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~~Low-Q~~ Wideband Antennas Miniaturized with Adaptive Tuning for Small-Platform Applications

Johnson J. H. Wang, Life Fellow
Wang Electro-Opto Corporation (WEO)
Marietta, GA USA

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Introduction

- Since mid-1990s, antenna designs for small platforms have used Real-time Adaptive Tuning (RTAT) mechanism for impedance matching, pattern diversity, etc. to enhance performance or reduce antenna size.

  R. Schneiderman, "Antenna makers set 'Smart' goals," *Microwaves & RF*, May 1995.

- While others invariably applied RTAT to narrowband (resonant) antennas, this author applied it to wideband antennas.
  - inspired by rapid drop in cost of CMOS devices and advent of Microelectromechanical systems (MEMS).

    "Air Interface®" (US trademark reg. No. 2,049,604, 1997)

    J. J. H. Wang, "Low-Voltage Long-Life Electrostatic Micro-Electromechanic System Switches for Radio-Frequency Applications," US Patent # 6,020,564, 1 Feb 2000.

However, this author's wideband-antenna/RTAT approach did not gain momentum until recent years because:

- Legacy systems rarely needed broadband or multi-band (except for military applications) until recent years; and increasingly more so in the foreseeable future.
- Wideband antennas are generally larger, heavier, more expensive, and slightly lossier than narrowband antennas.

Recent resurgence of this research energized by:

- Advances in RTAT technology
  - Lower price and higher-performance COTS (commercial-off-the-shelf) parts and devices are available for development work.
- Market thirst for ever more bandwidths and features on rapidly growing wireless platforms
  - Smartphones/tablets
  - UAVs (Unmanned Aerial Vehicles).
- WEO has a new generation of **ultra-wideband Traveling Wave Antennas (TWA**s) with even broader bandwidth and smaller size, weight, and cost, e.g.:
  - J. J. H. Wang, "Ultra-wideband omnidirectional antennas via multi-mode three-dimensional (3-D) traveling-wave (TW)," U.S. Patent 8,497,808 B2, 30 July 2013.
  - J. J. H. Wang, "Miniaturized ultra-wideband multifunction antennas via multi-mode traveling-waves (TW)," U.S. Patent 9,024,831 B2, 5 May 2015.
  - Ultra-wideband Conformal Low-profile Four-arm Unidirectional Traveling-wave (TW) Antennas with a Simple Feed, US 9,065,176 B2, 23 June 2015.

Basic concept of the present approach

- Using wideband traveling-wave antennas (TWA) miniaturized by Real-time Adaptive Tuning (RTAT).
- Focused on developing an Adaptive Miniaturized Ultrawideband Antenna (AMUA) for smartphone/tablet applications

A very tall order!!!

So we started with a small tablet.

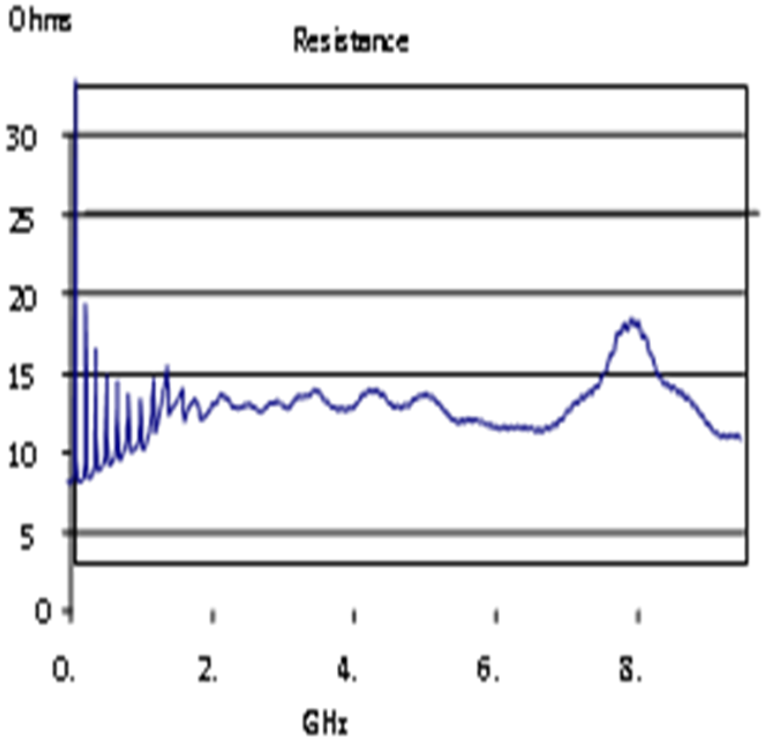
Adaptive Ultrawideband Miniaturized Antenna (AMUA)

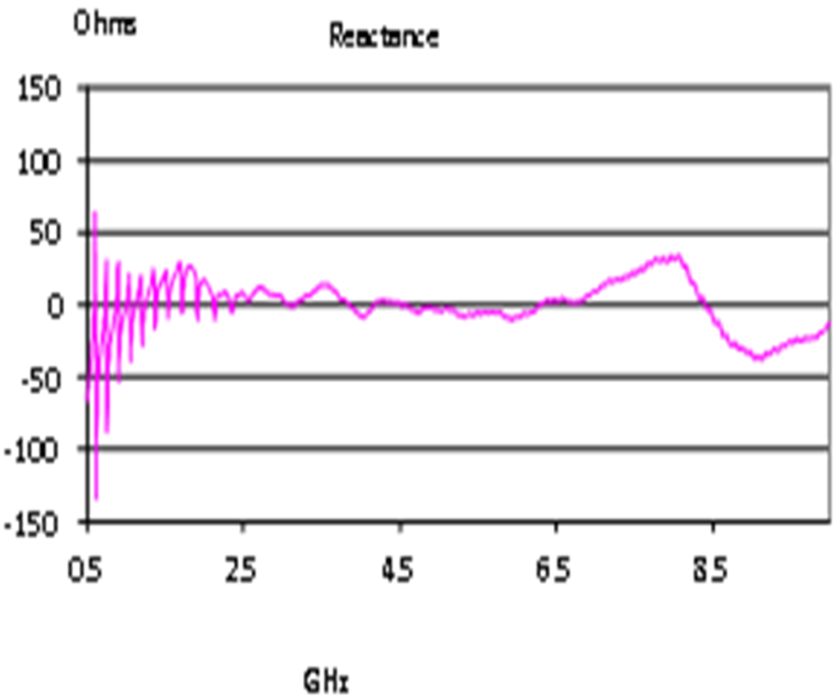
- Real-time impedance and pattern adaptation → Fewer dropped calls
  - Switchable impedance and pattern that smartly adapt, in real time, to the changing user/multipath environment in the mobile RF link with enhanced diversity gain
  - Real-time adaptation mitigates problem of buffering in voice stream → No halting, delay or loss of voice connection
- Patented ultrawideband miniaturized Traveling-Wave Antenna (TWA) enables high-performance low-cost implementation.
- S/N improvement of 5 to 10 dB as a first goal
- Cost competitive with other technologies
- Has exhibited conceptual feasibility by breadboard *embedded* in tablet
- Adequate patent protection and IP rights (inhouse and licensed).

The present approach has the following advantages

- Readily covers desired higher-frequency bands (being wideband)
- RTAT needs only to tune for low frequencies

Example (a 2-D TWA on a small platform)





Major difficulties and limitations to be overcome

- For small smartphones, reactance is still large and radiation resistance too small for existing MEMS-based RTAT.
  - RTAT's speed and tuning ranges in impedance and frequency are very limited as LTE extends down to 700 MHz and up to 2700 MHz.
  - e.g., tuning ranges of a vendor's COTS MEMS chips (with 4 capacitors):

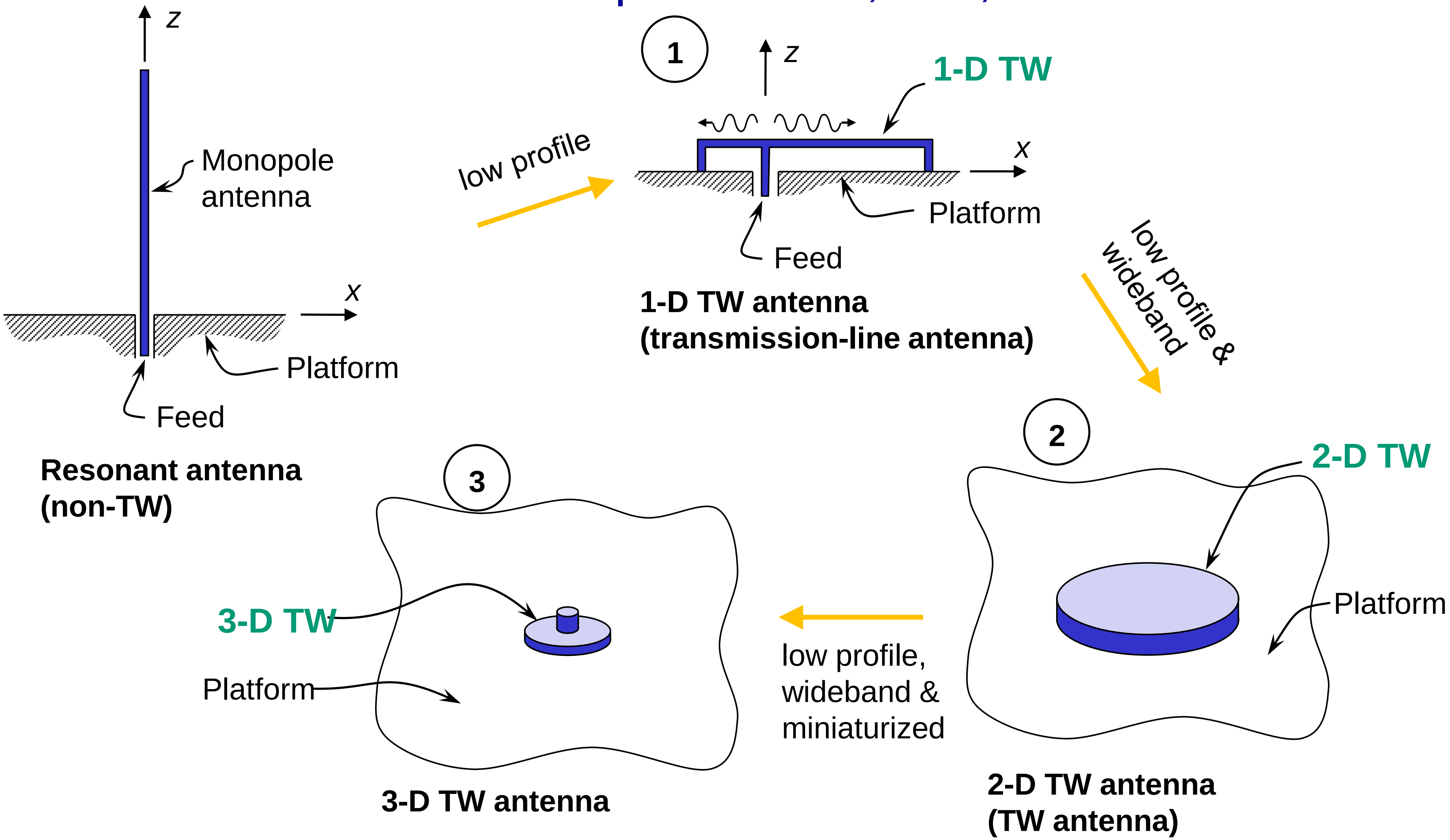
    Model A: 0.3 pf – 2.9 pf

    Model B: 0.2 pf – 1.5 pf

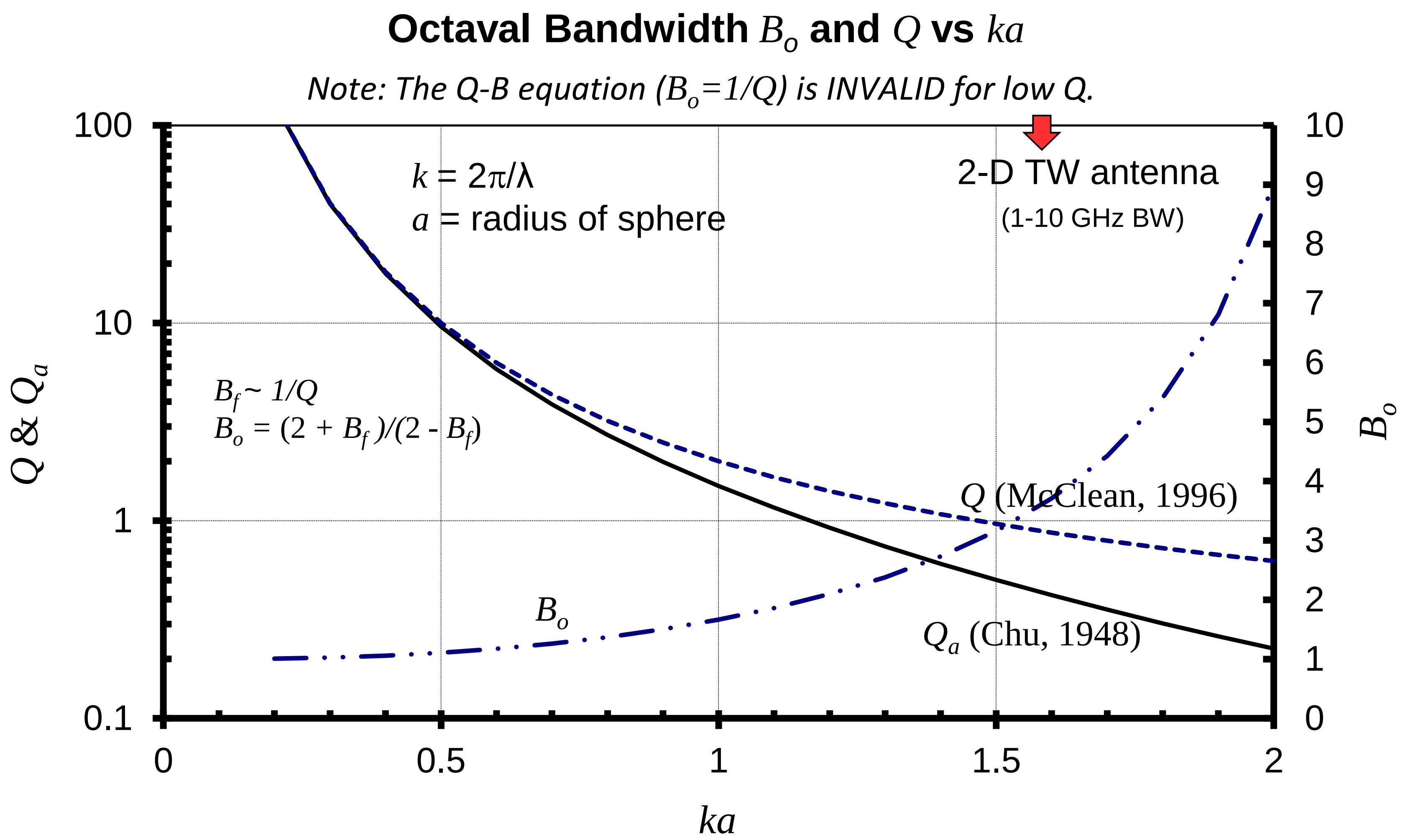
    Model C: 0.15 pf – 0.8 pf

    Model D: 0.5 pf – 5.8 pf

Platform-compatible omnidirectional antenna: Evolution from monopole to *1-D, 2-D, and 3-D TWA*



A broadband 2-D Traveling Wave Antenna (TWA) has circumvented the Chu Limit on antenna gain-bandwidth (Wang paper PIERS 2005)



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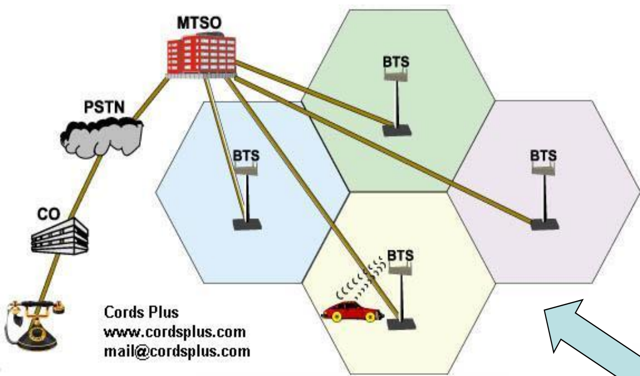
Tuning range of RTAT greatly reduced and relaxed by using broadband TWA

- Adaptive mechanism at present limited to impedance matching only, with no pattern diversity
- As a first step, RTAT's range of adaptation for load impedance Z_L is set to be over
  - $2\Omega<\mathrm{Re}(Z_L)<500\Omega$ and $-500\Omega<\mathrm{Im}(Z_L)<0\Omega$;
- RTAT's frequency range is set to be over 800-1500 MHz where RTAT is crucially needed.
- RTAT is set to be based on MEMS.

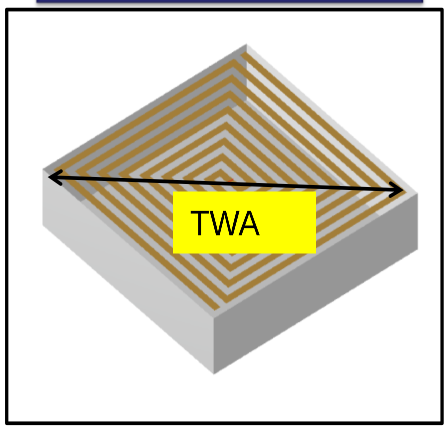
Design Concept

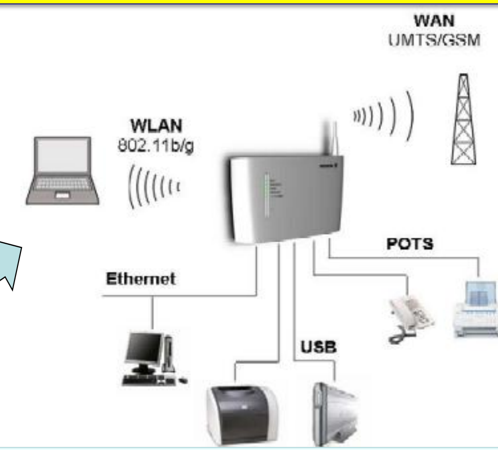
Adaptive Miniaturized Ultrawideband Antenna (AMUA) covering 800MHz to 10GHz band



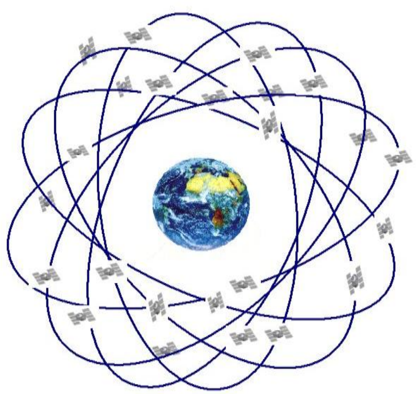
GSM (800MHz), PCS (1700MHz), DCS (1800MHz)

Enhancing access to the radio spectrum (EARS)





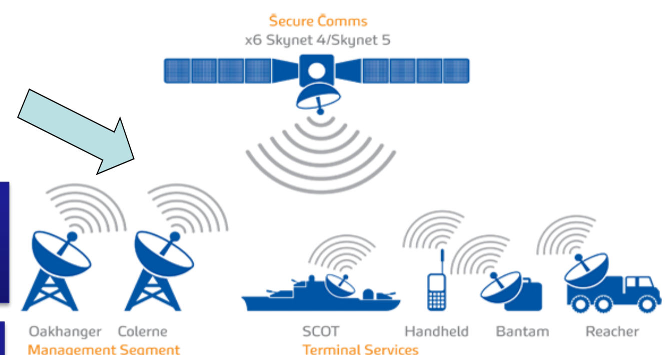
WLAN frequencies: 2.4GHz, 5GHz.



GPS system: L1~L5 band (1176~1575MHz)

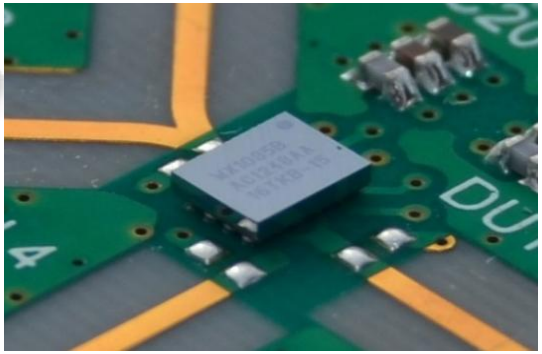
D=1" (SW model) with dual-mode (0 and 1)

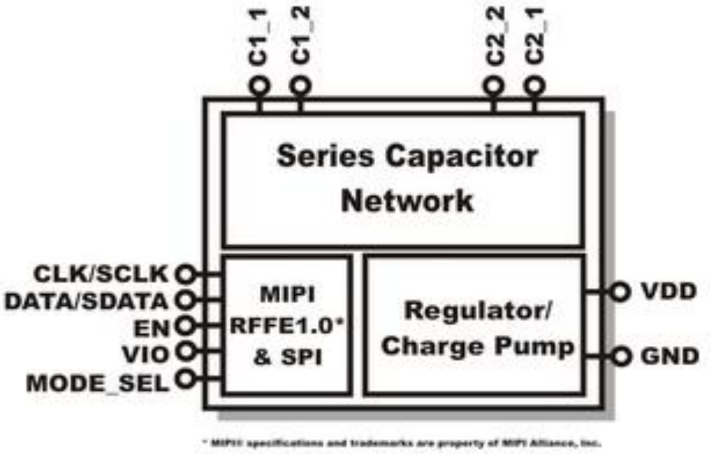
Challenge: Impedance matching at low frequencies



Satellite Frequencies: 5~14GHz

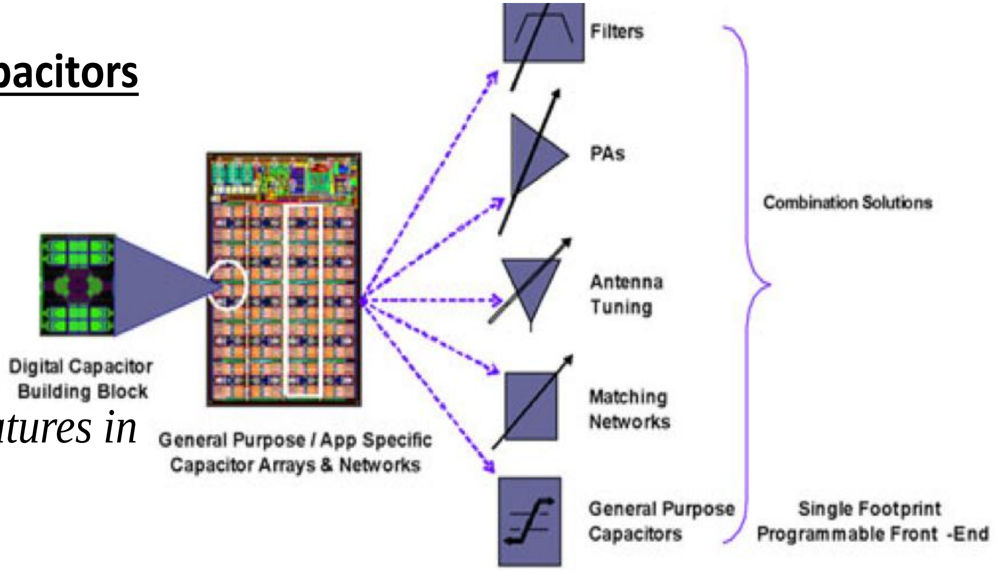
Breadboard Using RF MEMS for Smartphone/Tablet



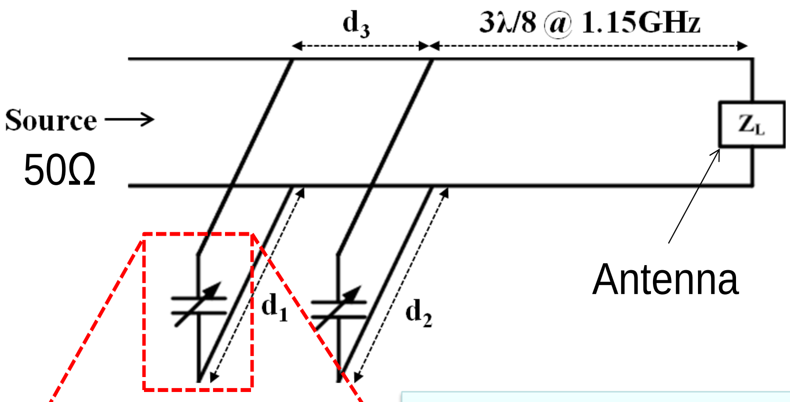


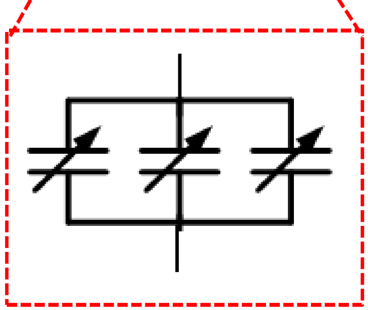
<u>Using CMOS digitally tunable MEMS capacitors</u>

- 700MHz to 1600MHz
- Capacitance value: 1~15pF
- Ultralow power consumption
- High quality factor and high linearity
- Small size
- *Samsung has a product with simple features in its 2012 smart phones ⇨ confirming practicality of approach*

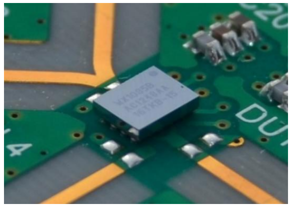


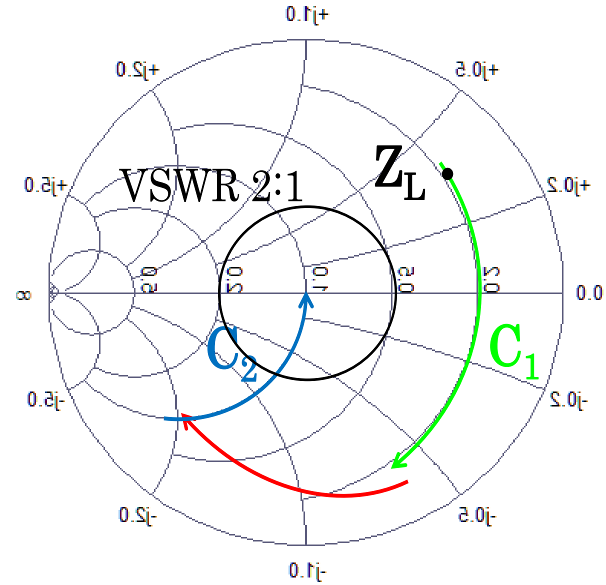
Designed Double Stub Impedance Matching Circuit





MEMS chip





MEMS Capacitor bank
Tunable range: 1pf~15pf
Quality factor: 40

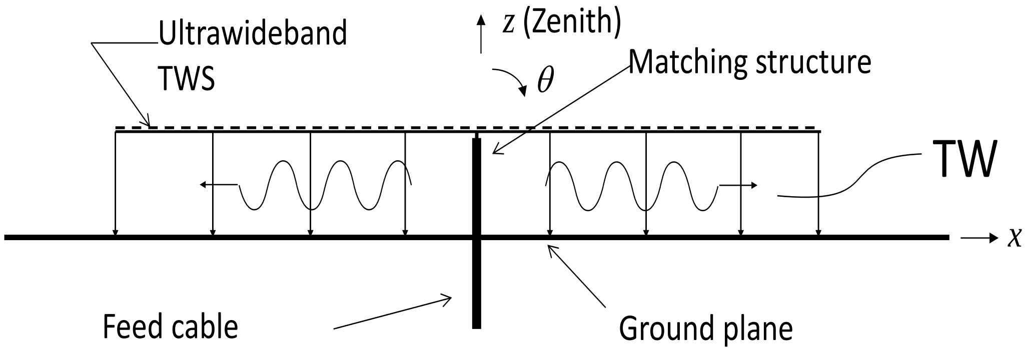
Advantage of double stub tuner:

(1) Two adjustable stubs yield wide matching agility
(2) Low insertion loss (no lossy inductors used)

Optimized stub and inter-stub length:

- Stub length: d_1=10.21°, d_2=30.08° (@1150MHz)
- Inter-stub length: d_3=29.118° (@1150MHz)

Pattern Diversity can also be realized using TWA

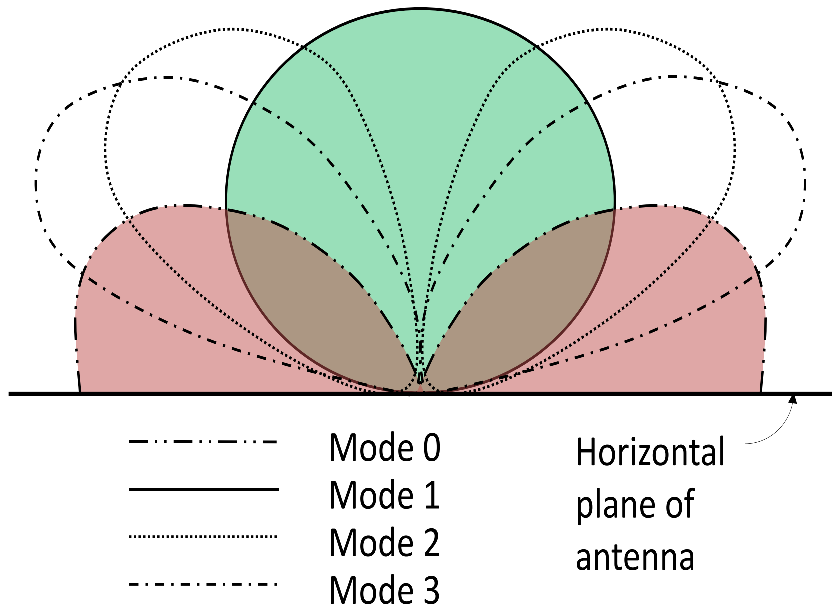


Mode-0 and Mode-1 are most practical and complementary!

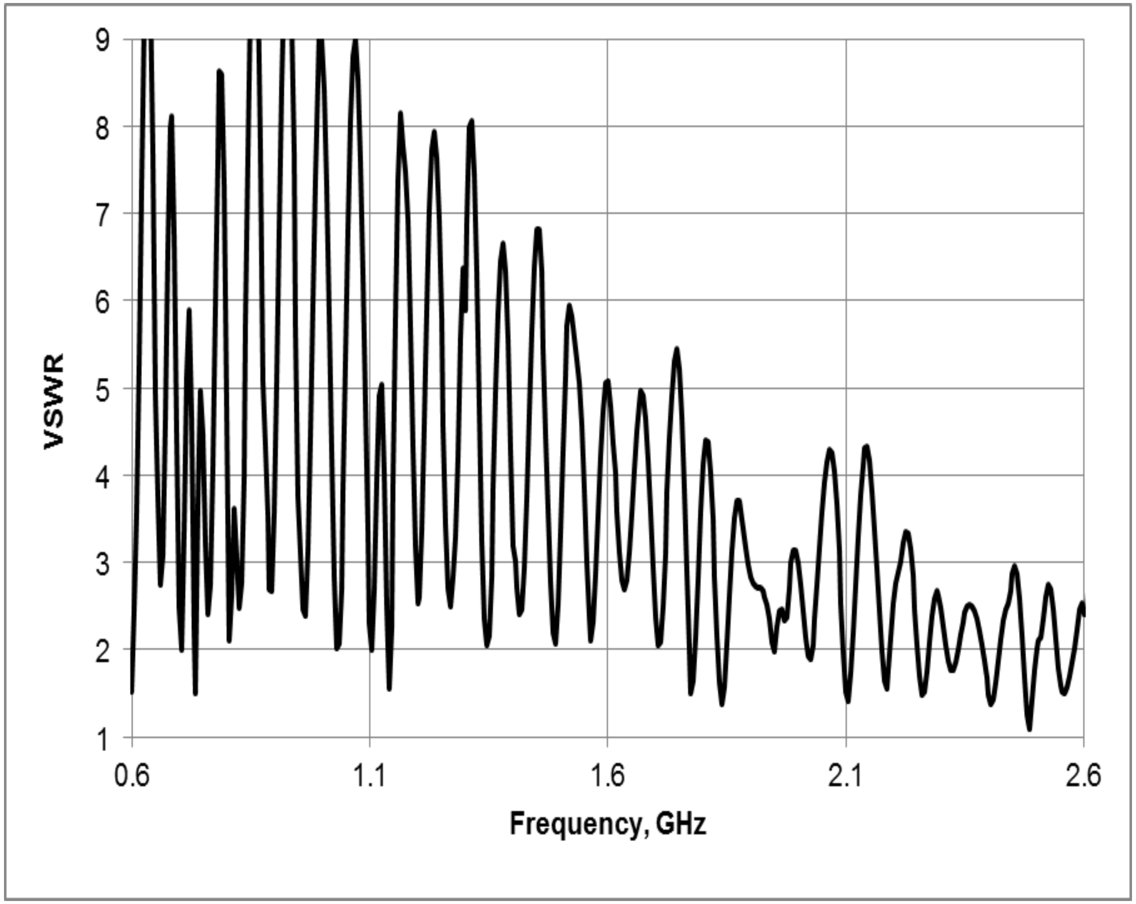
Radiated far fields in terms of wave function modes (in cylindrical coordinates):

$$\Psi_n = \exp(jn\phi)\int_0^\infty g(k_\rho)J_n(k_\rho \rho)\exp(jk_z z)\, k_\rho \mathrm{d}k_\rho$$

where *n* specifies the mode number.



Tuning resonances down to 600 MHz for a tablet (not by dynamic MEMS RTAT)



Feature	Advantage	Benefit
Broadband and multiband	Handles multifunctionality and not vulnerable to detuning	More robust wireless connectivity
Real-time adaptive impedance matching	Can overcome detuning caused by changes in operation or installation environment	Mitigating call drops and improving call quality
Small size/weight and low cost	Can be integrated into wireless communications systems, in particular smartphones and tablets	Amenable to installation into smartphones and tablets at low cost

Integration to a tablet and then to smartphone

Further miniaturization and performance enhancement are anticipated

- Antenna size can be reduced to one half by using the slow-wave technique, successfully employed using newly available COTS high-ε substrates.
- A new 3-D (three-dimensional) TW antenna can be employed for further size reduction and performance enhancement.
    - (As a side note, 3-D TW antenna's bandwidth >100:1 and size-weight reduction over the 2-D TW antenna have both been demonstrated.)