An Adaptive Impedance Matching System and Appropriate Range for Control Elements

Ichirou IDA[1], Jun-ichi TAKADA[1], Takeshi TODA[2], and Yasuyuki OISHI[2]

[1] Dept. of International Development Engineering, Tokyo Institute of Technology
ida@ap.ide.titech.ac.jp, takada@ide.titech.ac.jp

[2] Fujitsu Limited
ttoda@jp.fujitsu.com, yasu@labs.fujitsu.com

ABSTRACT

An adaptive impedance matching system is proposed. This system employs only a simple algorithm for convergence, therefore does not need any complicated mathematical formulation for modeling of the system itself as well as its nonlinear control elements. Also the proposed system utilizes only simple digital circuits for timing generation and basic analog circuits. In addition to that, the appropriate range of the control elements (varactors) is investigated. With a parametric simulation, appropriate range of the capacitance for the varactors, which can make the reflection coefficient between the antenna and RF front end considerably small while the antenna impedance fluctuates. Furthermore, a method is proposed, which makes it possible to use the commercially available varactors to realize the suitable range of the capacitance for the varactors. As a result, the improvement in the mismatch is observed by 4dB or more over an impedance matching circuit with fixed capacitances.

Keywords: Adaptive impedance matching, Varactor, Mobile communication terminals

1. INTRODUCTION

The rapid development of the recent mobile communication systems and terminals has tried to catch up with demands for the higher data rate. It is inevitable, however, that the mobile terminals are subject to unexpected environmental changes e.g., a human body and other objects in the vicinity of the users. Because the current distribution on the antenna is affected by those objects near the mobile antennas [1], the antenna impedance changes from the default value, and the degree of the change is unexpected, hence problematic. Thus, there exists a mismatch between the antenna impedance and the input impedance of the RF front end. In the case of transmission, such impedance mismatch leads to a damage of the power amplifier due to the power reflected back to its input, and it also causes a shorter battery lifetime due to excessive energy consumption. While in the receiving path, it causes degradation in the carrier to noise ratio (CNR), although employment of a higher data rate should be supported by a higher CNR. Thus, such impedance mismatch should be avoided as much as possible.

One way to avoid the mismatch is to give multiple antennas to a mobile terminal and to selectively use the antenna, which is least affected by the nearby objects. This method is, however, not easy to implement, while the adaptive adjustment of the circuit constants in the matching circuit seems to be much simpler.

Another way is to prepare a few matching circuits, and utilize one of them adaptively according to the impedance mismatch information. This method, however, can realize only a rough control, because the resolution of the matching is limited by the number of the available matching circuits.

In addition, there has been a method, which employs an L, C bank to realize a good impedance matching with combination of those inductors and capacitors. Like the system above explained, this system, however, has only a limited resolution of the impedance matching. Besides the use of varactors combined with driving motors has a prohibitive volume for most of mobile communication terminals.

More recently, an adaptive impedance matching systems with the steepest gradient algorithm for convergence has been reported [2]. When some mathematical formulation is required, however, a precise modeling of the overall system and control elements are vital. This is often difficult, therefore sometimes causes the deviation of the theory from the reality.

Considering the problems above mentioned, we propose an adaptive impedance matching system, which utilizes only simple digital circuit for generation of the timing signals and basic analog circuits. The adaptive control is conducted in a sequential manner, and it does not need any complicated mathematical formulation.

In this system, only the elements to be controlled are two varactors in the matching section. Therefore, it is easy to understand that the range of the capacitance for those varactors determines the performance of the adaptive impedance matching.

In this paper, we first show the configuration of the system as well as some merits of the proposed system. Second, some simulational results are depicted to show

how the range of the capacitance for the varactors affects the overall performance of the adaptive impedance matching. Also the procedure to realize the required performance using a commercially available varactor is shown.

2. CONFIGURATION OF THE SYSTEM

Figure 1 shows the configuration of the system. The system is now intended to be used in the transmitting path. It consists of (1) Matching circuit, (2) Mismatch measurement circuit (directional coupler), (3) Switch, (4) Timing generator for switching, and (5) Time constant generator (RC low-pass filter).

The varactors (variable capacitors) are used for the control elements in the matching circuit. In this configuration, however, the available information to be used for the impedance matching is only the absolute value of the reflection coefficient between the RF source and the input of the matching circuit. Thus as long as we cannot measure the phase information of the reflection coefficient, we don't know the correct direction of the control to minimize the mismatch. To solve this problem, we employ a test signal to observe if applying the test signal increases or decreases the mismatch. Then we know for the first time if the direction of the control was correct or wrong.

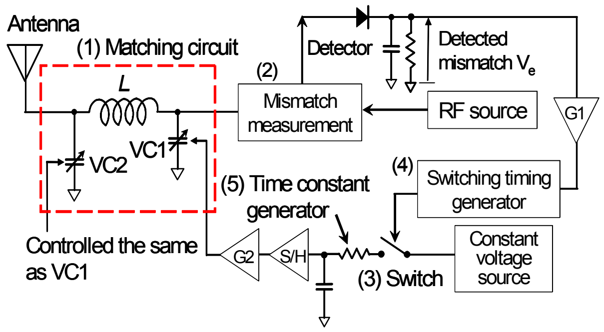

Fig. 1: Configuration of the proposed adaptive matching system

The adaptive matching protocol of the proposed system is as follows: (a) The latest value of the mismatch is measured through the detection circuit (2). (b) The switch (3) is turned on, i.e. the control voltage to the varactor 1 (VC1) is increased. (c) The mismatch is again measured right after turning on the switch. Here, if the mismatch has been increased compared with the previous measurement, then the system recognizes that the direction of the control was wrong, and the switch is turned off to decrease the control voltage to the VC1. If the mismatch has been decreased compared with the previous measurement, the system recognizes that the direction of the control was correct, and the switch is kept turned on until the end of the control frame for the VC1. During the VC1 frame, the control voltage to the 2nd varactor VC2 is held to the value at the end of the last frame of the VC2. This voltage holding is conducted by the sample and hold circuits. After the VC1 frame is finished, the control voltage for the VC1 is held and the VC2 frame is commenced.

The advantages of the proposed system are as follows:

(1) Compared with systems, which employ the steepest decent algorithm for optimization, the proposed system does not require such a complicated mathematical modeling.

(2) When a mathematical modeling is necessary, the control elements of the matching circuit should also be modeled precisely. In this case, nonlinearity of the varactors and etc. can be very problematic for a good convergence, because formulation of such nonlinear elements is difficult. The proposed system can accept also such nonlinear control elements.

(3) In addition, varactors with any range of capacitance are applicable to the proposed system, because its criterion for the control is to reduce the mismatch as much as possible, thus no goal for convergence like in the steepest decent method. In other words, it simply tries to match the impedance with the available capacitance range of the varactors.

3. SIMULATION RESULTS

Some simulational consideration was made by using Simulink from The MathWorks Inc. Figure 2 shows the simulation result for the improvement of the mismatch with the adaptive impedance matching system. Here it is evaluated by observing the time characteristics of the reflection coefficient between the matching circuit connected with an antenna and the RF front end with 50ohms of characteristic impedance. The resistance and reactance of the antenna input impedance Z_a are sinusoidally fluctuated with ranges of 55±30ohms and

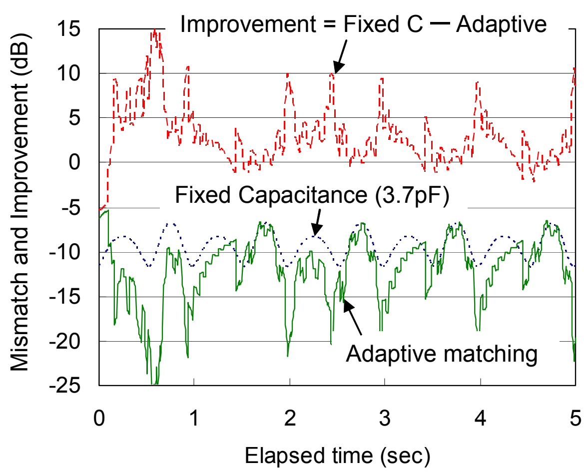

Fig. 2: Mismatch and its improvement

25±10ohms, respectively. The frequency of the fluctuation is 1Hz. In general, we confirmed that the smaller the amplitude of the fluctuation of the antenna impedance is, the better the adaptive matching works.

A fixed impedance matching system without variable elements is also simulated for comparison. In Fig. 2, the improvement in the mismatch value is illustrated as the subtraction of the value of the adaptive system from that of the fixed capacitance system. The parameters for the simulation are: Operating frequency 2.45GHz, Range of capacitance for varactors 2.5pF – 4.0pF, Fixed capacitance for the compared system 3.7pF, Inductance for the matching circuit 2.4nH. The values of the fixed capacitance (3.7pF) for the fixed capacitance matching system and the inductance (2.4nH) for both systems were chosen so as to give about –12dB to –7dB of the reflection coefficient, when the fluctuation of the antenna impedance Z_a is applied. The range of the reflection coefficient is so determined because in practice, the VSWR of 1.5 (≈ –14dB) to 2.0 (≈ –10dB) is good enough for a good energy transmission, thus the impedance matching may be made within this range, i.e. –12dB or so. Also, the upper limit of the range, i.e. –7dB is a rough estimation for the condition where the impedance mismatch occurs due to an environmental change around the mobile antennas. A variety of combinations between the values of the capacitance and the inductance, however, are possible in addition to this example.

The time constant for the time constant generator is 0.1sec. The range of the fluctuation for Z_a is assumed to move only within the upper half of the Smith chart, i.e. the antenna impedance Z_a is always inductive. We confirmed it with an experiment, where a monopole antenna (rooftop type for automotive covered with resin) was placed on a metallic table, on a concrete floor, and in the vicinity of a human body. The monopole antenna was even grasped and measured. Thus we use the above assumption of the inductive antenna input impedance Z_a in the present consideration.

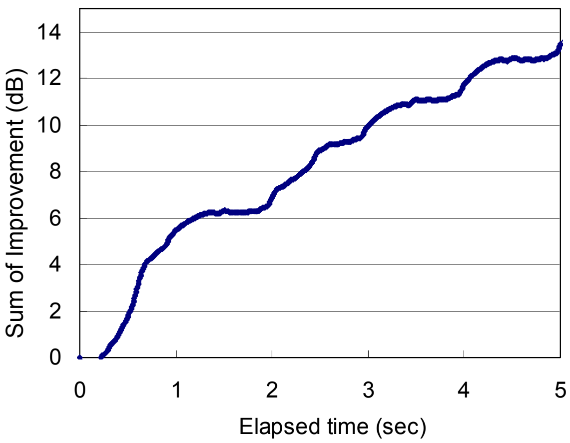

Fig. 3: Time integration of improvement in Fig. 2

Figure 3 shows the time integration of the improvement in Fig. 2. The amount of the integration is decreased while the mismatch of the adaptive system exceeds that of the fixed system. Through dividing the integrated value by the elapsed time, we obtain the average improvement of the mismatch. In Fig. 3, about 2.7dB of the mismatch improvement is achieved at 5 sec.

4. APPROPRIATE CAPACITANCE RANGE OF THE VARACTORS

In Fig. 4, we investigate an appropriate range for the capacitance of the varactors. The improvement in the mismatch over the fixed capacitance matching system is shown changing the range of the capacitance for the varactors. Note that the value of the fixed capacitance 3.7pF is included in every range of the capacitance. The range of 3.0pF – 4.0pF gives the best improvement among the four samples, as shown in Fig. 4. This is neither the narrowest nor the broadest range of the capacitance. From this result, we can conclude that the broader range of the capacitance for the varactors does not always give a better improvement in the mismatch.

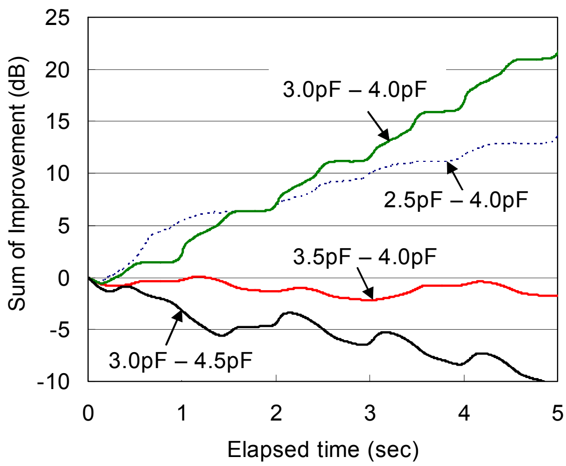

Fig. 4: Effect of the range of capacitance for the varactors on the mismatch improvement

Here a procedure for searching the better range of the capacitance for the varactors is shown.

(1) First, the range of the variation for the antenna impedance should be estimated on a basis of application.

(2) Second, the varactor should be chosen. The varactor should obtain as better impedance matching as possible with the variation of the antenna impedance. The appropriate inductance L should be chosen so as to achieve this goal. This can be realized by parametric simulations. We choose the range of the capacitance so that a good matching is achieved at as many points as possible. If a good matching is obtained only in a small portion of the range of the capacitance, the

improvement in the mismatch over the fixed matching system might not be satisfactory.

(3) Actually, we cannot always obtain such a varactor with the appropriate range of the capacitance, because of its availability from the market. In that case, we may utilize a varactor, which has a broader range of the capacitance than desired, by limiting the range of the control voltage.

Fig. 5 shows the results of the control voltage limitation. Improvement over the fixed capacitance system is illustrated. The condition of the simulation is the same as in Fig. 2 and 3, except the range of the capacitance for the varactors, i.e. 2.5pF – 6.0pF.

Two examples of the control voltage limitation are shown in Fig. 5. (1) One is a way in which the control voltage experiences a smaller gain (G2 in Fig. 1) so as to satisfy the appropriate range of the capacitance considered in Fig. 4. A bias voltage is necessary to give the lower limit of the control voltage. In Fig. 5, the gain G2 is about 0.6 compared with 2.0 in Fig. 2. Also the bias voltage is 16.7V. Then, the range of the capacitance moves between about 3.0pF and 4.0pF, which corresponds to the best range of the capacitance in Fig. 4. (2) The other way of the voltage limitation is to forcibly restrict the range of the control voltage without changing the gain G2. This means that a limiter is inserted between G2 and VC1 in Fig. 1, and the control voltage can move freely to give the control of 2.5pF – 6.0pF, just before the limiters for VC1 and VC2. The lower and upper limiting voltages are determined so as to give the same range of the control voltage as method (1). Then the range of the capacitance for the varactors is confined to 3.0pF – 4.0pF.

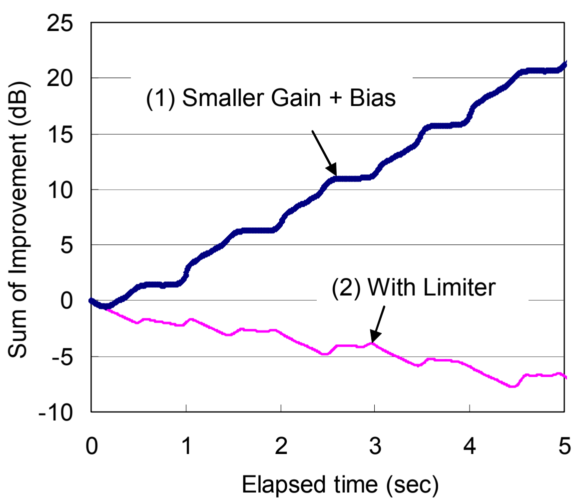

Fig. 5: Time integration of improvement between two limiting methods, (1) smaller gain + bias, and (2) forcible limiter. Note that the range of the capacitance for the varactors is 3.0pF – 4.0pF for both limiting methods.

As explained above, the range of the capacitance for both limiting methods is the same in Fig. 5. The improvement, however, is quite different. About 4.2dB of the time averaged improvement is observed in (1) at 5sec, while in (2) the value of the improvement is negative, i.e. it performs worse than the fixed capacitance system. We may conclude that in the method (2) the performance of the matching is degraded due to overshooting in the control, while in the method (1), such overshooting happens less frequently, because of the small gain.

5. CONCLUSIONS

An adaptive impedance matching system for mobile communication has been proposed. The improvement of the mismatch in a time averaged sense by about 4dB or more over the fixed matching circuit has been confirmed by using the simulation. Also the appropriate range of the capacitance for the varactors was investigated. In addition to that, a useful way has been indicated in order to achieve a better improvement in the mismatch employing the available varactors from the market.

An implementation of the proposed system to existent mobile systems would be rather easy, because it doesn't need any command signal from the existent system, and requires only one or two additional components for the reflection measurement. The measurement components might be directional couplers or simple coupled lines. Also the total area of the system is expected to be less than several mm^2 in the form of an analog ASIC. The tradeoff here is how much of the improvement in the impedance matching will be consumed by the loss caused by the introduction of the proposed system. However, the insertion loss of the proposed system will be continuously alleviated with the advent of a varactor, whose loss is smaller compared with currently available ones.

The experimental study will be reported in the next occasion.

6. ACKNOWLEDGEMENT

This research was supported by the Telecommunications Advancement Organization of Japan.

7. REFERENCES

[1] K. Ogawa, T. Matsuyoshi, and K. Monma, "An analysis of the performance of a handset diversity antenna influenced by head, hand, and shoulder effects at 900MHz: Part I – effective gain characteristics," *IEEE Trans. Vehicular Technology*, vol. 50, no. 3, pp. 830-844, May 2001.

[2] T. Takahashi, Y. Koyanagi, K. Ogawa, and K. Ito, "Automatic impedance matching of an active antenna near the human operator by the steepest gradient algorithm," *Proceedings of the 2003 IEICE general conference*, p. 61, B-1-61, March 2003 (in Japanese).