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# A Sensitivity Adjustment for Tunable Antenna Using Predictive Data

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***Abstract*—New wireless communication standards and multi-functionality such as smartphones demand the development of an antenna that can cover wide band frequency but keeping smaller size. As an antenna equipped with their features, tunable antennas have been developed. The tunable antennas enable us to change its frequency characteristic by an electrical signal. In this paper, we propose a method to adjust the electrical signal of tunable antennas for keeping maximum sensitivity. We uses the golden section search as a fundamental technique to adjust the sensitivity of a tunable antenna. It, however, fails the search because of measurement errors. Therefore, we first determine the range of that the golden section search succeeds, and then, apply the golden section search on. This will prevent the failure of the search. Further, we use predictive data to follow the change of the sensitivity of a tunable antenna caused by frequency changes and/or environmental disturbances.**

## I. INTRODUCTION

Recently, mobile devices have a lof of function such as telephone, e-mail and web browsing, which requires the connection to the Internet. Such a frequent communications decrease sustainable time of the battery of a mobile device. The consumption of the battery tends to increase when communication errors and signal amplification happen. We need to decrease the communication errors and signal amplification for the increase of the sustainable time of a battery.

On the other side, new wireless communication standards, LTE (Long Term Evolution), is ready to be used. LTE uses different frequency band from GSM and CDMA to prevent interference of electrical signals. To cover the wide frequency band, we need to equip several antennas in one mobile devise, however, some mobile devises such as smart phone may not afford to equip them. Thus, we demands the development of an antenna that can cover wide band frequency but keeping smaller size. As the antenna equipped with their features, a tunable antenna [1][3] has been developed. The tunable antenna enables us to change its operational frequency by controlling the level (logic) of a variable capacitor. Since the communication errors and signal amplification happens when the operation frequency of an antenna does not match with the frequency of electrical signal, we can decrease them by the adjustment of the operational frequency.

In this paper, we proposes a method to adjust the operational frequency of a tunable antenna for keeping maximum sensitivity. We uses the golden section search as a fundamental technique to adjust the sensitivity of a tunable antenna. It, however, fails the search because of measurement errors. Therefore, we first determine the range of that the golden section search succeeds, and then, apply the golden section search on. This will prevent the failure of the search. Further, we use predictive data to follow the change of the sensitivity of a tunable antenna caused by frequency changes and/or environmental disturbances.

The remainder of this paper is structured as follows. In section II, we mentions related works. After that, we explain a tunable antenna in section III. In section IV, we proposes a method to adjust the operation frequency of a tunable antenna, and conducts experimental results in section V. Finally, we conclude the paper in section VI.

## II. RELATED WORKS

Sun et al[6] realizes an antenna working on the wide variery of frequency by changing the impedance of the antenna. However, it requires much electricity. Thus, tunable antenna[2][4], which works on the wide variery of frequency but does not consume much electricity, has been developped. Nishio et al[2] proposes to use MEMS variable capacitors for a tunable antenna. Oba et al[4] discusses the miniaturization of a tunable antenna. These studies discussed the configuration of a tunable antenna, however, does not discuss how to adjust the characteristics of a tunable antenna for corresponding to disturbances and the changes of frequency.

Firrao et al[8] proposes a method to adjust the impedance of antenna caused by disturbances such as a table, a head or a hand, and confirms the validity at 900MHz. Boireau et al[9] discusses to share an antenna in several communication ways. Razavi et al[10] proposes a method to increase the efficiency of an antenna by changing the slope of the antenna. These studies improves the sensitivity of an antenna, however, does not take a tunable antenna into consideration.

A method to adjust the sensitivity of tunable antenna are reported in [11] and [12]. Mckinzie et al[11] proposes a method to adjust the sensitivity by using a look-up table which has frequency and ipedance pairs. [12] proposes to adjust the length of a tunable antenna based on received signal strength indicator (RSSI) and signal-to-interference and noise ratio (SINR). These studies, however, does not explain the detail of their method, further, does not focus on disturbances.

## III. TUNABLE ANTENNA

Generally, the sensitivity of the antenna is expressed in VSWR (Voltage Standing Wave Ratio). VSWR has a value of 1 to $\infty$. An antenna has most suitable sensitivity when VSWR

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is 1 because of no reflection wave. A tunable antenna enables us to change its suitable sensitivity as shown in figure 1. The antenna has most sensitive in the communication with 950 MHz when we adjust the logic to 0; most sensitive with 710 MHZ when the logic is 31.

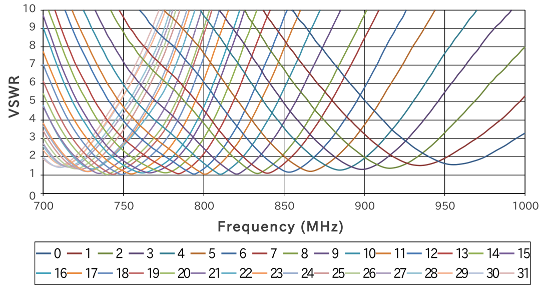

Fig. 1. Characteristic of a Tunable Antenna.

Moreover, the sensitivity of the antenna is affected by neighboring environment. For example, the sensitivity of the antenna changes by the change of temperature, the approach of a human body and/or metal [5], as shown in figure 2. Figure 2 means an antenna is more sensitive when the reflection voltage is lower. For example, logic 15 is most sensitive in no diturbance environment . By adjusting a logic to keep most suitable sensitivity, we can suppress the consumption of a battery.

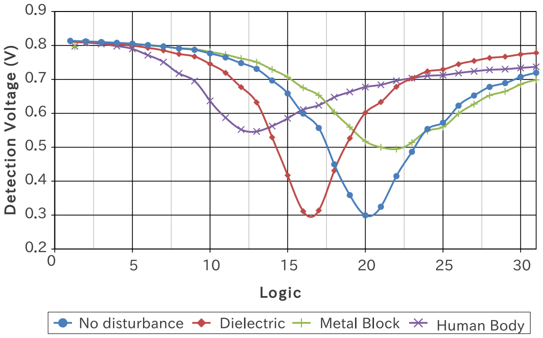

Fig. 2. Change of Antenna Characteristic in Different Environments at 750 MHz.

As shown in figure 1 and 2, the characteristic of a antenna becomes a monomodal graph . Therefore, the most suitable logic becomes the peak of a monomodal graph. Thus, we need to find a peak logic for keeping most suitable sensitivity. Also, on the specification of an antenna, we can use only reflection voltage for the peak logic search. A peak logic can be found easily if we obtain the reflection voltage of all logics. It, however, requires a lot of swithes of a logic, which consumes a battery. Therefore, we need to reduce a number of the switch of a logic to find a peak logic.

## IV. PEAK LOGIC SEARCH

The characteristic of tunable antenna is monomodal graph. Since the golden section search is the most effective peak search technique in monomodal graph, we uses the golden section search as a fundamental technique to adjust the sensitivity of a tunable antenna. It, however, fails the search because of measurement errors. The difference of reflection voltages between adjacent logics around a peak logic are big. It, however, is almost same in distant adjacent logic from a peak logic. This may cause the reversal of reflection voltages by a measurement error. Therefore, we must first determine the range of that the golden section search succeeds, and then, apply the golden section search on. This will prevent the failure of the search.

In addition, a peak logic changes when frequency and/or environmental disturbances change. Therefore, it is necessary to search a peak logic again. Here, the change of a peak logic is detected by the change of reflection voltage measured. We infer a new peak logic by using the change of its reflection voltage. For example, as shown in figure 3, we can infer a new peak logic exists near an old peak logic when the change of its reflection voltage is small; in figure 4, a new peak logics exists far away from an old peak logic when the change is big. Therefore, we prepare predictive data to infer a new peak logic. By using predictive data, we can narrow a search range. It enables to follow the change of the sensitivity immediately.

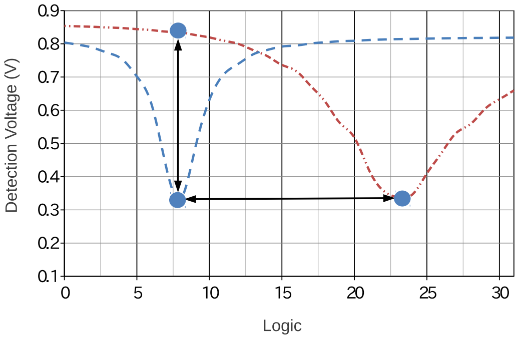

Fig. 3. Peak Logic when the change of reflection voltage is big.

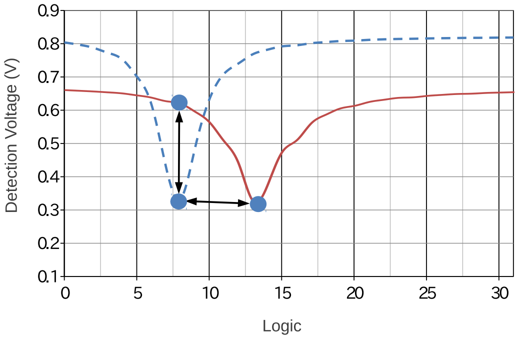

Fig. 4. Peak Logic when the change of reflection voltage is small.

The flow chart of our search method is illustrated in figure 5. we first determine the range of that the golden section search succeeds. Then, we find a peak logic within its range by using the golden section search. After that, data are transmitted and received in its logic until the change of reflection voltage detected. If the change of reflection voltage is detected, we determine the search range by using predictive data, then, uses the golden section search on.

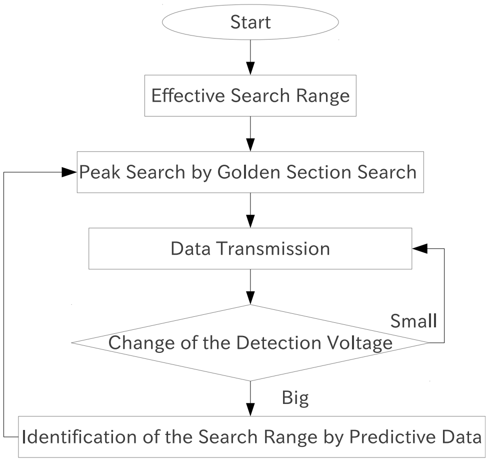

Fig. 5. Flow Chart of Peak Logic Search.

### A. Determination of the Search Range

When the reversal of reflection voltages happens by measurement error, the golden section search fails. However, if measurement error does not cause the reversal, it has no problem. Thus, when the different of the reflection voltage between adjacent logics is more than measurement error, the measurement error does not cause the reversal. Therefore, we measure the reflection voltage of each logics beforehand; discover a group of logics which does not cause reversal; and put the number of logics in the group as $a_0$. When we measure the reflection voltage of every $a_0$ logics, we can certainly measure a logics which the measurement error is ignorable. If we apply the golden section search on logics around it, the golden section search will not fail.

### B. The Golden Section Search

The golden section search is an algorithm for finding the extreme value in monomodal function by successively narrowing the search range of values inside which the extreme value is known to exist. In the golden section search for a tunable antenna, we calculate point $x_1$ and $x_2$ which divide search range$[x_0,\ x_3]$ into $1 : \phi,\ \phi : 1$ where $\phi$ is $1+\frac{\sqrt{5}}{2}$. Next, we compare the value of $x_1$ with the value of $x_2$. Then, if $x_1 > x_2$, we narrow a search range to $[x_1,\ x_3]$. Otherwise, we narrow a search range to $[x_0,\ x_2]$. By repeating above steps recursively, we can find the extreme value. The figure 6 is an overview of the golden section search in tunable antenna.

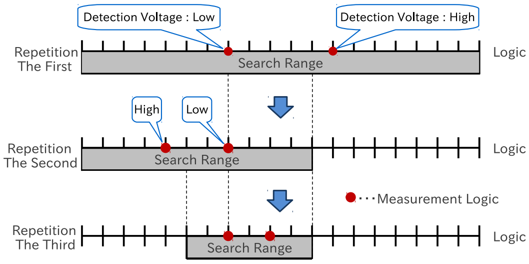

Fig. 6. Golden Section Search for Tunable Antenna.

### C. Golden Section Search with the Determination of Search Range

After we determine a search range (we call it as $effective\ search\ range$) for the golden section search, we find a peak logic within the effective search range by using the golden section search. Here, we consider to reuse the reflection voltage of a logic measured in the determination of the effective search range.

When we search a peak logic within range$[x_0,\ x_3]$ by the golden section search, we need to measure the reflection voltage of logics of $x_1$ and $x_2$. Therefore, if a logic used in the determination of the search range is $x_1$ or $x_2$, we can reuse it for the golden section search. To reuse it, we define that the number of logic included in $[x_0,\ x_2]$ is $a_0$, and the number of logic included in $[x_0,\ x_1]$ is $a_1$. For example, if $a_0$ is 12 and $x_0$ is logic 0, $x_1$ is logic 7 (so that, $a_1$ is 7), $x_2$ is logic 12 and $x_3$ is logic 19. The golden section search succeeds when a search range is narrower than $a_0 + a_1$.

Here, we assume that search range is $[y_0,\ y_7]$. At first, we measure the reflection voltage of $y_1$ which is $a_1$ distance from $y_0$, and $y_2$ which is $a_0$ distance from $y_1$. If the reflection voltage of $y_1$ is smaller than the reflection voltage of $y_2$, the effective search range becomes $[y_0,\ y_2]$. Here, we can obviously reuse $y_1$ for the golden section search within $[y_0,\ y_2]$.

Otherwise, after the measurement of $y_2$, we repeat to measure the reflection voltage of $y_{n+1}$ which is $a_0$ distance from $y_n$ until the reflection voltage of $y_{n+1}$ is smaller than the reflection voltage of $y_n$, where n is 2, 3, .... Here, we assume $y_3$ becomes smaller than $y_2$. In this case, there are two probable graph patterns as shown in figure 7. However, we cannot find a peak logic by the golden section search because the objective range is too broad. Therefore, we measure the reflection voltage of $y_4$ which is $a_1$ distance from $y_3$. Then, the reflection voltage of $y_4$ is bigger than $y_3$, the effective search range can be determined as $[y_2,\ y_4]$. Since this range is equal to $a_0 + a_1$, the golden section search succeeds; the reflection voltage of $y_3$ can be reused for the golden section search within $[y_2,\ y_4]$.

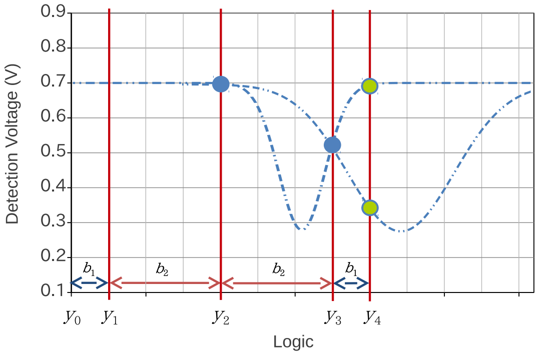

Fig. 7. Probable graph patterns when $y_2 > y_3$.

If $y_4$ is smaller than $y_3$, a peak logic exists in $[y_3,\ y_7]$. Since this range is too broad for the golden section search, we measure the reflection voltage of $y_5$ which is $a_0$ distance from $y_4$. If $y_5$ is bigger than $y_4$, the effective search range becomes $[y_3,\ y_5]$, which is successful ranges of the golden section search and $y_4$ is reusable. If $y_5$ is smaller than $y_4$, we measure the reflection voltage of $y_6$ which is $a_1$ distance from $y_5$. If $y_6$ is bigger than $y_5$, the effective search range becomes $[y_4, y_6]$ and $y_5$ is reusable. We repeat above steps until the search range has been determined.

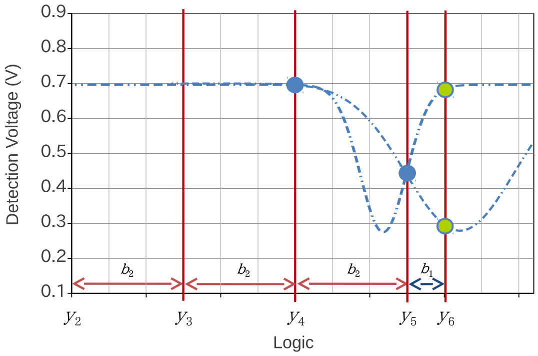

Fig. 8. Probable graph patterns when $y_4 > y_5$.

Thus, we can reuse the reflection voltage of a logic measured in the determination of the search range for the golden section search.

### D. Predictive Data

Since the change of a peak logic is detected by the change of reflection voltage measured, we can use its reflection voltage to infer a new peak logic. Therefore, we prepare predictive data in advance for the inference of a new peak logic. The predictive data is created by analyzing the reflection voltage of each logics.

Figure 9 is an example of analysis result at logic 0, where the vertical axis is a probable new peak logic number and the horizontal axis a reflection voltage measured. From figure 9, we can infer that a peak logic is one of logic 11 to 31 when the reflection voltage measured at logic 0 is 0.82V. Therefore, we prepare predictive data as the pair of a reflection voltage and probable new peak logic numbers.

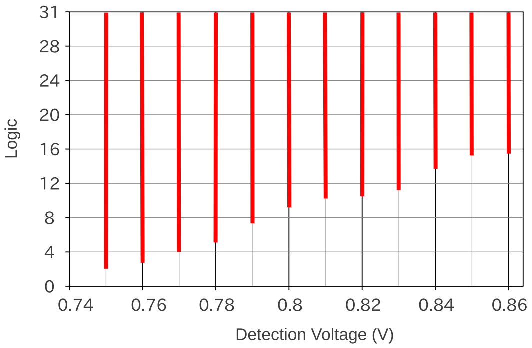

Fig. 9. Correlations between a reflection voltage measured and a new peak logic at logic 0.

When the change of reflection voltages is detected, we first get probable logic number by refering predictive data. After that, we find a peak logic within their logic numbers by the same process of section IV-C.

## V. EVALUATIONS

We evaluate our method on a simulater. Data used in the simulater are acquired on the environment shown in figure 10, that consists of a signal generator, a tuner, a coupler, a tunable antenna, a detector and a multi-meter. We assume the tunable antenna enables to swith a logic in 32, 64, 96 and 128 levels. Also, we prepared five disturbances, a human body at 10cm, 5cm, 2cm, 1cm distance from a tunable antenna, and no disturbance. We evaluated the number of logic switches when frequency and disturbanse change randomly. We show evaluation results in table I.

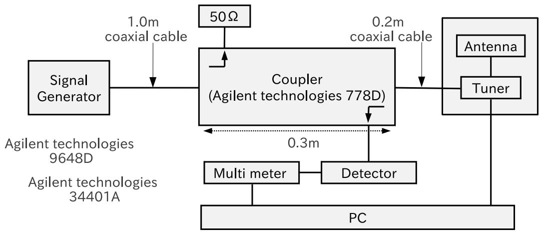

Fig. 10. The Experimental Equipment.

TABLE I. EVALUATION RESULTS.

| the number of logics | average number of logic switches | failure rate |
|---|---|---|
| 32 | 6.53 times | 0 % |
| 64 | 6.64 times | 0 % |
| 96 | 7.65 times | 3.49 % |
| 128 | 7.88 times | 10.49 % |

Peak logic search does not fail when the number of logics is 32 and 64, however, it cause 3.49 % failure when 96; 10.49 % when 128. The average number of logic switch increases when the number of logics increases, however, its degree is relatively slow.

## VI. CONCLUSION

This paper proposed a method to adjust the sensitivity of a tunable antenna. Our proposed method enables to find a peak logic efficiently while preventing failures caused by measurement errors. The result shows our method reduces the number of logic switches for the adjustment of the sensitivity of a tunable antenna. It will reduce the number of communication errors and signal amplification, and in the sustainable time of a bettery increases.

## REFERENCES

[1] MINEMURA Takashi, SUZUKI Hiromich, OHBA Isao: Tunable Antenna Technologies, TOSHIBA REVIEW, Vol.61, No.7, pp.33-36, 2006.

[2] NISHIO Masaki, TSUTSUMI Yukako, OBAYASHI Shuichi: Miniaturization Technologies for Tunable Antenna Using MEMS Variable Capacitor, TOSHIBA REVIEW, Vol.66, No.4, pp.16-19, 2011.

[3] SUZUKI Hiromich, OHBA Isao, MINEMURA Takashi, AMANO Takashi: A Study of A Compact Loop Antenna for Mobile Phone for Digital Terrestrial Broadcasting System, The Institute of Electronics, Information and Communication Engineers, Vol.105, No.188, pp.47-52, 2005.

[4] OHBA Isao, SUZUKI Hiromich, MINEMURA Takashi, AMANO Takashi: A Study of a T-shaped Antenna for Mobile Phone for Digital Terrestrial Broadcasting System, The Institute of Electronics, Information and Communication Engineers, Vol105, No.262, pp.85-90, 2005.

[5] SATO Kazuo, NISHIKAWA Kunitoshi, SUZUKI Noriyoshi, OGAWA Akira: Analysis of Antennas Mounted on Portable Equipment near Human Body, The Institute of Electronics, Information and Communication Engineers, J79-B-II, No.11, pp.892-900, 1996.

[6] Sun, Y. and Fidler, J.K.: High-Speed Automatic Antenna Tuning Ynits, Proc. 9th International Conference on Antennas and Propagation, pp.218-222,1995.

[7] Huang, L., Schroeder, W.L. and Russer, P.: Theoretical and Experimental Investigation of Adaptive Antenna Impedance Matching for Multiband Mobile Phone App;ications, Proc. Wideband and Multi-band Antennas and Arrays, pp.13-17, 2005.

[8] Firrao, E.L., Antenna, A.J. and Nauta, B.: An Automatic Antenna Tuning System Using Only RF Signal Amplitudes, IEEE Trans. Circuits and Systems II: Exp.Briefs, Vol.55, No.9, pp.833-837, 2008.

[9] Boireau, O., Townsend, K., Koplemanet, A., etal.: Antenna aharing techniques, US Patent. 7873385, 2011/01/18.

[10] Razavi, R.: Self-Optimisation of Antenna Beam Tilting in LTE Networks, Proc, Vehicular Technology Conference, pp.1-5, 2012.

[11] Mckinzie, W.E., Mendolia, G. and Manssen, K.: Adaptively Tunable Antennas Incorporating an External Probe to Monitor Radiated Power, US Patent. 8125399, 2012/02/28.

[12] Adaptation Tunable Antenna of the Radio Apparatus, QUALCOMM INCORPORATED, WO2009/114838. 2011-517519, 2011/06/09.