Design and Implementation of Low-price Business Card-size Portable Digital TV Set through High Integration DVB-T Solution

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Abstract - In this paper we provide a system design method to solve the problem of developing a miniaturized portable digital TV set. For such a portable device it is very important to reduce power consumption and extend operation time while the battery is the only power source in the system. The hardware circuitry shall be relatively compact according to the high integration of the system-on-chip (SOC) and the proper selection of key components. Not only miniaturization can be realized but also cost and power dissipation of the system decreased. Whether the implementation can be achieved also depends on antenna efficiency and DVB-T receiver performance. Therefore it is vital to select the right radio frequency architecture, which affects signal reception and power consumption. Based on the demands mentioned above we have chosen single conversion architecture for the receiver. Furthermore, our design has a better performance than earlier designs because of the use of a shielding case and the appropriate filtering of power ripples. Our efforts aim at making the antenna wideband, small-sized, low-profile, low-cost and omnidirectional. We implement the built-in antenna body by means of the printed circuit board at low cost. Meanwhile the spiral antenna is a good choice to fulfil the requirements of a wideband omnidirectional radiation pattern. Moreover, a heat sink conducts the heat outward and thus prevents overheating, ensuring operational safety.

I. INTRODUCTION

After digitization had been introduced, TV broadcasting little by little switched its systems from traditional analog into digital systems. Digital Video Broadcasting-Terrestrial (DVB-T) is currently being deployed in many countries, and it is planned to replace current analogue broadcasting schemes in most parts of the world [1]. DVB-T conquers the problems faced by analog systems, such as poor signal reception due to terrain and hence provides TV content with better sound quality and higher video resolution [2].

The DVB-T system provides a means of delivering the MPEG-2 Transport Stream (TS) via a variety of transmission media [3]. To provide a high data rate at an extremely low-bit error rate (BEK) for MPEG-2 video data transmission, coded orthogonal frequency division multiplexing (COFDM) technology has been adopted in DVB-T systems [4]. COFDM realizes a massive high-speed data transfer through the technique of carrier overlapping and narrowband orthogonal signals. It is mainly used for its robustness against multipath interference and for the full setup of a single frequency network (SFN). The DVB-T system transfers data in a flexible way, and under different circumstances various modulation schemes are available, for example QPSK, 16-QAM and 64-QAM. Besides that there are two transmission modes, 2k and 8k, based on the OFDM technique using different numbers of carriers [1].

DVB-T is capable of mobile reception, and similar applications have appeared in various kinds of consumer products [5]. However among those portable digital TV products which are on the market at present are set by many inconveniences like oversize, heavy weight, low resolution, poor reception and no replacement for the battery. Our digital TV solution gets over the many problems and provides an alternative with low cost, high portability and video quality. Our design fulfils the end user’s demand of being able to watch TV at any time and becomes a personalized consumer e-product.

This paper is organized as follows. In Section II the design flow of portable digital TV is demonstrated by the concept of the system design. An introduction to the hardware architecture is at the beginning of Section III, showing some of the problems arising during the developing process, for instance with the plan of the power source, antenna design, DVB receiver and cooling solutions. Afterwards measurement, analysis of the system performance and comparison of the results with products on the market are depicted. The last section presents our conclusions.

II. SYSTEM DESIGN

Fig. 1 shows the steps of the system design for the portable digital TV, and some points to be taken into account at each step are as follows [6]:

1. Specifications

In the planning stage it is necessary to formulate product specifications conforming to the industrial regulations.

2. Hardware design

During the hardware design stage, choosing components of low cost, minimum size and low power is given high priority. We have planned and examined the hardware circuits based on the specifications and component characteristics before drawing the schematics. Then we have made an overall inspection of the component properties before the PCB layout begins. Much attention has been paid to electromagnetic interference (EMI), electromagnetic compatibility (EMC), ESD protection, DVB-T front-end
3. Function test
   During the function test stage all hardware functions and defects have been tested and reviewed, making every effort to minimize any mistake in the design phase.

4. Thermal issue
   Long-term monitoring by infrared scanner has been used and the case temperature recorded during the stage of solving thermal issues. Our target is to reduce the temperature of the exterior case to below 39°C. A thermal meter has probed the IC surface temperature.

5. Receiver test
   During the stage of measuring the receiver, the performance of the DVB-T receiver has been measured to meet the specification requirements [1].

6. Antenna test
   We have made experiments on many different materials in the antenna test stage. FR4 has become the final candidate due to the cost constraint. Then the antenna performance has been examined and analyzed.

7. Integration test
   During this stage, the integration test between hardware and software has been carried out as well as the measurements of EMI, EMC and the verification of reliability and ESD protection.

8. Final stage
   During the final stage, after all uncertainties have been settled, our design had been accomplished. A comparison has been performed between our design and similar products.

III. THE INTEGRATION DESIGN OF THE BUSINESS CARD-SIZE PORTABLE DIGITAL TV

The system block diagram of the business card-size portable digital TV is shown in Fig. 2 and consists of several modules. The two basic parts of the portable digital TV system are the baseband and the RF sections. The baseband contains a DVB decoder, memory ICs, an IR receiver, power supply, a keypad and voice circuits. The RF sections include internal and external antenna and the DVB-T receiver which is composed of the DVB-T tuner and the COFDM demodulator.

There are several major parts in our system as explained below.

1. DVB Decoder
   The DVB decoder we have chosen is a single-chip digital TV processor of high integration which includes MPEG A/V decoder, MPEG transport de-multiplex processor, microcontroller and TV encoder onto a chip, facilitating a cost-effective solution for digital TV receivers.

2. Receiver
   The key members in this part are tuner, AGC circuit, COFDM demodulator, SAW filter and VGLNA. This receiver is designed to cover VHF channels from 170 MHz to 230 MHz and UHF channels from 470 MHz to 862 MHz.

3. Antenna
   To reduce volume, weight and cost while still maintaining a high level of performance and functionality [7], our antenna uses the microstrip type, unlike the rod antenna used by other products. Spiral antennas are known for their ability to maintain near-circular polarization, consistent gain and input impedance over a wide bandwidth, therefore the spiral shape has been adopted for the antenna design [8].

4. Memory
   Memory ICs include Flash, SDRAM and EEPROM. Flash acts as the storage for system firmware, SDRAM provides software programs with a temporary place to store the computation data, and EEPROM memorizes the user’s personal configuration.

5. Display
   The 2.5 inch display panel is made of Low Temperature Poly Silicon (LTPS) LCD with a resolution of 960x240 dots. This kind of LCD has the advantages of low profile, light weight, low power consumption and high resolution [9].

6. Audio
   The key members in this part are DAC (digital-to-analog converter), LPF (low pass filter) and audio power amplifier. The DAC translates the demodulated DVB-T signal into the analog audio output. The LPF has been applied before the amplifier which cleans out any noise higher than 24.9 kHz. The audio power amplifier of Class D type is highly efficient and suitable for the application of low power portable products [10].

7. Power
   The power system comprises DC/DC converters, charging circuitry and a rechargeable Li-ion battery. There are four voltage outputs (+7V, +5V, +3.3V and +1.8V) coming from...
the DC/DC converters. The Li-ion battery pack has a capacity of 1050mA/H.

8. Keypad and IR

Six function keys are defined for system operation; they are the Menu, Enter, Channel up, Channel down, Volume up and Volume down keys. The IR receiver is responsible for receiving remote control signals from the external TV. The TV output terminal provides video compatible with PAL, NTSC and SECAM formats.

A. The power plan of the Integration Design

Power consumption is an important factor in portable digital TV design. The power plan in the integration design of the portable digital TV is shown in Fig. 3. We have chosen the high-efficiency DC/DC converters to provide the voltage transformation. The power for the LCD panel backlight is provided by the built-in regulator whose efficiency is up to 90%. Besides efficient handling of power, the ICs behind the regulators are energy saving components. The LCD is shut down while the TV out terminal is in use, so the total power can be controlled under 2.6 watts, much lower than in current products on the market.

Table I shows the power analysis of each voltage source.

Table I: Power Consumption Analysis of Our Design

<table>
<thead>
<tr>
<th>Power mode</th>
<th>Power Consumption (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8V</td>
<td>0.33</td>
</tr>
<tr>
<td>3.3V</td>
<td>0.94</td>
</tr>
<tr>
<td>5V</td>
<td>1.03</td>
</tr>
<tr>
<td>7V</td>
<td>0.18</td>
</tr>
<tr>
<td>Backlight</td>
<td>0.09</td>
</tr>
</tbody>
</table>

B. Antenna Design and Performance Measurement

The DVB signal uses low-frequency carriers and occupies a wide bandwidth, which places certain physical constraints on the size and the gain of an antenna. However, size and gain are both critical essentials of a portable TV product, so how to make a small-size and high-gain antenna becomes a major point of our design. In our case the rod antenna would be a simple choice. Typically a dipole antenna for VHF/UHF bands requires a resonant length of about 40cm as a quarter of the electromagnetic wavelength in a vacuum. This is too long for portable equipment [11]. The length of a rod antenna can be adjusted between high and low frequency, but this gives a portable TV a bad look and causes inconvenience during operation. Consequently a printed antenna reveals its advantages comparing to a rod antenna. It is light, low-profile, easy to manufacture and can be mounted on any exterior. Thus we have chosen the microstrip antenna for our design.

The geometry of both spiral and fractal dipole has been presented in Table II. The data in Table III show that we have achieved a compact size; an area of only 50x50mm² is allowed for our antenna. This physical limitation and the goal of full VHF/UHF coverage have made our antenna more difficult to develop.

Table II: Return Loss and VSWR of Our Design

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Return Loss (dB)</th>
<th>VSWR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>-9.25</td>
<td>2.06</td>
</tr>
<tr>
<td>230</td>
<td>-8.92</td>
<td>2.08</td>
</tr>
<tr>
<td>470</td>
<td>-12.2</td>
<td>1.67</td>
</tr>
<tr>
<td>680</td>
<td>-22.7</td>
<td>1.15</td>
</tr>
<tr>
<td>810</td>
<td>-23.9</td>
<td>1.42</td>
</tr>
</tbody>
</table>

C. Performance Measurement of the DVB-T Receiver

The RF architecture of the DVB-T receiver has to be carefully surveyed since it directly affects receiving performance and power consumption. The DVB-T standard defines many requirements, such as noise figure (NF), sensitivity, dynamic range, interference immunity, as well as a frequency span of 800 MHz for VHF and UHF bands. The choice of a proper receiver structure governs the amount of components and the possibility of implementation. The single conversion allows the design over a wide bandwidth to be divided into 2 to 3 spectral sections and hence makes
the component specifications more relaxed and mass production less expensive [13-14]. The block diagram of the DVB-T receiver is presented in Fig. 5.

![Block diagram of the DVB-T receiver](image)

We have proposed some verification items and test procedures for receiver performance. The instrument we have used is the R&S broadcast test system (SFU) and the setup is shown in Fig. 6. The sensitivity and the multipath susceptibility have been measured to ensure conformity with the DVB-T regulations [1].

![Basic setup of measuring equipment for DVB-T receiver performance](image)

1. **Performance with noise figure and sensitivity**

   To improve the sensitivity and the dynamic range of the receiver we have chosen the low-noise and wide bandwidth VGLNA as the first-stage amplifier to improve the sensitivity of our system design.

![Basic setup of measuring equipment for noise figure](image)

2. **Performance with short delay echo and long delay echo**

   The influence of C/N ratio and multipath reflections is difficult to ignore. Besides having the C/N ratio above the threshold, the multipath noise must be effectively eliminated, while the system still needs to be functional under these circumstances. The equalizer inside the receiver is responsible for the suppression of multipath interference below a reasonable level. All channels of the receiver should be able to receive DVB-T signals with short and long delay echoes.

   The power level of a DVB-T wanted signal has been adjusted to -50 dBm. The digital television receiver should be able to receive the broadcast signal with a C/N value of 22.5 dB or less in 64-QAM mode after it has mixed with the long delay echoes as in Table IV and with the short delay echoes as in Table V. Apart from Tables IV and V, the test conditions have been configured as follows. Bandwidth = 7 MHz (VHF)/8 MHz (UHF), FFT mode = 2K, Modulation = 64-QAM, Code rate = 7/8, Guard Interval = 1/32 and Frequency = 177.5, 205.5, 226.5, 474, 522, 594, 618, 690, 714, 794, 802, 858 MHz.

![Measuring results of sensitivity](image)

<table>
<thead>
<tr>
<th>Delay (μs)</th>
<th>Path 1</th>
<th>Path 2</th>
<th>Path 3</th>
<th>Path 4</th>
<th>Path 5</th>
<th>Path 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative</td>
<td>0</td>
<td>5</td>
<td>14</td>
<td>35</td>
<td>54</td>
<td>75</td>
</tr>
<tr>
<td>Attenuation (dB)</td>
<td>0</td>
<td>9</td>
<td>22</td>
<td>25</td>
<td>27</td>
<td>28</td>
</tr>
</tbody>
</table>

![Measuring results of sensitivity](image)

Because the received signal strength varies with the propagation distance, the system should be able to handle a wide range of input power. The results from the measurement show that the sensitivity of the receiver is -80 dBm and the saturation point is -20 dBm, so its dynamic range is 60 dBm. The setup for the sensitivity measurement is shown in Fig. 9 and the configurations are Modulation = 64-QAM, FFT mode = 8K, Code rate = 7/8, Guard Interval = 1/32, C/N ratio = 20 dB, Bandwidth = 7 MHz (VHF)/8 MHz (UHF) and Frequency = 177.5, 205.5, 226.5, 474, 522, 594, 618, 690, 714, 794, 802, 858 MHz. The sensitivity obtained over the spectrum is shown in Fig. 9. This result shows that our design not only meets the standard [1], but our design is superior to both Products A and M, especially in regard to the UHF band. It has been achieved by offering a solid shielding and by flattening the power ripple of the receiver.
Table V

<table>
<thead>
<tr>
<th>Path</th>
<th>Delay (μS)</th>
<th>Relative Attenuation (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>2.8</td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>3.8</td>
</tr>
<tr>
<td>4</td>
<td>1.45</td>
<td>0.1</td>
</tr>
<tr>
<td>5</td>
<td>2.3</td>
<td>2.6</td>
</tr>
<tr>
<td>6</td>
<td>2.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Fig. 10 demonstrates that the design conforms to the regulation [1].

D. Thermal Issue of the Integration Design

Our DVB decoder IC was not designed for portable devices in the first place. The limited area of a business card, as shown in Fig. 12, turns heat control into a serious matter. The excess heat not well conducted will cause a long run deform for the device’s structure and cause thermal runaway and explosion in the Li-ion battery.

Fig. 11 illustrates that the case temperature was much lower with the heat sink added than without a heat sink. The highest temperature has been effectively reduced by 19%, from 48°C to 39°C.

E. Experiment Results

Proper selection of the key components and the DVB-T architecture has helped us to finish the integration of the portable digital TV. A snapshot of our system is shown in Fig. 12.

Table VI presents our supreme benefits in cost, weight, dimension, display resolution and power consumption. Our design also provides an OSD (On-Screen Display) user interface which is easy to use, available in eight languages and controlled by keypad or infrared remote. The video quality satisfies the requirements of the DVB-T MPEG-2 standard in company with stereo audio output. The frequency of our on-board antenna covers both VHF and UHF bands. Besides, the battery is exchangeable for longer operation time and is made from Li-ion cells compatible with many series [16].

Table VI

<table>
<thead>
<tr>
<th>Key benefits</th>
<th>Product M</th>
<th>Product A</th>
<th>Our design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (USD)</td>
<td>146</td>
<td>96</td>
<td>58</td>
</tr>
<tr>
<td>Panel size (inches)</td>
<td>4.2</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>180</td>
<td>300</td>
<td>120</td>
</tr>
<tr>
<td>Power consumption (watts)</td>
<td>3.1</td>
<td>4.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Display resolution (dots)</td>
<td>960x240</td>
<td>480x234</td>
<td>960x240</td>
</tr>
<tr>
<td>Dimension (mm³)</td>
<td>129x82x15</td>
<td>135x85x43</td>
<td>101x56x20</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

In this article we have demonstrated how to design a low-cost and high-quality portable digital TV set using the DVB decoder chip as the core. Although the high IC integration has helped to simplify the hardware design process, there have still been many challenges in shrinking a digital TV to the size of a business card. Those difficulties are how to improve the receiver performance, how to increase the antenna gain and bandwidth, how to resolve the heat accumulation and how to lower the total power consumption. We have accomplished this design with the aid of the system integration method. A good selection of both hardware platform and key components has helped us to decrease both cost and power dissipation. A spiral antenna is utilized based on the need for wideband and omnidirection. Our DVB-T receiver uses single conversion architecture, and receiver sensitivity is -80 dBm, RF input dynamic range is 60 dB and the noise figure is 4.5 to 5.5 dB. Compared with other products our system provides a better performance in noise figure, dynamic range and interference resistance. As for
cooling problem, the use of a heat sink effectively reduces the surface temperature by up to 19%.

The attractions of our design are low cost (USD 58), low power (2.6 watts), light weight (only 120g including the battery), replaceable battery, high resolution (960x240 dots), small size of business card-size, (101x56x20mm³) and built-in antenna with frequency supporting VHF and UHF bands. In the future consumer products will constantly bundle various kinds of function, and the portable digital TV is heading towards a low-power and multi-functional system. We plan to keep improving antenna performance, power consumption and cooling solution to gain a greater competitive advantage.

REFERENCES