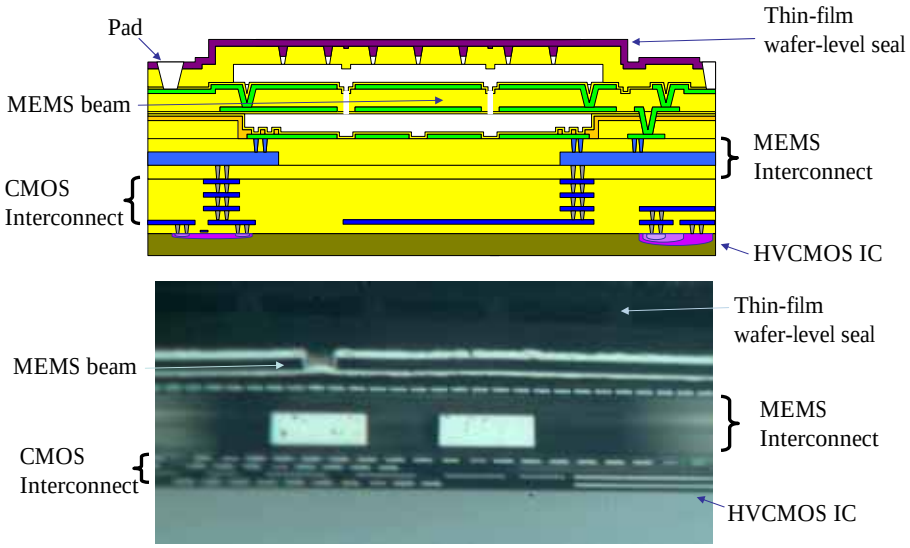
Silicon MEMS (On Top) Fabrication Process
(0.18um, 3/50V RF-CMOS Process; 8" Wafers)



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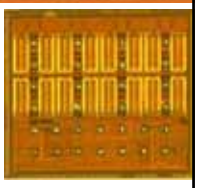
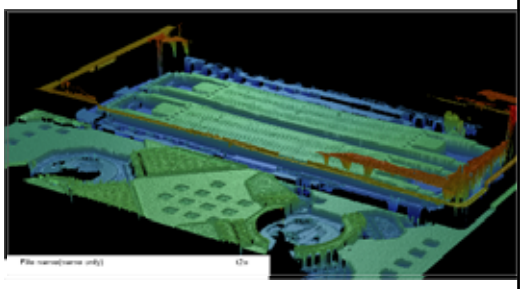
Tunable (MEMS) Digital Capacitor (TDC)

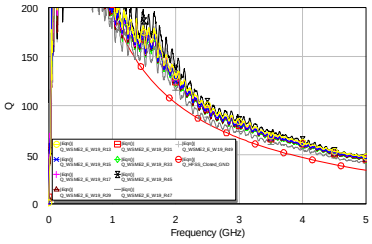
- Ultra Low Power Single Chip Integration with Superior Measured RF Performance
  - Low Loss
  - Extreme Linearity (>>65dBm)
  - 10:1 Tune Range
  - High Power Handling (>40Vrms)
    - 100Vrms Longer-Term Goal
- Separate Signal and Control Paths
  - No Off-Chip Components Required
  - High Device Density
- Bit / Cell Architecture
  - Precise Two State Operation
  - Wide Range of Values Available
- Demonstrated Manufacturable and Reliable Structures



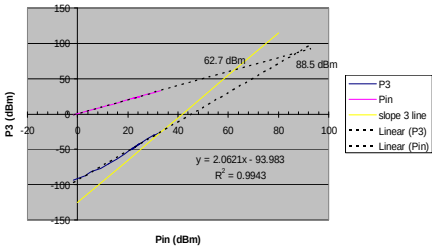


TDC Measured Data
High Performance

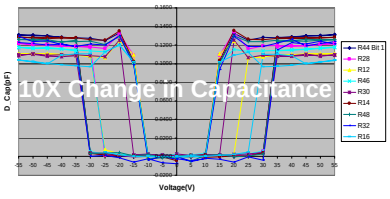
Q > 100 @ 2 GHz for 1pF Cell



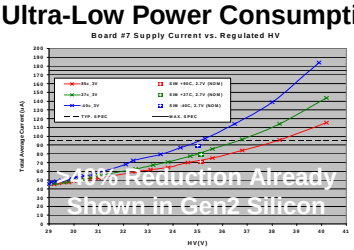
Ultra-Linear



High Capacitance Ratio

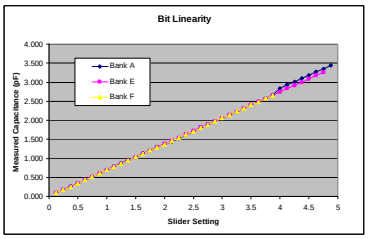


Ultra-Low Power Consumption

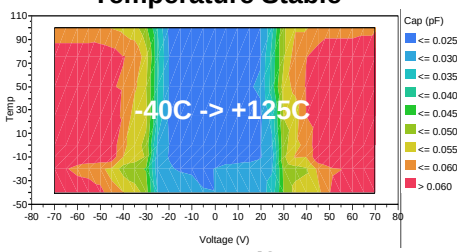


TDC Measured Data
Highly Reliable and Robust

Excellent Bit Linearity

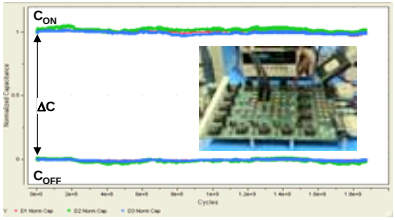


Temperature Stable



Hemeticity
(Wafer-level Encapsulation)

Long Life
(> 1B Cycles in Parallel Testing)



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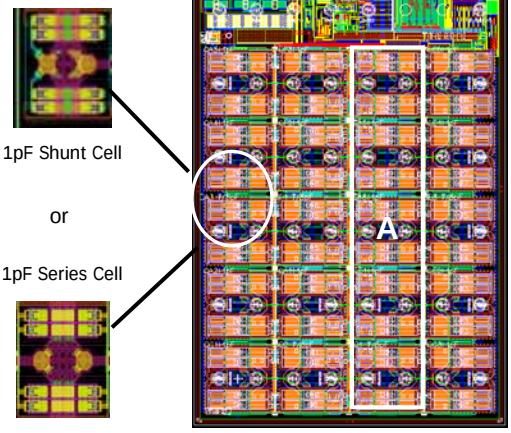
Tunable (MEMS) Digital Capacitor Arrays (TDCA)

- Programmable Generic Capacitor Array Supporting Application-Specific Network Topologies
  - Variable Total Capacitance
  - Variable Step Size
  - Intermixing of Series and Shunt Devices
- True Single-Chip Solution Containing CMOS and MEMS



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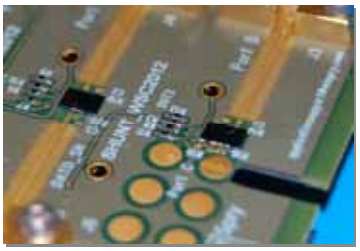
WSC2012 Tunable Digital Capacitor Array (TDCA) with Serial Interface

Features:

- High-Q RF shunt and series capacitor array
- Network fully configurable by the user
- 12 pF total capacitance variation
- Precise digital control over 3 wire SPI interface
- Fully Integrated ultra low noise charge pump
- Low power sleep mode
- Excellent RF-performance with outstanding Q
- Network tuning time less than 100 us
- Delivered as bumped die version 3.8 mm x 2.5 mm
- Samples, datasheet, application note & ADS simulation package available



Applications:

- Dynamic antenna tuning
- Tunable amplifiers
- Programmable filters & tank circuits
- Antenna diversity and beam forming
- Frequency generation
- Programmable matching

The Evaluation Kit:

- Series and shunt with SMA connectors
- Flexible bank allocation
- ADS models
- Board can be battery powered
- Backside can be used for antenna tests
- Easy to use PC SW with interface

WSK2012 Evaluation Kit

The WSC2012 is a technology demonstration vehicle and is not yet a qualified product

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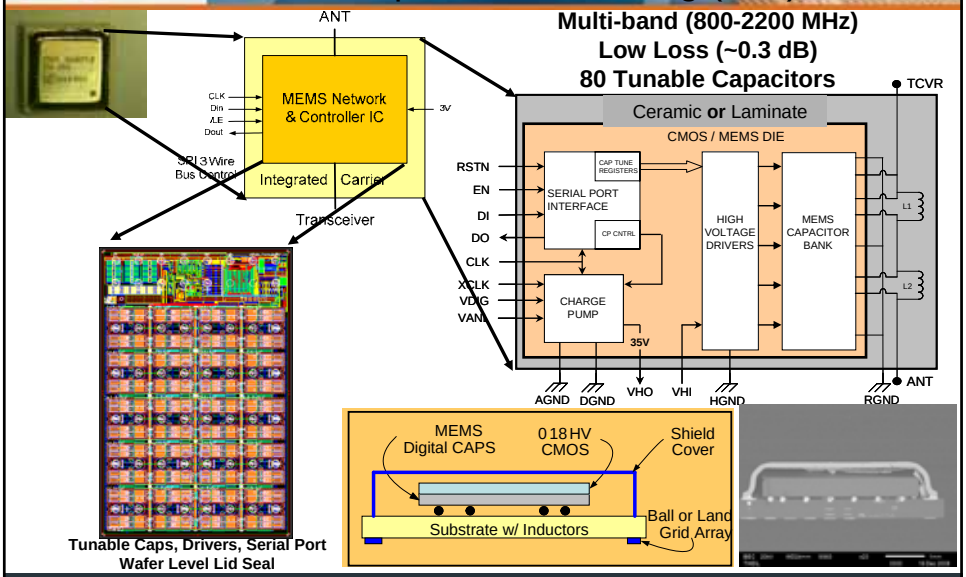
Example Application Tunable Impedance Matching (TIM) Network



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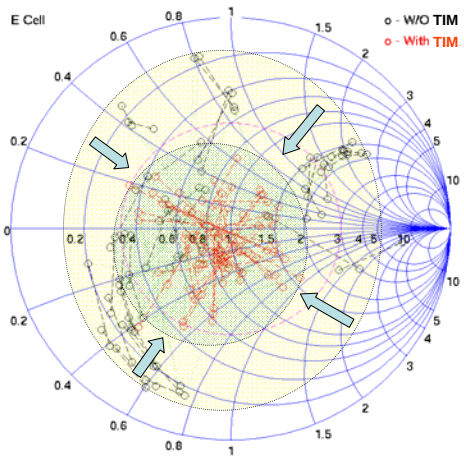
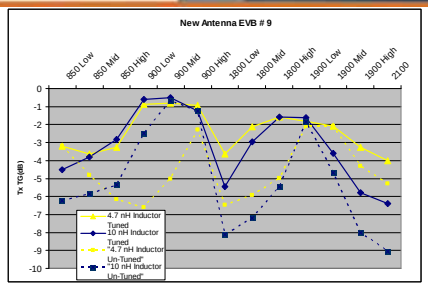
TIM Performance and Benefit
Simulated Data

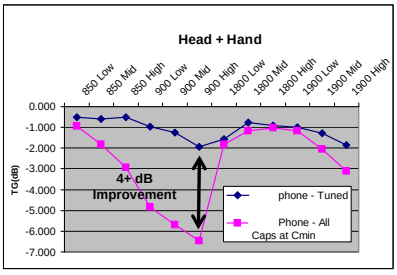


Dashed Lines Connect TX and RX Pairs.
Green Dots Connect With and Without

TIM Performance Improvement:
Transducer Gain (TG) – Measured Data



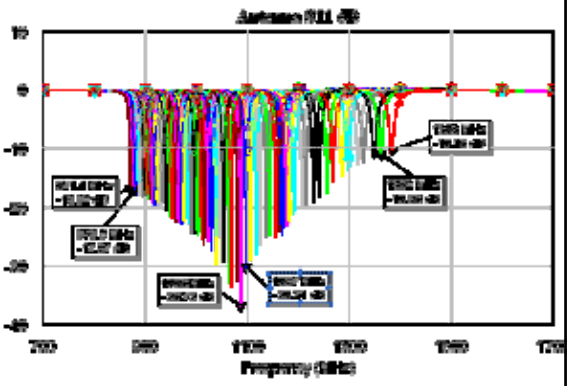
CSSP Provided in March 2009 & "Cut-In" on Second High Volume Production Phone



CSSP ES Provided in November 2008 & "Cut-In" on High Volume Production Phone

Tunable Antenna (TA) Demonstrator Measured Data

Demo TDCA tuning range – 3 to 11 pF



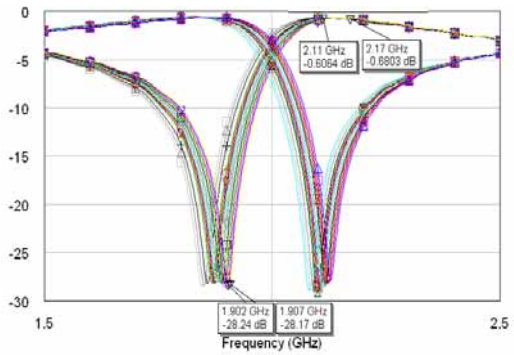
Low loss and highly linear tunable RF ICs enable antennas with:

- Tunability over at least one octave
- Sub-band operation
- Pre-select and spur suppression

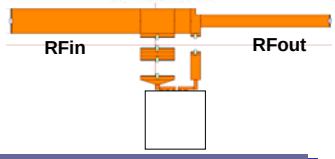
- Impact on antenna volume (space) & efficiency by enabling:
- Smaller volume & same efficiency, or
- Same volume & higher efficiency

- Fairly omni-directional patterns
- Well-matched
- VSWR < 1.5:1 over passband

Tunable Filters (TF): Notch Filter Demonstrator Measured Data

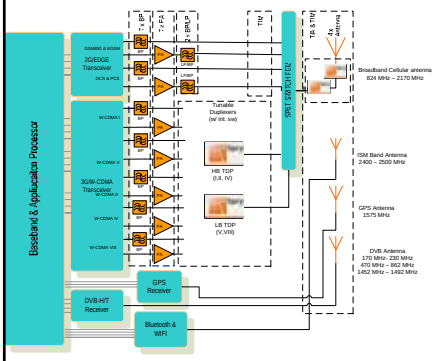


- Components:
  - SMD Air Core Inductor
  - Standard FR-4
  - Microstrip Line Based
  - 50 Ohms Input/Output
- Expected performance:
  - Insertion Loss ~0.7dB
  - Return Loss<-15dB
  - Rejection Level 23 dB
  - High-band Tunability
  - Variable Tx/Rx Spacing

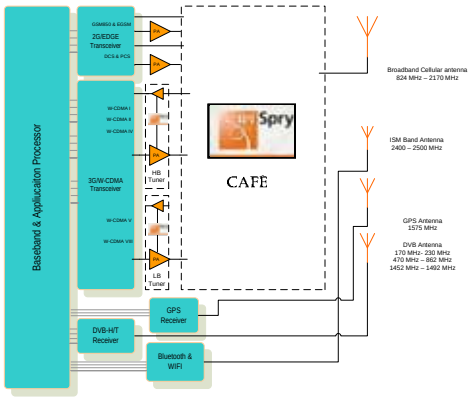


Cooperative R&D Effort with Tier 1 Network Operator

WiSpry's Solution: A Completely Tunable RF Integration Platform



Roadmap to a fully integrated Tunable RF Front-end



- Tunable Antenna **(TA)**
- Tunable LNA
- Tunable Impedance Matching **(TIM)**
- Rx & Tx Band-pass & Low-pass filters
- Tunable Duplexor (Band I,II, IV,V,VIII) **(TDP)**
- 3G PA Tuner **(TPA)** : LB & HB

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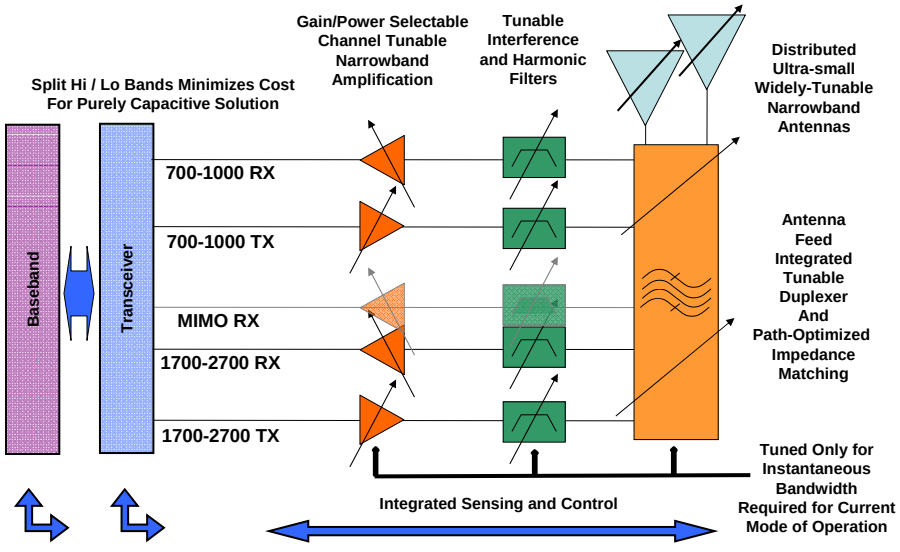
1st Generation Tunable Radio Front End



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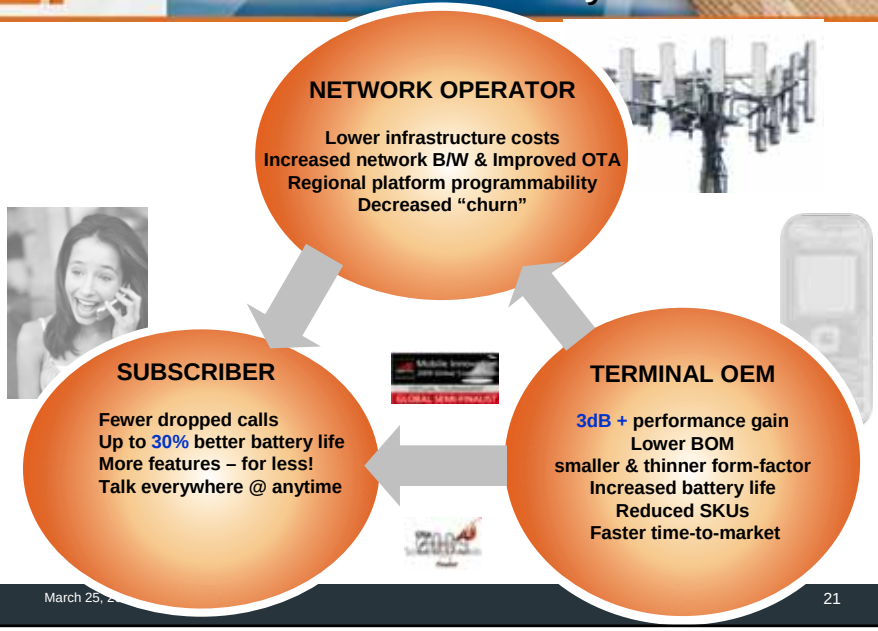
Tunable RF Benefits the Mobile Eco-System



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Integrated RF-MEMS Research Needs

- Sacrificial Materials and Release Techniques
- Integration of "Good" RF Contact Metals (with Silicon)
- Higher Frequency Mechanical Resonators
- In-Line and End of Line Metrology
- Wafer-Level Encapsulation and Hermeticity
- Low Cost, High Performance Packaging Materials and Systems
- Reliability Test and Acceleration Methods
- Design Tools and Methodologies

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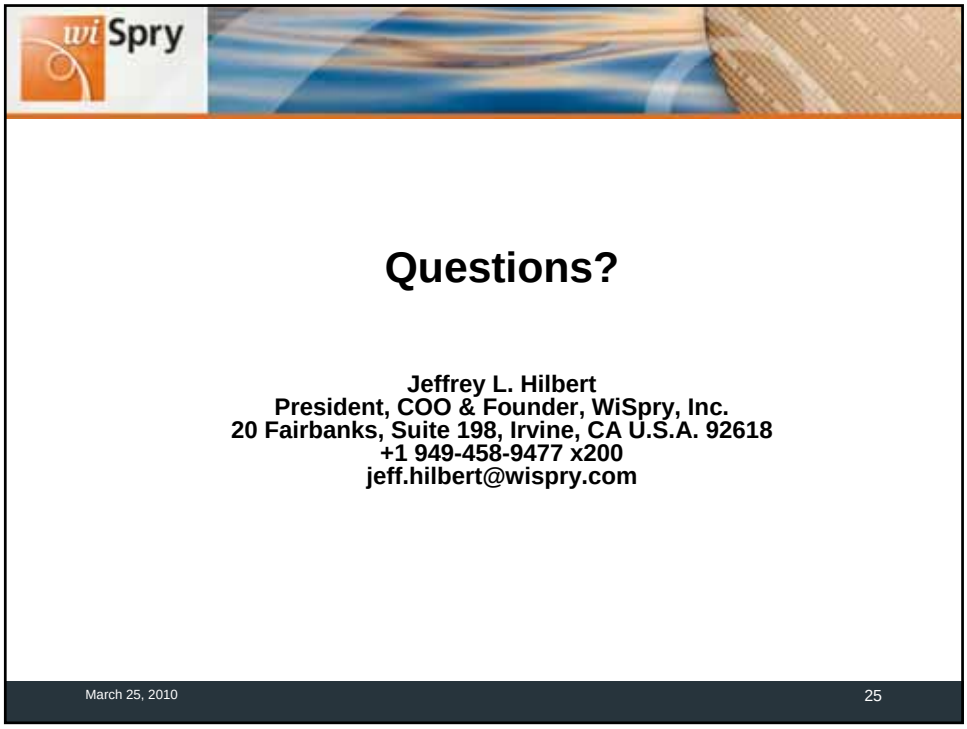
Tunable RF Technology: Competitive Landscape

Technology	CMOS MEMS	Fixed Passive	Silicon (SOI/SOS)	GaAs	MEMS	Ferro-Electric
Implementation Approach	**Digital Variable Capacitors**	**Static L-C Network**	**Switched Passives**	**Switched Passives**	**Switched Passives**	**Analog Variable Capacitors**
Tuning Range	**Very High**	None	Low	Low	Low	Medium
CMOS Integration Potential	Very High	Low	Very High	Low	Medium	Low
RF Performance	**Very High**	Low	Medium	Medium	Medium / High	High
Control	**Digital / Open Loop**	None	Digital	Digital	Digital	Analog / Closed Loop
Voltage	**2.7 – 5.0**	2.7 – 5.0	2.7 – 5.0	2.7 -5.0	2.7 - 50	1 – 28
Leader	**WiSpry**	Murata	Peregrine	Skyworks	TBD	Paratek
Other Players	NXP / EPCOS	EPCOS Handset OEMs	Infineon NXP EPCOS	RFMD Triquint MA-COM	RFMD XCOM Radant	AgileRF

Summary

- 3G / 4G Mobile Terminals Require New Approaches to Integration of RF Front-End Functionality
- Market Characteristics Make Adoption of New Technologies a Risky Proposition
- Tunable RF Components Based on Integrated RF-CMOS MEMS Balance Risk with Benefits
- Tunable Matching Networks, Antennas, and Filters Have Been Demonstrated Using a Digital Capacitor Array Architecture Implemented in 0.18um CMOS
- Research and Development of a First Generation Multiband Tunable Radio Front-End is in Progress


wiSpry
Questions?
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