Frequency Tunable Antenna for LTE (4G) Handsets Operating in the 2.3–2.7GHz Global Roaming Band

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Mobile Phones

CCS Insight
Worldwide Mobile Phone Forecast, 2015-2019

- 2.01 billion mobile phones will be sold
  - 1.45 billion of these will be smartphones
  - 0.77 billion of these will be 4G-enabled

- 2.24 billion mobile phones will be sold
  - 1.98 billion of these will be smartphones
  - 1.44 billion of these will be 4G-enabled

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Long Term Evolution (LTE), a.k.a. 4G

- Better spectrum efficiency,
- Higher data rates,
- Lower latencies, and
- Flatter IP core network architecture

**CHALLENGE:**
- LTE Spectrum is fragmented
- Carrier Aggregation
40 LTE Bands

Excerpt: LTE Bands by World Region

- **US/Canada**: 700, 850 MHz, 1.7/2.1, 1.9, 2.5 GHz
- **Europe**: 800, 900 MHz, 1.8, 1.9/2.1, 2.3, 2.5 GHz
- **Asia/Pacific**: 450, 700, 850, 900 MHz, 1.7, 1.8, 1.9/2.1, 2.3, 2.5 GHz
- **Latin America**: 450, 700, 850, 900 MHz, 1.7/2.1, 1.8, 1.9, 2.5 GHz
- **Africa & Middle East**: 450, 800, 850, 900 MHz, 1.8, 1.9/2.1, 2.5 GHz

Source: GSMA
Searching for a Global Roaming Band

Not about having one phone to roam globally

But about having fewer Stock Keeping Units (SKUs)

The International Wireless Industry Consortium (IWPC) Working Group for tunable RF front-end (RFFE)

Architecture for an Integrated RFFE module

2.3-2.7GHz is suggested as the global roaming band with the potential to reach 55% of the world’s population.

A Tunable RFEE will need a Tunable Antenna
Other Motivations

- Recovering from Detuning
  - Passive Antennas detune and there is no recovery
  - Tunable Antennas can recover

- Reducing Antenna Count in handsets

<table>
<thead>
<tr>
<th>850</th>
<th>900</th>
<th>1300</th>
</tr>
</thead>
<tbody>
<tr>
<td>1600</td>
<td>1800</td>
<td>1900</td>
</tr>
<tr>
<td>2400</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tunable Antenna #1  Tunable Antenna #2
Presentation Flow

- Impedance Tuning vs. Aperture Tuning
- Design
- Manufacturing
- Measured Data
Impedance Tuning vs. Aperture Tuning

Electric Current Density is high over the Lumped Circuit
=> **High Losses**

Matching Network

- **Radio**
- **Fixed Antenna Aperture**
- **Impedance Tuning Network**
- **Still Unmatched!**

Electric Current Density is lower over the Aperture
=> **Small Losses**

- **Radio**
- **Tunable Antenna Aperture**
- **Matched**
Design
Design

One state: 3 Ω
Off State: 10K Ω

(RO6010)
Frequency Tuning

(_LSB)
Recovering from Detuning
Recovering from Detuning

![Graph showing the relationship between frequency and return loss for various detuning sizes.](image)
Recovering from Detuning

![Graph showing return loss and frequency for different block locations.](image)

<table>
<thead>
<tr>
<th>Block location (mm)</th>
<th>VSWR</th>
<th>Tuning State</th>
<th>VSWR</th>
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</thead>
<tbody>
<tr>
<td>0.05</td>
<td>30.4</td>
<td>1101</td>
<td>1.3</td>
</tr>
<tr>
<td>0.1</td>
<td>17.2</td>
<td>1000</td>
<td>1.3</td>
</tr>
<tr>
<td>0.2</td>
<td>10.1</td>
<td>0110</td>
<td>1.2</td>
</tr>
<tr>
<td>0.5</td>
<td>5.5</td>
<td>0011</td>
<td>1.3</td>
</tr>
<tr>
<td>1.5</td>
<td>3.3</td>
<td>0010</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>0001</td>
<td>1.1</td>
</tr>
<tr>
<td>10</td>
<td>1.5</td>
<td>0000</td>
<td>1.4</td>
</tr>
<tr>
<td>20</td>
<td>1.1</td>
<td>0000</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Manufacturing (*)

- RF Feed
- Radiating Patch
- Wirebond
- Bare-die Switch
- FR4 (DC Control)

- RO3010 1/1 0.15" (3.81mm) Dk=10.2

Manufacturing
Manufacturing
4-bit and 6-bit versions

Finished Assembly: 16mm x 16mm x 5mm

Patch Antenna: 10mm x 7mm x 4mm

GP: 13mm x 10mm

2.3 - 2.7 GHz (16%)

2.2 - 2.9 GHz (27%)
Manufacturing

- HMC550, Hittite Microwave
- Bare Die 53502, SPST Reflective, Floating Ground
- Ron=5.9 Ohms, Coff=0.09pF
- 0.44mm x 0.45mm
Measured Data

10dB IBW = 50MHz
Measured Data

![Graph showing measured data with two lines for simulation and measurement.](image)
Measured Data

- Average Peak gain = -4.7 dBi
- High $R_{on}$ resistance (5.9 Ω) is to blame.
Enabling Technology: SPST Switches

- Solid State (GaAs or others)
  - HMC550: $R_{on} \times C_{off} = 531$ fSec
  - Current State of Art: 240 fSec
  - 60 fSec – Desired (4x Improvement)
  - Non-linearity

- MEMS
  - Yield
  - Cost
  - Speed ($\mu$s)
  - Hot-switching

**DESIRED SPECS**

<table>
<thead>
<tr>
<th>Switch Type</th>
<th>Bare Die, SPST, Reflective, Floating Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (mm)</td>
<td>0.4 x 0.4</td>
</tr>
<tr>
<td>Pad Configuration</td>
<td>2 DC bottom/RF opposite side (preferred)</td>
</tr>
<tr>
<td>Frequency (GHz)</td>
<td>0.6 – 3.0</td>
</tr>
<tr>
<td>$R_{on}$ ($)</td>
<td>2.0</td>
</tr>
<tr>
<td>$C_{off}$ (Pf)</td>
<td>.03</td>
</tr>
<tr>
<td>RF Power (watts)</td>
<td>1.0</td>
</tr>
<tr>
<td>Non-Linearity (IP3)</td>
<td>50 dBm</td>
</tr>
</tbody>
</table>
Manufacturing Option: Integrated CMOS IC

Switches and the control circuitry are integrated into a thin IC

Antenna PCB

IC (switches+control circuitry)

Solder Balls

- More expensive parts but
- Less parasitics and
- Cheaper manufacturing