The Design and Implementation of a TV Tuner for the Digital Terrestrial Broadcasting

Young-Jun Chong[1] . Jae-Young Kim[1] . Il-Kyoo Lee[1] . Jae-Ick Choi[1] . Seung-Hyeub Oh[2]

Abstract

The DTV (Digital TV) tuner for an 8-VSB (Vestigial Side-Band) modulation was developed to meet the requirements of the ATSC (Advanced Television Systems Committee). The double frequency conversion and the active tracking filter in the front-end were used to cancel interferences between adjacent channels and multi-channels by suppressing the IF beat and the image frequency. However, it was impossible to get frequency mapping between the tracking filter and the first VCO (Voltage Controlled Oscillator) in the existing DTV tuner structure which differs from the NTSC (National Television Systems Committee) tuner. This paper, therefore, suggests an available structure and a new method for the automatic frequency selection by mapping the frequency characteristics over the tracking voltage and the combined H/W which is composed of a Micro-controller, an EEPROM (Electrically Erasable Programmable Read Only Memory), a DAC (Digital-to-Analog Converter), an OP amplifier, and a switch driver.

Ⅰ. Introduction

High quality and multi-channel services can be offered in digital TV broadcasting with the development of digital signal processing and transmission technology. High audio and image quality is affordable due to the efficiency of the transmitting channel bandwidth. It prevents broadcasting signals from degrading image quality when recording the signal and also, reduces interference between signals being transmitted.

Since the receiver's selectivity and the linear dynamic range are major factors in the performance of communications system, the advantages and disadvantages of the tuner which has been used in the commercial broadcasting system are reviewed. The necessity of double frequency conversion and the advantage of using the tracking filter in the front-end of the tuner were investigated to improve the performance of DTV tuner.

1-1 The Use of the Frequency Double Conversion Method

There are two conversion methods concerned with the frequency conversion when using the commercialized TV tuner

- Single frequency conversion (including tracking filter) for all analog broadcasting tuners
- Double frequency conversion for cable TV and DTV tuners

While a simple structure and low costs are available in the existing NTSC tuner which uses single conversion, the UHF channel limitation is caused by the interference signals from other broadcasting channels.

All interference parameters must be included to find the output power level and the displacement of transmitters. The image response and the IF beat are important factors because they can degrade the performance of TV receivers. In addition, *the amount of leakage power radiation to the antenna port, due* to the LO power, is strongly restricted by the FCC (Federal Communication Commission) because it could have an impact on other communication systems.

Since the parameters mentioned above could be suppressed by the receiver's structure, the double frequency conversion is selected in order to overcome the performance degradation of the receiver. Even though this structure has the disadvantages of complexity and high cost in comparison with the existing analog tuner, its image response and IF beat characteristics are better than those of the NTSC tuner. The reverse LO leakage power radiation is neglected by the use of a tracking filter, therefore the impacts from the broadcasting channels of NTSC are ignored[1],[2].

1-2 Using Tracking Filter

A receiving system must be kept in operation to some extent under a strong interference signal and retain receiving sensitivity. A trade-off between these two parameters is necessary to maintain the balance. The commercialized DTV tuner containing the frequency double conversion is separated as follows depending

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[1] Radio Technology Department, ETRI, Daejon, Korea.
[2] Department of Electronics Engineering, Chungnam University, Daejon, Korea.

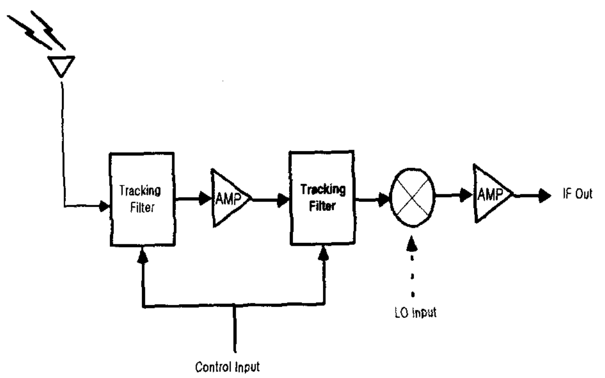

Fig. 1. The configuration of the tuner including the tracking filter.

upon whether the tracking filter in front-end exists or not.

- All signals in the broadcasting frequency bands are received without being separated
- All signals in the broadcasting frequency bands are received and separated into the three fixed bands
- All signals in the broadcasting frequency bands are received and then separated in the band by using a tracking filter

A receiver's linearity would be improved by using a tracking filter in the front-end, this, however, results in complexity of structure and an increase in size. Therefore, fine control is required to compensate for the tracking error. Since the dynamic range of the pre-selector in a receiver depends on the LNA and the mixer, the input loads are reduced by suppressing unwanted signals through the tracking filter at the input and output of the LNA as in Fig. 1.

Specifically, when using the tracking filter in a tuner which has broadcasting channels distributed close to each other over broad bands, the input linearity of the LNA and the mixer is improved by repressing other strong channels.

The digital broadcasting channel and the existing analog broadcasting bandwidth are supposed to be used at the same time during the transition period toward digital broadcasting. Therefore, interference between the two systems can occur. It must be considered to put the tracking filter in a TV tuner, like the existing NTSC tuner, for suppressing spurious responses when receiving multi-channels[2].

1-3 The Problem with Using the Tracking Filter and the Necessity of Frequency Mapping

The DTV tuner using the frequency double conversion and the tracking filter increases the linearity. It also improves inter-modulation, cross-modulation, saturation, and desensitization caused by spurious signals. But, the frequency mapping between the VCO and the tracking filter is not dealt with as easily as in the case of the NTSC tuner. Thus, the S/W control and frequency error correction function must be added though the complexity would be increased.

In contrast to the NTSC tuner [refer to Fig. 2], the DTV tuner, using the frequency double conversion and the tracking filter, selects one of three frequency bands in the front-end by using the tuning voltage. Since the first VCO covering the broadcasting frequency band (BW $\approx$750 MHz) over frequency tuning voltage does not exist, the additional function of frequency mapping is required [refer to Fig. 3]. In order to achieve the frequency mapping function, the tuner controller, which is composed of micro-controller, EEPROM, D/A, OP amplifier, and switch driver is introduced. The automatic frequency selection and frequency error correction of the DTV tuner with approximated function coefficient values for the mapping of frequency characteristics over tracking voltage are presented in this paper.

A comparison between the NTSC and the DTV tuner and the necessity of the tracking filter are mentioned previously. The

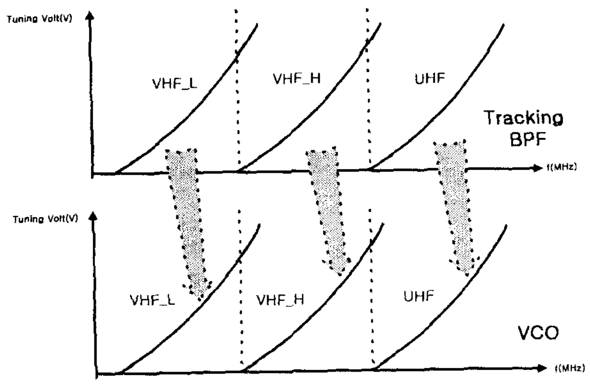

Fig. 2. The approximated frequency mapping function diagram of the NTSC TV tuner structure.

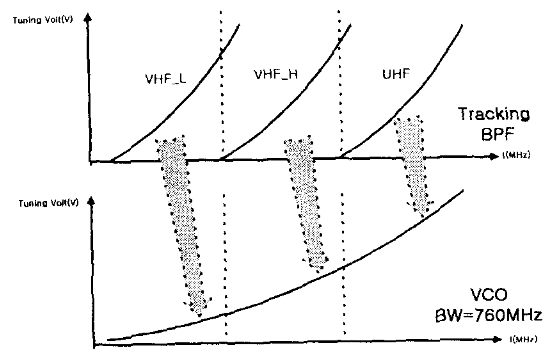

Fig. 3. The approximated frequency mapping function diagram of the DTV tuner structure including the tracking filter.

operation principle of the DTV tuner, the function of tuner controller for frequency mapping and frequency correction, and the design specifications of the next DTV tuner will be discussed. The measurement results of the DTV tuner will be described. The conclusions are reached by comparing the measurement results with ATSC specifications.

II. Operation Principle of the DTV Tuner

2-1 Structure and Function of the DTV Tuner

As shown in Fig. 4, the DTV tuner is the main module in determining the performance of the TV receiver. It is composed of an up/down frequency converters, frequency synthesizer, controller and front-end including the BPF and the active tracking filter as shown in Fig. 5.

The functions are as follows:

- Converting received broadcasting signals to an intermediate frequency (44 MHz)
- Selecting VHF/UHF frequency by switching
- Low noise amplifying with active track filtering
- *Controlling the gain by the AGC control voltage*
- Tuning of TV channel frequency
- Frequency error correction over circumstantial variation of the tracking filter
- Filtering the out-of-band signals and image frequency signal

The double conversion scheme is used to simplify the channel selection. The first intermediate frequency, 944 MHz, was selected to avoid interference between the first synthesizer and the second synthesizer. The active tracking filter was used to reduce

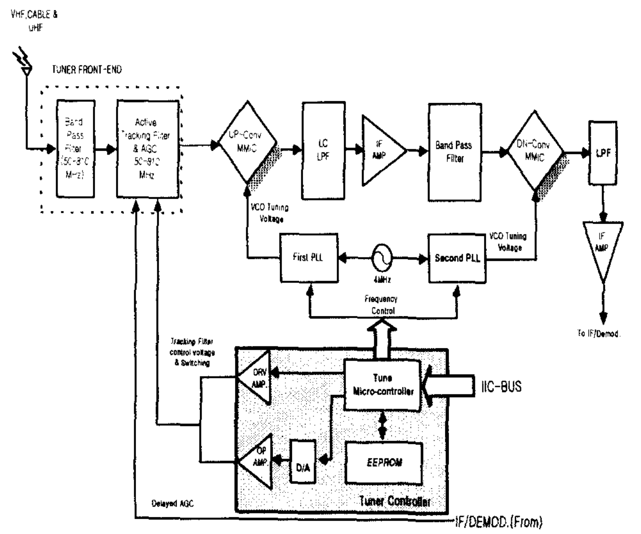

Fig. 4. Block diagram of the DTV tuner.

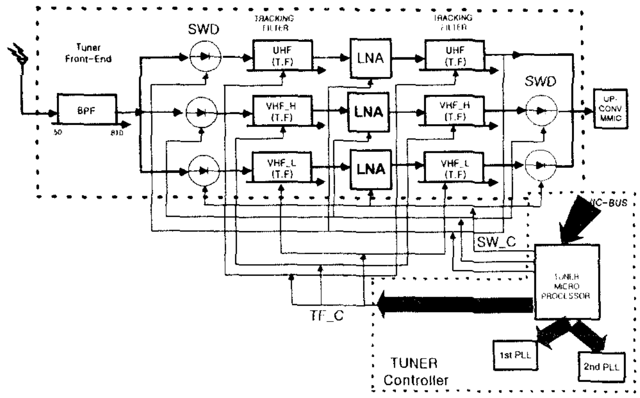

Fig. 5. Block diagram of the DTV tuner front-ends.

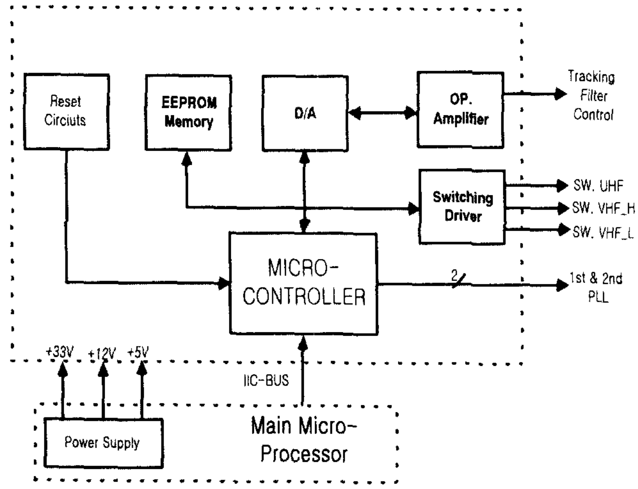

Fig. 6. Block diagram of the DTV tuner controller.

interference between the adjacent channels and multi-channels. The AGC function is included in the tuner front-end to control the input signal level for the mixer. Two separated PLLs shared a 4 MHz crystal oscillator as a common reference, which reduces the number of components and the price. The main function of the controller is to get the mapping of the control signal to the VCO and the active tracking filter.

2-2 Structure and Functions of the Tuner Controller

The tuner controller is comprised of a micro-controller, an EEPROM, a DAC, a differential amplifier and a switching driver as in the Fig. 6.

2-2-1 Description of the Tuner Controller

The tuner controller contains the following information :

- Frequency (channel) characteristics over control voltage of the active tracking filter of three frequency bands
- Frequency (channel) characteristics over frequency selection information (control voltage of VCO)
- Band switching for one channel selection of three frequency bands

2-2-2 Required Functions of the Tuner Controller

A. Initialization

- Set initial value and mode of timer
- Set values for interruption
- Initialize memory device
- Carry out channel selection for channel assignment

B. Functions of the main loop

- Check the IIC-BUS signal containing frequency information from master micro-processor
- Decode the frequency information
- Set data for the first PLL according to the frequency of the assigned channel
- Set variables for channel band switching
- Read and write frequency mapping coefficients of the assigned frequency band in EEPROM

C. Function of communications interruption

- Carry out the interruption while receiving information and save the analysis from beginning to end.

2-3 Operating Sequence of Frequency Mapping

As mentioned above, there was no frequency relationship between the VCO in the first PLL and the tracking filter over tuning voltage in the digital TV tuner with the frequency double conversion structure. However, it is possible to get automatic frequency selection of the DTV tuner by calculating the coefficients of approximated functions for frequency mapping over frequency characteristics, depending upon the H/W structure and the tracking voltage.

Signal flow of the controller for automatic channel selection is shown in Fig. 7 and the control sequence is as follows :

- First of all, measure the frequency characteristics on each of the three frequency bands over tuning voltage of the tracking filter in the front-end. By using the above data, coefficients (A0~A5) of approximated function of equation (1) for frequency mapping over three frequency bands can be obtained and then stored in the EEPROM.
- After initialization, the micro-controller of the tuner decodes the IIC-BUS data
- Operating values of the first PLL are set with the decoded frequency information, and then variables for band switching can be obtained
- The assigned frequency components are calculated by using the F(X) function in equation (1)
- The calculated values of the F(X) are transformed into analog values through D/A and then become constant DC through a differential amplifier. At the same time, the constant DC selects the assigned frequency bands (VHF_LOW, VHF_HIGH & UHF) and gives frequency tuning voltage to the tracking filter of the front-end in the tuner.

The frequency mapping is acquired by using the fifth polynomial of approximated function coefficients as in equation (1).

$$F(X) = A0 + A1X + A2X^2 + A3X^3 + A4X^4 + A5X^5 \quad (1)$$

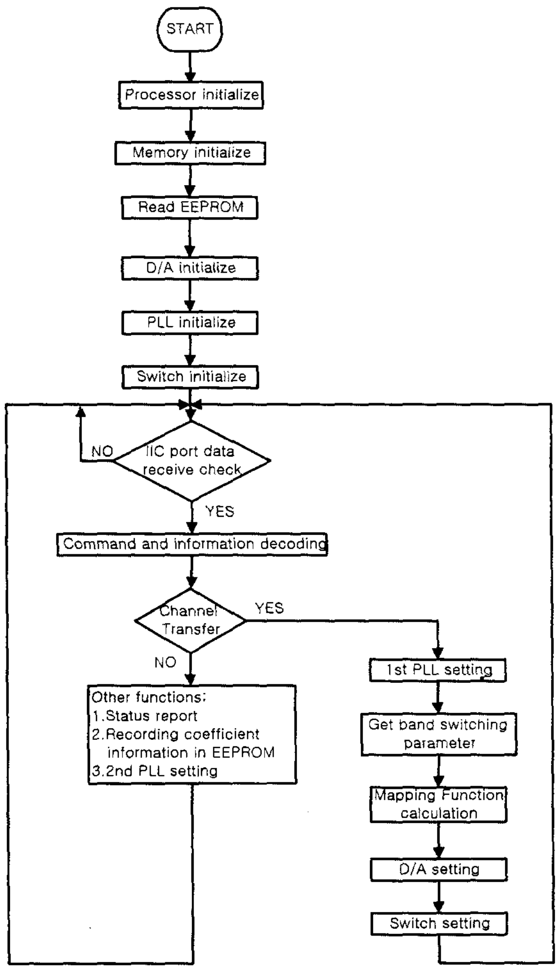

Fig. 7. S/W flow chart of the tuner controller.

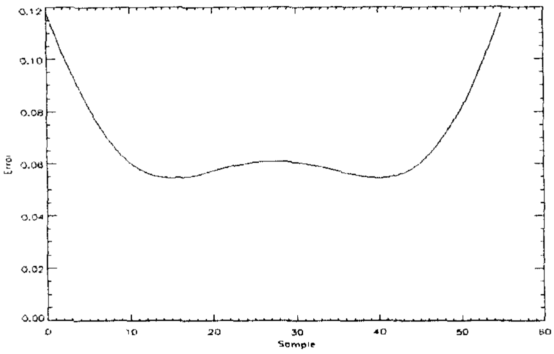

Fig. 8. Simulation results by use of frequency mapping coefficients (@ UHF Standard TV channels).

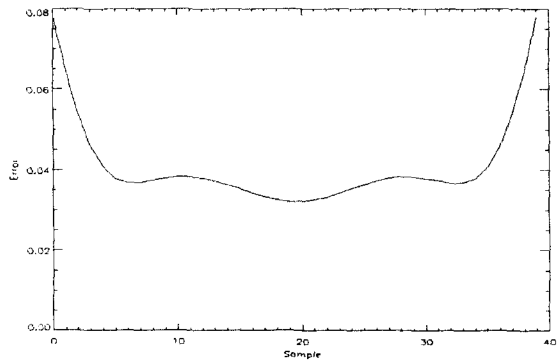

Fig. 9. Simulation results by use of frequency mapping coefficients (@VHF high band).

X: center frequency (TV Channels)
A0, A1, A2, A3, A4, A5: approximated function coefficients

Using the different values between the measured voltage of the tracking filter and the calculated values of equation (1), the simulation results over the VHF and the UHF TV channel are shown in Fig. 8, Fig. 9 and Fig. 10, respectively. Here, the X axis is TV channel number, the Y axis is the error between measured voltage and approximated function (unit: Voltage).

Ⅲ. Reauirements Specification on DTV Tuner

The specifications of the DTV tuner are described in Table 1.

Ⅳ. Experiment Results

The implemented DTV tuner is composed of the front-end, the frequency up/down converter, the frequency synthesizer and controller as in Fig. 11.

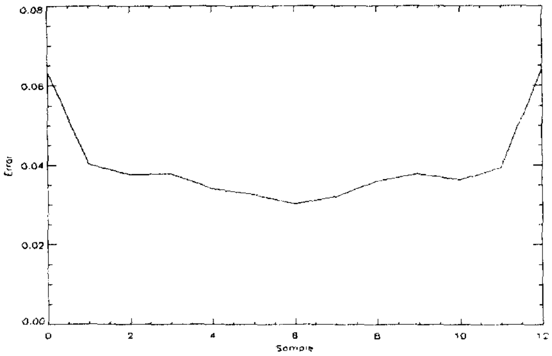

Fig. 10. Simulation results by use of frequency mapping coefficients (@VHF low band).

Table 1. DTV tuner specifications.

Tuner parameter	Tuner requirements
Operating band	54～806MHz
Noise figure	<10 dB
AGC dynamic range	>40dB
Power gain	40dB
Image rejection ratio	>60 dB
Pass-band ripple (@41～47 MHz)	<2dB (peak-to-peak)
Input/output impedance	75 Ω
Input/output VSWR	<3:1 / 2:1
Tuner phase noise (@41～ 47MHz)	<-80dBc/Hz @10kHz offset
Output frequency	44MHz

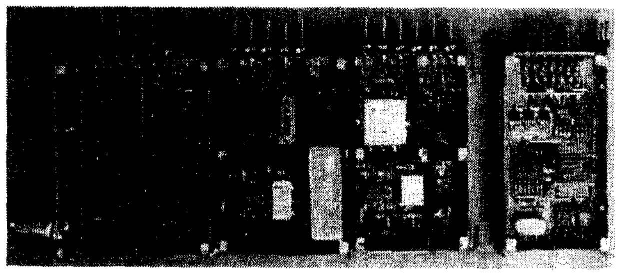

Fig. 11. The implemented DTV tuner (14.5×4×1.5cm).

It is not easy to measure NF with a noise figure meter due to the frequency double conversion structure of the DTV tuner. Therefore, the NF is calculated from equation (2). After putting the input signal of -80 dBm into the input port, the CNR (Carrier-to-Noise Ratio) over the VHF_LOW, the VHF_HIGH

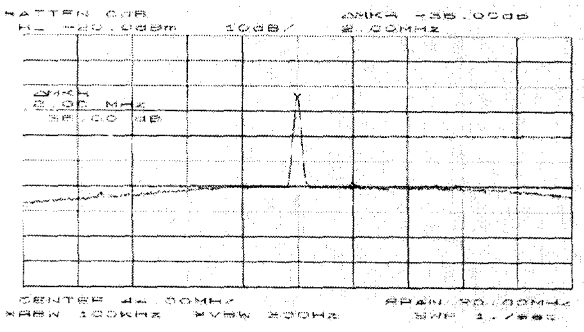

Fig. 12. The CNR at the output port (@CH.16).

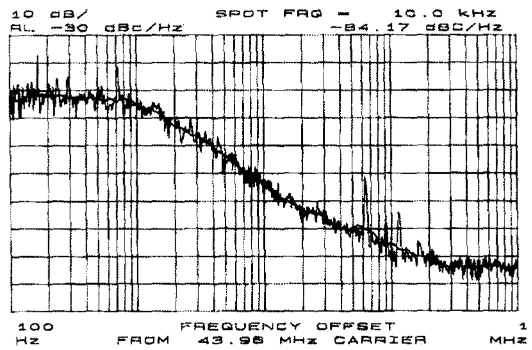

Fig. 13. The phase noise at the output port (@CH.2).

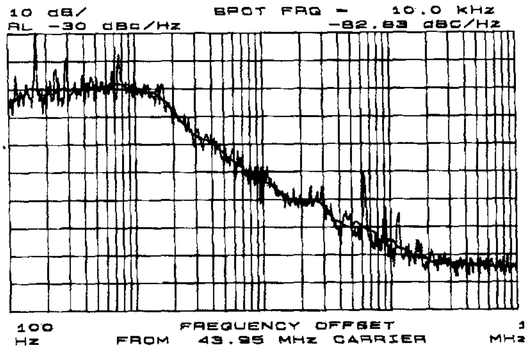

Fig. 14. The phase noise at the output port (@CH.69).

and the UHF was measured at the output port (resolution bandwidth=100 kHz).

An approximated NF of the receiver is expressed as

$$NF \cong (Pin + 174(dBm/Hz) - 10Log(RBW/Hz) + CNR \qquad (2)$$

Maximum NF of 8dB was obtained using equation (2) and the measured results of the CNR are shown in Fig. 12.

The frequency synthesizer of the DTV tuner provides frequency up/down conversion with two PLLs. The phase noise of the tuner was measured as shown in Fig. 13 and Fig. 14 for CH. 2 & 69, respectively. The measured phase noises are -84.17 dBc/Hz (@10 kHz offset) at the CH. 2 and −82.83 dBc/Hz (@10 kHz offset) at the CH. 69, which meet the requirements.

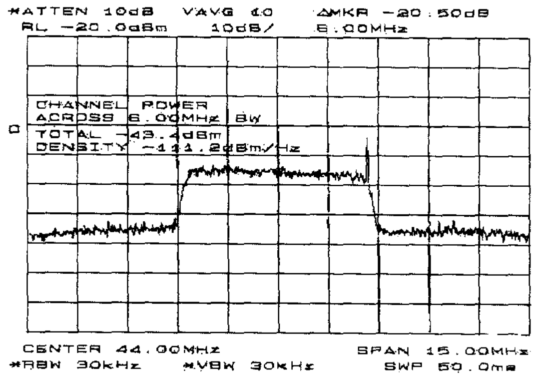

Fig. 15. 8-VSB characteristic of the tuner's output (Pin=-80 dBm, Pout=-43.4 dBm, @CH.14).

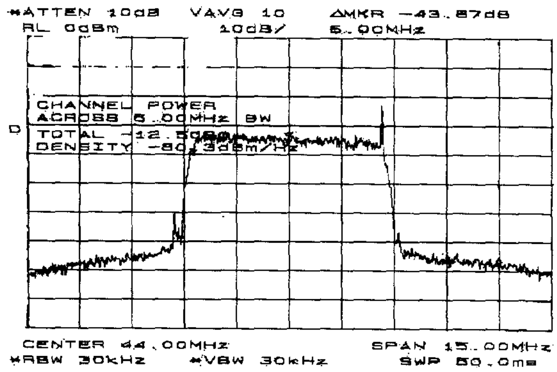

Fig. 16. 8-VSB characteristic of the tuner's output (Pin=-50 dBm, Pout=-12.5 dBm, @CH.14).

To measure an 8-VSB modulated broadcasting signal at the tuner output, channel 14, which is the output frequency of the transmitting modulator, is selected as the testing channel of digital broadcasting. The measured results of the CNR are shown in Fig. 15 and Fig. 16, respectively. Test results showed that the output power level and noise are increased in proportion to the increase of the input signal level of 8-VSB.

The other additional electric parameters, except for the above characteristics, are measured and summarized in Table 2.

V. Conclusions

The frequency double conversion and active tracking filter in the front-end were used to minimize the interference due to analog and digital broadcasting at the same time by suppressing

Table 2. The summary of the tuner's measurement results.

Tuner parameters	Measurement results
In / Output VSWR	<3.0:1/2.0:1
NF	7.17~8 dB
Tuner Phase Noise (@44 MHz Output)	<-82 dBc/Hz (Max)
In Band Flatness (@41~47 MHz)	0.52~1.52 dB
LO Leakage to Input (@2nd LO & 1st LO)	<-62.33 dBm (Max.)
Spurious Leakage to Input (@54~806 MHz)	<-97.83 dBm
Image Rejection	> 70 dB
IM3 out of Channel: Fud=fd±12 MHz, & fd±24 MHz @Full Gain; -49 dBm input	<-82.83 dBm (Max.)
IM3 in Channel: 2tone input (f, f+1 MHz) @Full Gain; -49 dBm input	<-58 dBc (Max.)
Size (including Tuner Controller)	14.5×4×1.5 cm

the IF beat, image band and interference in adjacent receiving channels as well as multi-channels. However, it was impossible to get the frequency mapping between the tracking filter and the first VCO in the existing DTV tuner structure. With the calculation of the approximated function coefficient for frequency mapping by S/W, and the change of H/W structure, it was possible to have frequency selection between the tracking filter and the first VCO in the DTV tuner. The results of the performance test on the developed DTV tuner meet ATSC requirements.

Further theoretical study and simulation to discover the influence of the integrated phase variation and phase noise of the DTV tuner on receiving sensitivity and BER (Bit Error Rate) will be necessary in the future.

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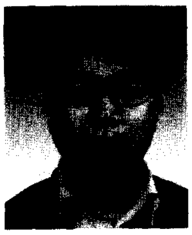
Young-Jun Chong

received the B.E. degree electronics engineering. in 1992 from Jeju University, Jeju and the M.E. degree in electronics engineering in 1994 from Sogang University, Seoul. Since 1994 he has been with ETRI, Daejon, Korea, where he is a senior member of the research staff of the Radio Technology Department. His research interests include RF circuit and systems. He is a member of KICS, KEES and IEEE.

Il-Kyoo Lee

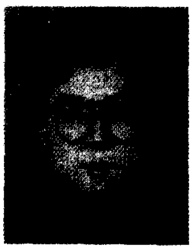


received the B.E. and the M.E. degree from Chungnam University, Daejon, Korea in 1992 and 1994 all in electronics engineering. Since 1994 he has been with ETRI, Daejon, Korea, where he is a senior member of the research staff of the Radio Technology Department. His research interests include RF/IF circuit and systems. He is a member of KICS and KEES.

Jae-Young Kim

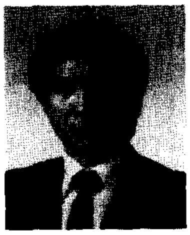
received the B.E., the M.E. and the Ph.D. degree from Yonsei University, Seoul, Korea in 1990, 1992 and 1996, all in electronics engineering. He worked for Daewoo Electronics, Ltd, from 1995 to 1998. Since 1999 he has been with ETRI, Daejon, Korea, where he is a senior member of the research staff of the Radio Technology Department. His research interests include Mobile RF circuit and system. He is a member of KICS and KEES.

Jae-Ick Choi



received the B.E., the M.E. and the Ph.D. degree from Korea University, Seoul, Korea in 1981, 1983 and 1995, respectively, all in electronics engineering. Since 1983 he has been with ETRI, Daejon, Korea, where he is a principal member of the Antenna Research Center. His research interests include RF circuit and antenna system. He is a member of KICS, KEES and IEEE.

Seung-Hyeub Oh



received the B.E., the M.E. and the Ph.D. degree from Yonsei University, Seoul, Korea in 1971, 1973 and 1982, respectively, all in electrical engineering. He worked for Tohoku University, Japan, from 1980 to 1981, as a guest researcher and Pennsylvania State University, USA, from 1985 to 1986, as a guest researcher. Since 1984 he has been with Chungnam University, Daejon, Korea, where he is an associate professor electronics engineering. His research interests include antenna engineering and digital communication RF sub-system design. He is a member of KICS, KEES and IEEE.