A STUDY ON THE HARDWARE RECONFIGURATION SCHEMES AND THEIR APPLICATIONS ON SDR-BASED MOBILE COMMUNICATIONS

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ABSTRACT

This paper presents hardware reconfiguration schemes and their applications on Software Defined Radio (SDR)-based mobile communication systems that are reconfigurable to multiple wireless access standards. We suggest two SDR-technology-based reconfiguration schemes using middleware: Unit-based Reconfiguration Scheme (URS) and Master-based Reconfiguration Scheme (MRS). In addition, we verify the feasibility of the suggested schemes by presenting a prototype system that adopts each reconfiguration scheme and by showing their successful reconfiguration tests through experiments.

1. INTRODUCTION

One of the main objectives of Software Defined Radio (SDR) technology is to implement a system capable of accommodating several standards for wireless communications through software changes on a single hardware platform using software blocks equipped with high-speed processing elements [1][2]. Therefore, SDR is interpreted as a technology enabling evolution from incumbent mobile communication market characterized by single-standard, single-frequency based on fixed hardware system to the multiple-standard, multiple-frequency based reconfigurable system [3]-[6].

Many study results on mode switching architecture and procedures using software download have been introduced mainly for access terminal [7]-[9]. Recently, studies on reconfigurable base stations have been conducted actively as on mobile terminals. For example, one of US companies, Vanu has provided trial cellular services based on reconfigurable base stations to Global System for Mobile communications (GSM) and Code Division Multiple Access (CDMA) in Texas [10]. In addition, Electronics and Telecommunications Research Institute (ETRI) in Korea has developed a double mode base station termed Reconfigurable Mobile Convergence for a two-mode access system (ReMo) which is reconfigurable to an IEEE 802.16d Worldwide Interoperability for Microwave Access (WiMAX) system based on Orthogonal Frequency Division Multiplexing (OFDM) technology and to a High Speed Downlink Packet Access (HSDPA) system based on CDMA technology [11].

This paper presents two SDR-technology-based reconfiguration schemes using middleware, so called Unit-based Reconfiguration Scheme (URS) and Master-based Reconfiguration Scheme (MRS) that are reconfigurable to multiple wireless access standards. These schemes improve the reconfiguration ability by adopting Software Communications Architecture (SCA) middleware standard layer on the General Purpose Processor (GPP) in functional hardware board units. Moreover, we verify the feasibility of suggested scheme by presenting a prototype system that adopts each reconfiguration scheme.

We present an SDR-based digital Intermediate Frequency (IF) transceiver for a mobile communication base station using a URS reconfigurable scheme that is reconfigurable to three bandwidth profiles: 1.75 MHz, 3.5 MHz, and 7 MHz, each incorporating the IEEE 802.16d WiMAX standard. It is also reconfigurable to the HSDPA standard. In addition, we suggest an SDR-based digital filter architecture with an MRS reconfiguration scheme applicable to a multiple-channel processing system such as a wireless mobile communication system using CDMA technology. The feasibility of the algorithm is verified by implementing a multiple-channel signal generator that is reconfigurable to other system profiles, including those of a Wideband Code Division Multiple Access (WCDMA) system and a CDMA system.

This paper is organized as follows. In section II, a conventional reconfiguration scheme and SDR-technology based reconfiguration schemes that can be used in base station will be discussed. In section III, we present the URS reconfiguration scheme and its prototype applied to Digital IF transceiver. In section IV, we propose another reconfiguration scheme named MRS and its prototype, multi-channel digital filter. Here, the software architectures and hardware implementations are presented and show that the suggested reconfiguration schemes are feasible and practicable. Finally, concluding remarks are presented in section V.

2. RECONFIGURATION SCHEMES

In this section, we present system reconfiguration schemes including suggested download schemes focused on mobile communication base stations. A conventional base station consists of an L2/L3 block, a modem block, an IF transceiver, a Radio Frequency (RF) transceiver, antennas, and a base station operation and maintenance (O&M) block that controls all functional blocks of the base station, as shown in Fig. 1.

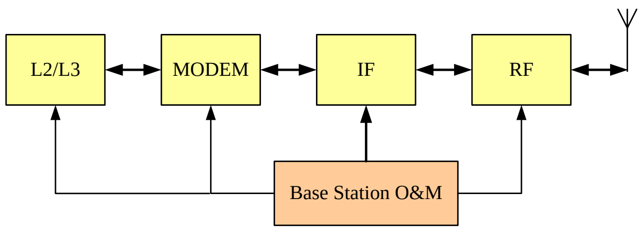


Figure 1. Typical structure of the mobile base station.

It is essentially impossible to reconfigure a base station to other systems because all functional blocks of the base station are designed and implemented by fixed hardware components according to a specific mobile standard. Only the base station O&M block provides limited board-level reconfiguration capabilities when the system needs to be upgraded to introduce new services such as increment of service capacity.

As hardware blocks of base station have been digitalized over time, various reconfiguration schemes to multiple mobile communication standards onto identical hardware platform have been studied. For example, Fig. 2 shows a reconfigurable digital IF transceiver using Read Only Memory (ROM) boot that switches among systems selectively using loadable devices such as a Field Programmable Gate Array (FPGA) with several ROM contained downloadable waveforms.

That is, when the transceiver is reconfigured to a different standard profile, a mechanical switch is adjusted to the selected ROM storing the desired binary file. But cellular service could be suspended for a long time during reconfiguration and it is a critical error for the service provider. In addition, the limitation of the number of service profiles cannot be avoided by the number of ROM and physical board size.

Fig. 3 presents a diagram of an SDR-technology based mobile base station. The characteristic of an SDR-technology based mobile base station is the flexibility of reconfiguration onto identical hardware through software download. It mainly consists of an L2/L3 block that has Radio Resource Control (RRC) and Medium Access Control (MAC) functions, a modem block, an IF transceiver, an RF transceiver, antennas, and an SDR base station manager.

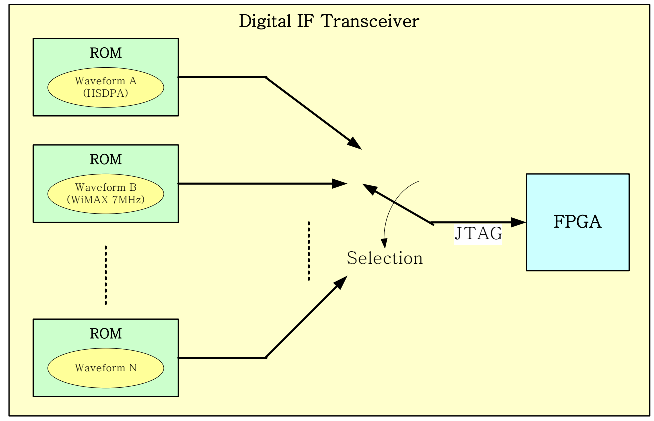


Figure 2. Reconfiguration scheme using ROM boot.

The SDR base station manager controls reconfiguration to an entirely different air interface system when the system needs to be altered, for example according to user traffic variations or propagation environmental changes, while it executes operation and status management function of the overall base station. All hardware components of the SDR-based base station consist of loadable devices such as FPGA and Digital Signal Processor (DSP).

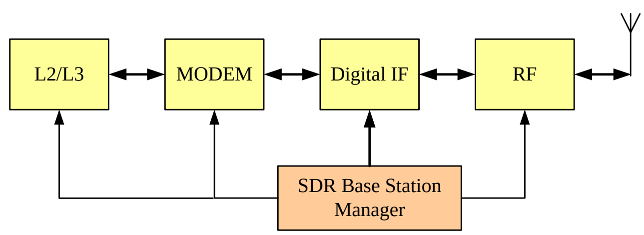


Figure 3. SDR-based base station architecture.

Fig. 4 presents a detailed hierarchical block diagram of each functional block of the SDR-based base station. Unlike a conventional base station designed with fixed hardware components and devices for specific mobile communications standards, SDR-based base stations have functional hardware blocks which contain software stacks layered by firmware, operating systems, and middleware. These software stacks enables the SDR-based base station manager to reconfigure to other standard systems or system profiles through only software downloading.

SDR technology guarantees the portability and reusability of the software, hardware, and also ensures the compatibility of mutual software component among products based on the SCA standard. The application component implementing the wireless communication protocol is arranged to the common terminal hardware based on this policy and requirement. Therefore, an SDR-based base station is capable of extending to multiple modes of operation if it adopts the open architecture provided through SCA based Application Programming Interface (API) operability to other air interface modes.

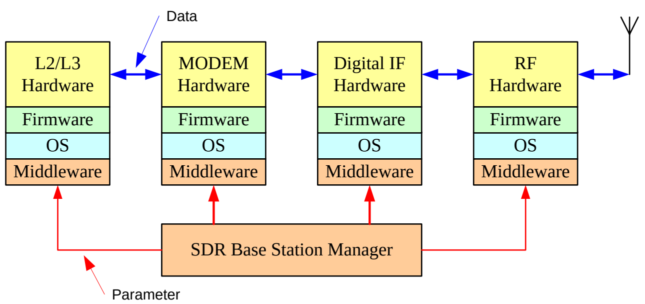


Figure 4. Software architecture of SDR-based base station.

ETRI in Korea developed a double-mode base station termed ReMo to verify the feasibility of SDR technology to a mobile communication base station. ReMo is reconfigurable to an IEEE 802.16d WiMAX system based on OFDM technology, and to a HSDPA system based on WCDMA technology. ReMo uses SDR technologies in which modems and other functional blocks can be reconfigured easily by software downloaded onto identical hardware platforms. The software download interface of ReMo is shown in Fig. 5.

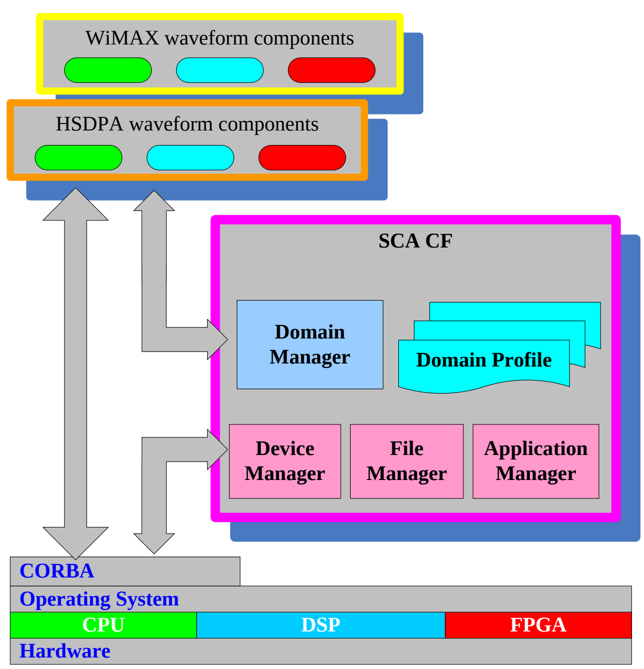


Figure 5. Software download interface of ETRI ReMo.

In a ReMo base station, all software blocks are defined by SCA-based devices or components and the connections between software blocks are defined by interface based on Common Object Request Broker Architecture (CORBA) software bus. In addition, all hardware blocks of ReMo contain CORBA software bus interface functions to support SCA standards. Therefore, all hardware blocks can be reused and portable to any resources or any components only if they follow the requirements of the SCA standard using eXtensible Markup Language (XML) language.

3. URS RECONFIGURATION SCHEME

In this section, we introduce the URS scheme which is all the functional hardware unit comprising system has middleware providing the reconfiguration function by the command from the reconfiguration master. Fig. 6 shows a concept diagram of the suggested URS.

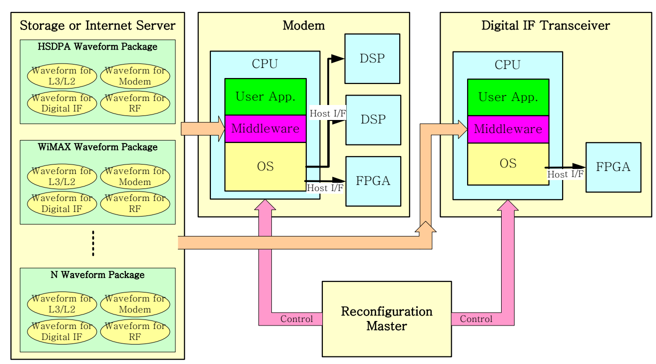


Figure 6. Block diagram of URS.

The URS scheme overcomes the reconfiguration restriction of a conventional base station by adopting SCA frameworks to the GPP mounted on each functional block of the SDR-based base station. The SCA frameworks are based on middleware such as CORBA as well as Real Time Operating System (RTOS) such as Montavista Linux which consists of general device drivers and a kernel. URS is a software download scheme to improve the reconfiguration speed because the GPP on all functional hardware units comprising the base station have software stacks including middleware and internal bus during reconfiguration.

The GPP located on the hardware unit download the data through host interface by receiving from mass storage or internet server through the user command. The data is usually binary-formatted waveforms of new standards and new version to the on-board FPGAs or DSP processors. The control signal from the reconfiguration master to each hardware unit may consist of: the location of the file to be downloaded, authentication information and the communication mode such as Gigabit Ethernet.

We verify the feasibility of the suggested URS scheme by presenting a Digital IF transceiver prototype. The implemented Digital IF transceiver is reconfigurable to three bandwidth profiles: 1.75 MHz, 3.5 MHz, and 7 MHz each incorporating the IEEE 802.16d WiMAX standard and HSDPA standard. An implemented transceiver manages the digital IF function in the ReMo base station, which incorporates heterodyne architecture.

Fig. 7 shows the download scheme diagram of a GPP containing an SCA CORBA middleware layer within a digital IF transceiver. The waveform binary data is downloaded to the FPGA chip responsible for digital signal processing function through the FPGA Device Driver. The virtually unlimited standard or standard profile waveforms can be stored in an internet server and retrieved through Internet protocol such as Gigabit Ethernet by user demand.

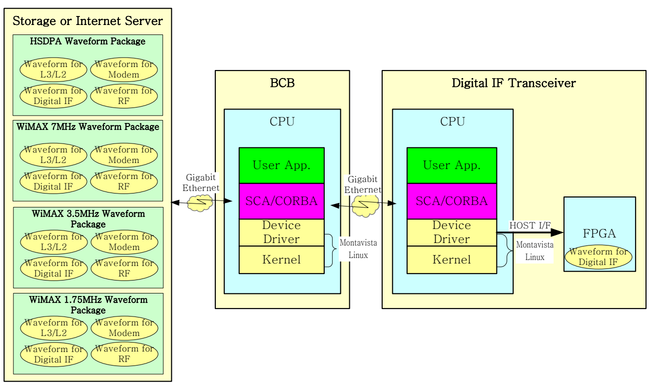


Figure 7. URS scheme of the Digital IF transceiver.

The user application program in the Base station Control Block (BCB) of Fig. 7 is a client program of the SCA/CORBA middleware at lower layer and provides Graphic User Interface (GUI) functionality and connectivity with storage or internet server while it manages operation and maintenance of the overall base station. The host interface called Host Port Interface (HPI) between GPP and FPGA in the Digital IF transceiver is vendor specifically designed. The implemented transceiver hardware board is represented in Fig. 8.

The transceiver board is operated at the Digital Processing Sub-system rack, which manages external network interfaces and the digital signal processing function of the SDR-based mobile communication base station. To verify the reconfiguration ability of the HSDPA system, we measured the spectrum and constellation of the downlink IF output using Vector Signal Analyzer (VSA) equipment that is commercially available. The measured Error Vector Magnitude (EVM) value of the HSDPA signal is shown in Fig. 9 as -39.2 dB. The minimum requirement for transmit modulation is that the EVM shall not be worse than 12.5 %rms when the base station is transmitting a composite signal that includes 16 Quadrature Amplitude Modulation (QAM) modulation [12]. The EVM value of 12.5 %rms is evaluated to the SNR of 18.1 dB.

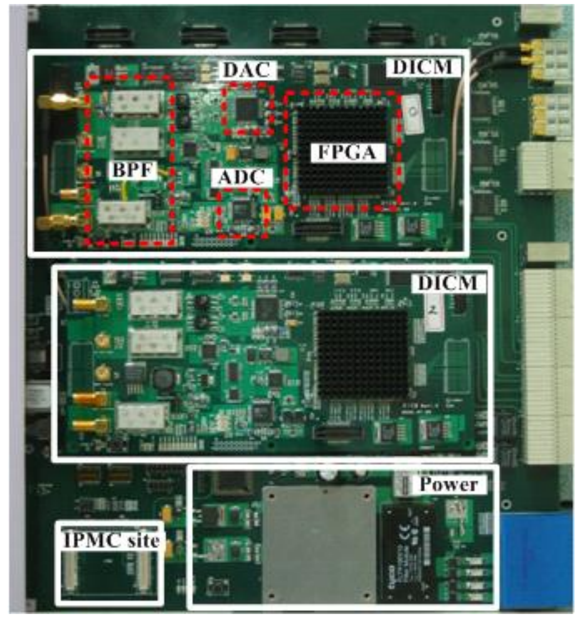


Figure 8. Implemented digital IF transceiver hardware.

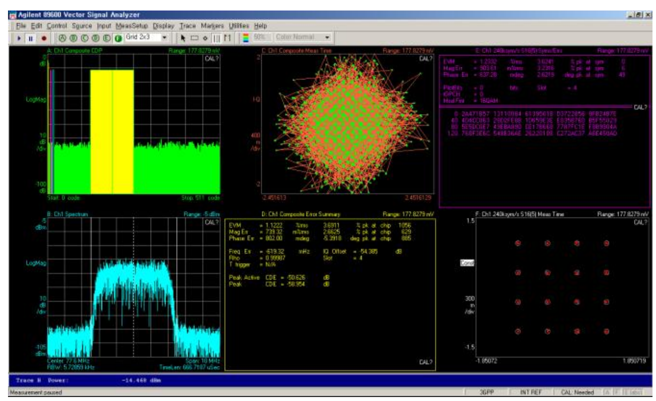


Figure. 9 Performance of the HSDPA (EVM = -39.2 dB).

We also conducted the same test for the WiMAX systems. The test results of the three WiMAX profiles are presented in order in Figs. 10, 11, and 12. In a WiMAX system, the term Relative Constellation Error (RCE) is preferred over EVM, though these terms are equivalent. As it can be seen in Figs. 10 through 12, EVM values of less than -43 dB were obtained regardless of the operating WiMAX bandwidth profiles. The recommended allowed transmitter SNR performance of 64 QAM - 3/4 burst type Modulation and Coding Scheme (MCS) is less than -31 dB of EVM (and the same as 31 dB of RCE) [13][14]. This result indicates that the output EVM value of the Digital IF transceiver should be less than -40 dB to meet the recommended criteria.

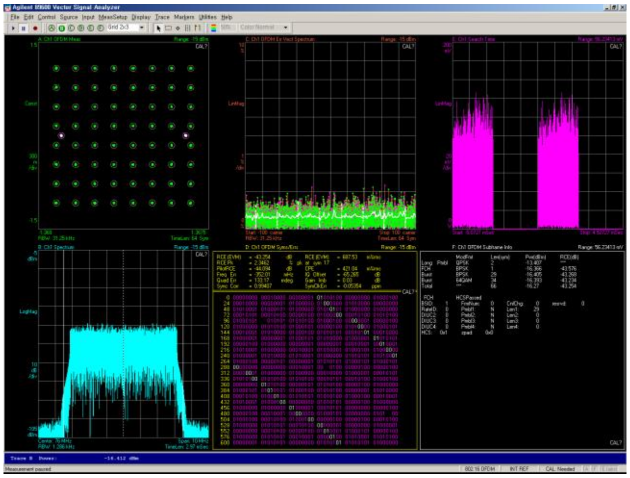


Figure 10. Performance of the WiMAX 7 MHz profile (EVM = -43.2 dB).

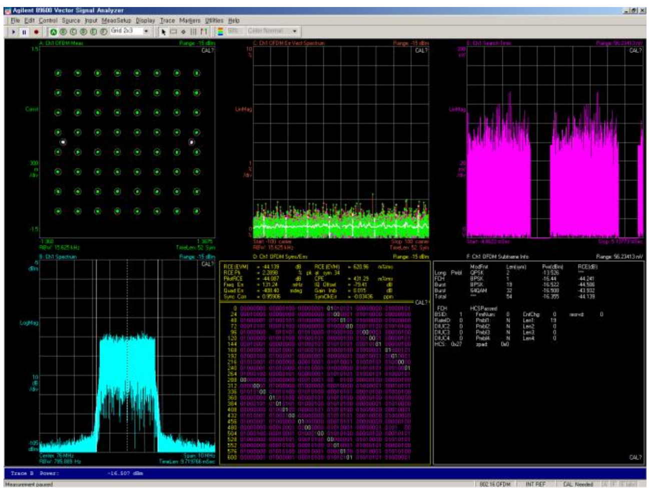


Figure 11. Performance of the WiMAX 3.5 MHz profile (EVM = -44.1 dB).

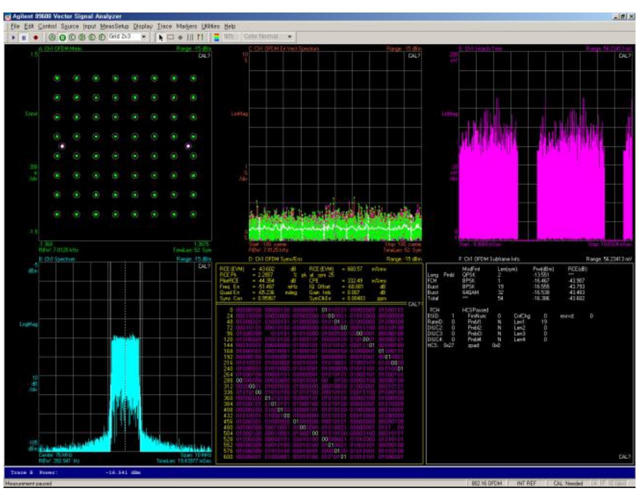


Figure 12. Performance of the WiMAX 1.75 MHz profile (EVM = -43.6 dB).

4. MRS RECONFIGURATION SCHEME

To utilize the URS scheme, all hardware units should be equipped multi-layered software stacks such as firmware, Operating System (OS), and middleware as shown in Fig. 6. Therefore there is a tradeoff between flexibility and complexity accompanying cost. Here, we suggest another scheme based on reconfiguration master termed MRS that is implemented with lower cost and is more suitable to simplified systems. The block diagram shown in Fig. 13 presents an SDR-based base station with the suggested MRS.

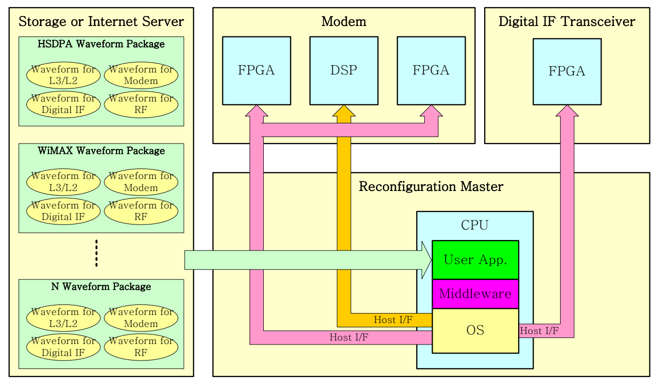


Figure 13. Block diagram of MRS.

The Reconfiguration Master (RM) works as an SDR-based base station manager in Fig. 3 that is equipped with open frameworks based on RTOS and middleware. The RM downloads the binary formatted waveforms data of new standards and new version to the on-board FPGAs or DSP processors through host interface of GPP in RM by receiving from mass storage or Internet server through the user command. Some simplified systems can be implemented without middleware or other software layers in RM GPP software stacks. Because MRS scheme download the binary waveform data through external data bus, the GPP is not needed. Therefore a simplified system can be implemented with lower cost and simple hardware and software structures.

This paper also presents digital filter architecture applicable to a multiple-channel processing system prototype using an MRS reconfiguration scheme and verifies the feasibility of the suggested MRS scheme [15]. The implemented hardware board of the multiple-channel signal generator is shown in Fig. 14.

A Z-80 series micro-processor is in charge of the operational control of the overall system, the user interface, and the filter coefficient calculation according to the intended system profiles. The digital BPF is reconfigured to other system profiles in real time through downloading a filter coefficient set, which are generated by the controller. The implemented multiple-channel signal generator is shown in Fig. 15 for reconfiguration schemes that have GPP software stacks comprising user application and OS layers, but without middleware layer.

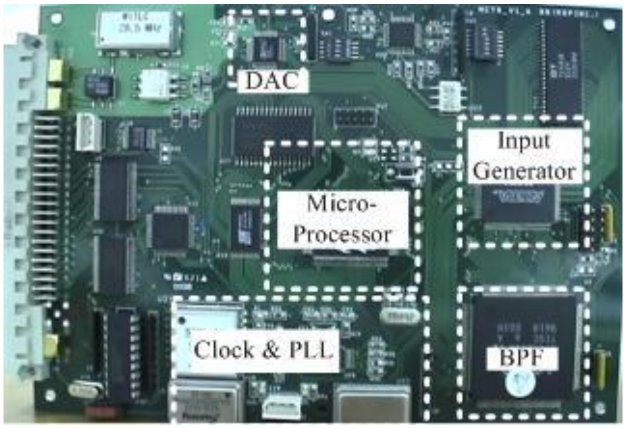


Figure 14. Implemented multiple-channel signal generator.

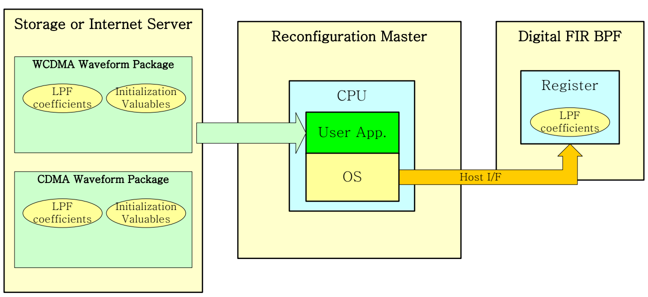
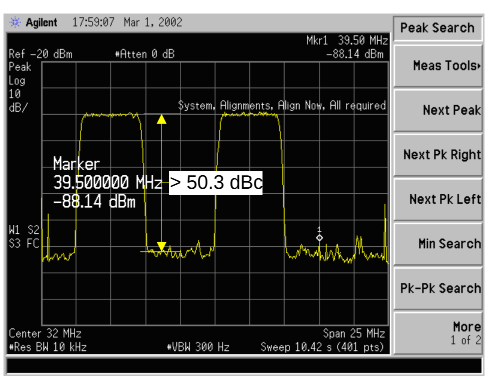
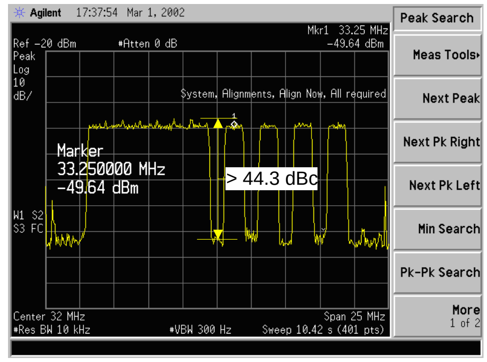


Figure 15. Structure of the digital filter using MRS.

Fig. 16 shows the output signals of the implemented multiple-channel signal generator at a low IF spectrum. In the example shown in Fig. 16 (a), the BPF is reconfigured using the filter coefficients generated by the micro-processor according to the WCDMA system profile and channel selection information to activate the first and third channels. Fig. 16 (b) illustrates the output signals of the generator when reconfigured to a CDMA system.



(a)



(b)

Figure 16. Output of the generator (a) WCDMA system, (b) CDMA system.

5. CONCLUSIONS

This paper proposed two SDR-technology based reconfiguration schemes, URS and MRS, according to the location of the software stacks that take part in the reconfiguration function. Additionally, we verified the feasibility of both suggested schemes by implementing a prototype system that adopts each reconfiguration scheme and by showing test results.

The experimental results show that both suggested schemes successfully enable reconfiguration to other system profiles through software. In addition, the developed mobile communication systems satisfy the recommended performance criteria for all supported system profiles. If the suggested SDR-based reconfiguration architecture were applied to next mobile communication systems, especially in upcoming 4G systems with various bandwidth profiles, rapid deployment to the upgraded technology would be possible with low cost and time to market.

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