White Paper

The Future for Multi-Band RF CMOS Tuners

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What is driving demand for multi-band digital receivers?

There is a school of thought that the consumer has an insatiable demand for digital consumer electronics products that are ever more complex, providing a medley of digital multi-media functions and features, all contained in a pocket sized battery powered appliance.

Such products have been bulky, power hungry and expensive and although the compromises that consumers have had to make have been reduced over time, we are still a long way from nirvana. There are a number of reasons for this; semiconductor devices are becoming ever more integrated reducing PCB board area; power consumption of integrated circuits is falling as supply voltages drop and process geometries fall; and companies are finding innovative ways to make better use of existing solutions like the radio receiver.

On the other hand, consumers who were once satisfied with a phone being a phone have re-drawn their benchmark and now want it to take pictures, send text messages, play music and games, and just occasionally make a telephone call. This in turn requires more silicon and hence more PCB real estate, and higher power drain from the battery. It clearly also drives up the bill-of-material cost for manufacturers, creating problems for the operator who ultimately has to pass on the cost to the consumer or figure out how to make more money from services.

However, just when you thought that technology companies had caught up with consumer demands with the release of products like the Apple iPhone, along comes another raft of applications that create all the same problems all over again.

Mobile digital consumer devices from mobile phones to portable media players have become a gateway for a host of multi-media content. Operators and broadcasters are exploring new ways to deliver this content using a number of different video and radio broadcast standards.

Whilst it would be nice to believe that industry could agree a unitary standard for the wireless distribution of audio and video content, political and spectrum allocation issues across the world have created a situation where there are multiple standards. Indeed there are some companies who actively support using traditional analogue transmission techniques for radio and television onto a mobile device. However it is generally accepted that digital transmission techniques will be used for this new generation of multi-media services as they are spectrally more efficient for a given data rate and use less power.

Data Transmission Standards

Multi-media audio and video services can be delivered to the phone in a number of ways including transmission via cellular, satellite and terrestrial broadcast, see Figure 1. The traditional view was that text would be delivered to mobile phones via GSM data services, still pictures would come via 2.5G (GPRS) and TV and video from the very expensive 3G network. However, although cellular TV services offer a relatively easy path for the operator to generate additional revenue, TV and radio signals take up much more capacity than a simple voice call and this becomes the limiting factor in the rapid expansion of such services in the future.

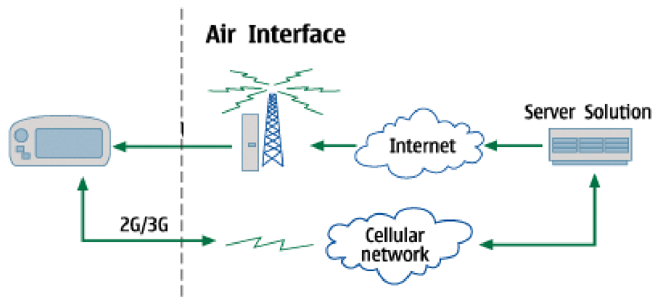

Figure 1: Air Interface for Broadcast Signals

Although cellular networks have transitioned from ‘unicast’ systems where information is sent to a single destination to ‘multicasting’ where this same information is sent to a group of destinations, both are still very capacity intensive. Broadcasting these signals to the phone over an air interface offers the opportunity to offer multiple channels of high quality video and audio without compromising network capacity for other voice and data traffic. However, this method does come at a cost. It relies on the installation of new broadcast network infrastructure, and the provision of new services that ultimately will have to be paid for by the consumer. There are a number of barriers to overcome before services and equipment are universally available but already, many companies in places such as Korea and Japan have jumped in to deploy initial services.

	DVB-T	**DVB-H**		**T-DMB**		**DMB-T**	**ISDB-T**
Geography Channel	Europe, Australia, India, Russia	Europe/US		S Korea		China	Japan
Frequency Band	UHF Band IV and V, VHF Band III	UHF Band IV and V	VHF Band III	UHF Band IV and V	UHF Band IV and V	UHF Band IV and V	UHF Band IV and V
Frequency Range (MHz)	470-854	470-854	170-245	470-854	470-770	470-854	470-770
Bandwidth (MHz)	6,7,8	6,7,8	1.536	8	6	8	6

Table 1: Different TV Broadcast Standards Across the World

	FM	DAB	
Geography Channel	Europe, Australia, India, Russia	S Korea, Worldwide	
Frequency Band	VHF Band II	VHF Band III	L Band
Frequency Range (MHz)	64-108	170-245	1452-1492
Bandwidth (kHz)	50-100	1536	1536

Table 2: Different Radio Broadcast Standards Across the World

The challenge for equipment makers and by implication the semiconductor companies, is to come up with solutions that can accommodate the myriad of different air interfaces that are either being used or proposed. Tables 1 and 2 show some of the current standards. In an ideal world, the solution would be a flexible digital radio receiver that could be dynamically re-configured either at the factory or in the field dependant on the user requirement. However the technical challenges in providing such a product are enormous.

For example, the spectrum of signals shown in Figure 2 indicates that the radio front end needs to accommodate frequencies from 64-108MHz for the traditional FM band through to the top of L-band for DVB-H (1670 - 1675MHz). The radio receiver needs to be very sensitive to ensure that it is capable of recovering the broadcast data, particularly in applications where the signal will be weak (for example inside a car traveling at high speed). It must be low noise and it needs to be able to select the desired band of interest within the context of a very crowded frequency spectrum.

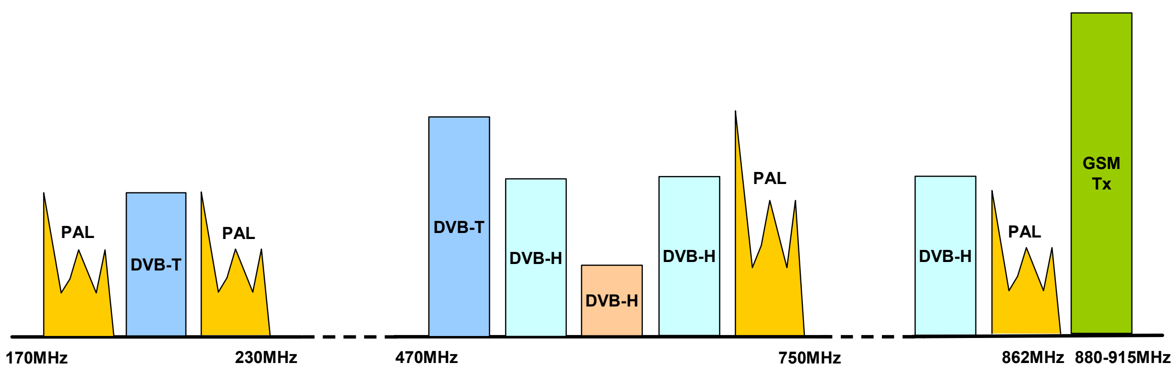

Figure 2: Frequency Spectrum of Services

The reality is that these challenges are very difficult to meet when measured against the other commercial requirements that exist today; namely low power consumption, small PCB footprint, and low cost. However, companies such as Elonics are making progress towards this goal, creating solutions that accommodate some of the more popular broadcast standards.

Market Analysis and Requirements

Although there are a number of platforms that are capable of using the new digital broadcast receiver technology including PC USB dongles, PCs and portable media players, this white paper will focus on the high end multi-media phones and smartphones because they highlight the problems that must be overcome.

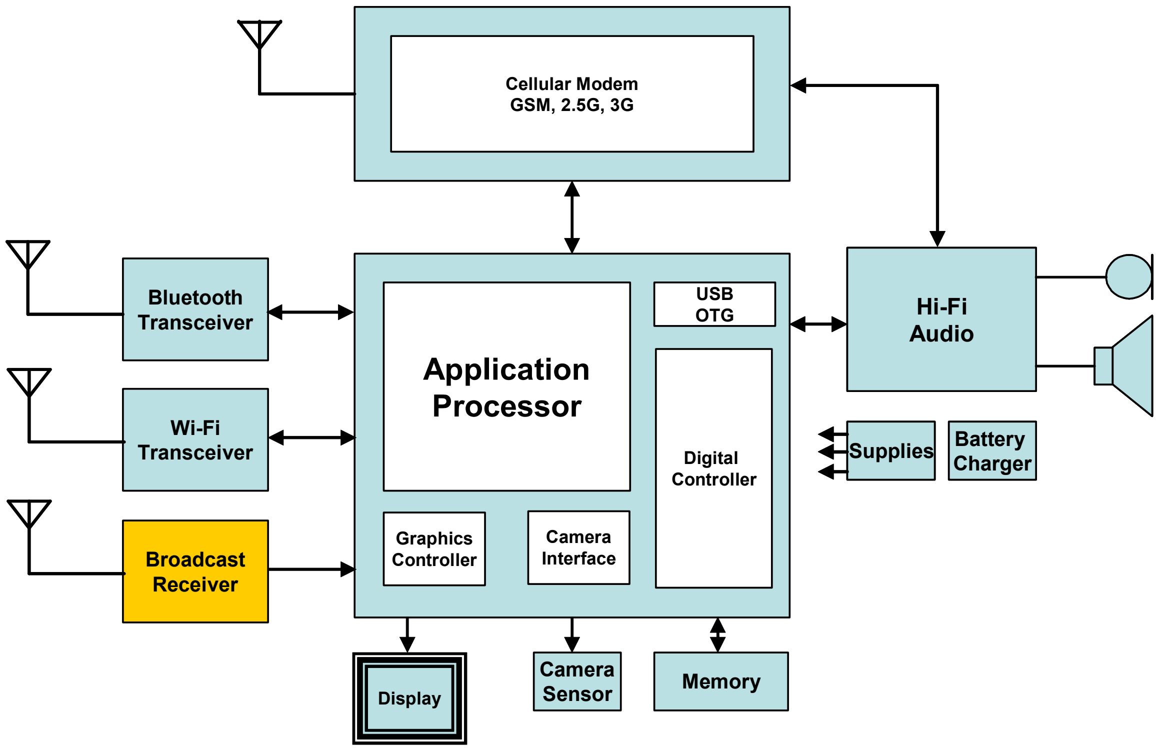

Figure 3: Mobile Phone Architecture

High end phones have been the driving force behind many technology developments in recent years. However it is the desire of the cellular operators to continue to improve the average revenue per subscriber in the face of intense competition that is giving rise to the current exploration of offering new multi-media capabilities.

Modern high end phone architectures such as that shown in Figure 3 may be described as consisting of two connected but functionally separate sections. The cellular modem communications sub-system is generally thought of having the 'primary' radio interface although in practice it may consist of many different radio sub-systems including 2G and 3G.

The applications sub-system that will run the phone operating system and be capable of handling all of the applications including advanced graphics and video, gaming and audio also has the capability to interface to an alternative 'secondary' radio interface. Today the secondary radios will predominantly be Bluetooth and Wi-Fi transceivers. However, the application processor will also be expected to handle the reception of analogue and digital radio or the new generation of digital broadcast video standards as well as potentially GPS.

The challenge for the designer is to be able to add these new requirements without burdening the mobile phone design with excessive power consumption, adding to the increasingly restricted PCB area and managing the inevitable additional cost.

System requirements

The broadcast digital radio receiver shown in Figure 4 may be thought of consisting of three basic constituents, namely a mixed-signal RF tuner, a baseband processor, part of whose function it is to demodulate the data and then a digital control block. Traditionally, the radio receiver has been a self contained function, which has been unique for each broadcast standard. However, in the last few years, designers have begun to implement the digital baseband decoder functions, not as a dedicated circuit block but on a re-configurable core. This has become feasible primarily due to advances in processing technology making digital silicon cheaper and increases in processor clock speeds.

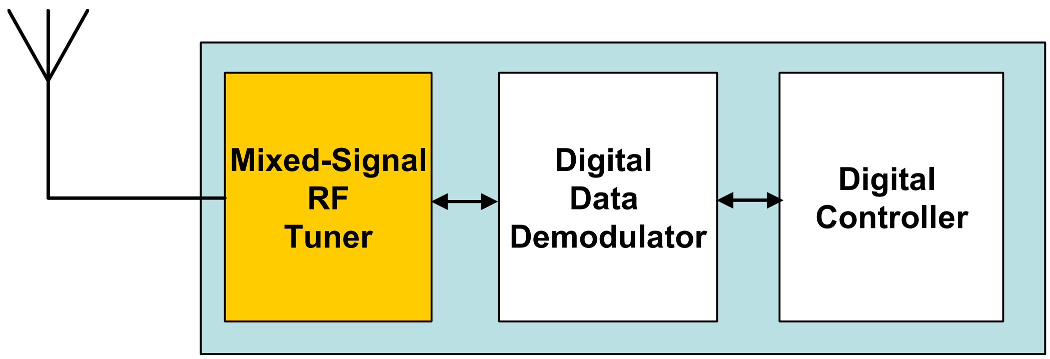

Figure 4: Digital Receiver Architecture

The arguments for implementing the decoder functions as part of a re-configurable digital core are clear. It saves PCB board area, reduces system power consumption and potentially saves cost.

The next obvious step to undertake is to implement the radio frequency mixed-signal tuner as a re-configurable function. As indicated earlier, this presents some extremely challenging issues for the tuner designer. The requirement to cover broadcast standards from FM to DAB and DVB-H mean that the tuner must cover frequencies from VHF (64MHz) to over 1.6GHz. All the while, the tuner must consume minimal power, yet have high sensitivity and selectivity, low noise and few external components.

RF Tuner Design Requirements

The major challenges facing companies such as Elonics who are designing mixed-signal tuner front ends like the E4000 shown in Figure 5, are to balance the system trade-offs to maximise the devices' usability in the widest variety of circumstances. . The most significant design parameters for Elonics are input frequency range, noise figure (NF), dynamic range, linearity, selectivity and power consumption and bill of material cost.

Although the essential building blocks of a tuner are fundamentally similar from device to device, the implementation strategy for each block and the design architecture are critically important in being able to achieve reasonable performance in all the above areas.

The core of this technology is DigitalTune™, designed to meet the requirements of re-configurable CMOS RF front end products. Elonics DigitalTune™ is a patent pending radio frequency architecture that enables the design of multi-band RF front ends using a single monolithic CMOS IC. The digitally programmable multi-band architecture is used in the E4000 tuner family to cover the complete spectrum from VHF to L Band (64MHz to 1.70GHz) for mobile broadcast applications. However, DigitalTune™ is a universal architecture and is capable of supporting other RF applications where re-configuration is highly desirable.

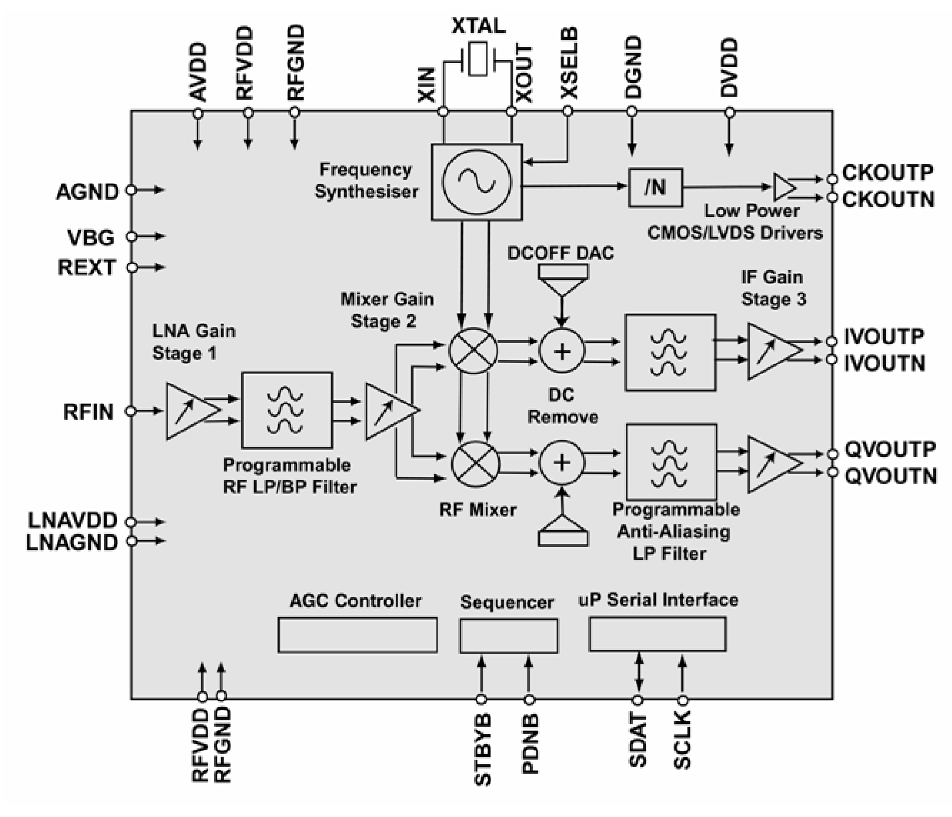

Figure 5: E4000 RF Tuner Block Diagram

Frequency Coverage

This parameter denotes the ability of the tuner to amplify and down-convert to baseband frequencies across the specified input range. This capability is determined by a number of different circuits including the input low noise amplifier (LNA), the mixer and the frequency synthesiser. In the case of the E4000, the frequency synthesiser has the ability to cover the entire range from 1900MHz all the way down to less than 60MHz, making it suitable for most of the current and emerging TV and radio broadcast standards as listed in tables 1 and 2 with sufficiently low phase noise so as to not compromise the integrity of the mixer output.

Noise Figure

The noise figure is a measure of degradation in the signal-to-noise ratio between the input and the output of the tuner. The signal-to-noise ratio is the ratio of the desired signal power to undesired noise power and therefore depends on the signal power. Noise arises from a variety of sources, some dependant on the type of process used and others on the circuit topology and detailed circuit implementation. The major concern for the designer is minimising the noise figure, typically to less than 5dB whilst restraining current consumption in the circuit.

The sensitivity is a measure of the performance of the complete digital receiver at the output of the digital error correction circuits. It is normally defined as the as the minimum received field strength C_{min} needed at the input of the RF front-end to give "Quasi Error Free" (QEF) performance (i.e., a Bit Error rate of $2x10^{-4}$) after digital error correction.

The calculated sensitivity is given by the following formula:

$$C\min_{dBm} = NF_{dB} + \left(\frac{C}{N}\right)_{dB} + 10\log(B_{MHz}) - 174$$

NF: Noise Figure of the receiver in dB
C/N: Carrier to Noise Ratio in dB
B: Bandwidth of the receiver in MHz

The sensitivity of the radio is therefore determined in the analogue domain by the noise figure of the RF front end. For a multi-standard radio, the design challenge is maintaining a low noise figure across the spectra from VHF and UHF through to L-band. In the past this has been addressed via multiple tuned RF front ends. Elonics RF front end performs this trade off with success with a single LNA.

Likewise, companies have looked to processes such as SiGe or BiCMOS to conquer the noise problem. These exotic boutique processes come at a cost; they are intrinsically more expensive than the CMOS processes used by Elonics. At Elonics, the unique nature of the design architecture results in world-class noise figures and hence higher sensitivity even when using CMOS.

Dynamic Range

As previously discussed, the TV or radio receiver has to cope with being able to select the required channel bandwidth (typically 6, 7 or 8MHz wide) across a very wide frequency range. The problem is that the tuner needs to be able to select the desired signal of interest whilst rejecting other adjacent interferers. The tuner also needs to be capable of amplifying this channel even when the signal is adjacent to much larger signals and relatively small in comparison.

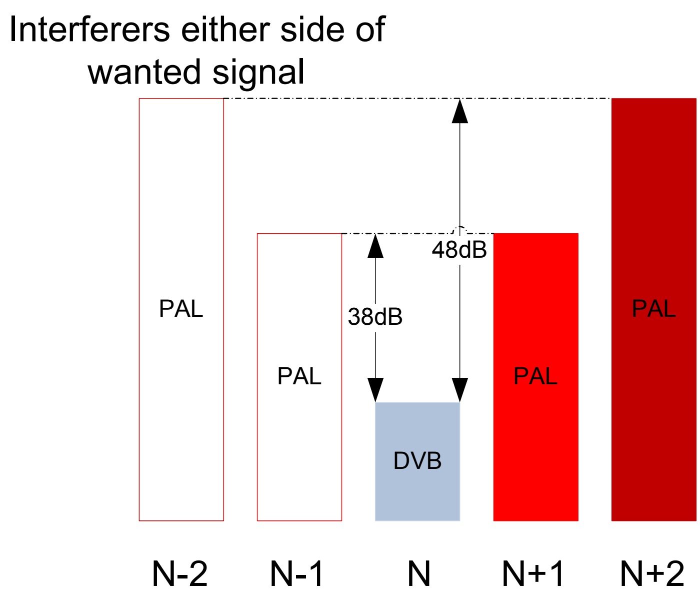

Figure 6: Channel of Interest with Interferers

Figure 6 illustrates the kind of dynamic range scenarios placed upon DVB-T tuners. The RF front end must have the capability to absorb wanted and much larger unwanted signals whilst maintaining the overall receive chain performance in terms of noise figure and linearity. Dynamic range must be budgeted from the RF front end through to the tuner output prior to the ADC.

Linearity

A tuner's ability to tolerate several signals that are present at the same time outside the desired signal band of interest is determined by its linearity. The tuner linearity is often represented by the third order intercept point (IP3) which is a key figure of merit for the low noise amplifier front end.

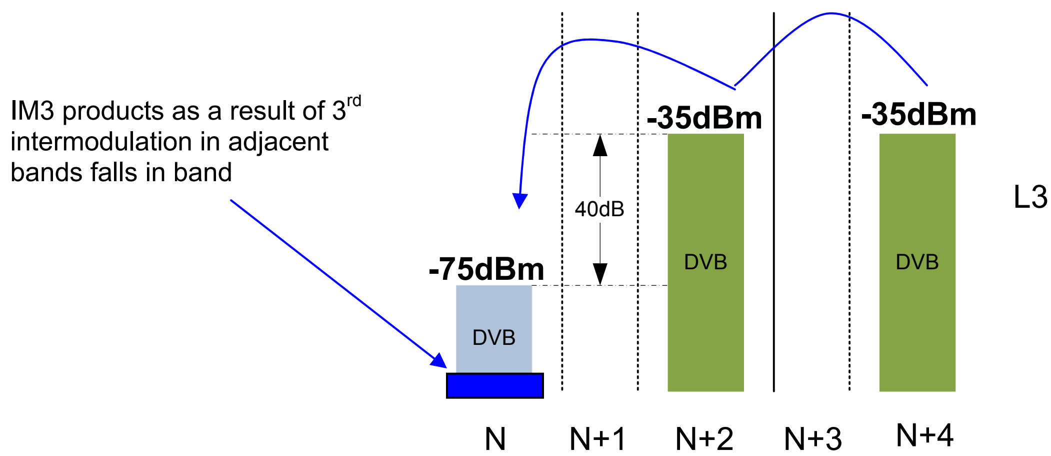

Figure 7: Channel of Interest with Alternate Channel Interferers

Alternate channel interferers can intermodulate resulting in 3rd order IM products that fall into the wanted band. Therefore, we need to ensure the RF front end has adequate IP3 performance such that any IM3 products generated are below the noise floor.

Selectivity

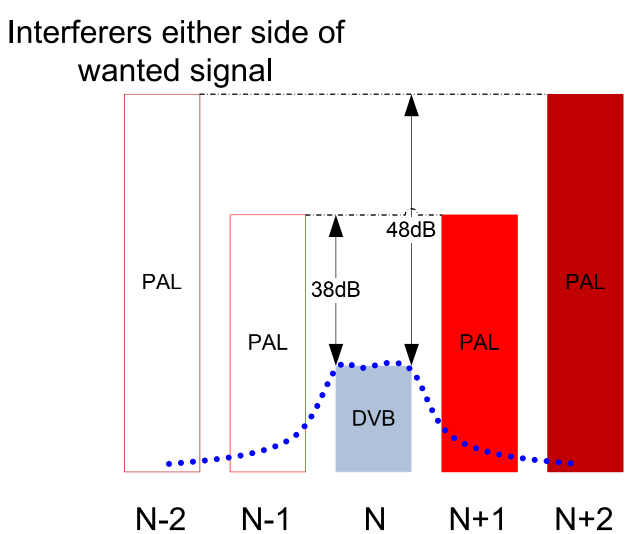

Figure 8: Channel of Interest with Adjacent Channel Interferers

In order to provide immunity from these out-of-band interferers, the receiver has to be able to filter the wanted signal. There are a number of strategies to do this. Out of band filtering is achieved through RF bandpass filtering to optimize RF front end performance. Baseband filtering to remove close in interferers, as shown in Figure 8 can be undertaken either wholly in the tuner, or in combination with the digital demodulator front end.

Elonics believes that the ideal system partitioning is to combine baseband anti alias filtering to remove alternate channel interferers, supported by sharper and more accurate filtering in the digital domain to remove adjacent channel interferers. This dramatically reduces the tuner power consumption and reduces its cost.

Power Consumption and PCB Footprint

In a portable application, power consumption and printed circuit board (PCB) real estate are clearly paramount considerations for the designer. With the E4000 series of RF front ends from Elonics, there are some distinct and unique advantages. Unlike competing solutions, the E4000 has a single input LNA that is able to cope with the very wide input frequency range requirements from FM through to DVB-H. This feature saves pin count and silicon area.

The direct conversion zero IF architecture is designed to save power and lower system cost and it eliminates the requirement for expensive and bulky external components such as SAW filters and RF baluns.

The fine geometry CMOS process used by Elonics offers the capability to create tuner front ends with extremely low power consumption. The Elonics E4000 tuner consumes less than 100mW in fully active mode, and less than 10mW in its TDMA mode when used for DVB-H. This makes it probably the lowest power solution on the market today.

Bill of Material Cost

The E4000 family of RF tuner front ends has been designed in the full knowledge that the consumer market needs low cost, alongside state-of-the-art performance. At Elonics, we don't believe that our customers should need to compromise one or the other.

The Zero IF architecture does not need major external filter components. The only major external component needed for a complete tuner front end solution is a simple crystal needed for the frequency synthesiser. The small 5mm*5mm QFN package size of the E4000 also reduces expenditure on PCB board area

Unlike competing solutions, all Elonics products are manufactured using a baseline CMOS process with extensions specifically for RF. This means that we can leverage the economies of scale that come from using industry standard processing equipment and the large volume of wafers processed on these tools.

Summary Benefits of Elonics Technology

Elonics innovative technology allows manufacturers to design high performance multi-band radio transceivers with unrivalled power consumption and low system cost. The innovative DigitalTune™ architecture enables manufacturers to significantly improve upon today's solutions offering support for multiple standards with a common re-configurable RF front end.

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.

Elonics first product family is the E4000 series of silicon tuner solutions targeted at the reception of multi-standard digital TV and radio including DVB-T, ISDB-T, T-DMB, DVB-H, ISDB-H, DMB-T, DAB and FM radio.

Figures

Tables

Author Biography

Julian Hayes is vice president of marketing at Elonics. He joined Elonics following a nine year period at Wolfson Semiconductor where he held the position of vice-president of marketing, heading up the company's global marketing team. In this role he was responsible for the development of the company's strategy for the audio industry. Prior to joining Wolfson, he worked at Analog Devices in a number of sales and marketing positions.

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.

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Elonics' first product family is the E4000 series of silicon tuner solutions targeted at the reception of multi-standard digital TV and radio including DVB-T, ISDB-T, T-DMB, DVB-H, ISDB-H, DMB-T, DAB and FM radio. Elonics secured £2M ($4M) Series A funding in February 2008. Key investors include Braveheart Investment Group, Scottish Venture Fund and a number of private investors including Brian Souter and Sir Tom Farmer.

About DigitalTune™

Elonics DigitalTune™ is a patent pending radio frequency architecture that enables the design of multi-band RF front ends using a single monolithic CMOS IC. The digitally programmable multi-band architecture is used in the E4000 tuner family to cover the complete spectrum from VHF 2 to L Band (76MHz to 1.70GHz) for mobile broadcast applications. DigitalTune™ is a universal architecture, and is capable of supporting other RF applications where re-configuration is highly desirable.

The direct conversion zero IF architecture is designed to save power and lower system cost. It eliminates the requirement for expensive and bulky external components such as SAW filters and RF baluns, yet offers extremely high performance. Elonics innovative DigitalTune™ architecture enables manufacturers to significantly improve upon today's solutions offering support for multiple standards with a common re-configurable RF front end.
Website: www.elonics.com