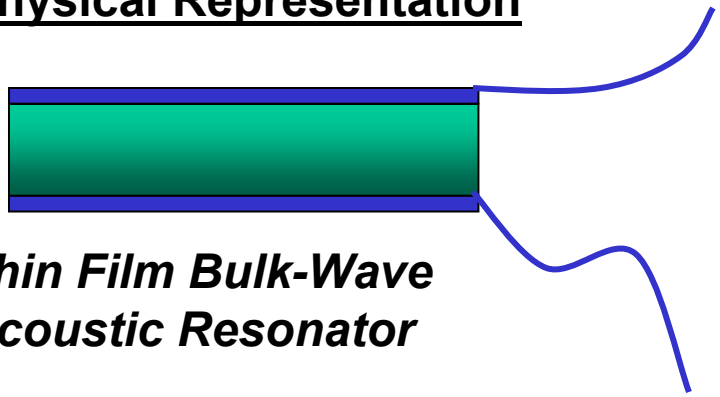
DUPLEXERS

Abstract: Phone performance using CDMA protocals (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, tolerence 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

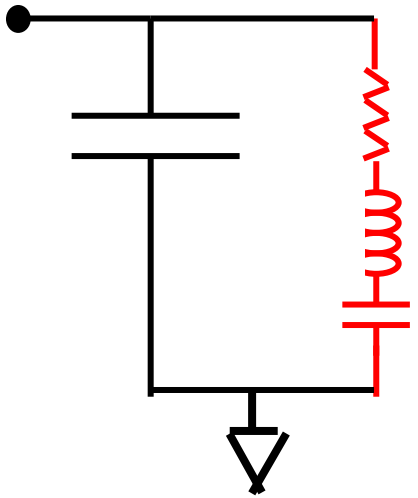
Physical Representation



Thin Film Bulk-Wave Acoustic Resonator

FBAR

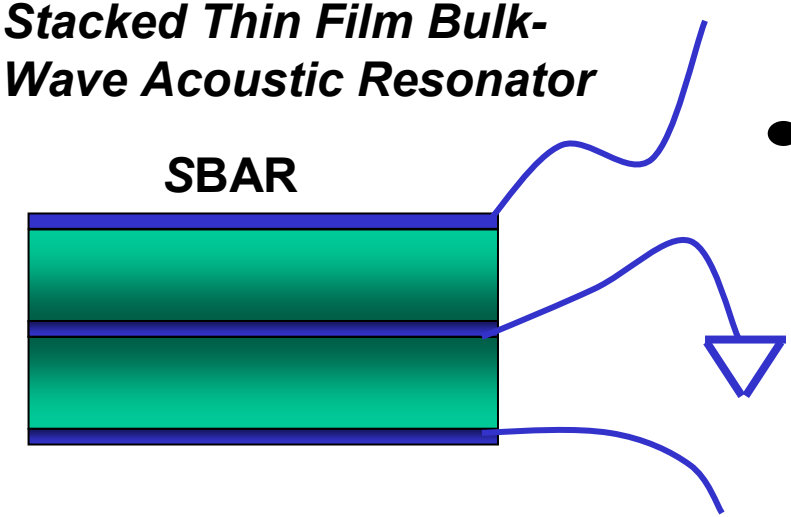
Electrical Analog

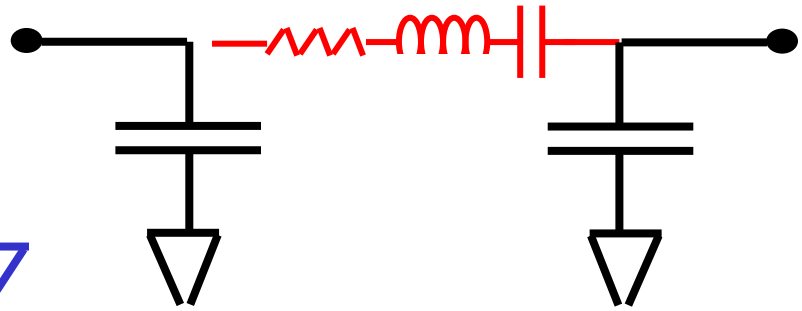


One Port Resonator

Stacked Thin Film Bulk-Wave Acoustic Resonator

SBAR





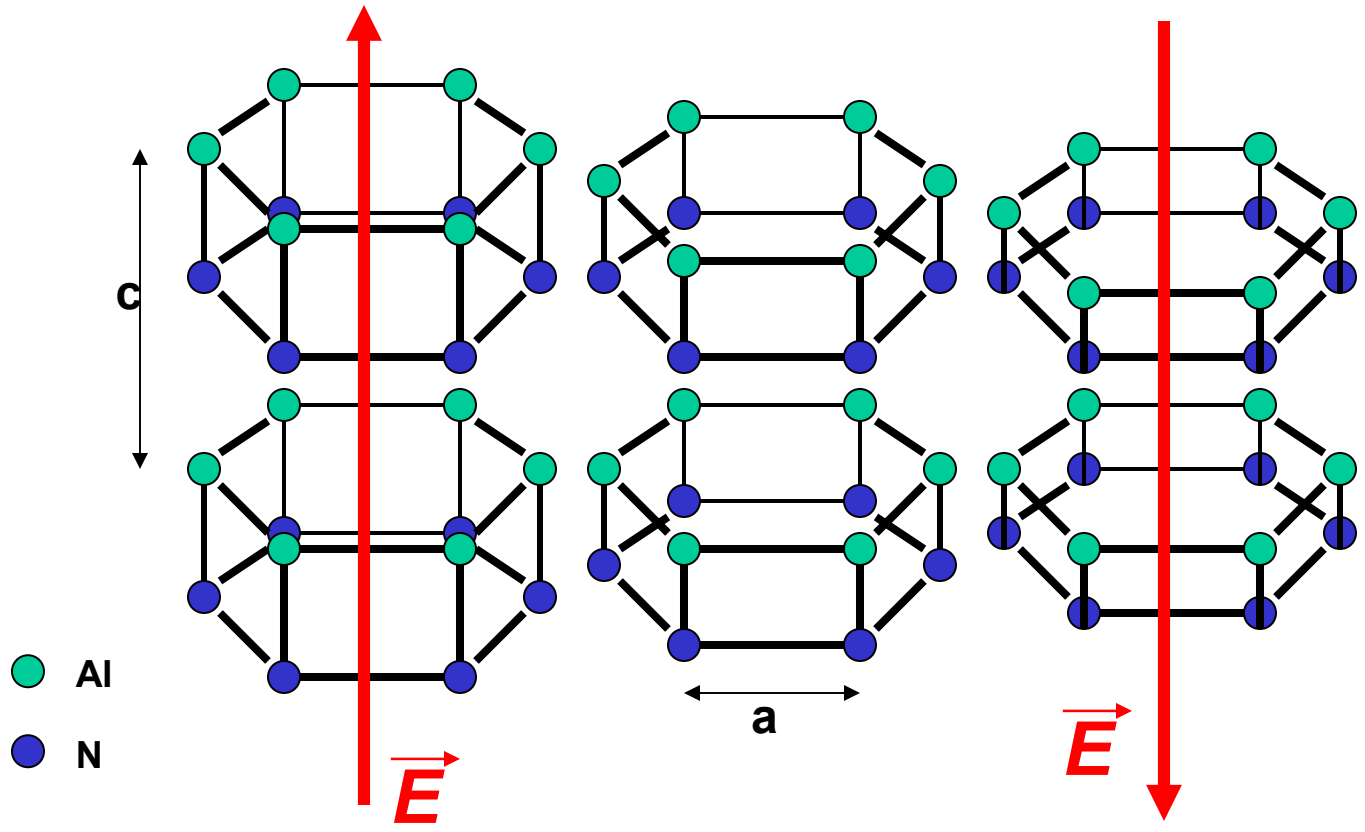
Two Port Resonator

Physics of FBAR Resonators I

Unit Cell:

Wurtzite Structure
a = 3.111A
c= 4.98 A

<002> Orientation



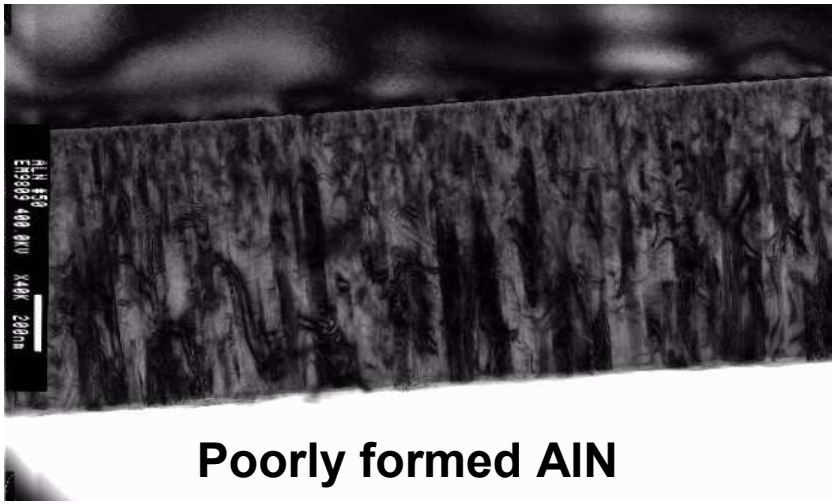
Constitutive Equations (1D)

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

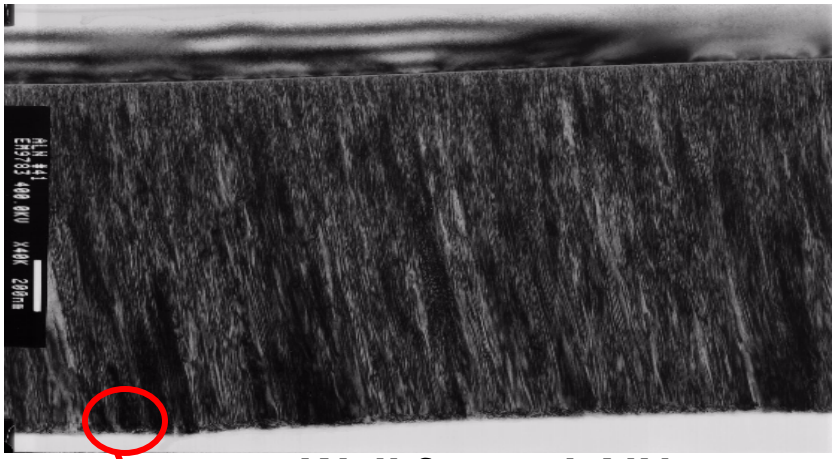
S = Strain; T = Stress; E = E field
e = piezoelectric Stress Constant

ε_r = relative dielectric constant

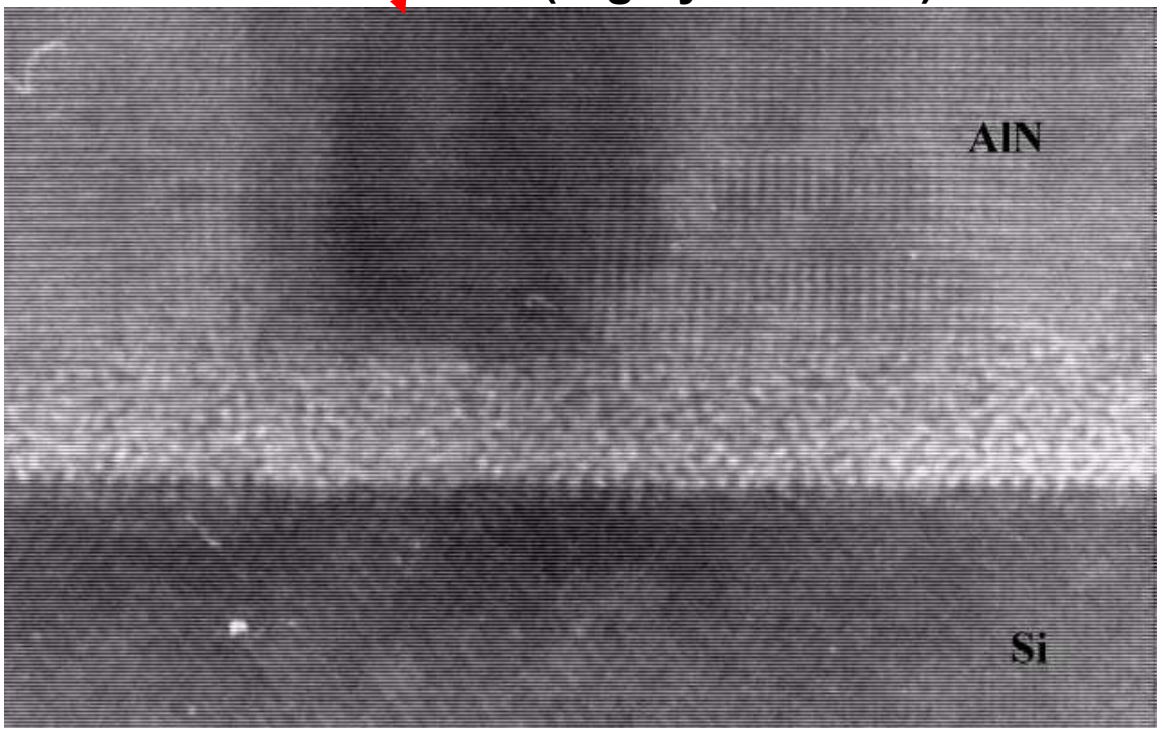
Physics of FBAR Resonators II



Poorly formed AlN



Well formed AlN
(Highly Textured)

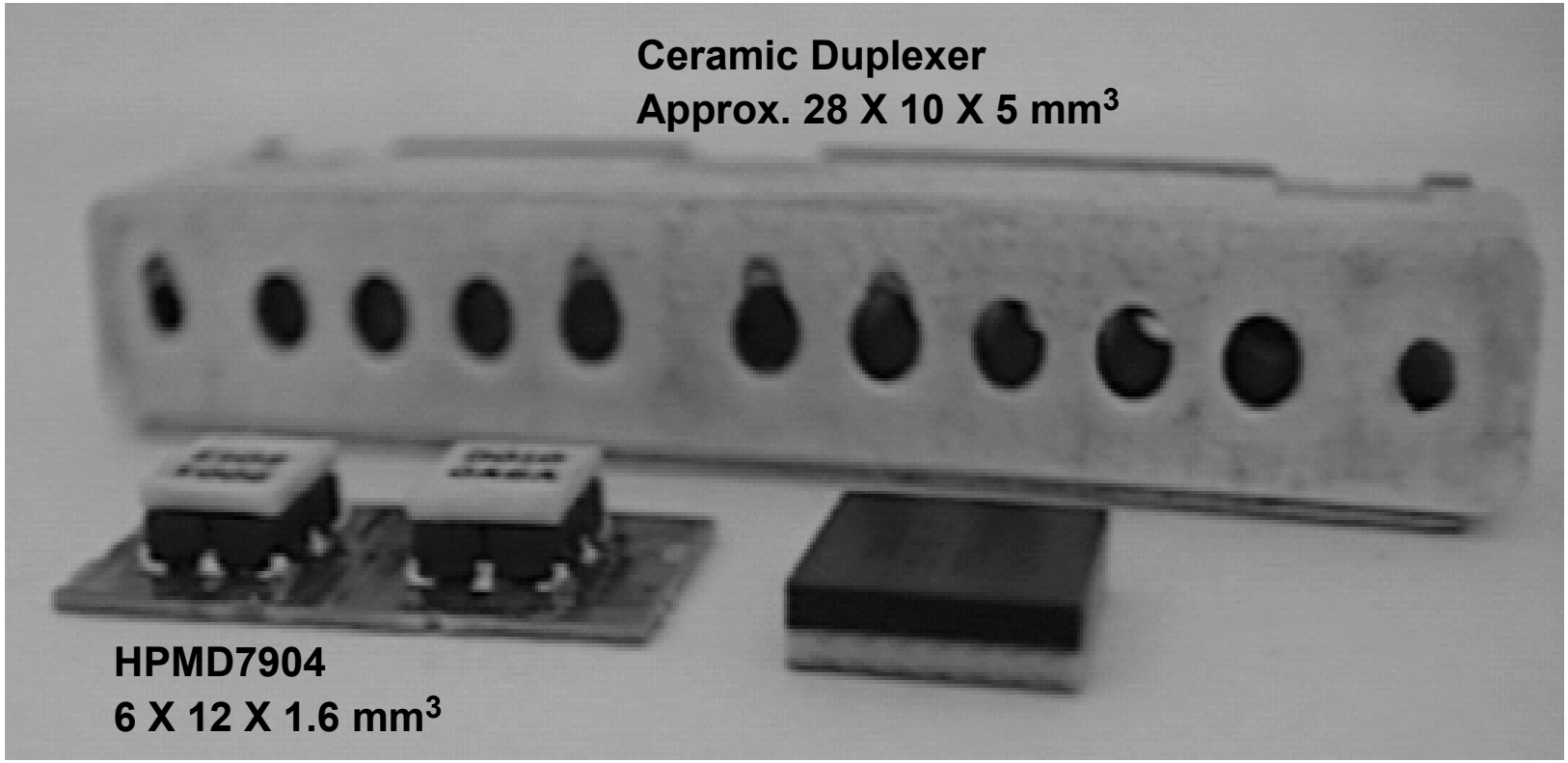


GrainSize: 30 - 50 nm

Aspect Ratio: 40 to 1

%<002>: ~100%

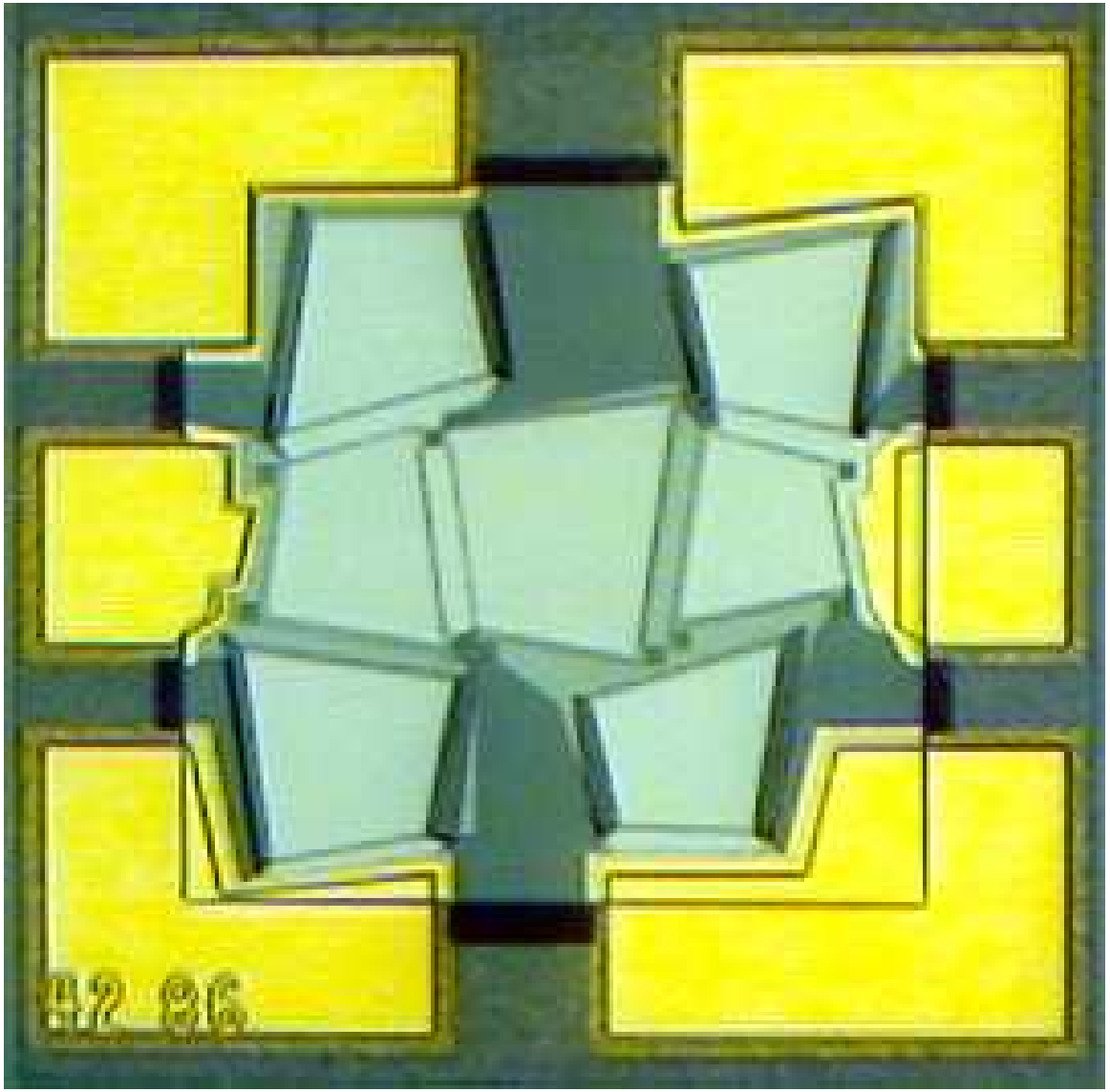
%Flipped Domains: ~5%



Agilent's newest duplexer

~~5 X 5 X 1 mm^3~~

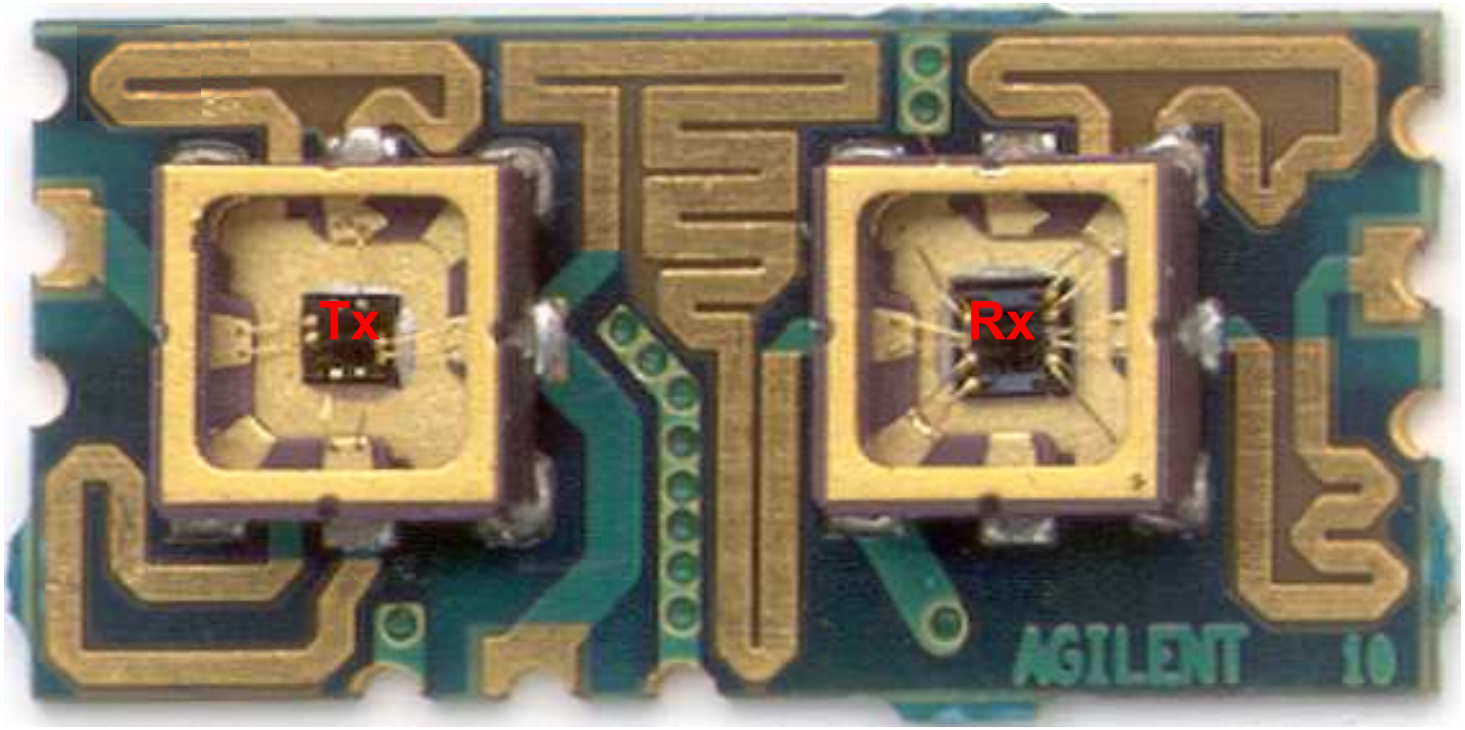
3.8 x 3.8 X 1 mm^3



US PCS 1900 MHz Duplexer

11.5 mm

5.8 mm

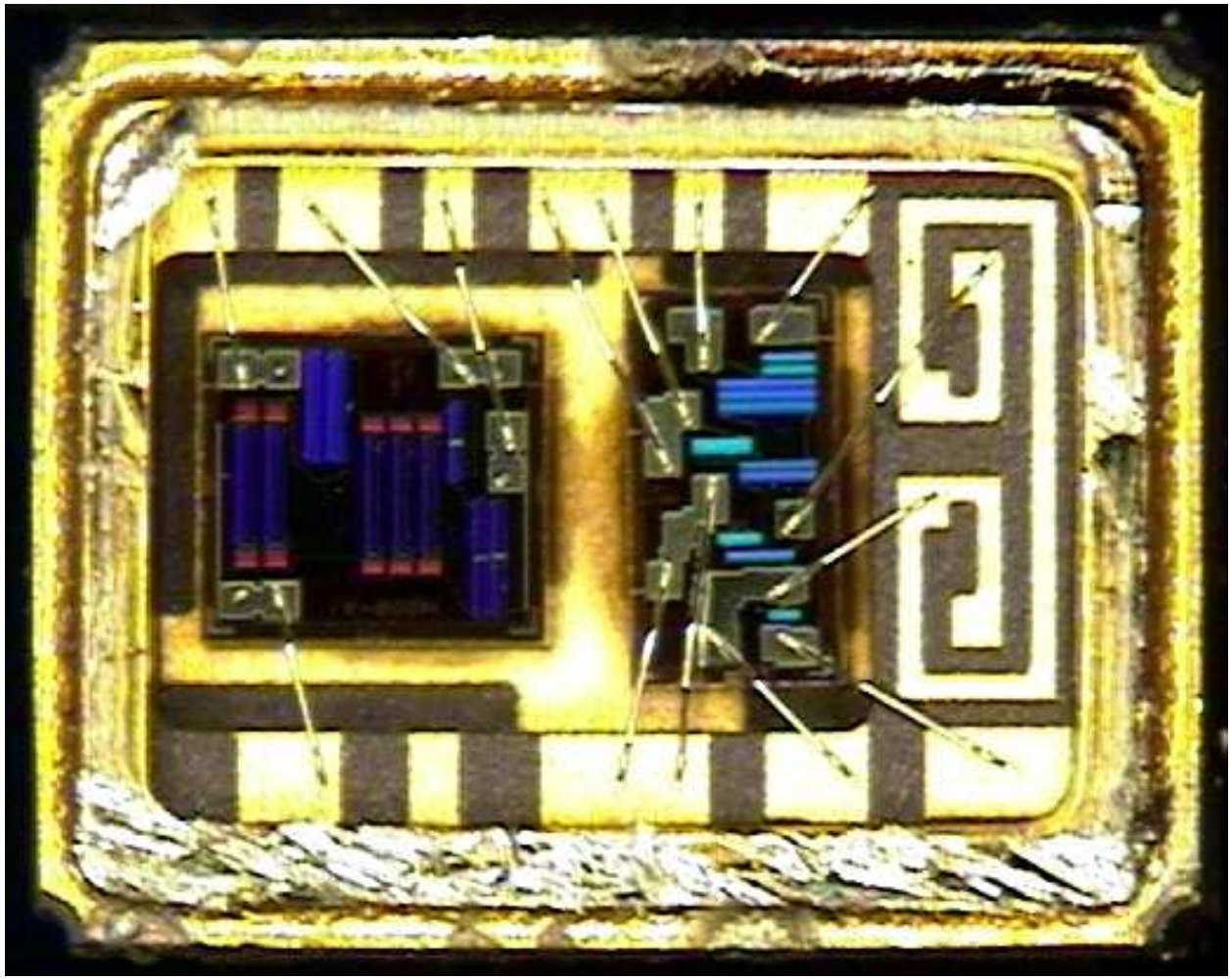


1.8 mm height

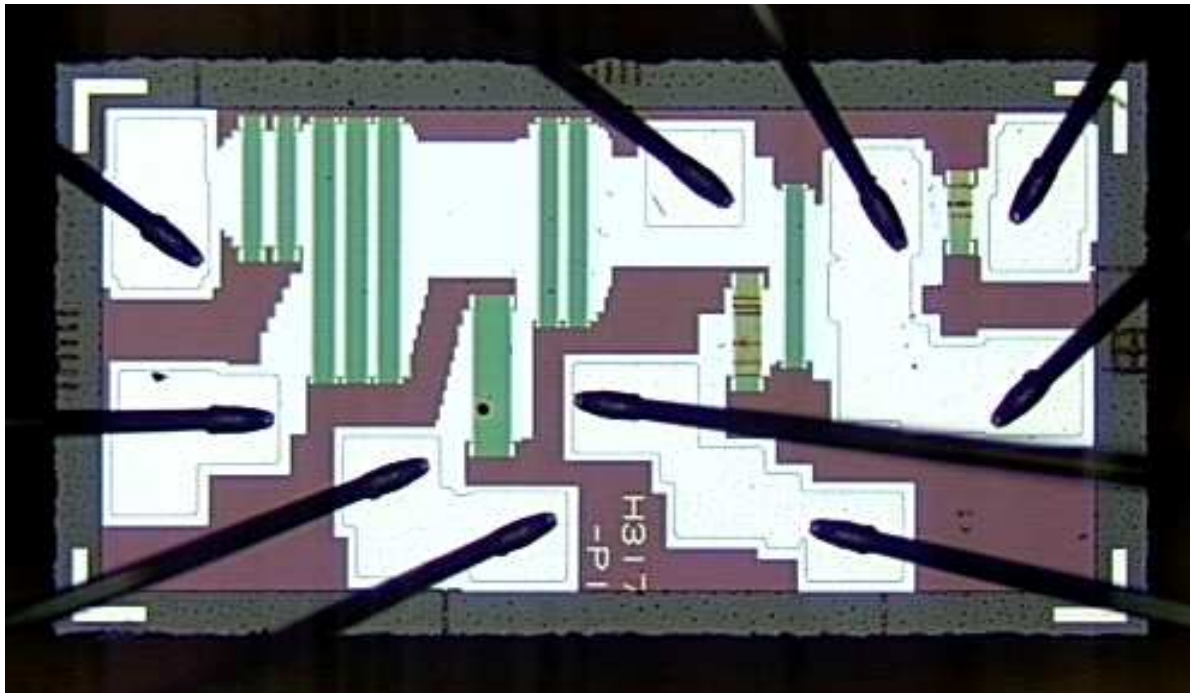
HPMD-7904

Two LCC packages (Lids removed)

Overall IC’s Photo After Decapsulation



Die Size Measurement
Photo at 50X



775 um

1485 um

FBAR Conclusions

- **FBAR is a Bulk Device → This leads to**

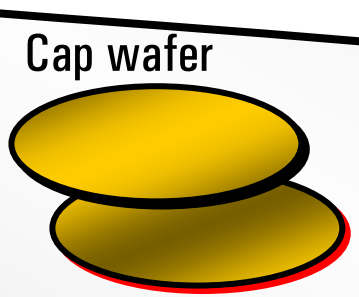
  High Q
  "Intrinsic" coupling coefficient
  Excellent Power handling abilities

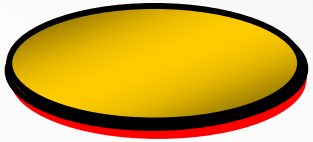
In contrast,

- **SAW devices are surface devices → This leads to**

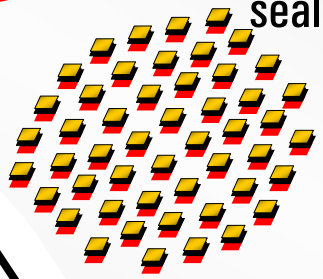
  Issues of Q
  Issues of ESD
  Issues of power handling

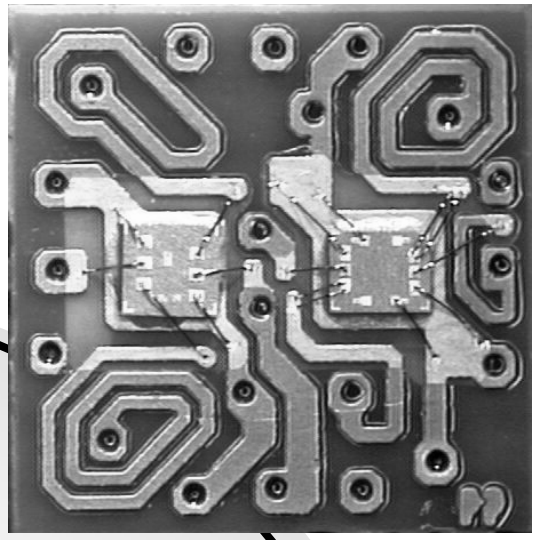
Microcap Packaging





Grind both wafers & singulate individually sealed filters

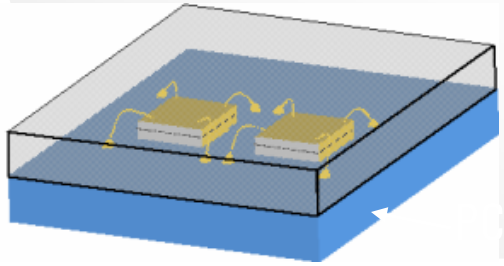


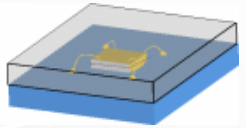


Wire bonded microcapped die

Overmold

MCOB packaged parts

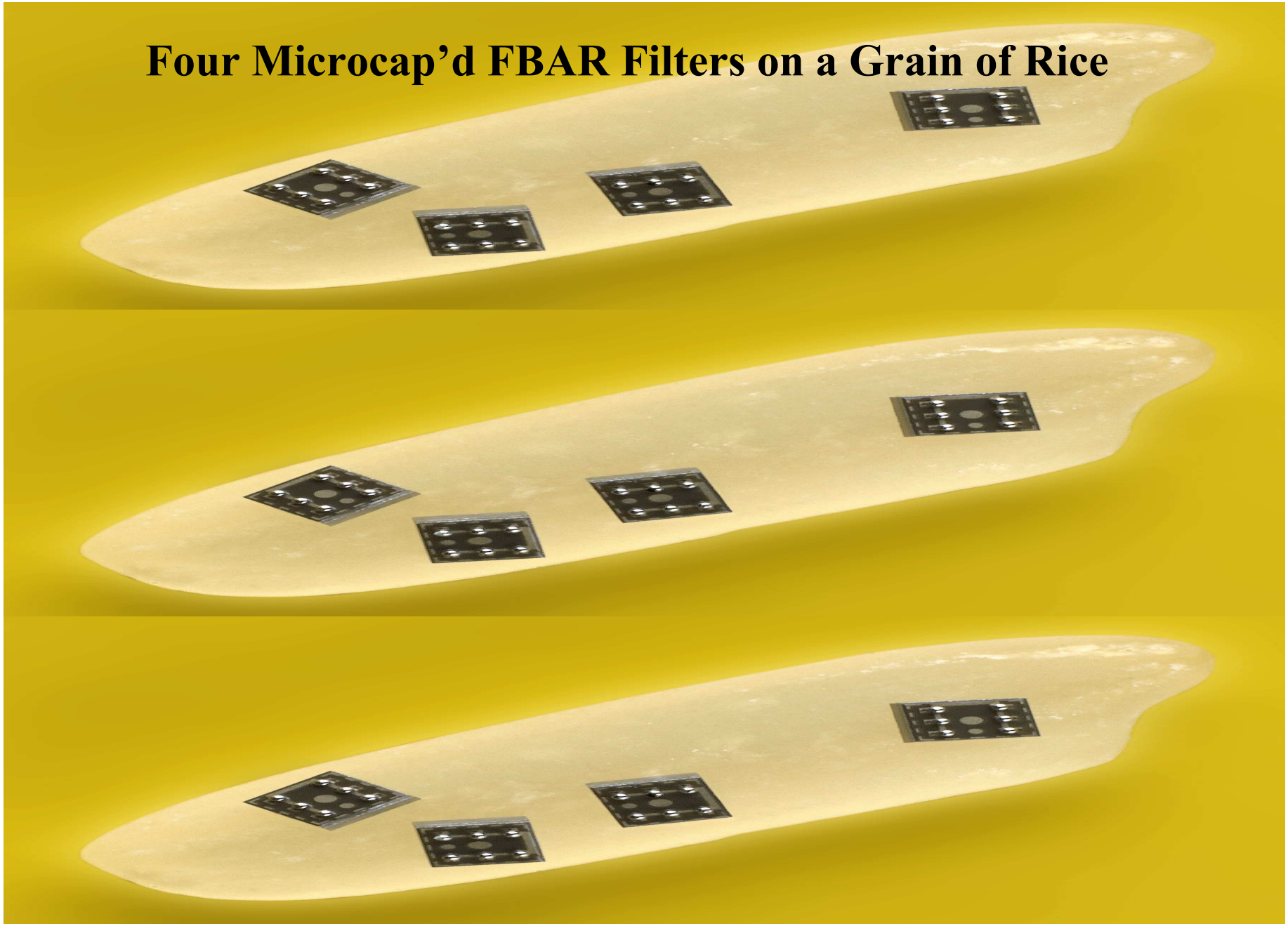




Next Generation packaging for further miniaturization and integration

- ✓ 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

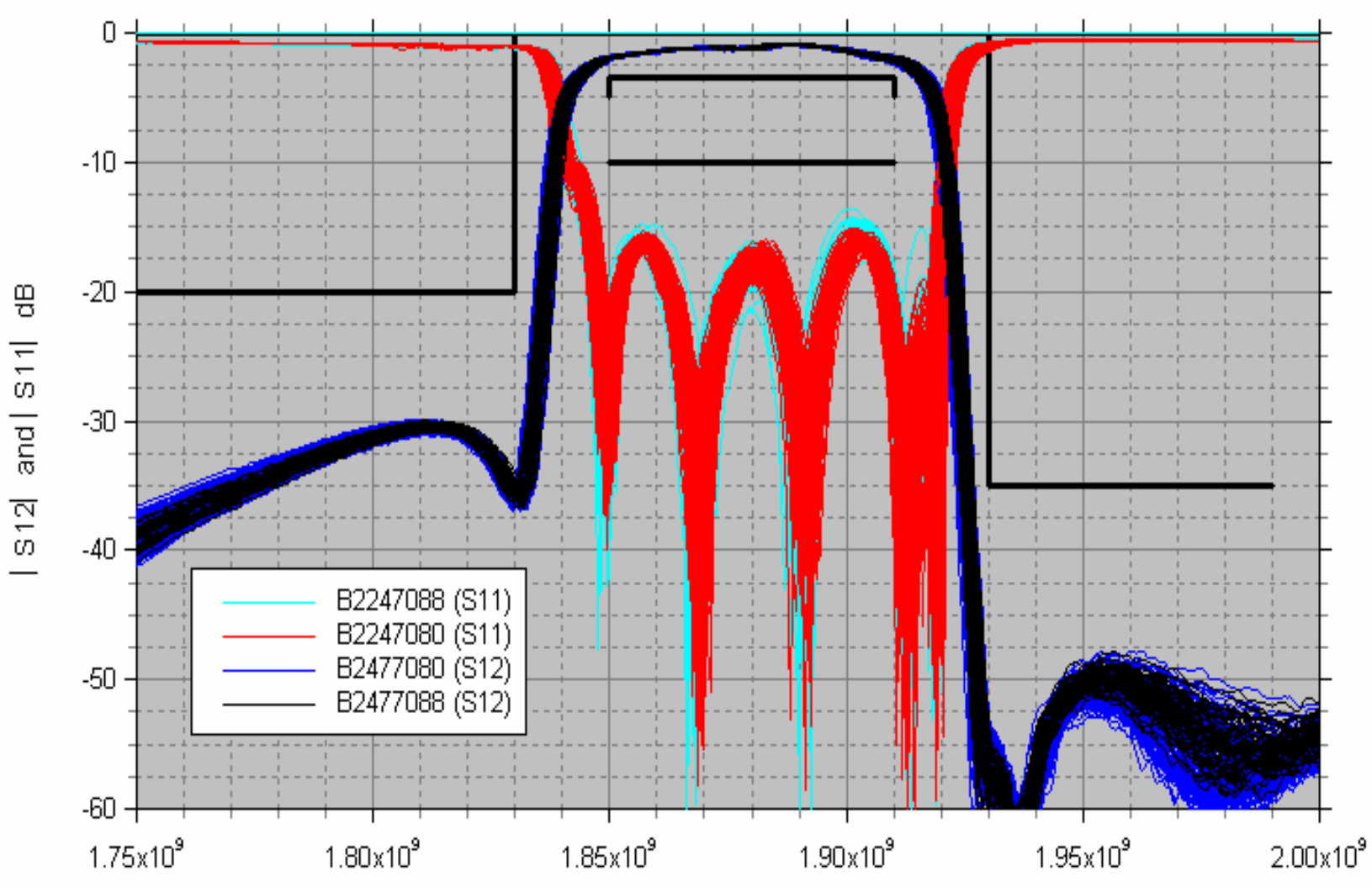
In contrast,

- **SAW devices are built on LiTiO3**

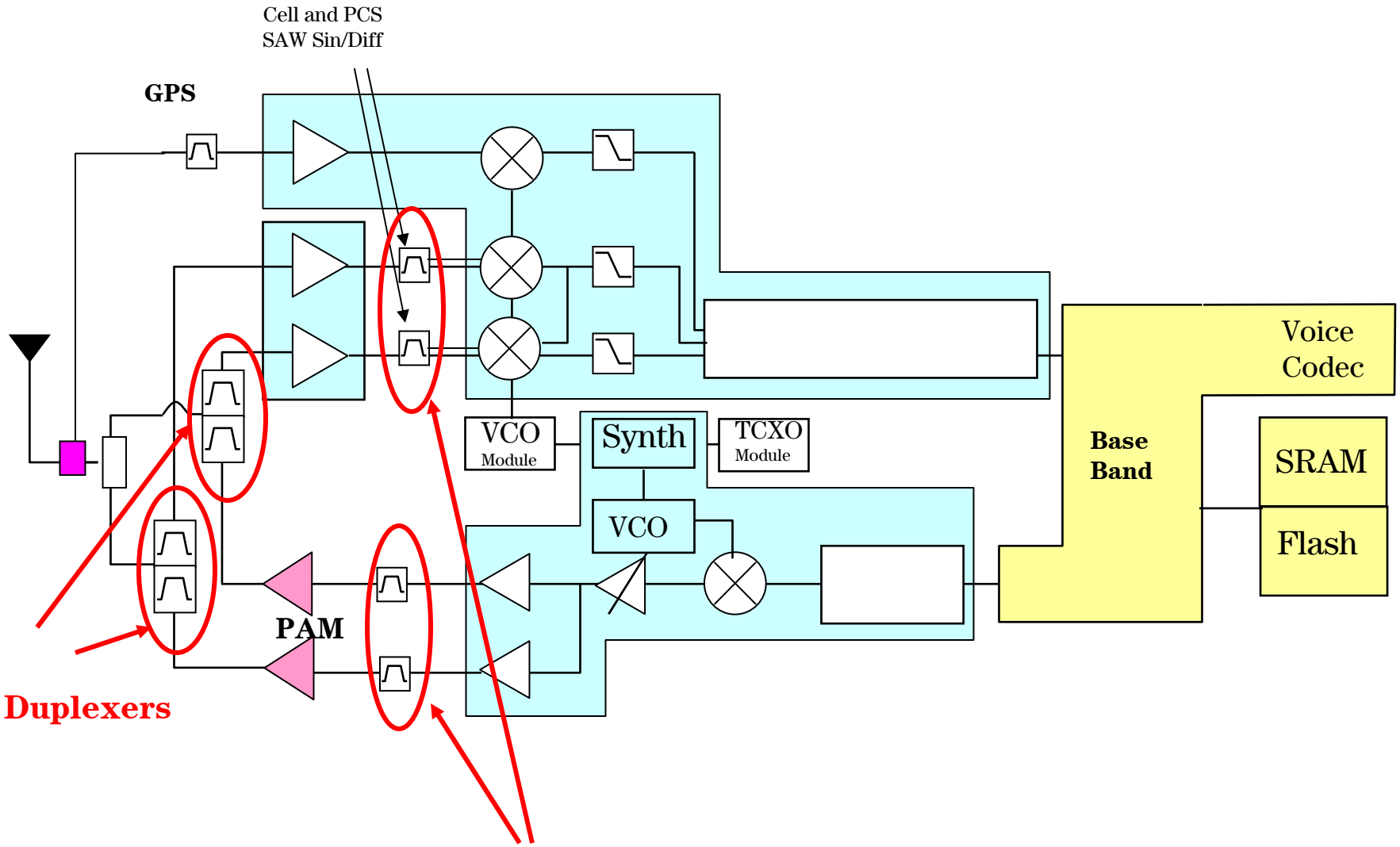
  Issues of TCE
  Issues of size and shrinkage
  Issues of package cost
  Issues of future integration

Narrow band performance from 2 MPV wafers (400 units)

Incredible Performance – not so "incredible" prices



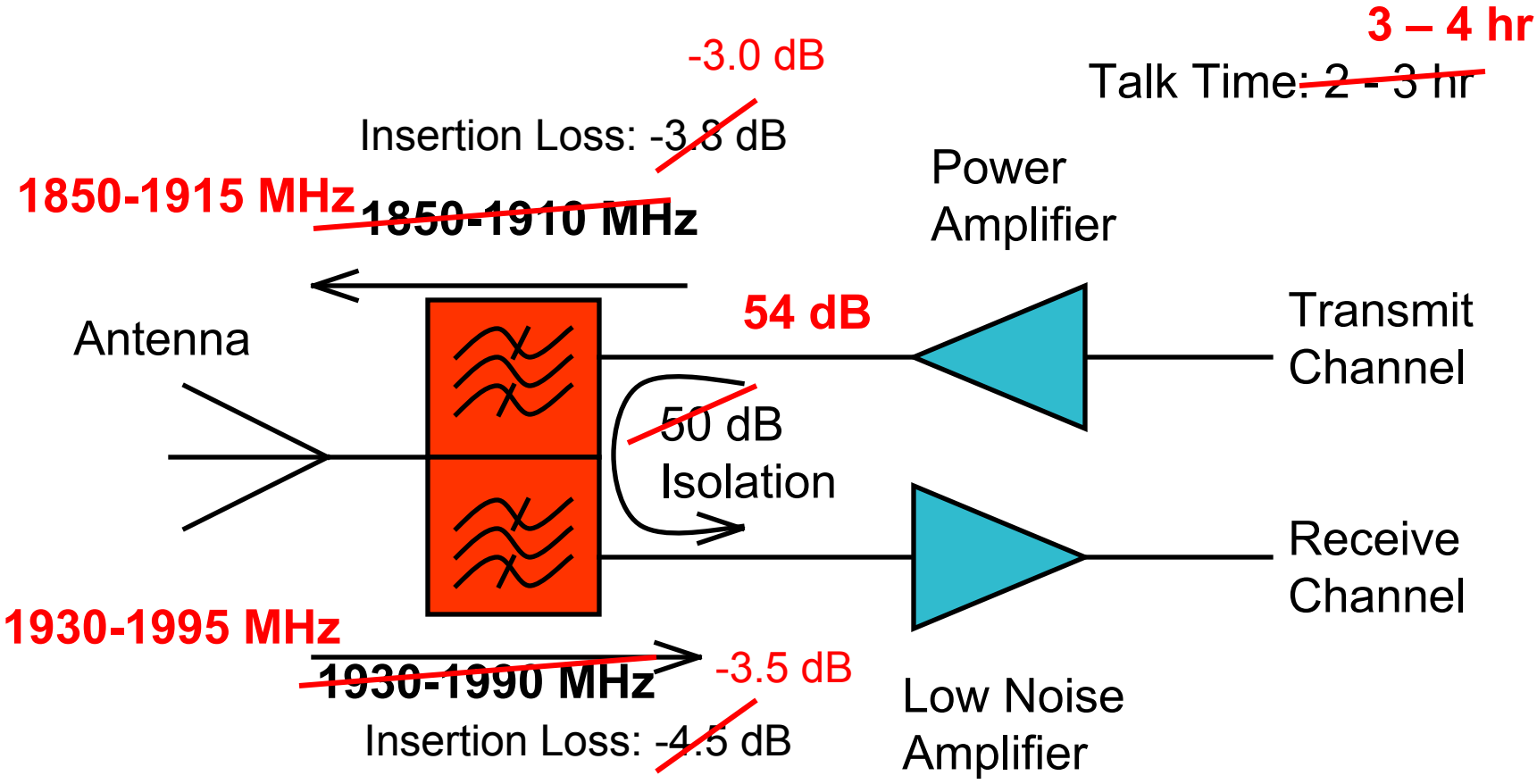
CDMA Block Diagram -- “Point” Filters



Rx and Tx“Point” Filters in CDMA Architecture

1900 MHz CDMA Handset Duplexer

The "bar" keeps getting raised!



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!

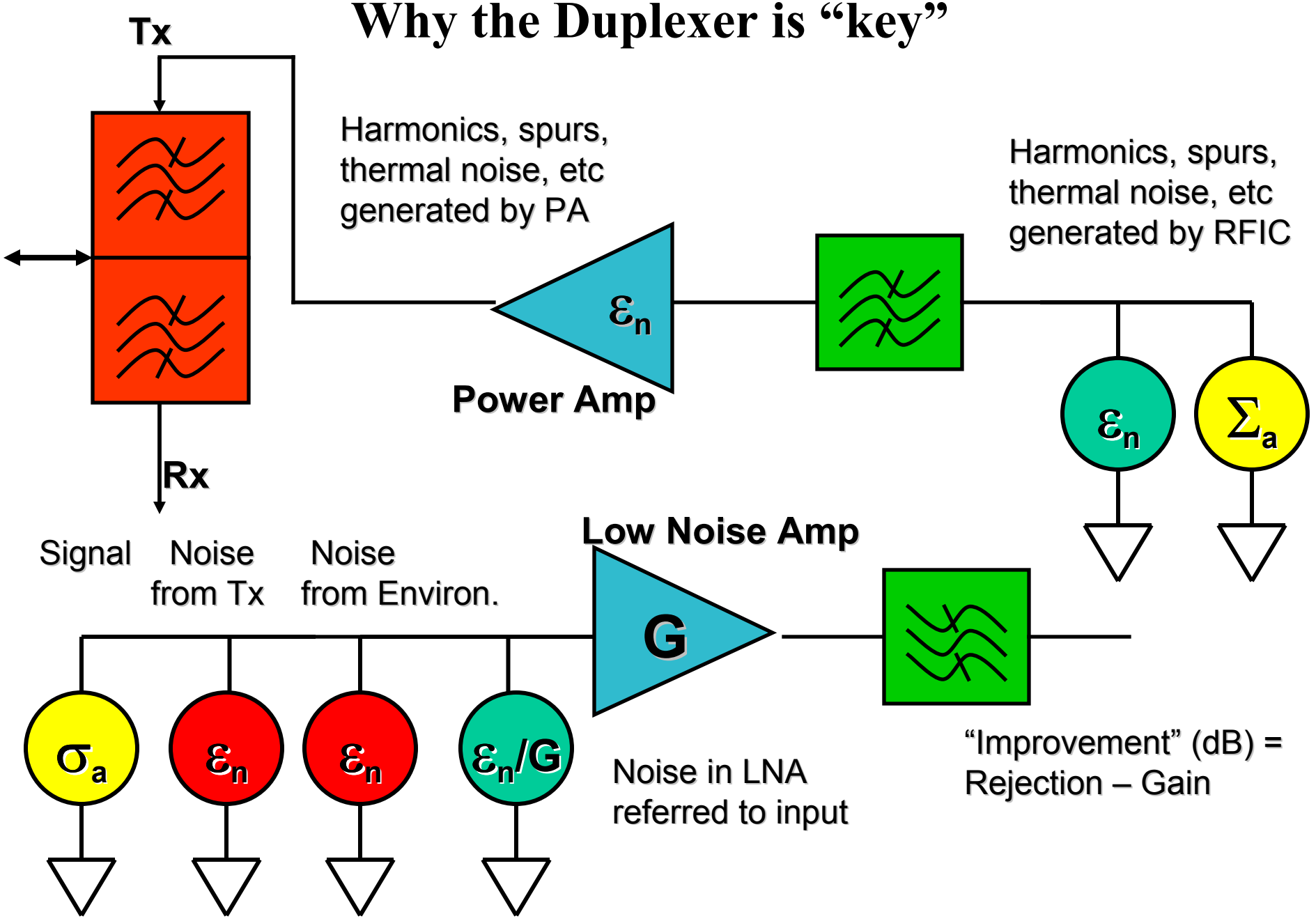
- Duplexer performance will drive handset performance and allow for future features such as
  1. Concurrent GPS
  2. Intennas (internal Antennas)
  3. G-Block & H-Block Bands (1910 to 1915 and 1915 to 1920 MHz)

- 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)

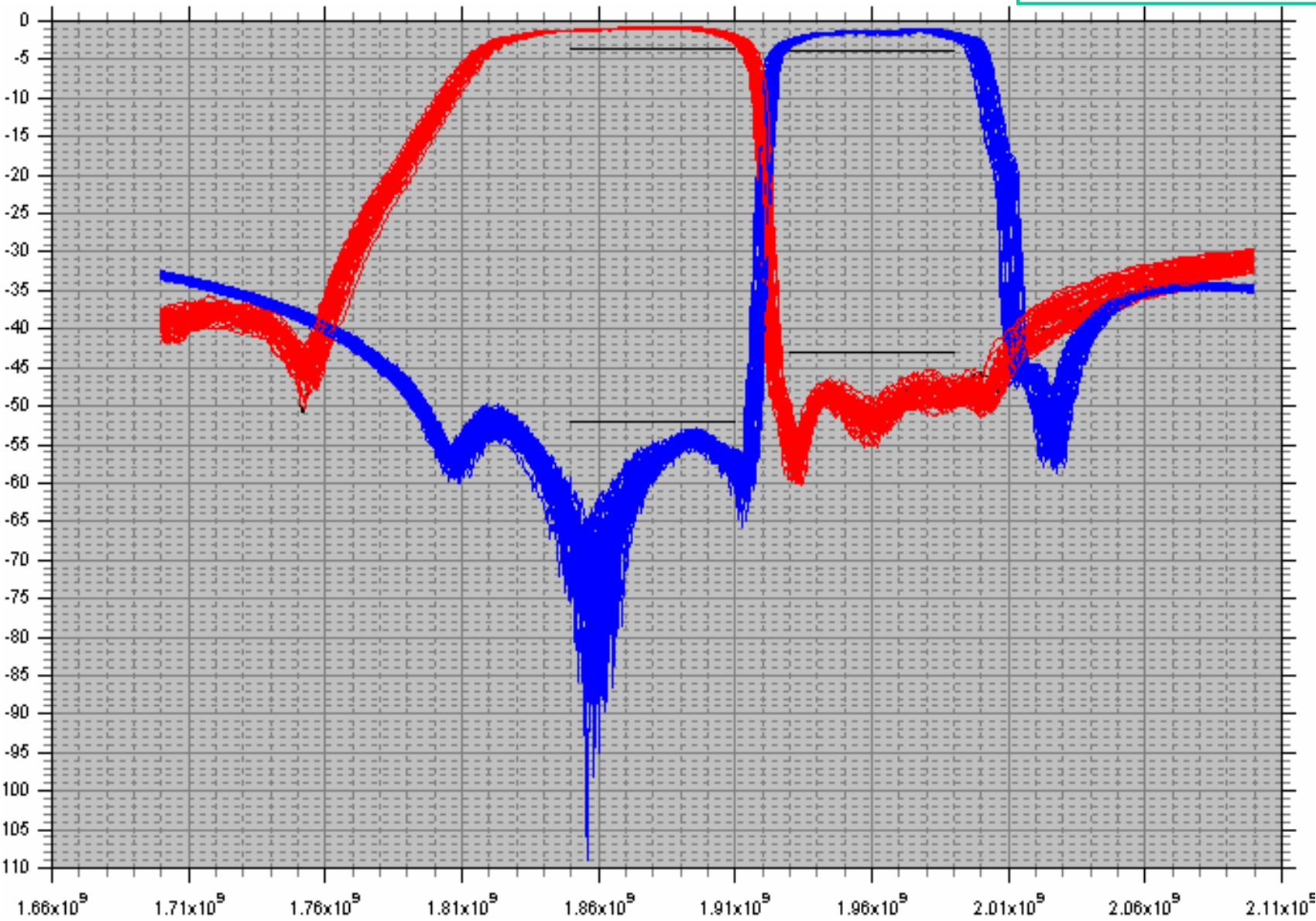
- A “superb” duplexer may remove the need for “point” filters, but, “superb” point filters will never remove the need for a good duplexer!

Why the Duplexer is "key"

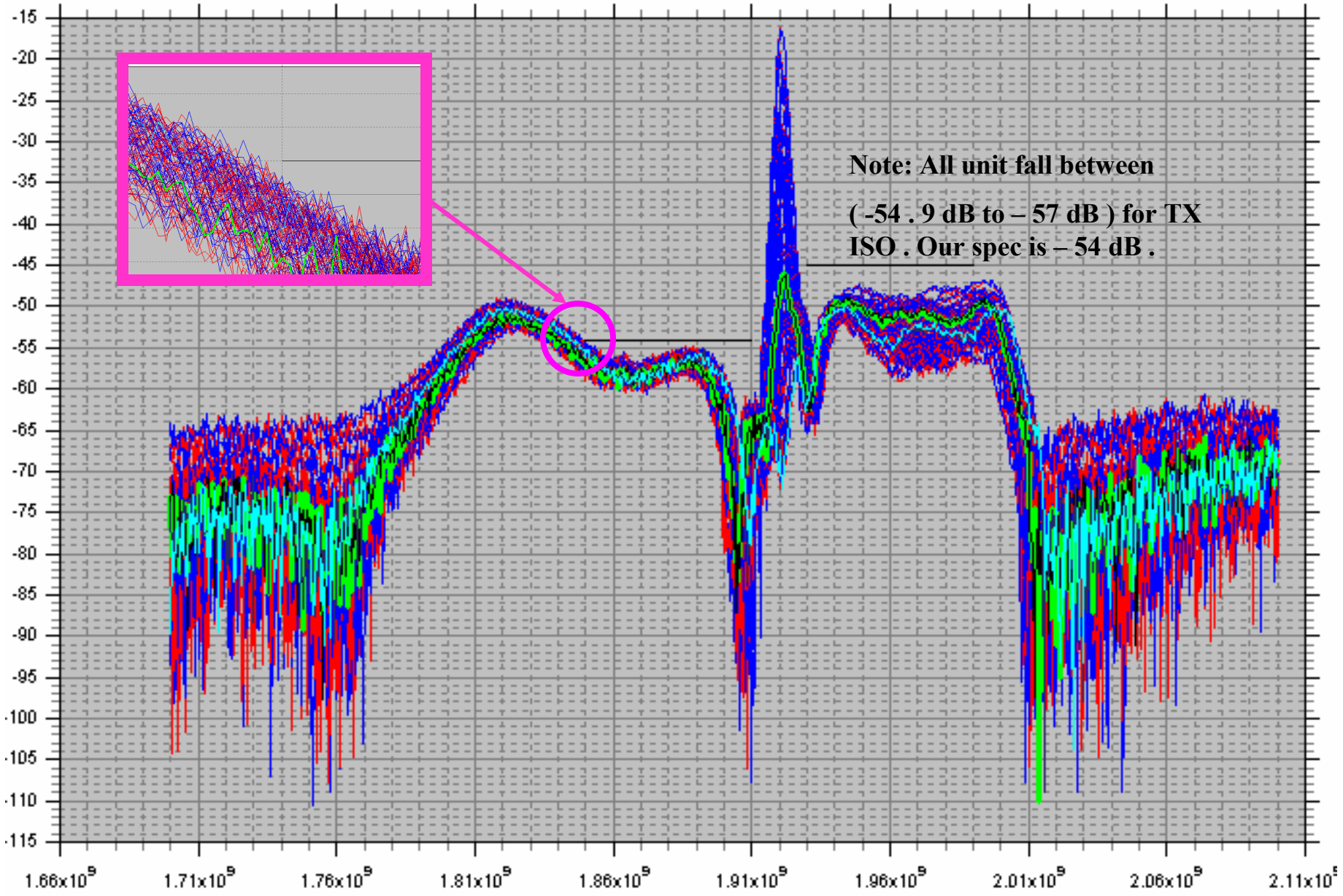


160 3.8X3.8mm PCS Duplexers

For this build, Tx and Rx dice was randomly selected



160 3.8X3.8mm PCS Duplexers – Isolation



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

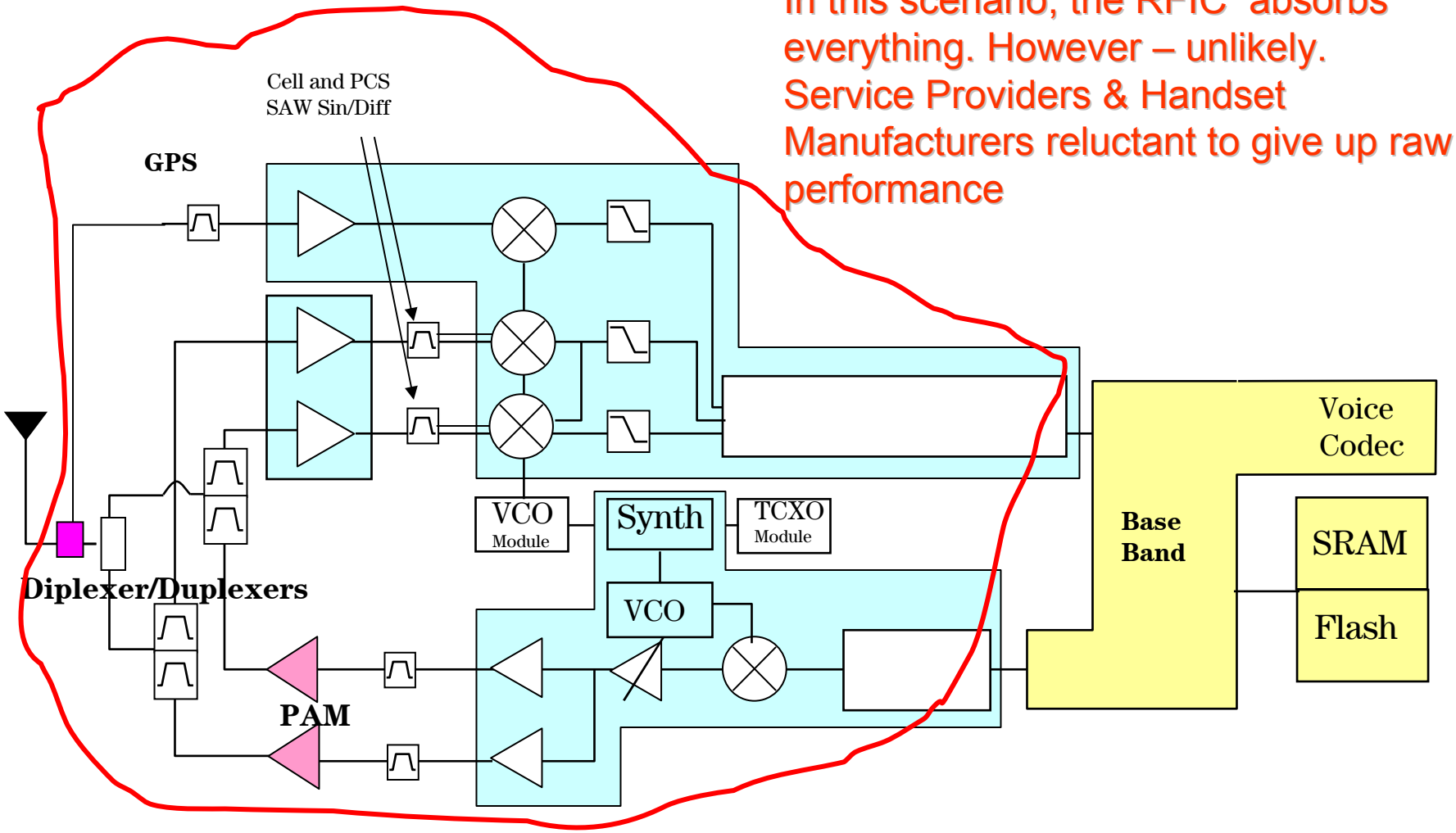
- But, majority of customers say,

"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)

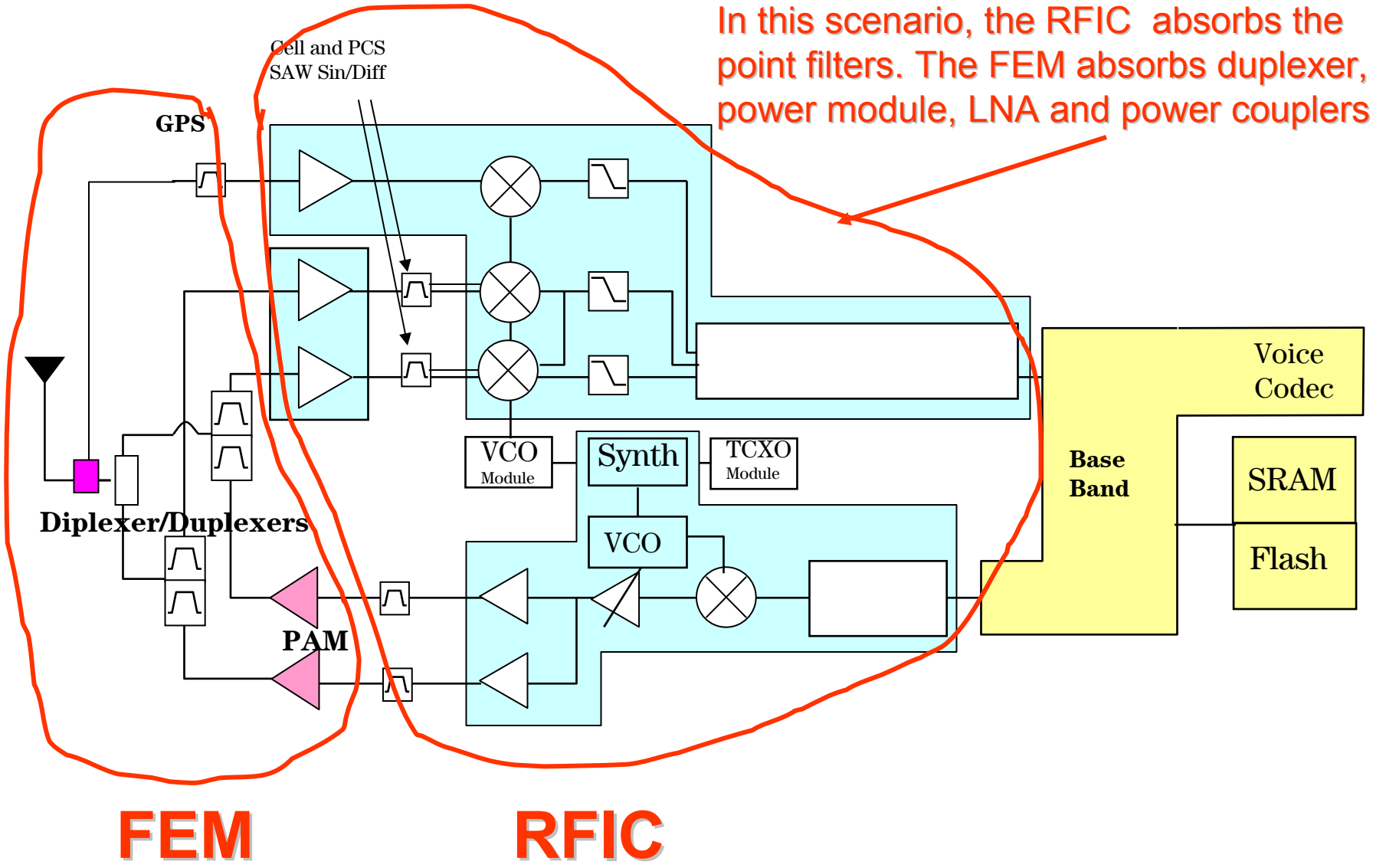
CDMA Block Diagram

In this scenario, the RFIC absorbs everything. However – unlikely. Service Providers & Handset Manufacturers reluctant to give up raw performance

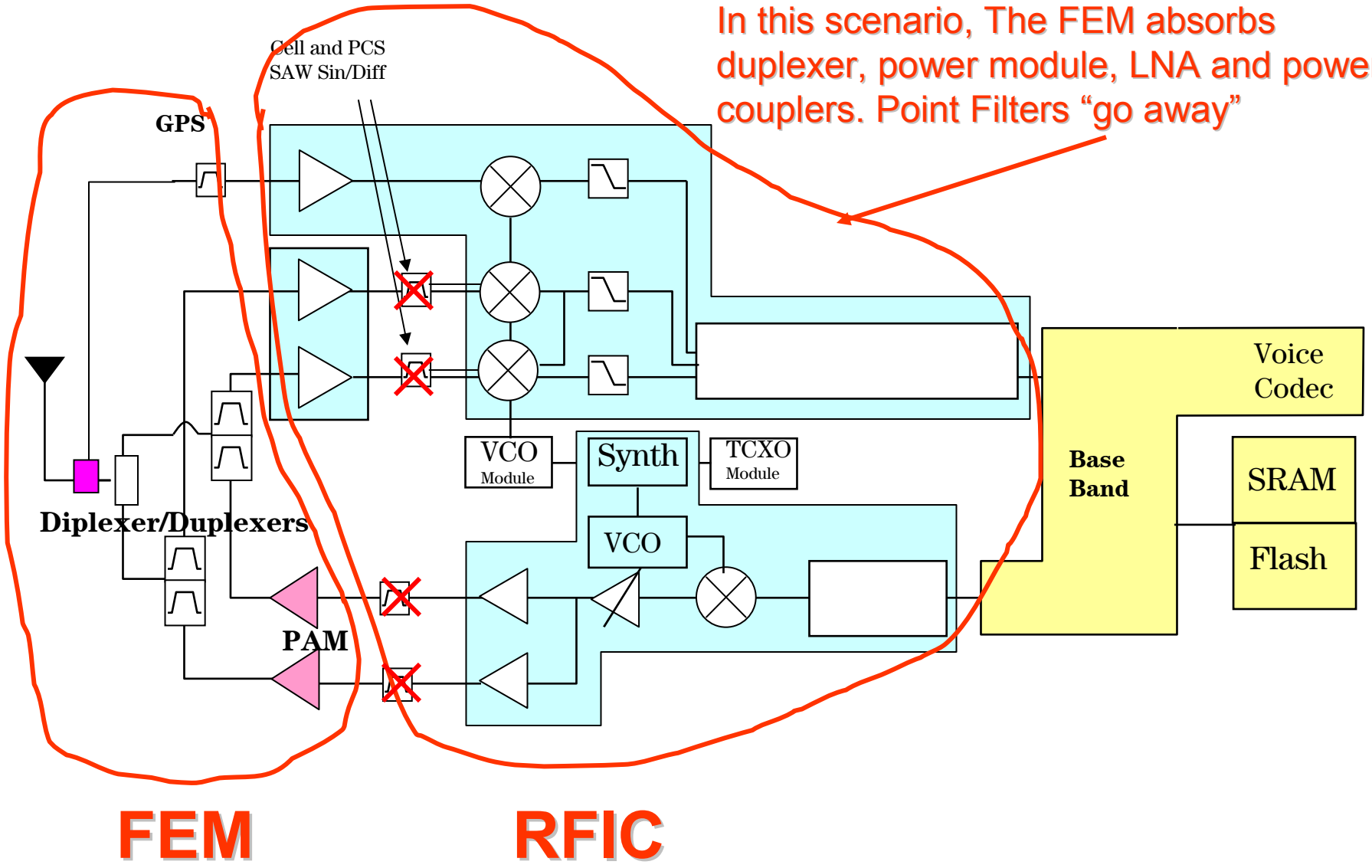


RFIC

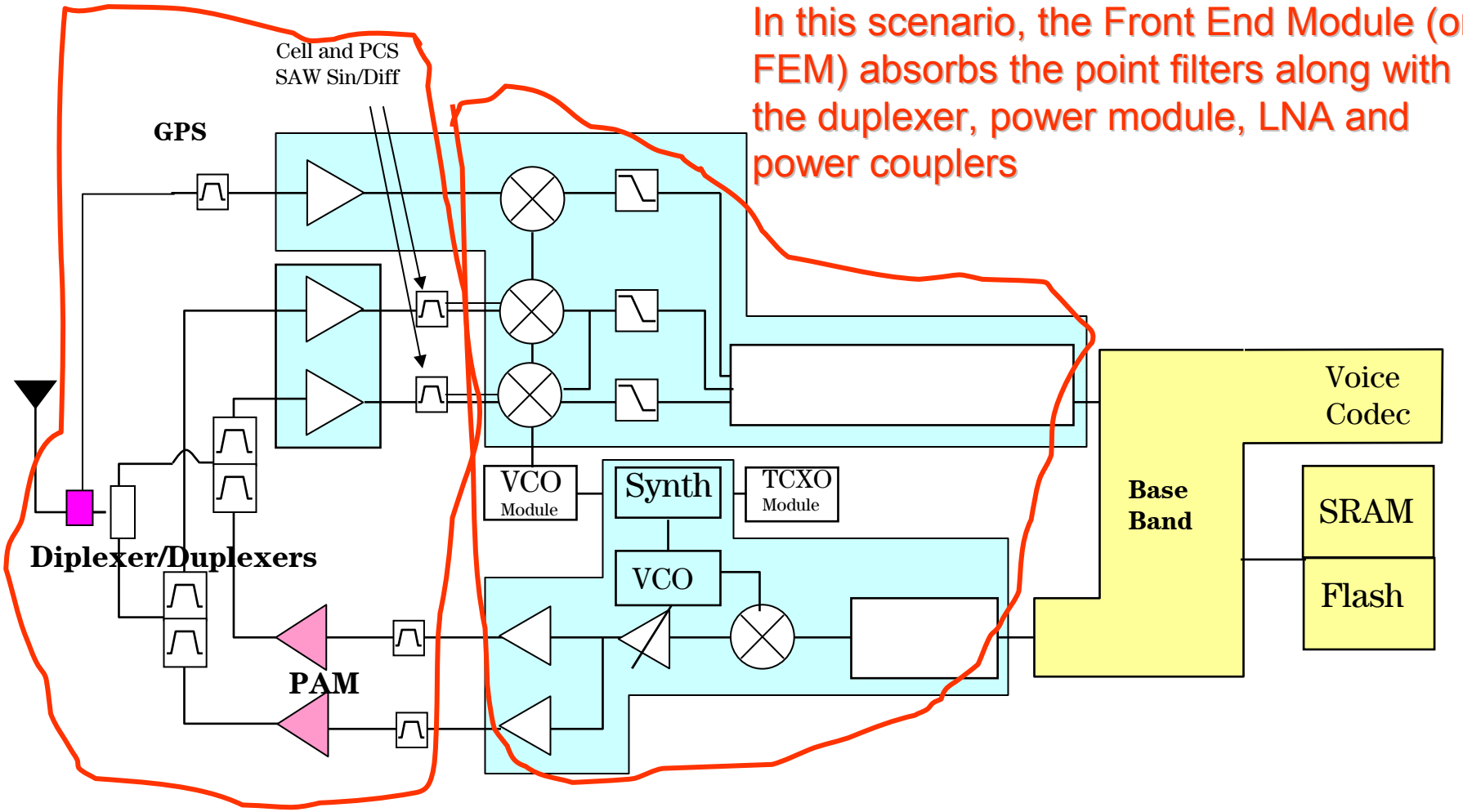
CDMA Block Diagram



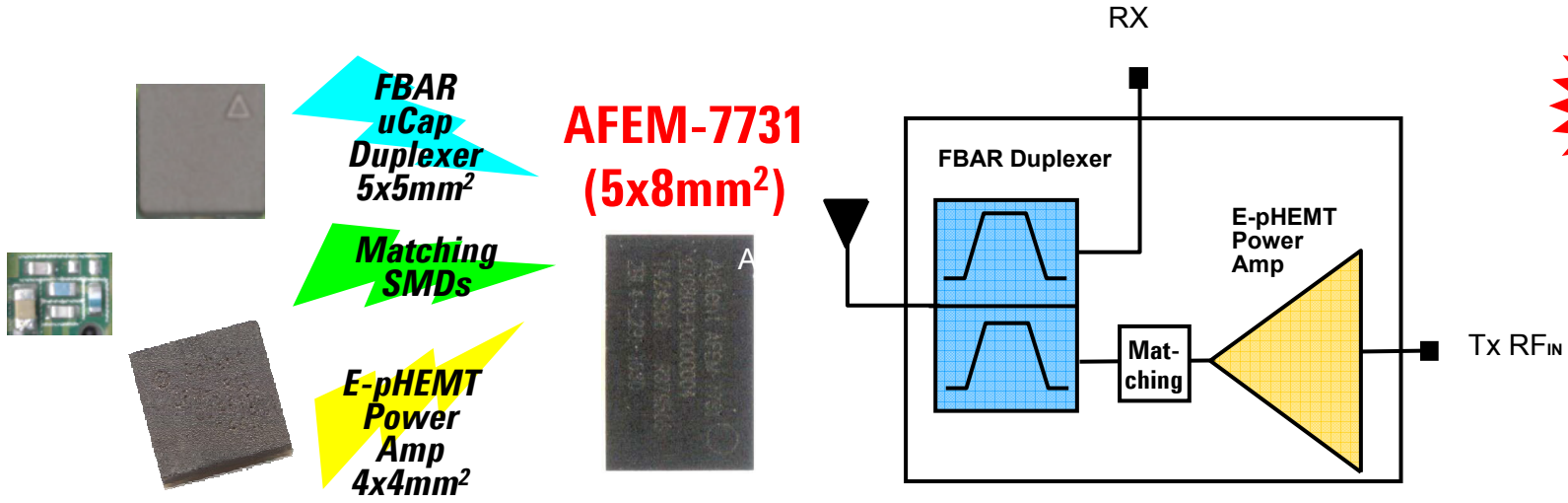
CDMA Block Diagram



CDMA Block Diagram



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