An Overview of Automatic Antenna Impedance Matching for Mobile Communications

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Abstract

- This paper reviews recent developments in automatic impedance matching and antenna tuning for wireless and mobile communications. UHF Tunable Matching Network (TMN) topologies are considered together with electronic device technologies for tuning a TMN and automatic tuning algorithms. Integrated Power Amplifier (PA) matching/antenna tuning, downlink (receive only) antenna tuning and antenna tuning for Multiple Input Multiple Output (MIMO) are also included.

I. INTRODUCTION (1)

- Challenges for designers of 4G/5G mobile devices
- Continuous pressure to reduce the size of antennas while retaining overall power efficiency
- Automatic impedance matching and antenna tuning - latest research aimed at 5G wireless and mobile applications
- Many constraints and trade-offs in antenna design for portable devices - "electrically small" antennas some frequencies, e.g. 700 - 800 MHz range used in LTE.
- The following example illustrates the design challenges for an antenna and TMN covering a wide range of frequencies 800MHz - 2.6GHz.

I. INTRODUCTION (2) - impedance of a λ/4 monopole 800MHz - 2.6GHz

- Min feedpoint impedance 36 + j0 at 900 MHz
- Max approx. 1035 + j270 at 1800 MHz.
- Feasible to match a λ/4 monopole or a PIFA using a TMN around 800 - 960 MHz and around 2600 MHz where the length is approaching 3λ/4
- Difficult at 1800 MHz as λ/2, length presents high impedance at feedpoint.

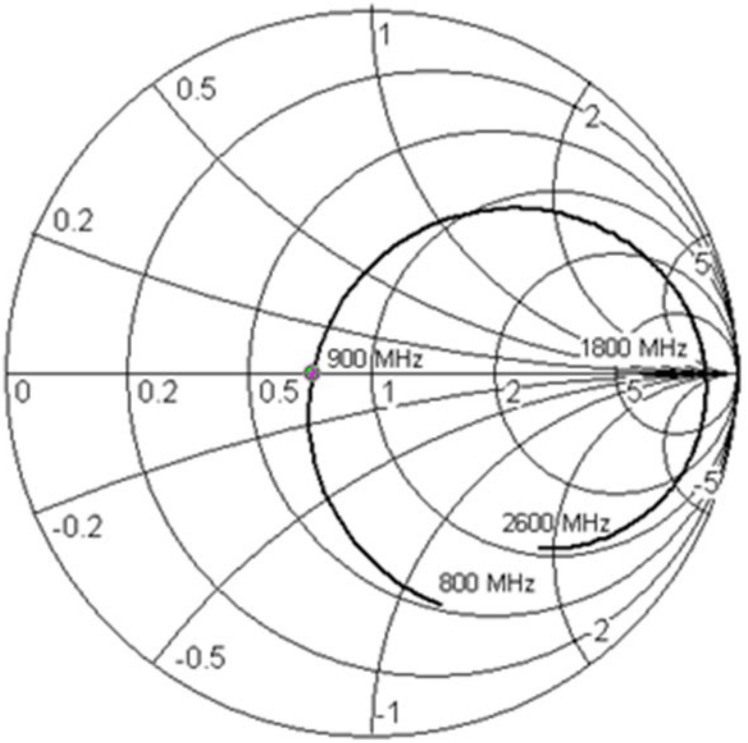

Fig. 1. Feedpoint impedance of a quarter wavelength monopole antenna from 800MHz - 2.6GHz

I. INTRODUCTION (3) - Matching networks

- Impedance matching network between antenna and transceiver for good PA efficiency or optimum LNA noise performance
- For an "Electrically small" antenna with reasonable efficiency, matching network inherently has a relatively high 'Q' Factor.
- Impedance varies rapidly with frequency and environmental effects, e.g. proximity of the user's hand or other conductive objects. This absorbs RF power and detunes the antenna.
- This paper considers:
  - Tunable matching networks (TMN) at a system level
  - A summary of TMN topology
  - A review of electronic devices for use in a UHF TMN
  - An outline of some tuning algorithms [4], [5].
  - Recent developments; integrated PA/output matching [6], [7],
  - downlink (receive mode)

II. TUNABLE MATCHING NETWORKS

- Tunable impedance matching network with a control loop between Tx/Rx and antenna
- Capable of adaptively adjusting to changes in antenna impedance, operating frequency or environment for optimum performance.

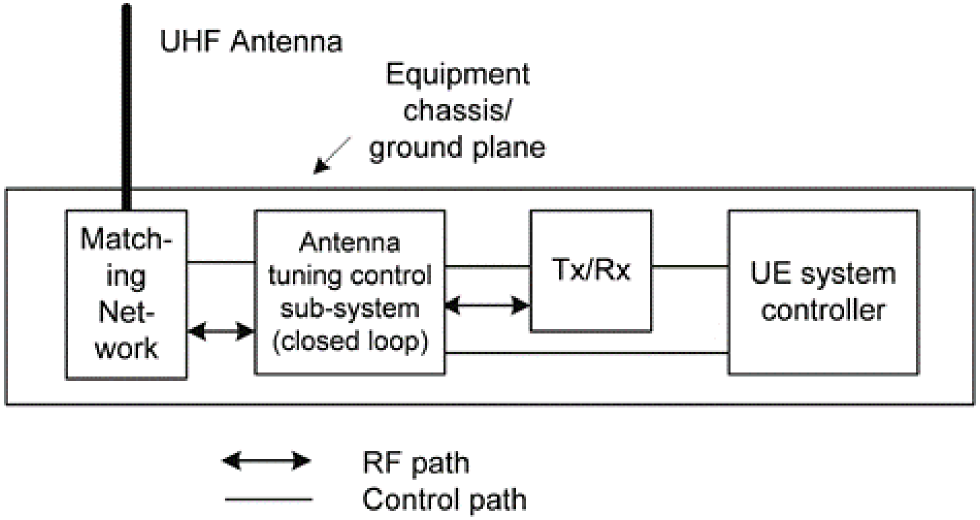

Fig. 2 A block diagram of a TMN for a UE

- Fig. 2 shows a block diagram of a possible implementation of an automatic antenna tuning system for a mobile communication User Equipment (UE).

II. A. TUNABLE MATCHING NETWORKS - TMN topologies (1)

- Switch or vary reactive components using electronic devices suitable for frequencies and power levels used in mobile communication systems.

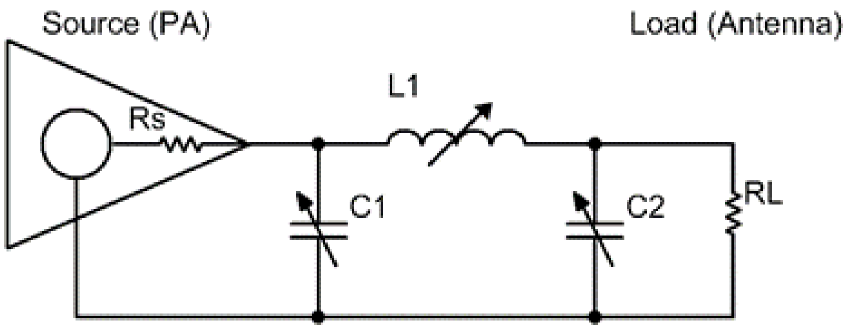

Fig. 3 A 'Pi' Network for a TMN

- Types of matching network include the Pi network [11] shown in Fig. 3 - discrete-component [3] or on-chip [6] antenna tuners.
- Conjugate impedance matching between any input impedance and output impedances but circuit losses and Standing Wave Ratio (SWR) bandwidth need to be considered

II. A. TUNABLE MATCHING NETWORKS - TMN topologies (1)

- Other TMN topologies can be derived from the Pi-Network.
- Transformed matching network for limited bandwidth applications.
- Two cascaded Pi-networks
- Fixed series inductors

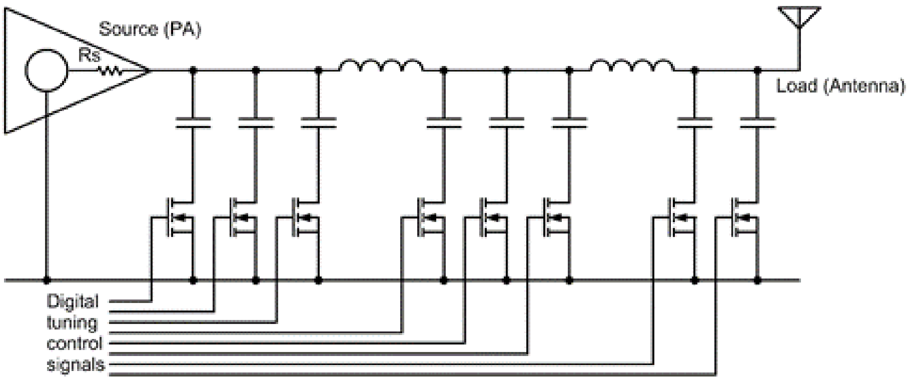

Fig 4. A modified Pi-network for a CMOS on-chip tuner

- Network is tuned by means of a shunt tunable capacitor between the two networks.
- This topology can be used for CMOS on-chip tuner application with shunt capacitor tuning

III. A. ELECTRONIC DEVICE TECHNOLOGIES FOR TMN - Variable Reactive Components

- Continuously variable electronic devices
  - Silicon varactor diodes
  - Micro Electro-Mechanical System (MEMS) varactors
  - Barium Strontium Titanate (BST) thin film voltage tunable capacitors.
- Non-linearity of Silicon varactor diodes. MEMS and BST variable capacitors generally have better large signal handling capability.
  - Digitally controlled devices
  - Digitally tunable capacitors
  - MEMS switched capacitors
  - P-Intrinsic-N (PIN) diode switches
- MEMS switched capacitors - issues with reliability, [14].
- PIN diode switches - very good power handling but additional power consumption due to d.c. bias current [14].
- Digital binary switched arrays of capacitors or inductors.
- On-chip digitally controlled tuning in mobile radio RF chips [3].

IV. TMN ALGORITHMS

- Iterative tuning algorithms are generally used.
- Various automatic antenna tuning algorithms have been published and various factors influence the design of a suitable algorithm [4].
- Fast tuning speed, of the order of milliseconds, to compensate for rapid changes in environmental conditions of the antenna.
- For systems with a relatively small number of states, tuning speed can be enhanced by table or 'dictionary' of tuning settings
- With a large number of states, functional tuning algorithms can be used with a sensor that detects complex reflection coefficient.
- An example of a practical implementation of a UHF TMN is a self-tuning TMN for a fixed frequency 406 MHz antenna in an emergency personal locator beacon [16]. Time-varying environmental conditions affect the antenna due to proximity of the human body and proximity of sea water.

V. INTEGRATED PA MATCHING/ANTENNA TUNING

- A conventional transmitter Power Amplifier (PA) contains matching components that match the RF power transistor to the designed load impedance, such as 50 Ω.
- TMN transforms the antenna feed point impedance to present the PA output with its designed load impedance, e.g. 50 Ω.
- With separate Tx and Rx antennas, a PA with integrated Matching/Antenna Tuning can be used, as described in [6].
  - TMN consists of a two stage L-C matching network with three digitally switched capacitors.
  - TMN input is driven directly from the output of the CMOS PA which has a source impedance of 10 + j10 Ω.
  - TMN can match the PA to a load impedance Z_{load} of 50 Ω resistive or a mismatched antenna with any reflection coefficient Γ of up to 0.3 (relative to 50 Ω reference).
  - On-chip impedance mismatch detection circuitryonly uses voltage amplitude information, without the need for any phase information.

VI. DOWNLINK ANTENNA TUNING

- Downlink (Receive mode) antenna tuning is a recent development [8].
- Tunable matching circuit in receive mode without requiring antenna impedance information from a transmitter.
- A UE for a mobile communications network needs to receive a signal from the Base Station (BS) before communication starts.
- Downlink (Receive mode) antenna tuning offers advantages near the edge of the coverage area of the BS as poor antenna matching may prevent communication from being established
- Useful in receive-only communication systems such as a Global Navigation Satellite System (GNSS) with small fade margin.
- Downlink (Receive Mode) antenna tuning only has access to information about the amplitude of the received signal.
- Signal fading and multipath effects need to be considered.

VII. MIMO ANTENNA TUNING (1)

- In a Single Input Single Output (SISO) system, adaptive tuning of a TMN can be implemented by measuring the complex reflection coefficient at the input to the TMN.
- In a Multiple Input Multiple Output (MIMO) system with an array of antennas, antennas interact. This affects impedance, matching and SWR of each antenna. Consequently:
- Mutual coupling between antennas impairs the performance of the MIMO system if not compensated.
- Measurement of the complex reflection coefficient of one antenna is affected by power received from other antennas.
- A technique known as 'Decoupling' at baseband or RF can be used to compensate for the effects of antenna coupling [17].

VII. MIMO ANTENNA TUNING (2)

- MIMO systems may use 4 or 8 antennas on a UE and up to 64 on a 'Massive MIMO' base station. Antenna tuning can improve matching to the PA in MIMO systems but this needs to be applied to multiple antennas. An approach described in [9] is a Multiple Antenna Port Multiple User Port (MAPMUP) antenna tuner with 4 user ports and 4 antenna ports, as shown in Fig. 5.

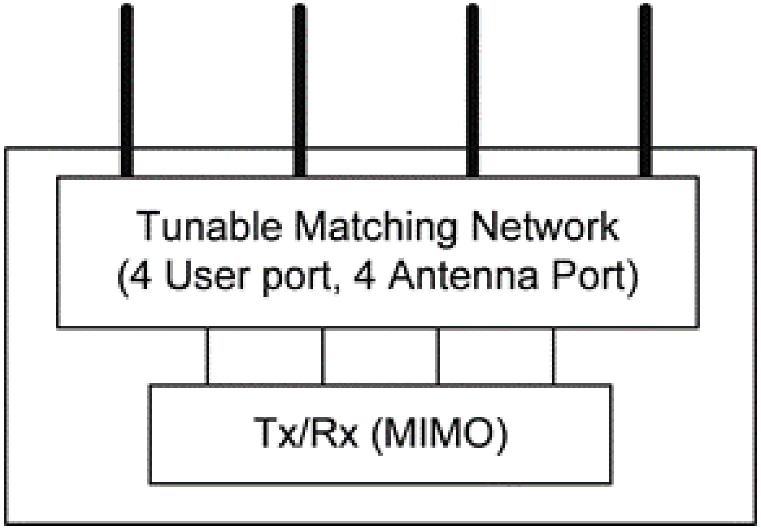

Fig. 5. A TMN for 4 x 4 MIMO

VII. MIMO ANTENNA TUNING (3)

- The TMN is implemented as a multi-dimensional 'Pi' network where each branch needs to be tuned separately.
- This approach can in principle perform both decoupling and antenna tuning but the task of tuning is complex and differential gain and phase errors must be low to avoid impairing the performance of the MIMO system.
- The number of branches is proportional to the number of ports squared, so this approach is not scaleable.
- An alternative approach to a TMN for MIMO is to perform decoupling at baseband using 'vectoring' techniques and to perform antenna tuning only at RF. This allows a separate Single Antenna Port Single User Port (SAPSUP) antenna tuner to be used for each antenna.

VIII. CONCLUSIONS

- An overview of the need for TMNs
- Various circuit topologies to implement a TMN.
- Electronic devices suitable for a UHF TMN
  - continuously variable devices such as varactors
  - digitally controlled devices such as MEMS switched capacitors and PIN diodes.
- An overview of impedance sensors and TMN tuning algorithms
- Some recent developments:
  - integrated power amplifier matching/antenna tuning
  - downlink (receive mode) antenna tuning.
  - design challenges in state-of-the-art MIMO antenna tuning including the need to compensate for mutual coupling between antennas.
- The future direction of automatic antenna impedance matching includes more widespread use of integrated PA/antenna tuning and tackling the complex issues in MIMO antenna tuning.

Any questions?