Development of a DTV RF Signal Capture, Analysis, and Regeneration System

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ABSTRACT

In this paper, we developed a DTV RF (Radio Frequency) capture, analysis, and regeneration system adapting digital signal processing and high speed hard disk interfacing techniques and analyzed characteristics of captured RF signal.

This system can be used in the various field of DTV transmission because this system can capture the receiving real DTV signals and analyze captured RF signals that contain the complex characteristics of the real-world RF environments and regenerate it in a laboratory without the performance degradation.

The system can capture and replay the DTV RF signals in real-time on hard disk. Therefore, there is no limit for the amount of captured data within the installed storage capacity.

We can expect various possible applications for this system such as a tool for the development of the receiver performance analysis, design, and analysis for the DTV coverage areas, etc. This system can also be used as RF signal analyzer.

INTRODUCTION

Same as analog broadcasting environment, there are so many reasons why we need field-tests in real world. One of the most important reasons is the need to analyze many RF propagation characteristics. Since '90. many countries have been preparing DTV broadcasting and some countries now broadcast their own DTV signals. In contrast to analog signals, digital RF signals have their own propagation characteristics and analyzing these characteristics is very important. Because it is needed to improve reception quality of DTV signals and also improve the receiving abilities of DTV set-top boxes. These kinds of channel analysis are usually made by the cooperation of academic world, broadcasters, and electronics companies. But it is difficult to analyze field-test results objectively because these results are changed by field-test time, its method, etc. That's because we need the method to analyze field-test result more easily without modification, repeatedly.

There are so many techniques about making channel propagation environment in laboratories. Among these, real RF signal recording technique is one of the most appropriate techniques nowadays. The price of memory chips is getting cheaper and it make possible for PCs or test equipments to have high-speed memory with big capacity. The number of test equipments that can record real RF signals is increased. ATTC (Advanced Television Technology Center, USA) tried a real RF ATSC[1] signal-recording project. Every 30 point near Washington DC, real RF signals are recorded about 24 seconds (1Gbyte) from June, 2000 using RF recording equipment.[2]

But almost all RF recording equipments can support recording only on memory chips. The capacity of recording is usually limited under 1Gbyte. Most of all, this kind of equipment is very expensive.

In this paper, we propose a new algorithm and equipment that can enable the recording capacity to be expanded to maximum HDD capacity using high-speed HDD data recording techniques, analog to digital signal converting techniques, and digital signal processing techniques.

Major techniques applied to RF signal capturing system are divided into hardware development and related software development. Hardware system consists of RF to IF down-converting system, A/D translation from IF signal, digital signal processing, and real-time recording techniques. Software system consists of hardware interfaces, data recording and regeneration user interface, and DTV software analyzer. The proposed RF capturing system is made in type of PCI PC card on ordinary PC systems and it can make use of this system easy and comfortable.

EXAMPLE OF I (IN-PHASE) SIGNAL CAPTURING

RF capturing system made by ATTC[2] is for helping develop set-top boxes by making real RF test bed. It consists of RF demodulating, capturing system and regeneration system.

RF input signal is passed through variable attenuator and tuner, and then down-converted to IF frequency, and sampled into digital data at RF digitizer. Sampling rate is 21.52MHz to be the twice of the symbol frequency. If analyzer software is used, multipath signals in band can be extracted by PN sequence autocorrelation at every 27usec. It uses another regeneration system to regenerate RF signal in any band. Signal distortion at signal receiving part is little and bandpass filter is very precise.

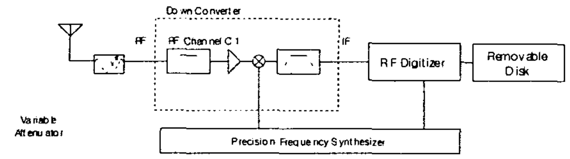


Figure 1. RF Capturing System Block Diagram of ATTC

Recording capacity is about 1GB and it's recorded at memory of RF digitizer first, and copied into Gbyte tape driver. Spectrum of recorded signal is shown in Figure 2. The center frequency is 5.38MHz, which is the quarter of the sampling frequency.

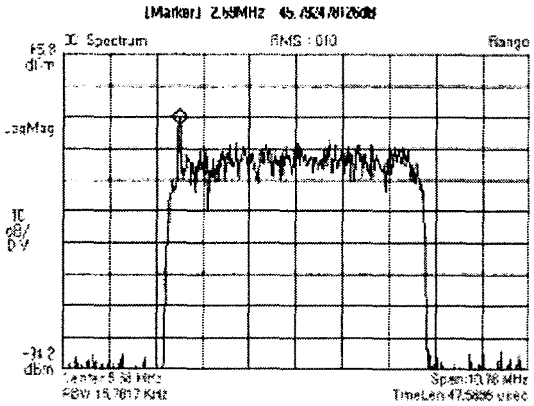


Figure 2. Captured Signal of ATTC

COMMONLY USED TEST EQUIPMENTS

Generally, equipment companies have their own signal capturing techniques. In the case of 89441V(Agilent), one of the most famous vector signal analyzer, digitally demodulated baseband I, Q signal is captured at time domain. [3] In case of measuring instrument, capturing parameter such as sampling frequency is decided by frequency span, resolution bandwidth, point per symbol, etc. Capturing the signal is possible using matched filter when digitally demodulated signal is captured. Capturing capacity is changed by expanded memory option component. [4] In case of 89640A, a new revision of 89441V, it can capture 1Gbyte with special option component. [5]

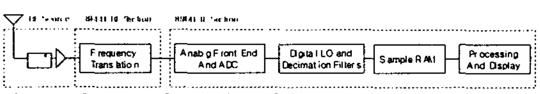


Figure 3. RF Capturing System Diagram of Agilent 89441V

In Figure 4, there is I, Q signal frequency response. It is captured by 2 point per symbol and the sampling frequency is 21.52MHz. The center frequency is 2.69MHz and the pilot frequency is 0Hz.

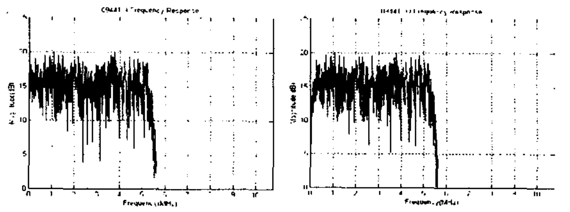


Figure 4. 89441V Captured signal

PROPOSED RF CAPTURING SYSTEM

Structure of the proposed RF capturing system is described below and block diagram is shown in Figure 5.

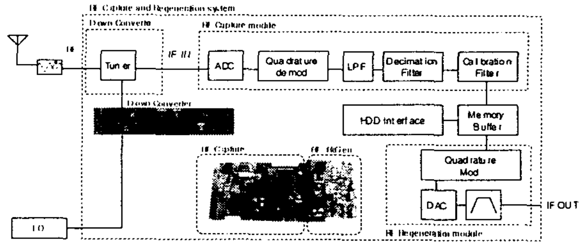


Figure 5. Proposed RF Capturing System Hardware Block Diagram and Developed Hardware

At downconverter block, it is very important to limit signal distortion and phase error to desired level because whole processing of this block is analog processing. There are two popular algorithms about frequency downconversion. One is double conversion algorithm and the other is single conversion algorithm. It is easy to change the RF channels without a mirroring effect when double conversion method is used but the signal path contains two-conversion process that can cause signal distortion and phase error.

It is difficult to change channels and have a mirroring effect when single conversion method is used, but single conversion method contains only one conversion process that can cause signal distortion and phase error. Block diagram of the single conversion method is Figure 6.

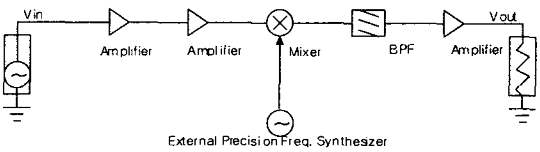


Figure 6. Block Diagram of single conversion type downconverter

S/N reduction in simulation result is below 1.0dB when external precision frequency synthesizer is used as LO of mixer. A RF regeneration ability is embodied to use captured signal efficiently. A I/Q modulation technique is used to embody RF regeneration part. The demodulation part of RF signal capture system and the I/Q modulation system with frequency synchronization is attached to the proposed system. Demodulation and modulation frequency is synchronized with PLL (Phase Locked Loop). The I/Q modulation part is composed with commercial I/Q modulation module of Teleview Co. LTD. Final output is D/A converted analog IF signal.

One of the most important merit of the proposed system is that not the bassband signal, but the IF signal is converted to digital signal, therefore the possibility of signal distortion which may be generated during converting process in analog domain from IF to bassband is 0%.

Another merit of the proposed system is that center frequency of captured signal is 0Hz bassband. It can make possible to use LPF instead of BPF. It make easier to limit the band using less tab digital filter, improve linear characteristics of system and loosen the burden of complex hardware.

RF SIGNAL ANALYZER S/W

The RF signal capturing system has ability to analyze the RF signal and compensate signal distortion. To embody this ability, characteristics of captured signal must be analyzed and digitally demodulated as 8VSB. In this software, constellation and eye diagram can be seen and 8VSB parameters such as S/N (Signal to Noise ratio), EVM (Error Vector Magnitude), etc. can be measured via the 8VSB parameter measurement procedure.[6] A matched filter is used to improve S/N of receiving part.

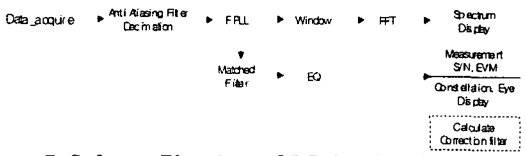


Figure 7. Software Flowchart of RF signal analyzer S/W

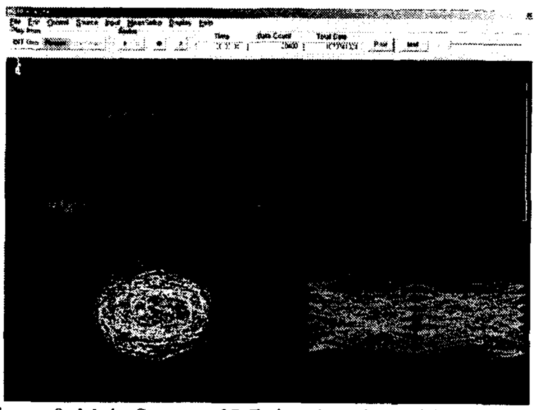


Figure 8. Main Screen of RF signal analyzer S/W

The major functions of this S/W is as follows

Signal Generation
- Single tone, Multi tone
- VSB Signal
* Variable Center Freq. Phase, Magnitude

Noise Generation
- AWGN Noise Generation

Multipath Simulation
- 6 path Multipath signal generation
* Brazil Ensemble&CRC preset

Regeneration of Captured RF signal
- KBS/Teleview RF signal capture system
- ATTC/Sencore RF capture system

Spectrum measurement
- Variable Center freq., Span
- Variable Resolution B/W
- Variable Window (Uniform, Gaussian, Hamming, Hanning, ...etc.)

Digital demodulation measurement
[Option 1: VSB demodulation]
- Freq. & Phase Sync
- Freq. Offset measurement&compensation
- Signal analysis
  S/N, EVM, Mag. Err., Phase Err., Pilot Level, Freq. Err.
- Display
  Constellation, Eye Diagram, Spectrum, Measured data

The Structure of signal generation block is figure 9.

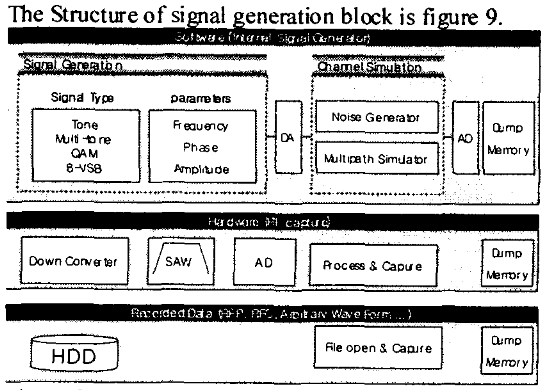


Figure 9. The Structure of signal generation block

Digital demodulation function screens are as follows.

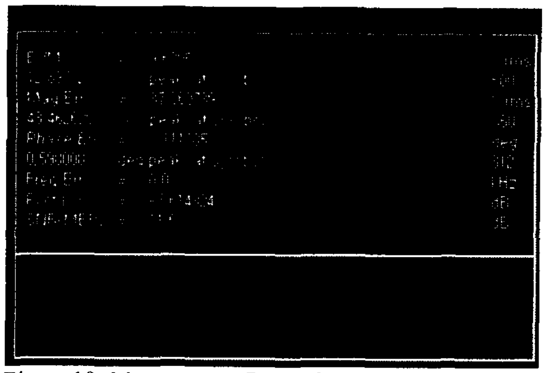


Figure 10. Measurement Result Screen

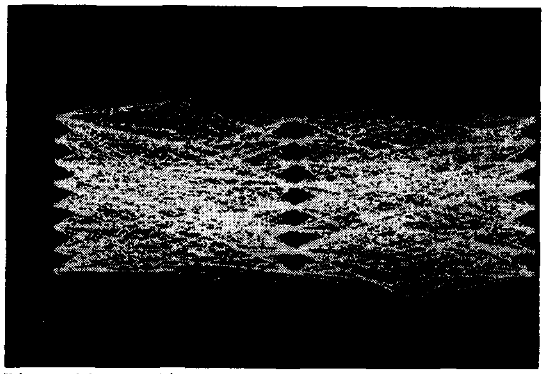


Figure 11. Eye Diagram

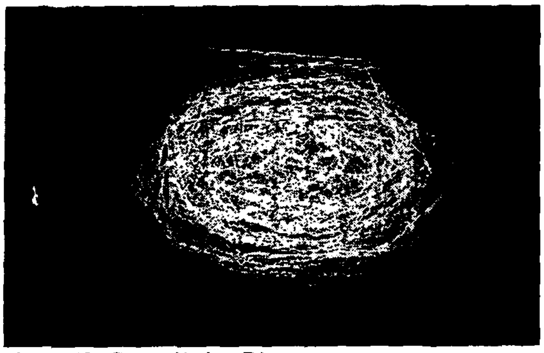


Figure 12. Constellation Diagram

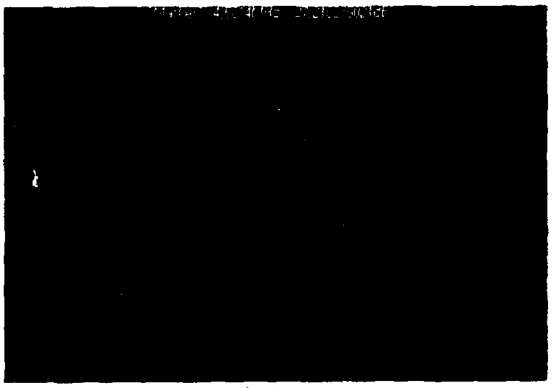


Figure 13. Spectrum Analysis

EXPERIMENT & RESULT

[Measurement Synopsis]

To measure the performance of the proposed system, a lab test system is composed as follows. On-air signal and IF output of DTV modulator with TS stream server is used as the RF sources. When IF signal is used as source, it is connected to the RF signal capturing system directly, and when RF signal is used as input, it is connected via channel downconverter to the RF signal capturing system.

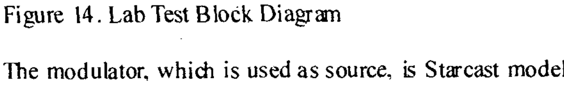


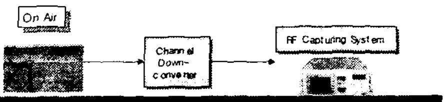
Figure 14. Lab Test Block Diagram

The modulator, which is used as source, is Starcast model developed by co-work of KBS technical research institute and LG Electronics Company. It is used at KBS Kwan-ak Mountain DTV transmitting site and KBS Nam Mountain DTV transmitting site.

A vector spectrum analyzer 89640A of Agilent and a Prodemod professional set-top box of Zenith are used as measurement device. Measurement items of each device are as follows

1. Agilent Vector Signal Analyzer 89640 VSA
   Spectrum Measurement, Constellation, Eye Diagram, S/N, EVM, etc.
2. Professional Set-top Box ProDemod (Zenith)
   VSB Decoding (TS output),
   Segment error,
   S/N before&after EQ (Equalizer)

[Experiment : On-Air Signal as RF source]



Device 1	17.4dB	17.0 dB	17.0dB
Device 2	12.1/24.2dB	11.6/25.0dB	10.6/24.2dB

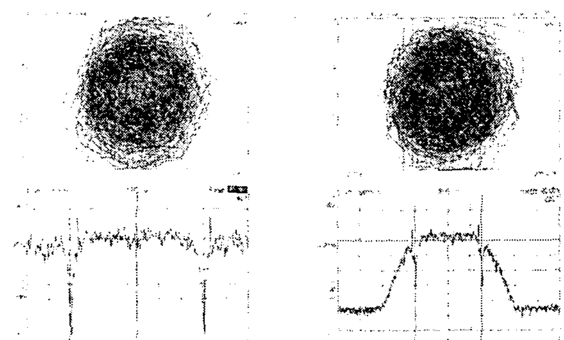
Device 1. S/N Result of 89640VSA
Device 2. S/N (Before EQ/After EQ) of Zenith ProDemod
Figure 15. Block Diagram and Result of Experiment 2.

It is used as on-air RF signal that UHF channel 15(center frequency 479MHz) signal from KBS Kwan-ak mountain transmitting site via KBS technical research institute 5-story building roof antenna. Received signal contain 5 adjacent DTV signal from channel 14 to channel 18.

* 4dB S/N degradation at the channel downconverter, 0dB S/N degradation at the RF capturing system is observed using VSA.
* 5dB S/N degradation at the channel downconverter, 1dB S/N degradation at the RF capturing system is observed using ProDemod preEQ parameter.
* 0.8dB S/N improvement at the channel downconverter, 1dB S/N degradation at the RF capturing system is observed using ProDemod postEQ parameter.

The reason for S/N improvement at the channel downconverter is why performance of professional set top box ProDemod RF tuner is worse than that of the channel downconverter specially designed for this project.

It is observed that adjacent channel signal is band limited by bandpass filter in output part at output signal of the RF capturing system.



(a) (b)

Figure 16. Comparison between received On-Air Signal (a) and Regeneration Signal of RF Capturing System (b)

CONCLUSION

The proposed system enables us to capture real-time DTV signals to make a real RF receiving environment in laboratory. This system can also analyze captured RF signal. Both capturing and analyzing could be implemented easily in one system because this system is based on PC hardware. This system can be implemented on ordinary PC system because PCI card with ordinary SDRAM is used as capturing device. If server PC system having high-speed HDD controller is used, RF signals may be captured to maximum HDD capacity.

The proposed RF capturing system can be used in most of the RF applications with limited bandwidth capturing architecture. It means that the system can capture not only ATSC RF signal, but also all signals of which bandwidth is less than 8MHz such as DVB-T. ISDB-T. etc.

It is expected that the proposed system could make a big contribution to digital broadcasting environment research because it can help analyzing various channel environment in laboratory easily, objectively, and repeatedly.

Further work is needed for the proposed system to improve RF characteristics such as S/N, linearity, etc. and system distortion correction ability is also needed to enhance the precision of this system.

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