Microcontroller Programming for Smart Antennas: *Implementation*

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1. Introduction

The controller unit incorporated into the switched beam smart antennas plays very important role as the intelligent part. In practical operation, this part continuously performs two main tasks; ***firstly,*** to detects, to processes, and to interprets the received RF signal and ***secondly,*** to decides what sort of actions required to maintain the performance of wireless communication system. The controller system is not a perfect and complete unit to capable for fully handling all the possible utilities the smart antenna system can do, as for example [1-2]:

1. to mitigate the multipath fading effect (to enhance the signal reliability)
2. to improve the electromagnetic compatibility (to minimise the interference effect from and to nearby objects).
3. to increase the efficiency of the frequency use
4. to track more than one target continuously

To perform one of those functionalities, it requires the additional external electronics parts to build the self adaptive control mechanisms for the whole antenna system [3-5]. These parts can be classified into two groups i.e. the RF signal processing part and the beamforming unit. The first part may consist of the low noise amplifier (LNA), RF filter, RF-splitter/combiner, RF detector, the signal conditioning circuit (SCC), the external preset power threshold circuit, and DC power supply. The signal processing system is connected to the input line of the controller. The beamforming unit can be constructed using one of several different functional units i.e. RF switching components (such as p.i.n. diodes and varactor diodes) or phase shifter components. These components must be combined with other parts such as resistors, capacitors, and inductors (or RF Chokes) to support the beamforming unit to perform in an appropriate way. This unit are connected to each corresponding output pins of microcontroller. The intelligent circuit track printed underneath the antenna elements (active or passive).

In spite of the many applications the smart antenna systems can perform, in this part of tutorial the author would like to share his experience on developing the controller programming algorithm that applicable for an electronically beam steering. The physical prototype of smart antenna was constructed to form a circularly monopole array (CMA) mounted on the circular cylindrical hollow ground structure. The RF intelligent circuit printed under the circular ground plane was designed to perform the following tasks:

1. to continuously sense, process and translate the received RF signal
2. to simultaneously evaluate the equivalent value of RF signal power fed to the input port of the controller part
3. to periodically forward the messages, in terms of bit-bit sequences, to the output port of controller in order to steer the activation of the beamforming unit as the wireless environment change (i.e. the received power level drop below the preset threshold power).

2. Controller Programming Techniques: *Comparison* and *Selection*

The fast development and the broad applications of smart antenna technology at the recent and future eras of the wireless communication network could not be separated from the recent advancements of the following three aspects including [6]

1. the development of the low-cost and sophisticated DSP (digital signal processors) modules widely available in the market place,
2. the advancement in the general purpose processors (and ASICs—Application-Specific Integrated Circuits) including PIC-Chips, Chipcon, ATMEL and so on,
3. the innovative and attractive researches and developments (R&D) of wireless software-based signal-processing techniques (algorithms)

The tremendous development of those technologies significantly influences the variety and capability of the constructed intelligent unit. The determination of what sort of controller algorithms the designer are going to use really depending on the main goal and functionality of whole smart antenna design. In particular application, perhaps, an engineer prefers to have the best performance design rather than thinking the manufacturing costs of the smart antenna system. If this is the goal then the designer can utilise the excellence and complete parts of DSP/controller modules with the programming software included. At another situation, people may choose the cheapest price of controller device available in the market in order to press the manufacturing cost without sacrificing the performance of the designed antenna. For such option the designer must find a separate and free licence of programming tool to write and to up load the programmed algorithm to a microcontroller device.

According to the author experience on developing the couples of switched beam smart antenna prototypes there are some microcontroller devices, which are relatively cheap, small size and low power consumption, can be utilised. These are including PIC Chip, Chipcon, and ATMEL controllers. Terminology, PIC stands for peripheral interface controller. The PIC 16F62X [7] and CC1010 ChipCon [8] controllers were extensively used [3-4, 9] in a number of published papers of the author [3-4], [9]. Besides, there is also another family of PIC chip can be used i.e. PIC16F87X. These chips, in contrary to PIC16F62X (which have eight possible configuration of comparators), only have one set of A/D converter. The proper selection whether to use the 16F62X or 16F87X is depending on how complex the signal processing algorithm is going to implement. If we only want to compare the RF reception with the preset power threshold (resemble the fading threshold allowed) at a time instant then the selection to use PIC16F62X is appropriate. However, if a designer is going to construct the intelligent unit which capable to detect the RF power level from all possible directions and then select only the stronger signal at certain time period as fading occurred on the network, PIC16F87X is an appropriate choose to use. The reason is because PIC16F87X can be programmed to capable for detection, memorising, and selecting the maximum numerical value of the equivalent RF power from many possible RF levels received at an instant scanning period.

For the simplicity and efficiency on transferring all the contents of the manuscript/tutorial, in this workshop, the author would like to focus the entire discussion only on the programming technique for the PIC 16F62X device. This device is an 18-Pin-FLASH/8-bit microcontroller chip of low cost, high performance, CMOS and fully static. The PIC16F62x family is supported by a full-featured macro assembler, a software simulator, an in-circuit emulator, a low-cost development programmer and a full-featured programmer. A third party "C" compiler support tool is also available [7]. Moreover, this chip has another special feature to reduce the external components such as 1-bit ADC (comparator) and oscillator device, thus reducing system cost, enhancing system reliability and reducing power consumption. The capability of PICC ANSI C Compiler to combine the C standard and Assembly languages in one source code has also contributed to strengthen the art of PIC chips programming for the special application purposes.

The second interesting controller device that can be used to form RF intelligent and beam control unit for the designed smart antennas is CC1010 ChipCon device. This was used to implement ***a dual band steerable directional antenna*** [9] and ***rectangular patch with parasitic folded dipoles:*** *reconfigurable antenna* [10]. The controller used in the antenna design was initially programmed using C-compiler of Keil uVison2. This device is a single-chip transceiver configured together with single MC8051 of 32 kB flash program memory. The transceiver has relatively wide operation band. It spans at the frequencies starting from 300 MHz to 1 GHz [8]. The special characteristics of ChipCon controller is the device only require few external electronics components to make a single transceiver unit works. This will make the prototype of smart antenna design is simple, compact and low power consumption. In terms of implementation costs this scheme offers the cheapest antenna design. This controller device can be programmed in such away to improve the quality of communication by involving BER checking functionality and can be used with and in-built frequency hopping spread spectrum (FHSS) technique. There are two data error correcting methods available in CC1010 i.e. NRZ (non return to zero) and Manchester coding. Both data coding techniques are widely used for RFID applications. A typical antenna design can be power-up using battery elements of 3 Volts or less. Due to the small size characteristic of the CC1010 ChipCon device, on the process for downloading the executed programming algorithm into the chip and for connecting and soldering the electronic circuit one should pay an extra attention and treat them carefully.

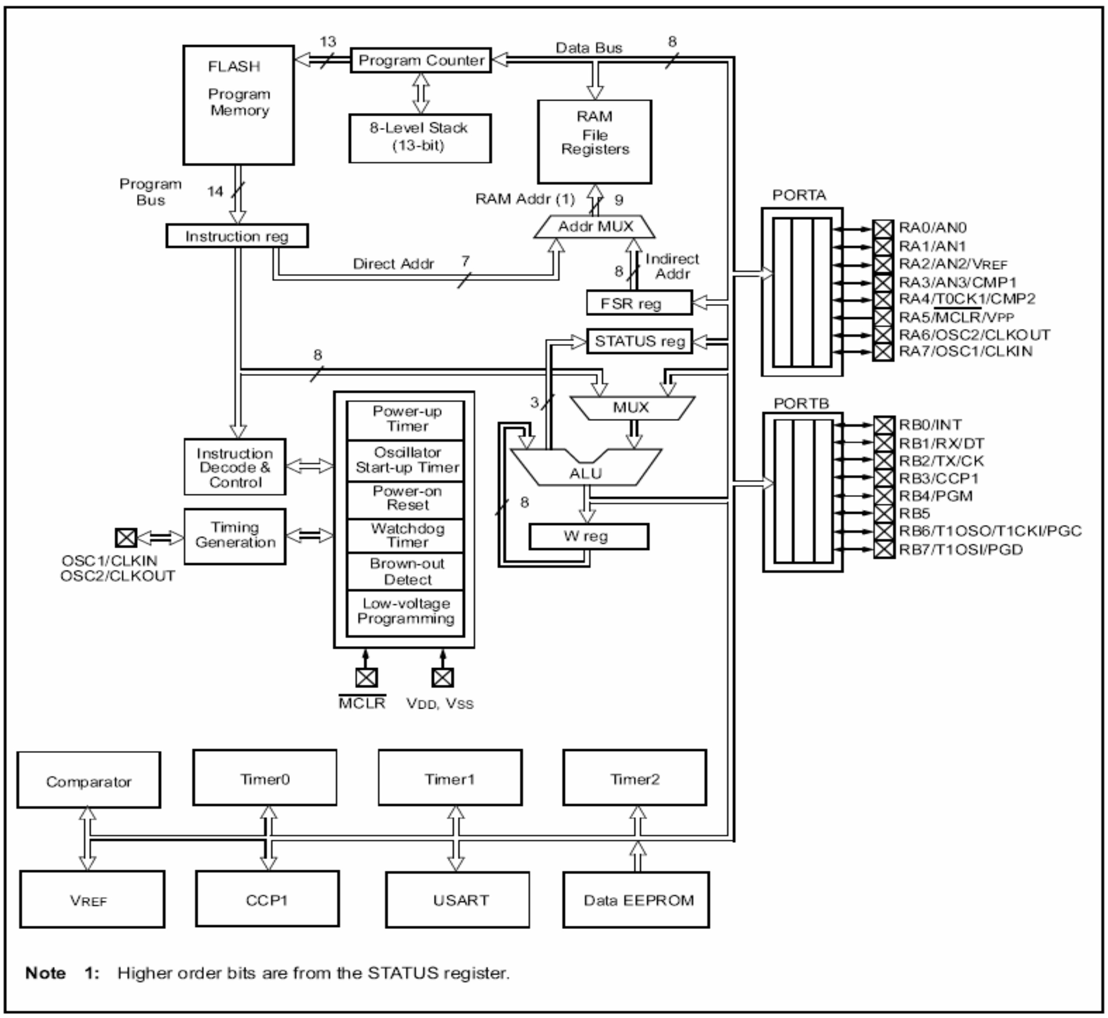

Figure 1: PIC 16F62X Architecture [7]

3. Programming Procedures for Microcontroller Device [11]

There are three processes involved on the microcontroller programming in order to set-up its functional algorithms to be suitable with the application requirements of wireless communication system. These processes are described in Figure 2. First of all, the C-language source code is written in a personal computer using the available C compiler, as an example, for PIC chip controller using HI-Tech software. When one file with the extension hexadecimal of the compiled-original source has been successfully generated, then this hex file can be downloaded into the microcontroller device using USB-PIC programmer unit and DYI microPro software for any application constructed using the PIC Chip devices. The last important process is to test the real performance of the microcontroller on the circuit board of wireless system design. Some times, the above processes can be repeated for many times depending on the condition whether the purpose of microcontroller design has been achieved or not. At the present time, there are many PIC programming techniques reported for various applications. All these textbooks could be optimalized as preliminary guideline for exercising in order to be familiarised with the controller programming procedures.

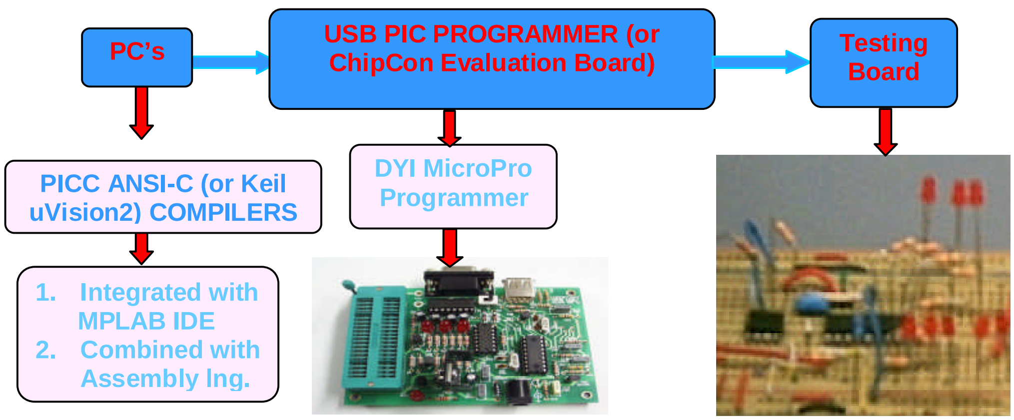

Figure 2: The programming procedures for the microcontroller [Adopted from [11]]

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It has been well known that to form the intelligence level in the designed antenna array such as switched parasitic antenna (SPA) [12], therefore the programmed controller devices (or processors) must be added inside the antenna system as an integrated part. This technique is useful, especially, when the plug and play antenna will be created. In the antenna design process, the designer should also consider what the design requirements will be achieved. This may help to select the proper controller device that provides suitable properties for the antenna construction. In these criteria, the selection may include some aspects such as what block functional features the controller has, the memory capacity to download the programmed algorithms, the electrical properties and the speed of instruction execution.

Initially, the controller algorithm required to implement the switched beam smart antenna is relatively simple technique that could detect the variation of RF power level due to multipath fading effect, at the reception. The fluctuated RF signal levels are classified into ***fade*** (bad quality of signals, low SNR and high BER), and ***non fade*** (good quality). While in the transmit stage the antenna is focusing the pattern only to the intended direction. Therefore, according to that design requirements of intelligent antenna construction it is sufficient enough to use the controller device that capable to distinguish the RF signal based on the criteria of bit logic "1" to represent the presence of fading effect and bit logic "0" used if fading not appear. This simple controller algorithm can be built using 1-bit ADC (or comparator). From many options, for instance in PIC controller families, there are two chips are of interesting i.e. PIC 16F62X or PIC16F877. All chips meet the above antenna design requirements. For instance, both controller devices can works on those bit logic manipulation based on the signals processing results from previous stages. However, if PIC16F877 is chosen the programmed computation algorithm become bigger and complex. Beside, the physical size of this chip is relatively bigger than PIC16F62X, about twice bigger.

To manufacture one type of SBSA antenna fabrication, PIC16F62X was chosen and programmed. The required, external and internal, circuit configuration of PIC16F62X to implement the adaptive controller algorithms should be determined through an appropriate design. This internal circuit configuration was installed using the downloaded controller programming algorithm. For instance, the configurations of comparator unit which can be installed inside PIC16F62X as illustratively drawn in Figure 3 could be selected just one configuration to perform the required design purpose. This installation is automatically done and involved in the programmed algorithms, for an example, as shown in the flowchart diagram (Figure 4). Meanwhile, the external circuit configuration such as the crystal oscillator, supply voltage circuit (V_{cc} *line*), and input/output lines configuration was constructed based on the improvisation from the chip datasheet and some other textbook references as mentioned previously.

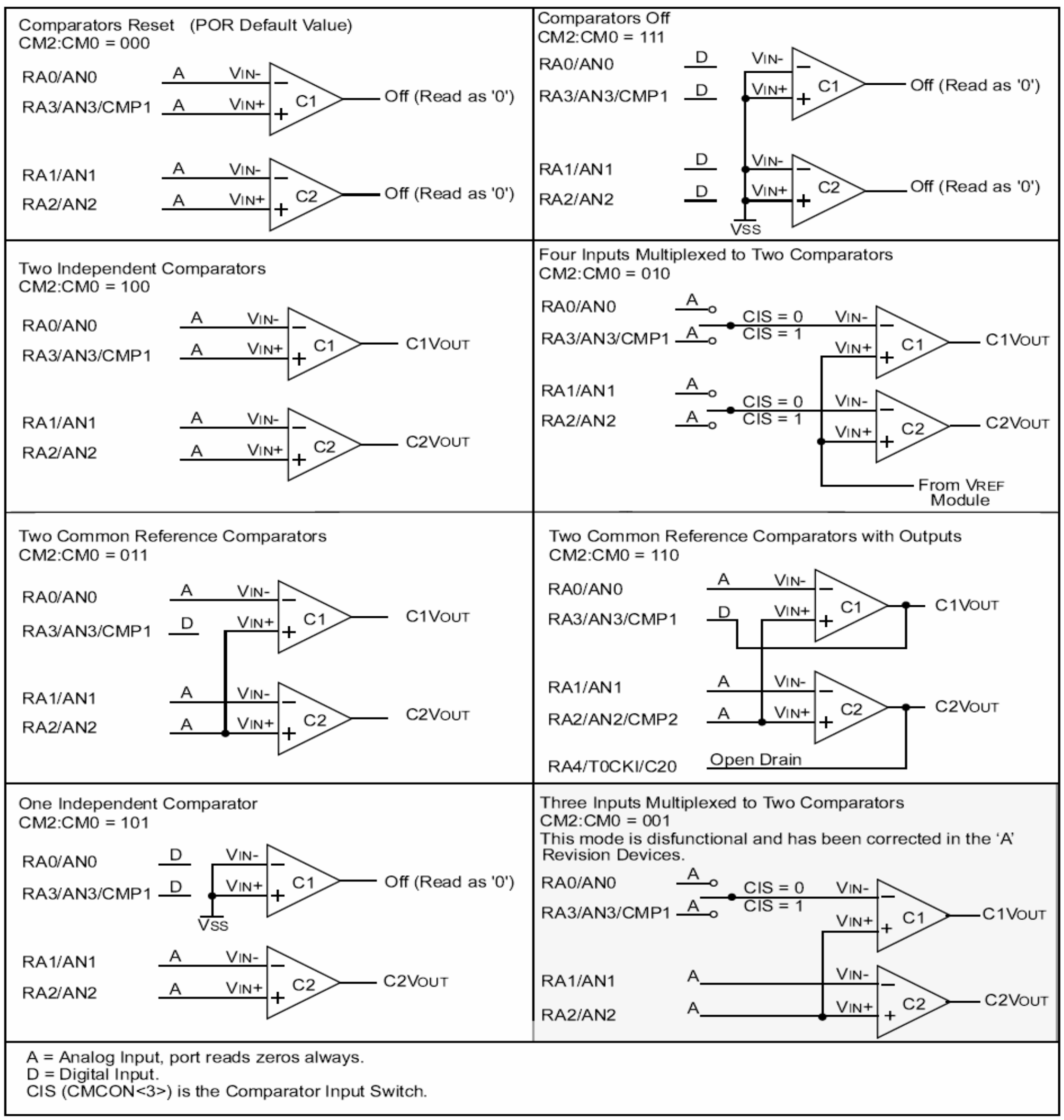

Figure 3: Various comparator configuration of the programmed PIC16F62X chip possible to implement.

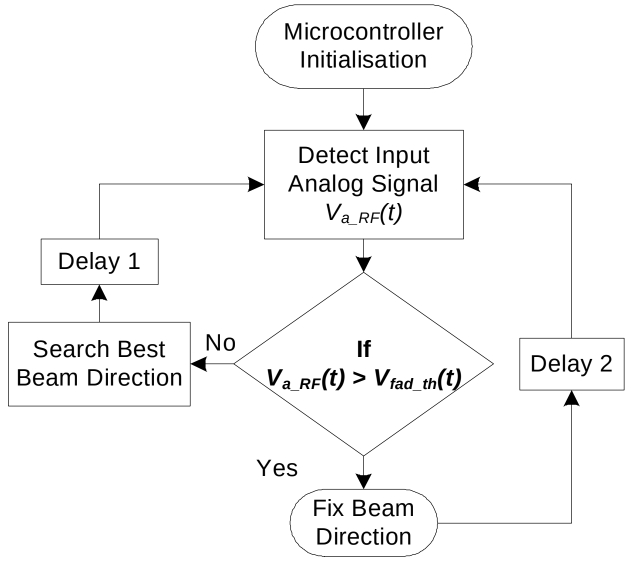

Figure 4: Computation algorithm of microcontroller system

The above algorithm was designed based on the RSSI (received signal strength indicator) parameter obtained directly from the antenna device in order to maximize the SNR of the transceiver. In practical implementation, PIC microcontroller has been programmed to have two main functions. The first function is to act as a 1-bit ADC to detect the RF signal from antenna via the RF signal processing part and then compare this signal with the fading power threshold (See Fig.4 and 5). In this case, the fading power threshold can be set up externally through the input pin 1 (RA2/V_{REF}) of microcontroller system. This value may vary depending on the dynamic range of the designed RF intelligent part. The proper selection of RF devices such as LNA and RF detector to be incorporated into the commercial PCB lay-out results the wide dynamic range. Previous antenna design provides the threshold that can be set up to the boundary value between –80 dBm to +5 dBm. This set-up is matching to the sensitivity (dynamic range) of RF signal processing part.

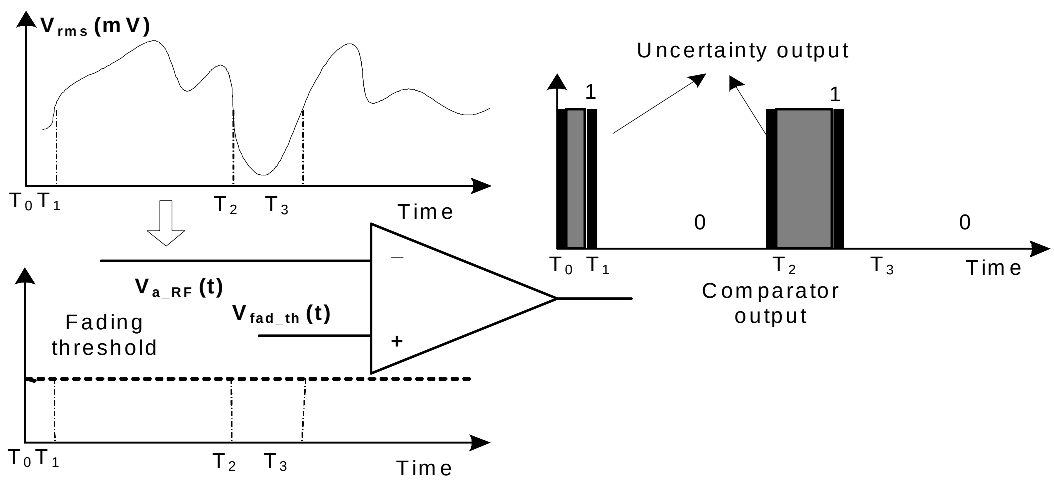

Fig.5: A comparator unit and its corresponding typical input–output signals programmed inside PIC controller. The output bit sequence of 1 0 1 0… resembles the RF signal condition relative to the power fading threshold. The time interval T_0-T_1 and T_2-T_3 representing the RF signal is under multipath fading or interference effect (indicated by output logic 1). *Vin* analog is the equivalent conversion of RF signal level produced from LNA and RF detector stages [11].

Another important function of the microcontroller is to decide the sequence of binary digits being generated to steer the five parasitic wires of SPA to be switched on/off near the resonance frequency (1.5 GHz). Using this scheme the best beam direction can be achieved. In fact, the activation of those passive elements is solely done by the switching network (SN) consisted of p.i.n. diodes, resistors and RF inductors, by simply supplying the bit sequences from PIC chip. To actualise this concept at least one bit of "low logic level" and the remainders of "high logic level" must be configured to get one parasitic monopole open circuited and the remaining monopoles short circuited to the ground. Each of the five parasitic wires is connected to the corresponding output pin of the controller device via an individual SN.

In Figure 4, the task for tracking the optimum direction of antenna radiation/reception will be initiated when the RF-power level received from the antenna device dropped below the set-up fading power level. The time required to do this beamforming process is only a factor of few microseconds due to the time required to execute the delay loop process. This time is determined by a Delay 1 loop (Figure 4). The update time of beam pattern tracking can be computed using the simple procedure. When the maximum direction has been achieved, which is indicated by the value of V_{RF} greater than $V_{Fad\text{-}Th}$, the microcontroller will keep its output to be the same as the previous one for a long time. On the flowchart diagram this is represented by the Delay 2 loop. The programming algorithm of Delay 2 is quite straightforward and worthwhile. It is basically done by recalling Delay 1 loop in the infinite loop routine. This will be executed continuously until there is a changing of bit logic on the output gate of 1-bit ADC from 1 to 0 (see Fig.5).

For a clear explanation, consider the output of microcontroller 01111111 with the condition of V_{RF} greater than $V_{Fad\ Th}$ is detected at a certain time interval. If during this time the condition is still the same then the microcontroller output will not change. The microcontroller will then generate the new output of 10111111 for the next detection if and only if $V_{RF} < V_{Fad\ Th}$ occurred. Furthermore, due to the fading and interference effects encountered in the communication link that cause the power level of the received RF-signals dropped far below the fading threshold power for another specified-time interval, then the microcontroller will sent the binary digit of 11011111, 11101111, 11110111, sequentially. It will be repeated to start from the output 01111111 as long as the algorithm of computation logic $V_{RF} < V_{Fad\ Th}$ is still satisfied on the microcontroller. Each of this output bits will correlate with the main beam directions as for simple illustration let's say 0^0 (360^0), 72^0, 144^0, 216^0, and 288^0, respectively and then loop back to $360^0/0^0$. The required output of the microcontroller and its corresponding beam directions are shown in Table 1.

Table 1: The microcontroller output and the equivalent beam directions

Messages at the output port of microcontroller	Steps (N)	Equivalent Beam Directions ($^{\mathbf{0}}$)
0 1 1 1 1 1 1 1	1	0/360
1 0 1 1 1 1 1 1	2	72
1 1 0 1 1 1 1 1	3	144
1 1 1 0 1 1 1 1	4	216
1 1 1 1 0 1 1 1	5	288

The time required for tracking the maximum direction of smart antenna can be computed using the straightforward method i.e. by translating the C-source code program into the assembly language. This time is determined by the delay algorithm of the microcontroller flowchart. The clock rate of 4 MHz frequency is used to control the operation of microcontroller. Then, the clock time T_{clock} can be computed using such formula adopted in [11] $T_{clock} = 1/f_{clock}$.

The clock rate of 4 MHz frequency crystal oscillator was considered to trigger the operation of microcontroller. Theoretically, this oscillator generates about 0.25 µSec of internal clock period. This value also implies the time required by the microcontroller device to execute one instruction cycle. The number of clock cycles to execute the Delay 1 loop relies on the number initialized to the program counter. In this case, the initial number of 255 decimal, which is equal to 0xFF (hexadecimal number), was selected. This number is counted down in a loop until it equal to zero. Thus, the total counting for the Delay 1 algorithm requires 255 cycles. If the additional 3 cycles to enter and exit the Delay-1 routine of Fig.4 are also considered, therefore the total internal clock cycles equal to 258 cycles. Finally, the time required for Delay 1 loop is about 64.5 µSec. However, this time could be decreased to obtain the faster tracking time by reducing the required time to compute the Delay 1 loop and changing the clock frequency up to 20 MHz. While programming the PIC16F62X family one thing should be noted that the uncertainty of output signal of 1-bit ADC component would always appear due to the response time and input offsets in microcontroller itself. This output signal is illustratively described in Fig.5. In practical situation, this will influence the sensitivity of wireless system to be slightly slow on responding the RF signal fluctuation. This may generate the delay, by a factor of few microseconds, before changing the bit sequences immediately for the adaptive beam steering purpose.

4. Further Works on Controller Programming

In many cases, the impacts of multipath propagation is not a serious matter while speech signals are transmitted through the channel, even though really disturbing, they are not essentially critical in wireless network [13]. Those may become serious problems when the data or signaling is involved in the transmission. In such particular wireless communication system employed TDMA technology, any erroneous on the transmitted frames will impact to the degradation of system performance, indicated by the high BER or the significant delay. Moreover, the drop-off in performance of a typical digital communication network tends to be more dramatic whether the network works or not.

In the special circumstance of wireless digital communication system, the application of the threshold crossing controller algorithm as previously explained is insufficient to tackle the data error transmission due to the effects of more complex system and channel environment. Therefore, the bit error rate (BER) checking must also be involved on the controller algorithm. In principle, this algorithm is the expansion of previous algorithm by inserting one more programming routine to evaluate the level of BER whether satisfy the requirement or below. This algorithm was developed because in practical situation of digital wireless communication even though the received signal strength is good this is not guaranteeing that the serious of data errors does not occur. Therefore, the algorithm to verify the rate of bit error is very important to be involved. The typical model of the developed controller algorithm based on bit error rate checking was introduced to support the operation of the plug and play smart antennas [3, 9].

The programmed RF intelligent unit was designed to detect the RSSI level and BER, and to steer the antenna beam in the best possible direction. Indeed, in this tutorial the author is still using 5 beam directions. For a certain RSSI level and BER below the specified threshold requirement, the intelligent unit will send a different bit output that changes the SN configuration of each parasitic monopole. Alternatively the controller chip will retain its bit output to maintain the beam direction. This will maintain the best quality of signal, independently from the unpredictable effects of fluctuations in the communication channel due to multipath propagation, mobile communication nodes, local noise, or other phenomena. The smart antenna design implemented using this method is particularly suitable to be deployed as the base station terminal for short range communications including Bluetooth networks, wireless sensor networks, and the read antenna of RFID systems when tracking mobile and active nodes.

There are two possible methods to implement the algorithm straightforwardly as an integrated part of RF intelligent circuit for the designed smart antennas. However, the author only limits the scope of this tutorial on utilising the PIC chip 16F62X. Inside the chip, one must generate the couples of 1-bit ADC (comparator). These must be reconfigured by loading the HEX file containing the required controller programming into the chip device. If the previous threshold crossing algorithm using the code instruction CMCON = 0x05 to configure the comparator, it is therefore other seven possible configurations of PIC comparator may be optimalised. For the design requirement of BER checking algorithm two independent comparators can be selected by writing the code instruction CMCON = 0x04. To clearly imagine the comparator configuration refer again to Fig. 3. There are two other comparators need to be installed and connected to the corresponding input and output ports of microcontroller. Four input lines of the configured 1-bit ADC are connected to ports RA0/AN0, RA3/AN3/CMP1, RA1/AN1, and RA2/AN2 of PIC16F62X, respectively. In contrary, two output lines, i.e. C1Vout and C2Vout, are used to represent the output conditions of both comparators. For instance, C1Vout can be chosen to represent the signal condition based on RSSI meanwhile C2Vout is used for BER indication which corresponding with E_b/No (or CINR) level at the end receiver. To guarantee the BER algorithm is working, one should note that the RF intelligent circuit should be placed close to the transceiver part. In addition, many experimental measurements must be conducted to train the designed smart antenna to suit certain applications of wireless network.

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5. Conclusion

It has been demonstrated that the roles of the programmed controller devices (or processors) on constructing the robust smart antennas are vital. With the recent advancements in the microelectronics devices with the high speed of signal processing and low cost are the good sign on resolving the traditional barriers on the development smart antenna technology such as the trade off between intelligent circuit complexity (or performance) and implementation costs.

To obtain the remarkable performance of controller algorithm there are some aspects need to be considered. For instance, the constructed RF intelligent circuit must support and provide the high accuracy and wide dynamic range of the signals processing capability to the controller unit on its practical operation, otherwise it may result the improper execution in the controller programming algorithms. In other word, without these requirements the controller unit will not operate properly. In the worst situation, these might result the wrong interpretation and decision. To guarantee the BER algorithm is working, one should note that the RF intelligent circuit should be placed close to the transceiver part. In addition, many experimental measurements must be conducted to train the designed smart antenna to suit certain applications of wireless network.

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