DUPLEXERS
Abstract: Phone performance using CDMA protocols (CDMA-2000 and WCDMA) is strongly dominated by the choice of those components closest to the antenna. The first component after the antenna (on the phone side) is the duplexer. The duplexer separates the transmit frequencies of the phone (output power up to about 1 Watt) from the incoming receive frequencies (as low as -110 dBm or \(10^{-11}\) Watts). As the first component after the antenna, the duplexer has perhaps the biggest influence on the radio performance of the phone. Traditionally, bulky ceramic duplexers (made large to get high Q) were the only technology capable of meeting the phone specs. This has changed with the introduction of FBAR technology -- FBAR technology with the revolutionary microcap wafer-to-wafer bond package technology. Besides having the best specs due to the high Q, tolerance to high input power, the "all-silicon" package filter die are the smallest filters in the world. This talk will cover the FBAR performance and why it is so good, as well as an overview of microcap wafer-to-wafer hermetic "all-silicon" package.
What is a Thin Film Resonator (TFR): FBAR

Physical Representation

Thin Film Bulk-Wave Acoustic Resonator

FBAR

Stacked Thin Film Bulk-Wave Acoustic Resonator

SBAR

Electrical Analog

One Port Resonator

Two Port Resonator
Physics of FBAR Resonators I

Unit Cell:

Wurtzite Structure
a = 3.111Å  
c= 4.98 Å

<002> Orientation

Constitutive Equations (1D)

\[ D = \varepsilon_r E + e S \]
\[ T = c S - eE \]

\( S = \) Strain; \( T = \) Stress; \( E = \) E field
\( e = \) piezoelectric Stress Constant
\( \varepsilon_r = \) relative dielectric constant
Physics of FBAR Resonators II

Poorly formed AlN

Well formed AlN (Highly Textured)

Grain Size: 30 - 50 nm

Aspect Ratio: 40 to 1

%<002>: ~100%

%Flipped Domains: ~5%
Ceramic Duplexer
Approx. 28 X 10 X 5 mm³

HPMD7904
6 X 12 X 1.6 mm³

Agilent’s newest duplexer
5 X 5 X 1 mm³

3.8 x 3.8 X 1 mm³
US PCS 1900 MHz Duplexer

11.5 mm

5.8 mm

1.8 mm height

HPMD-7904

Two LCC packages (Lids removed)
Overall IC’s Photo After Decapsulation
Die Size Measurement
Photo at 50X

775 μm

1485 μm
FBAR Conclusions

- FBAR is a Bulk Device $\Rightarrow$ This leads to
  
  High Q
  “Intrinsic” coupling coefficient
  Excellent Power handling abilities

In contrast,

- SAW devices are surface devices $\Rightarrow$ This leads to
  
  Issues of Q
  Issues of ESD
  Issues of power handling
Microcap Packaging

- Cap wafer
- Bonded wafers
- FBAR wafer
- Grind both wafers & singulate individually sealed filters
- Next Generation packaging for further miniaturization and integration
- Overmold

- Wire bonded microcapped die
- MCOB packaged parts

- Wafer-wafer bond
- Batch process
- Assembly can be wire bond or flip-chip
Four Microcap’d FBAR Filters on a Grain of Rice
Microcap’d FBAR Conclusions

• FBAR lends itself to an “all-silicon” package

  Brings packaging into fab → helps spread costs
  Encourages die “shrink” → wafer + package cost the same, regardless of
  10,000 die or 20,000 die on a wafer
  Ultra Small Size
  Compatible with silicon IC chips

In contrast,

• SAW devices are built on LiTiO3

  Issues of TCE
  Issues of size and shrinkage
  Issues of package cost
  Issues of future integration
Narrow band performance from 2 MPV wafers (400 units)

Incredible Performance – not so “incredible” prices
CDMA Block Diagram  -- “Point” Filters

Duplexers

Rx and Tx “Point” Filters in CDMA Architecture
The “bar” keeps getting raised!

1900 MHz CDMA Handset Duplexer

1850-1915 MHz

1850-1910 MHz

1930-1995 MHz

1930-1990 MHz

Insertion Loss: -3.8 dB

Insertion Loss: -4.5 dB

50 dB Isolation

54 dB

-108 -> -110 dB

103 dB

Power Amplifier

Receive Channel

Transmit Channel

Low Noise Amplifier

Talk Time: 3 – 4 hr

Stand By: 7 – 10 days

3 – 4 hr

Note: “Intennas”, GPS, PTT, Camera/flash, PDA have since been added at the same time, phones have gotten smaller!
Duplexer Comments

- The most “dramatic” impact to CDMA wireless radio will be made by the duplexer!

- Duplexer performance will drive handset performance and allow for future features such as
  1. Concurrent GPS
  2. Intennas (internal Antennas)
  3. G-Block & H-Block Bands (1910 to 1915 and 1915 to 1920 MHz)

- Duplexer more directly influences “Talk Time” and therefore battery life of handset

  Compare “talk time” for a phone (given in hours) vs. “standby time” (given in days or weeks)

- A “superb” duplexer may remove the need for “point” filters, but, “superb” point filters will never remove the need for a good duplexer!
Why the Duplexer is “key”

- Harmonics, spurs, thermal noise, etc generated by PA
- Harmonics, spurs, thermal noise, etc generated by RFIC

Low Noise Amp

Noise in LNA referred to input

“Improvement” (dB) = Rejection – Gain

Signal from Tx
Noise from Tx
Noise from Environ.

\[ \sigma_a, \epsilon_n, \epsilon_n, \epsilon_n/G \]
160 3.8X3.8mm PCS Duplexers

For this build, Tx and Rx dice was randomly selected.
160 3.8X3.8mm PCS Duplexers – Isolation

Note: All unit fall between 
(-54.9 dB to -57 dB) for TX 
ISO. Our spec is -54 dB.
Where will the CDMA “point” filter ultimately end up?

Three Possibilities: Front End Module (FEM), RFIC, Nowhere

• Starting to see papers on integration of BAW with CMOS (Infineon, IMS 2004, ST @ the GSM Congress 2004, LETI presentation at ISSCC feb. ’05)

• Could put microcap’d FBAR filters directly on CMOS die

VS.

• One customer has FEM requirement that “point”’ filter be in FEM

• But, majority of customers say,

  “Fine, if point filter is in FEM, but, don’t expect us to pay more”

• “By-Band” Power module with FBAR duplexer (in production by Agilent)
In this scenario, the RFIC absorbs everything. However – unlikely. Service Providers & Handset Manufacturers reluctant to give up raw performance.
In this scenario, the RFIC absorbs the point filters. The FEM absorbs duplexer, power module, LNA and power couplers.
In this scenario, The FEM absorbs duplexers, power module, LNA and power couplers. Point Filters “go away”
In this scenario, the Front End Module (or FEM) absorbs the point filters along with the duplexer, power module, LNA and power couplers.
Agilent CDMA Front-End Module

- Combines Best-In-Class CDMA PA and Duplexer with optimized interface
- Smaller Size (up to 50% board space savings)
- Reduced Part Count (up to 65% parts count reduction, including passives)
- Enhanced Radio Performance with guaranteed system level specs
  - High Effective PAE, which includes duplexer and matching loss
  - Low “Full-Duplex NF” for high sensitivity
  - Low “Tx Power at Rx” for STD test
- Excellent Low Voltage Performance for DC-DC Converter operation
- Less susceptible to Interference because the signal trace and reference ground plan are contained in the module.
- Bulky and costly isolator is eliminated
To Date: 39 Phone Design Wins
Conclusions

• Commercially, there are two major markets for SAW/BAW/FBAR;

  Duplexer and “Other”

• PCS, WCDMA duplexers dominated (or soon will be) by FBAR
  Cell Band Duplexer & GSM “point” filters dominated by SAW

• The most “dramatic” impact to CDMA wireless radio will be made by the duplexer!

• Duplexer performance will drive handset performance and allow for future features such as
  1. Concurrent GPS
  2. Intennas (internal Antennas)
  3. G-Block & H-Block Bands (1910 to 1915 and 1915 to 1920 MHz)

• Duplexer influences “Talk Time” and therefore battery life of handset via Tx insertion loss

• Duplexer influences the effective range of base stations via the Rx insertion loss