White Paper

Optimising RF Tuner Performance Using DigitalTune™ Signal Processing

By Franck Banag, Product Marketing Engineer

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Abstract

The introduction of digital TV reception capability in mobile phones and PMPs (portable multi-media player), which are already crowded with numerous other features is a significant design challenge. In addition to the constraints on space and power, an issue specific to portable devices is the multiplicity of reception conditions that they can encounter, potentially degrading the received signals. The E4000 RF tuner IC developed by Elonics brings an unprecedented answer to these issues. Integrating multiple RF signal processing circuit elements with extensive digital programmability allows the system to optimise the tuner stages in real-time, which helps to ensure optimal reception quality.

Background

The latest trend in the increasing number of features provided in mobile phones is the addition of mobile TV reception. Digital TV transmission that allows a more efficient use of the spectrum has been recognised for its superiority over analogue TV. Already several countries like the UK and the US are planning a complete switch-off of analogue TV transmission.

There is a strong emphasis on setting up new standards around the world to allow over-the-air broadcast digital television reception on portable and mobile devices. Several countries are in the process of defining or implementing new digital TV transmission standards. In practice, DMB-T/H and CMMB are still in discussion in China, T-DMB and S-DMB are already deployed in Korea and Japan, which has succeeded in the adoption of ISDB-T 1-seg is in the process of upgrading to ISDB-T full-seg. There are also DVB-T and DVB-H, originally published by ETSI (European Telecommunications Standards Institute), which is being heavily promoted as the official standards in Europe and in the USA, ATSC has been chosen. The problem expands because even within one standard, technological implementations will differ. For example, DVB-H allows the use of bandwidths of 5, 7 or 8MHz, as well as 2k, 4k or 8k transmission modes. Even for those countries that have chosen to implement similar standards, the limited availability of spectrum may imply different frequency bands. The possible transmission frequencies cover the VHF, UHF and L-band (from 30MHz to 2GHz).

Most observers agree that the world-wide convergence of standards is unlikely to be achieved and the diversity of system requirements will give an advantage to RF tuners capable of receiving multiple standards and frequencies. The obvious example is the successive enhancements in mobile phone technology that has transitioned from single-band models to quad-bands models.

The technical demand on Digital TV receivers is more stringent when they are aimed at mobile devices. In addition to the obvious constraint of limited space and power, channel imperfections like fading and doppler effects that adversely affect the signal reception are magnified in a mobile environment. However, good quality reception is required to guarantee the commercial uptake of mobile digital TV. It is accepted that new technological solutions are required to provide good digital TV reception on mobile devices.

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TV Reception Quality

The main goal of TV transmission is to receive the picture exactly as it is broadcast. This is not always an easy task for over-the-air analogue transmissions. For analogue transmission, the quality of reception is highly sensitive to disturbances in the air-channel and most of us would have noticed analogue TV pictures affected by "ghost", "snow" or distortion effects.

From that perspective, digital TV has a strong advantage as it is less sensitive to those perturbations. With digital transmission the information received is to be, after demodulation, the exact same transmitted sequences of symbols, so receivers are more likely to regenerate the image with the same level of quality as it has been transmitted. Even when considering that digital transmission and demodulation processes suffer from errors as well, it is interesting to note that image quality problems are significantly different. The impact of erroneous symbols creates flicker by changing individual pixel colours or luminance. To evaluate and measure digital TV transmission quality, the emphasis is on the measure of the proportion of erroneous symbols received. The measurements used are BER (Bit Error Rate), MER (modulation error ratio) and EVM (Error Vector Magnitude). Despite those measurements not being directly linked to the image quality for the viewer, they are reasonable indicators to estimate the losses happening during digital transmission.

The other important feature of digital transmission is the addition of error correction, where redundant information is encoded in the transmitted signal. Using the redundant information gives some ability for the demodulator to reconstruct the transmitted symbols correctly in the case of an imperfect channel transmission. There are different implementation choices and it is possible to trade-off error protection strength against bandwidth because the code rate, the ratio of redundant bits over the total number of bits transmitted is variable. Such technology called Forward Error Correction (FEC) has been implemented in standards like DVB-T and DVB-H and helps to increase the robustness of the transmission well above analogue transmission capabilities.

This results in the ability of digital TV to maintain better image quality when the received signal weakens or the C/N (carrier to noise ratio) decreases whereas an analogue TV image will see a progressive degradation. The error correction capability of digital transmission is obviously not infinite. Above a certain level of degradation of the received signal, the corrective scheme is overloaded and the receiver looses the ability to recover the transmitted information. This can result in picture freezing or disappearing abruptly. In an effort to normalize the performance of the digital TV receivers and to prevent such issues, the EICTA (European Information & Communications Technology Association) has defined the MBRAI (Mobile and Portable DVB-T/H Radio Access Interface) specification that provides a recommendation for the performance from DVB-T and DVB-H tuners under a variety of test conditions.

The Tuner

Architecturally, a digital receiver is made of two stages. The first stage is the tuner which is analogue and the second is the demodulator which is digital. The capability of the demodulator to reconstruct the symbols with the lowest BER depends heavily on the performance of the analogue tuner.

The function of the tuner is to amplify the signal from the antenna and then to filter and frequency-translate it in order to make the information decodable by the demodulator. Although tuner architectures are relatively well known, tuner technology is evolving quickly. In a portable appliance like a mobile phone, where every square millimetre of PCB space is accounted for, the only viable solution for size and power is the use of integrated silicon tuners. Traditionally, RF tuners have come in the form of tuner cans with a combination of high cost, high power and large

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size. Nowadays, innovative solutions and new process technologies have allowed the creation of monolithic integrated tuners with similar or better specifications than canned tuners.

Tuner specifications are also evolving with the generalisation of digital TV transmission. One advantage of digital transmission is a more efficient use of the spectrum bandwidth, which is limited in most of the world. For example, in Japan, the ISDB-T standard allocates only 6MHz bandwidth to transmit High Definition TV. The solution to increase the amount of information transmitted within a limited spectrum bandwidth is to use modulation techniques encoding multiple bits per received symbol. For example, the modulation technique BPSK (Binary Phase Shift Keying) transmits 1 bit per symbol, whereas QPSK transmits 2 bits per symbol, 16-QAM transmits 4 bits per symbol and 64-QAM, 6 bits per symbol. Figure 1 shows the constellation diagram for several modulation techniques. We see, for a given transmitted power and coverage, that as the number of symbols increases, the distance between them decreases, which makes the reception more sensitive to the noise level in the signal path and particularly the RF tuner.

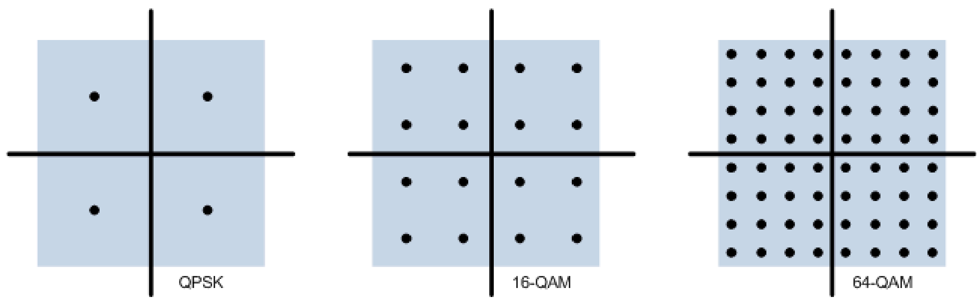

Figure 1: Ideal constellation diagram for QPSK, 16-QAM and 64-QAM

This constraint is acknowledged in the MBRAI specifications for DVB-T/H with a parameter called the carrier to noise ratio (C/N) through the receiver chain. A C/N of 14dB is required for 16-QAM (CR=3/4) and 20dB is asked for 64-QAM modulation. The capability of the receiver to maintain such high C/N depends on the tuner performance, particularly its linearity, sensitivity and noise figure.

The tuner itself is essentially a sequence of analogue processing steps. At the transmission frequencies of digital TV (VHF to L-Band), the tuner noise performance is impacted by factors as various as signal bandwidth, impedance mismatches, oscillator phase noise, clock distribution, capacitive and inductive coupling, transistor flicker and thermal noise. Because the noise figure (NF) limits the receiver sensitivity, a lower noise figure is required for the best sensitivity.

From theory, we know that the noise figure of a tuner is mainly limited by its first signal amplification stage, the Low Noise Amplifier (LNA). Wide-band LNAs with low noise figures are difficult design challenges. Most of the existing solutions use several narrow-band LNAs in order to cover the wide input frequency range required for a tuner designed to handle several standards. Achieving good performance over several transmission standards implies multiple trade-offs that could prove sub-optimal for a traditional analogue tuner design.

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DigitalTune™

Elonics has defined an evolved architectural model for its RF signal processing called DigitalTune™. It is differentiated from traditional RF tuners by using extensive digital control to optimise the signal path.

There is no alternative currently to using analogue circuits to process high frequencies signals from the antenna. However problems such as process variations can have a significant impact on tuner performance. Whilst a combination of expensive process technology, good circuit design and layout can overcome many of the issues, they cannot be eliminated entirely. The Elonics DigitalTune™ architecture is based on using high performance and modular RF blocks implemented in low cost CMOS technology with variations in analogue performance complemented and compensated for by using digital error correction algorithms.

Many novel technological choices were needed to implement the Elonics DigitalTune™ architecture used in the E4000 tuner, not least of which was the use of 130nm CMOS. Usually, high performance integrated tuners traditionally required expensive processes like SiGe and GaAs. However, newer low geometry CMOS processes with increasing Unity Frequency (ft) devices have improved RF performance. This trend has provided a foundation for Elonics to build high performance analogue RF functions in CMOS. The architecture chosen for Elonics first tuner is zero-IF (ZIF) where the input signal is directly mixed down to dc. This is the lowest cost approach as it saves external filters for the intermediate frequency.

The first stage of the Elonics tuner is a single LNA able to receive all bands from 64MHz to 1.7GHz selectable with digital control. The signal amplification is divided between 8 stages, each with individual control of gain and filtering characteristics. It allows the tuner to achieve a wide gain range, from 10dB to 102dB programmable in steps of 1dB. Such small steps give accurate control of the tuner gain to the system designer.

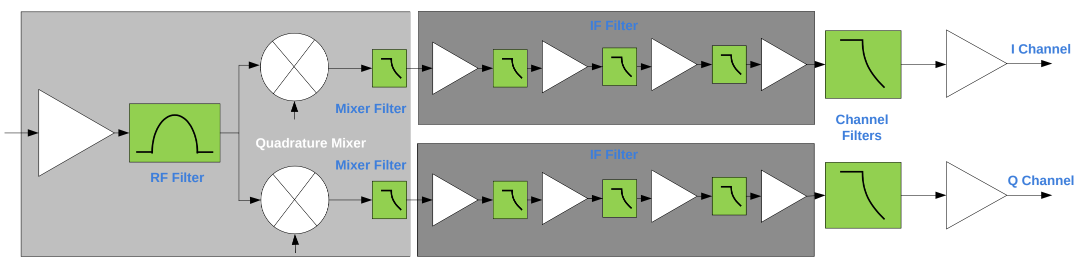

Figure 2: Elonics Tuner Architecture

For a ZIF architecture, the bandwidth of the signal received is limited by low-pass filters placed after the mixer. As bandwidth requirements vary between and within broadcast standards, the corner frequency of the low-pass filters have to be modifiable to adapt their corner frequency to half of the RF bandwidth. On the low side, ISDB-T 1-seg uses a 0.43MHz bandwidth whilst DVB-H could use 8MHz bandwidth on the high side. One method to address this issue is to serialise many filtering stages, each individually digitally controlled. This approach successfully provides an overall filtering transfer function with corner frequencies programmable over most of the required range with steps in kHz.

The signal chain characteristics are managed internally in the E4000 tuner with digital algorithms alongside external controls which are provided by a straightforward Pulse-Width-Modulation (PWM) input or a digital input pin control.

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The final design is a multi-band (from FM band to L-band) multi-standard flexible tuner, which requires only 8 external components and uses less than 100mW. At a system level, thanks to this flexibility, real-time optimisation of the tuner characteristics required to adapt to changing signal path conditions becomes possible.

Real-Time Optimisation

In a mobile environment, the air-channel characteristics such as attenuation and interferer levels can change rapidly. A mobile receiver can be placed indoors or outdoors, moving slowly at pedestrian speed or fast moving in a vehicle. The constraints placed on the receiver for each of those situations are different and require potentially conflicting specifications from the tuner. For example the linearity is better with the LNA at small gain settings, avoiding saturation of the following stages, but reducing LNA gain also degrades the sensitivity of the receiver. In order to overcome these issues and allow equally good reception for all possible scenarios, it is possible to take advantage of the real-time re-configurability of the tuner to adjust its characteristics based on the reception conditions.

Power Consumption Optimisation

It is possible for example to optimise the power consumption. It has been shown that variation by as much as +/-10dB in signal strength within a short distance even within the same room is not uncommon in a multipath reception environment. An improvement of 10dB on the received signal could be adjusted with a similar decrease of the tuner gain without impacting the reception quality. By reducing the gain by 10dB, it decreases the power of the tuner by 10%, thus lengthening the battery life for a mobile receiver. Equally interesting is the case where there are few high level interferers. By relaxing some of the filters parameters, the tuner power consumption could be reduced by up to 15%.

Maximum Sensitivity

Sensitivity is an important parameter with better performance allowing the user to maximize the distance at which reception is maintained. Using high sensitivity tuners allows the transmitter coverage to increase and helps to reduce the cost of a TV transmission network. The problem comes at the edge of the coverage zone, far from transmitters, when the signal weakens and the signal can only be received with a sensitive tuner.

By definition, sensitivity is the minimum input power to guarantee a defined ratio of Carrier over Noise power (C/N). The (C/N) is defined for a particular modulation scheme and for a given BER. Considering the DVB-H reception case depicted below, the sensitivity is computed by summing in dB units, the 1-Hz thermal noise power (-174dBm), the impact of the bandwidth, the receiver noise figure and finally the carrier over noise ratio. With the thermal noise floor being defined by the bandwidth, and the C/N defined by the BER, the key parameter important to improve the sensitivity is the receiver noise figure. A low noise figure for the receiver will give a higher sensitivity.

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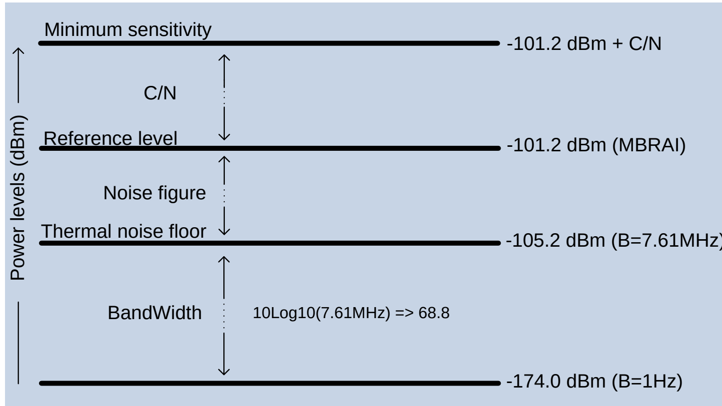

Figure 3: MBRAI receiver noise floor

For DVB-H with a bandwidth of 8MHz, the minimum sensitivity to be achieved is (–101.2dBm + C/N) as specified in the MBRAI document. This assumes 4dB of Noise Figure for the receiver. The noise figure (NF) represents the relative contribution on the output noise coming from the gain stage. An ideal noiseless receiver would have a 0dB noise figure. Because the active components of the gain stage also generate noise, noise figure is always several dBs. According to the following equations, the overall receiver noise figure is dominated by its first stage and the noise figure of a given stage is minimal when G, its gain is large.

One gain stage :

$$NF_i = \frac{\left(\frac{Sin_i}{Nin_i}\right)}{\left(\frac{Sout_i}{Nout_i}\right)} = \frac{\left(\frac{Nout_i}{Nin_i}\right)}{G_i}$$

Cascaded gain stages (n) :

$$NF = NF_1 + \frac{(NF_2 - 1)}{G_1} + \frac{(NF_3 - 1)}{(G_1 * G_2)} + \ldots + \frac{(NF_n - 1)}{(G_1 * G_2 * \ldots * G_n)}$$

Figure 4: Noise factor for one stage and multiple stages

Real-time trade-offs are easy to implement with the digital control available in the E4000 tuner. As stated previously, to minimize noise contribution in the reception chain and maximise the sensitivity, the first amplification stage and the most important contributor in the receiver noise figure equation has to be set for minimum noise figure. The option is then to increase the LNA gain. When choosing to increase the gain of the LNA, it is possible that this could cause saturation in the following stages if the gain is high too so the following amplification stages need to have their gain decreased at the same time. While keeping the overall tuner gain constant, the profile of the gain distribution can be updated in real time on the E4000 to maintain the lowest noise figure when it is required.

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Maximum Linearity

In a city situation where there are lots of transmitters, the key issue is not the distance from the transmitter itself, but the high level of interferers and blockers created by other sources of emissions in the close spectrum. MBRAI has specified a series of cases that the tuner has to resolve for good DVB-H reception.

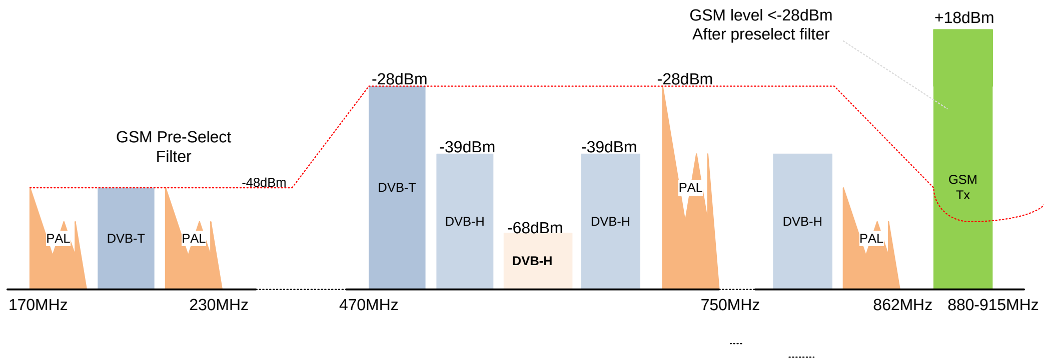

Figure 4: MBRAI Blocker Profiles

The graph shows that the tuner has to resolve wanted signals with blocker levels as high as 40dB above the level of the desired channel. The most important parameter to allow the handling of such high levels is the linearity of the tuner. Linearity in the LNA increases as the gain decreases, so to be maximised, the gain has to be reduced. The challenge is to maintain the overall gain of the tuner to maximise the dynamic range at the output prior to demodulator inputs. That leads to an increase of the gain for successive gain stages whilst filtering out the signal power at blockers frequencies. Shifting the gain from the LNA to the following stages in order to achieve the best linearity profile is easily done thanks to the versatility of the E4000 tuner controls.

Conclusion

With the implementation of the DigitalTune™ architecture in the E4000, these optimisation choices are possible in real-time. The tuner features automatic or external controls to modify individual signal path circuit path performances with short response times. This gives the opportunity to implement power, noise figure and gain or linearity trade-offs in the field and helps give the best mobile TV user-experience.

DigitalTune™ from Elonics gives designers a new degree of freedom in the resolution of the complex issues introduced with mobile TV systems design. These solutions are implemented in the new Elonics multi-standard RF TV tuners, which is unique in its ability to dynamically adjust radio frequency reception parameters, offering uncompromised performance at low cost and low power.

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Author Biography

Franck Banag is a product marketing engineer at Elonics. He joined Elonics as an IC designer, and is an expert in PLL circuits. Prior to joining Elonics, he held a number of design engineer positions at Cadence and STM.

About Elonics - "Wireless Silicon for a Digital Age"

Elonics Ltd. is a fabless mixed-signal semiconductor company specialising in the design and development of multi-band radio frequency (RF) IC products. Founded in 2003 and based in Livingston, United Kingdom, Elonics has developed an innovative radio frequency architecture called DigitalTune™ that is the foundation for a family of re-configurable CMOS RF front end products.

Elonics innovative technology allows manufacturers to design high performance multi-band radio transceivers with unrivalled power consumption and low system cost. Elonics products are targeted at high volume portable consumer electronics applications that require wireless multi-media connectivity where size, performance, price and power consumption are paramount.

About DigitalTune™

DigitalTune™ is a patent pending radio frequency architecture that uniquely allows each stage of the RF signal processing to be adjusted under digital control. This strategy has a number of benefits over traditional tuners that typically use analogue control voltages to manage the RF signal gain. As well as providing superior flexibility, it can be used to adjust the performance of the tuner for optimum linearity or noise figure according to the signal conditions. DigitalTune™ also helps overcome some of the inherent process limitations of CMOS, and allows Elonics to lower power consumption and reduce silicon cost.

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