Antenna Impedance Mismatch Measurement and Correction for Adaptive CDMA Transceivers

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***Abstract* — A tunable matching network has been developed to adaptively correct antenna impedance mismatch for CDMA transceivers. The tuning network consists of two L structures in cascade and is implemented with silicon-on-sapphire switches, fixed capacitors and inductors. Experimental results show the matching network can correct antenna impedance mismatch over a wide range. It has adequate linearity for CDMA applications and an insertion loss of 0.4 dB. A simple method has also been developed to measure the antenna load impedance based on the measurement of the envelope voltages at three points along a section of transmission line. This method is independent of input power to the antenna and source impedance seen by the antenna. This method could be integrated with the tunable matching network to correct the load impedance mismatch for an adaptive transceiver.**

***Index Terms* — Tunable circuits and devices, silicon on insulator technology, impedance matching, standing wave measurement.**

I. Introduction

Mobile handsets are used in a variety of configurations and positions, by users who manipulate the handset and, in particular, the antenna, in ways that are difficult to predict. While a nominal antenna provides an input impedance of 50 Ω, in actual usage the impedance at the antenna terminal can vary over a wide range, characterized by a voltage standing wave ratio (VSWR) of up to 10:1. It is a major challenge to maintain operation of the handset with such a wide range of impedances. For the receiver, the non-optimal source impedance degrades noise figure, gain and dynamic range. For the power amplifier, the impedance mismatch greatly impacts the efficiency, power gain, maximum output power and linearity. In the worst case, the high standing wave amplitude or possible oscillation caused by the mismatch in the circuit may damage the power amplifier. In past practice, an isolator or a VSWR protection circuitry was often inserted between amplifier and antenna to mitigate the problem, but it had a cost in terms of attenuation (and thus efficiency). Alternative approaches could be to correct the impedance mismatch using dynamic biasing of the power amplifier or by using a tunable matching network. In the latter case, the performance of the amplifier can be preserved even under severe mismatch condition. MEMS switches, varactors and thin-film barium strontium titanate tunable capacitors have been applied to design tunable or switched matching networks [1-3]. However, these approaches have disadvantages of either cost, tuning range (which generally corresponds with maximum available capacitance / minimum available capacitance), integration or linearity problems.

In this paper, we used silicon-on-sapphire (SOS) switches to implement the tunable matching network. Using a solid-phase epitaxial regrowth process [4], these SOS MOSFETs are built in a 100 nm film of silicon with transconductance and mobility that is comparable to bulk CMOS. At this thickness, the transistors are symmetric three-terminal devices that can be stacked in series to withstand very high voltage despite the low drain-to-source breakdown voltage with the gate shorted (BVDSS) of a single transistor. The insulating substrate also provides for very low parasitic capacitance and thus low insertion loss. The matched network implemented in this paper used 6 SOS switches. Depending on the load impedance, the switches are turned on or off to reduce the impedance mismatch. Measurement results show that this matching network has the advantage of large tuning ratio, low insertion loss and high linearity.

In practice, control of the tunable matching network in handset requires real time measurement of the load impedance. A method based on sectioned transmission lines has been proposed to measure the load impedance[5-6]. This technique estimates the load impedance by measuring the voltages at multiple points of the transmission line. However, the proposed approaches need either measurement at many points on a relatively long transmission line (a whole wavelength) or complex calculation, thus are relatively hard to be integrated with a handset. In this paper, this technique is simplified to a three-point measurement on a quarter wavelength transmission line.

Based on the tunable matching network and the technique for measuring the load impedance, a structure shown in Fig. 1 could be used to correct the impedance mismatch. In this structure, a controller (analog or digital) tunes the matching network based on the measurement of load impedance, thereby keeping the handset in an optimum working condition.

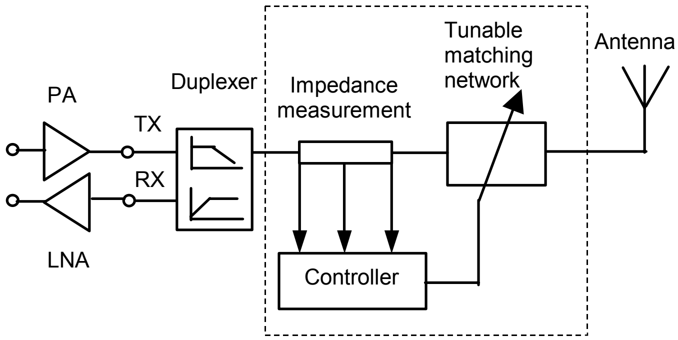

Fig. 1. Portion of the handset transceiver showing the connection between antenna and RF circuitry. The part in the dashed block is the proposed circuit to measure and correct the antenna load mismatch.

II. Design of Tunable Matching Network

L-topology is a commonly used design for impedance matching networks. However, a particular L matching network can only provide impedance match to 50 Ω over part of the Smith chart, i.e., there is a forbidden region for a particular L-topology [7]. In this paper, a cascaded L matching network consisting of 2 fixed inductors and two tunable capacitors is used (see Fig. 2a). Simulations show if the tuning ratio of the capacitors is large enough, most of the impedance range in the Smith chart can be matched to 50 Ω. To match all the impedance within the VSWR = 7:1 circle in the Smith chart, the capacitance tuning ratio is ~ 3:1. Larger tuning ratios are required for higher VSWR correction. In order to increase the tuning range, switches with shunt capacitors are used in this paper. In this case, the tuning ratio is defined by the fixed capacitors and the parasitic capacitance of the switches. Increasing the capacitance of the fixed capacitors can increase the tuning ratio.

If the tunable parameters in the matching network only consist of switches, tuning is a digital process. In this case, the tuning precision should be also considered when designing the matching network. More switches are preferred for more accurate control but will increase the cost and complexity of control. In this paper, 6 switches are used, which provides totally 64 available states. The fixed capacitors are selected to provide a relatively uniform distribution over the Smith Chart the impedances that the matching network can match to 50 Ω. For a particular mismatch circumstance, the best state is selected.

Another design consideration for the matching network is that there should be a state which does not change the impedance of 50 Ω, since most of the time, the handset is operated with a 50 Ω antenna. Fig. 2b shows the matching network used in this paper.

The SOS switch building block is a stack of six transistors which each has a BVDSS of approximately 4.0 V yielding a

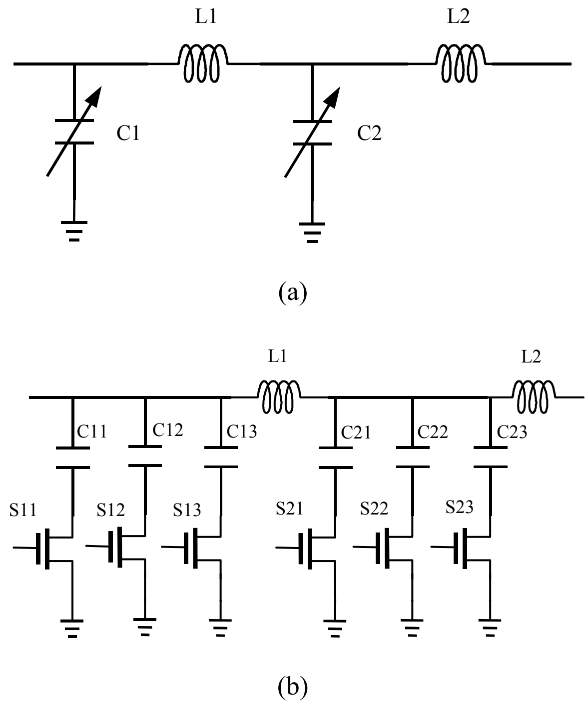

Fig. 2. (a) Schematic of the tunable matching network; (b) tunable matching network implemented using switches.

stack that can withstand a peak voltage 24 V. Integrated 30 kΩ blocking resistors are placed between the FET gates and the control pad to provide for proper RF voltage division across the FET stack when biased in the off condition. Inside the switch core there are six 1000 μm × 0.5 μm FETs in parallel which are combined by wire bonding. The on resistance for the total switch is ~0.5 Ω and the off capacitance is 1.8 pF. ESD protection is provided from the gates to ground node of the stack.

The tunable matching network was implemented on a PCB board with FR4 substrate and Au coating for wire bonding. Toko LL2012 (Q is about 40 ~ 90) chip inductors and ATC 100A Porcelain Superchip® multilayer capacitors were selected for the fixed elements. Unpackaged SOS switches were wire bonded to the PCB board. The size of the circuit prototype was about 4.3 cm × 2.7 cm.

III. Measurement Results of the Matching Network

Fig. 3 shows the matched load impedances using the tunable matching network. It is seen that the matched impedance is well distributed over the Smith chart, and there are some states that provide impedance close to 50 Ω.

CDMA communication systems require high linearity. In this paper, a highly linear class A power amplifier is used to characterize the linearity of the tunable matching network. Fig. 4 shows the spectra of the power amplifier with and without the tunable matching network between the amplifier

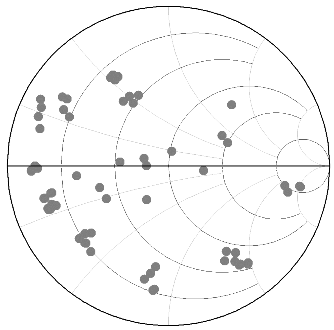

Fig. 3. Measured range of matched load impedance using the tunable matching network.

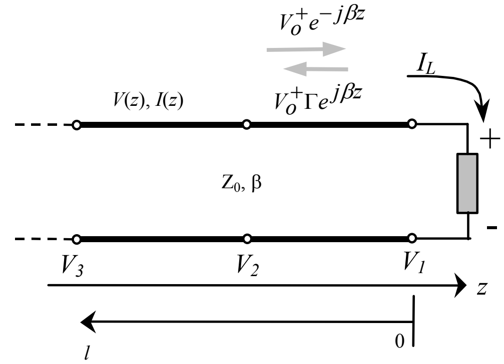

Fig. 5. Transmission line terminated in a load showing measurement points.

and a 50 Ω load with a CDMA IS-95 input. The switches were set to a state close to 50 Ω. The output power of the amplifier was adjusted to ~ 28.5 dBm to measure the ACPR. Measurements showed that even with a small mismatch (see Fig. 3), the ACPR1 of the output signal only changed from –59.5 dBc to –59.2 dBc, suggesting the tunable matching network did not significantly degrade the linearity of the system.

The insertion loss associated with the tunable matching network was also measured using CDMA IS-95. It is found the insertion loss was about 0.4 dB.

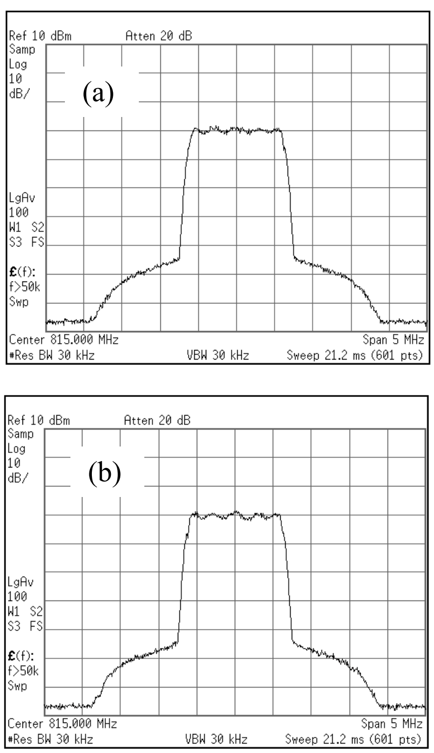

Fig. 4. Output power spectra for power amplifier (a) without and (b) with the tunable matching network.

IV. Circuit for Measuring Antenna Load Impedance

Figure 5 shows a transmission line terminated in an arbitrary load Z_L with a characteristics impedance of Z_0. For any two points on the transmission line, the ratio of the voltages is

$$\frac{V_{z1}}{V_{z2}} = \frac{e^{-j\beta z_1} + \Gamma e^{j\beta z_1}}{e^{-j\beta z_2} + \Gamma e^{j\beta z_2}} \qquad (1)$$

where β is the propagation constant of the transmission line, Γ is the reflection coefficient. In Equation (1) the voltage ratio of two points on the transmission line does not depend on the magnitude and the phase of the incident wave and the source impedance, but depends on the position of the points and the load impedance. The real part and the imaginary part of Γ (and thus the antenna impedance) can be obtained by solving equation (1) for two independent voltage ratios, i.e., the voltages at three different positions on the transmission line.

For easy validation, a quarter wavelength transmission line is used in this work. The voltage is measured at positions of 0^o, -45^o and -90^o from the load toward the generator on the transmission line. Selection of measurements at these positions simplifies equation (1), and gives relatively large difference between the measured voltages to alleviate the accuracy requirement of measurement. Theoretically shorter transmission lines can be used.

Figure 6 shows the schematic of the circuit used in this work. To measure the voltage at each position on the transmission line, a 1.9 kΩ resistor was used to couple the signal into a high impedance transmission line, which is connected to a power meter (represented by 50 Ω resistors in the schematic). The circuit was fabricated on Rogers RO4003C PCB board. Pure sinusoid signals with a frequency of 815 MHz and three different powers of 15 dBm, 18 dBm and 20 dBm and CDMA IS-95 with a frequency of 815 MHz and three different powers of 12 dBm, 14 dBm and 16 dBm were used for measurement. An impedance tuner was used to produce different load impedance. Equation (1) was solved numerically to obtain Γ and load impedance.

Figure 7 compares the average load impedance measured by the transmission line approach and the actual load impedance (measured by a vector network analyzer (VNA)). It can be found the loads measured by the transmission line approach are in reasonable agreement with the actual values. For loads with smaller voltage standing wave ratio (VSWR), the measured results are more accurate. Part of the large error for high impedance loads is caused by the perturbation to the circuit by the resistors and high impedance transmission lines used for measuring the voltage. It is also found that the loads measured by the transmission line approach do not depend the input power, in agreement with equation (1). Power measurement showed the insertion loss of this circuit is about 0.4 dB.

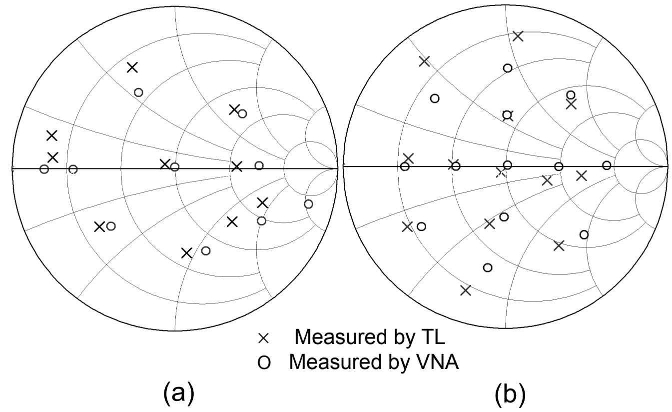

Fig. 7. Comparison of load impedance measured by a vector network analyzer and the transmission line method using a) single tone and b) CDMA IS-95.

V. CONCLUSION

From the above discussion, it can be seen that it is very promising to apply the tunable impedance matching network with the circuitry for measuring antenna load impedance for adaptive control of a CDMA transceiver. To facilitate this, the techniques can be further improved in several ways. Simulation showed that the size of the circuitry for measuring load impedance can be reduced by using a shorter transmission line or even lumped elements. The size of the tunable matching network could also be readily reduced since it does not need a delay. For the tunable matching network, more careful selection of the capacitors could improve the uniformity of distribution of matched impedances over the Smith Chart. Control algorithms should also be developed to dynamically tune the matching network.

In summary, a tunable matching network using SOS switches has been developed to correct antenna impedance mismatch. It provides high tunability of impedance, low insertion loss, and high linearity. A simple method based on transmission line is also proposed for measuring antenna impedance for wireless handsets, in which the complex load impedance is measured by measuring scalar voltages at three points along a transmission line.

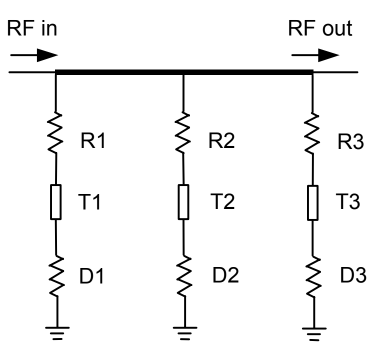

Fig. 6. Schematic of the measurement setup. R_1, R_2 and R_3 are 1.9 k Ω resistors. T1, T2 and T3 are high impedance transmission lines. D1, D2 and D3 are power meters. Different antenna load impedances are emulated by an impedance tuner.

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