How to Build the 'Right System'

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In the field of electronics design, designing a "best in class" product with a competitive roadmap for the future is vital. For medical designs, in particular, it is especially important to use the highest quality components to ensure longevity, as these products go through long approval and use cycles. To accomplish this, system designers need to design the "right system." But what does that mean?

I (Gene) have spent a good part of my career helping system designers find the right digital signal processor (DSP) for their system. I remember talking to a designer several years ago who was trying to cost reduce a personal medical device. It was a relatively simple product to help an individual remember to take their medicine. Their design used one of our DSPs, probably a TMS320C5x. They were hoping to reduce the BoM cost to less than $25.00. When we reviewed the options and their specific needs, we realized that a DSP was not the best solution. At that time, we already had the MSP430 microcontrollers (MCU) and our speech product line in Texas Instruments' [1] portfolio. Our suggestion to eliminate the DSP and all the necessary memory and analog to make it work and replace it with an MSP430 and speech synthesis device reduced the BoM far beyond the customer's expectation. We walked away having designed out one of our DSPs and the associated necessary circuits in favor of one of our much lower cost MCUs. So we reduced the net revenue to us from about $20 per system to less than $10 per system.

The reason I tell this story is to point out a very important concept. That is, no matter what the tradeoffs are, a technology vendors' job is to make sure that the system designer is using the most suitable parts for designing their system. Specifically, that means using the right software running on the right embedded processor interfaced to the right analog signal chain parts with the right power management.

This is not as easy as it sounds from a component point of view. My goal at TI is to sell TI devices. But, it is my goal as a systems expert to help the customer choose the best components for their system. That means my job is to make sure that the system designer is using the best fit I can find (i.e., within my portfolio of devices) and my portfolio consists of the very broad range of parts that TI offers, including analog, embedded processing, ASIC, RF, and power management. This full range of products allows us to comfortably meet the needs of any specific system constraint with best-in-class components. And as an added advantage, the ability to optimally integrate the system's chip set to fewer numbers with an end goal of one package (SiP) if not one device (SoC). This is an ability not possible when using multiple vendors or when using a vendor with a narrow product portfolio.

Choices

In any system design, there are always choices to be made. These choices begin with the list of features and capabilities the system needs to have. For example, when we think of medical products, we are actually thinking of a very broad category of systems. Each end-equipment (system) has a different set of features the end user needs. Table 1 is one way of looking at the broad market of medical and breaking it down into four categories, each with similar high level features and needs.

Table 1
One way to break the broad look at medical products into smaller segments, each with similar high level features and needs.

- Consumer Medical
    - In home usage
    - Pocket size
    - Low cost
    - Connectivity
- Patient Monitoring, Diagnostics & Therapy
    - Delivery systems
    - Hospital patient room
    - Doctors office examination room
    - Clinic
    - Implantable
        - Surgically implanted in the human body
        - Complete solution on a chip
        - Ultra-lower-power
- Medical Imaging
    - Medical imaging
    - Off line diagnostic equipment
    - Performance
- Medical Instruments
    - Surgical use

Obviously, these are not the complete set of features for a specific end-equipment but the table gives a flavor of what is important for each of the segments. For example, it is important for a system to be ultra low power in order to be successful as an implantable. Whereas, in a diagnostic imaging system such as MRI or ultrasound, the primary need is performance. Underlying these high-level features is a set of characteristics that distinguish each segment from the others. The specific needs range from ultra low power to ultra high performance in one aspect. Then the needs range from high reliability and accuracy to relatively low accuracy and reliability. The cost of the components is generally a small part of the overall system cost. What this means is that there is no one solution that fits all medical applications. A wide range of product offerings makes the task to assembling the right set of components possible but, at the same time, difficult to do.

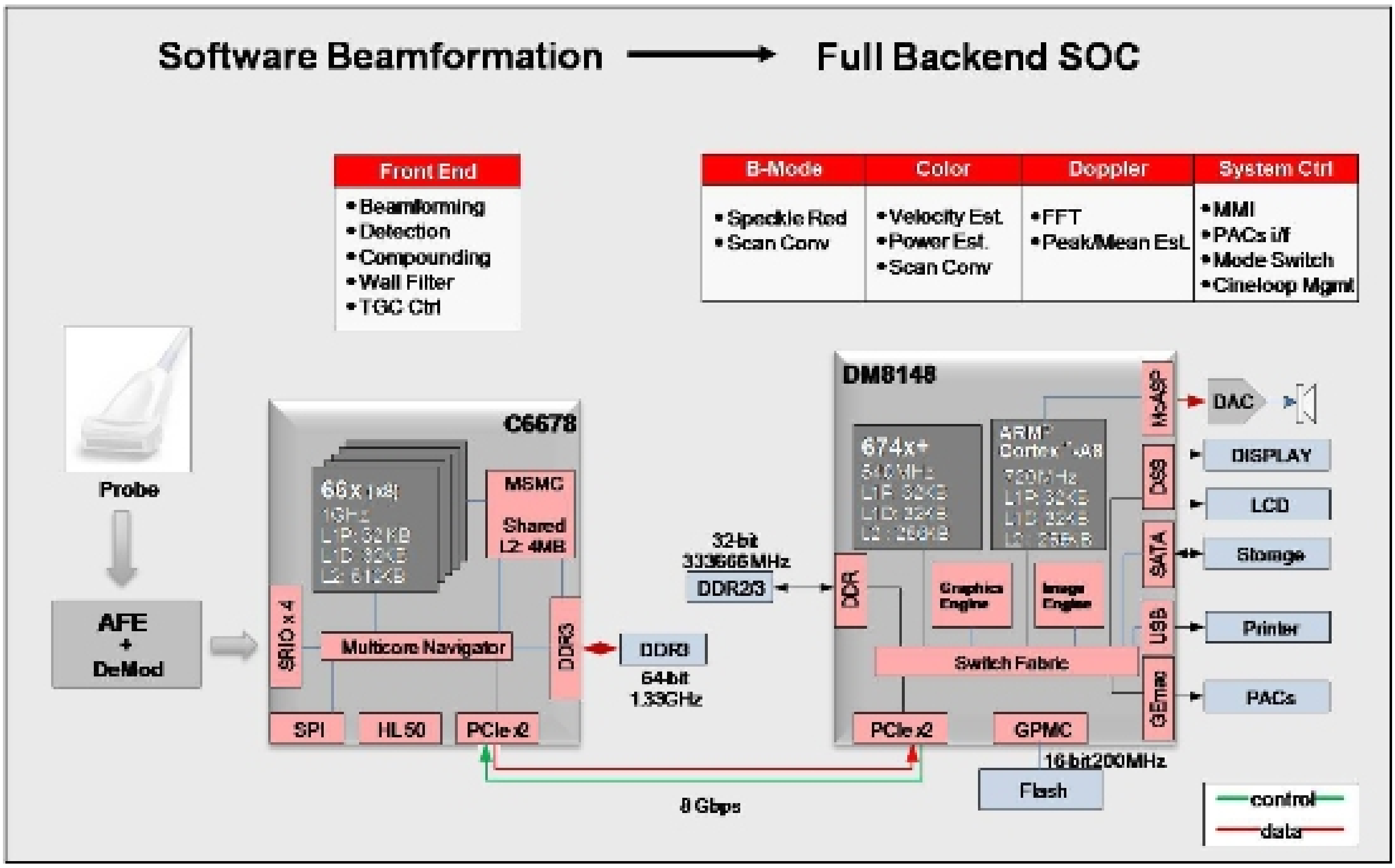
One way to begin the task of putting the right set of components together is to start with a set of components that best fit the high level needs of a specific end product. One way to go about that is to look at interactive system block diagrams on vendors' websites and check related collateral with selection tables. But these are only starting points and need to be refined into a specific set of right components for the application. The process of finding the right parts may also require some consulting with the application staff at the vendor or by a consultant. Additional resources, such as user groups, customer support lines, and local application engineers can make the process much easier than it first appears.

Example: Designing the 'Right' Ultrasound System
Ultrasound systems are a perfect example where the right combination of embedded, analog, and power management components can enable designs that surpass real-time image processing needs and power constraints. Key criteria, including clinical purpose, size, function, power, and time-to-market, drive the choices and trade-offs the designer makes when choosing components for the ultrasound system. For instance, in high-end, cart-based systems, image quality and performance are paramount, while in ultraportable systems, power, cost, and size drive the design.

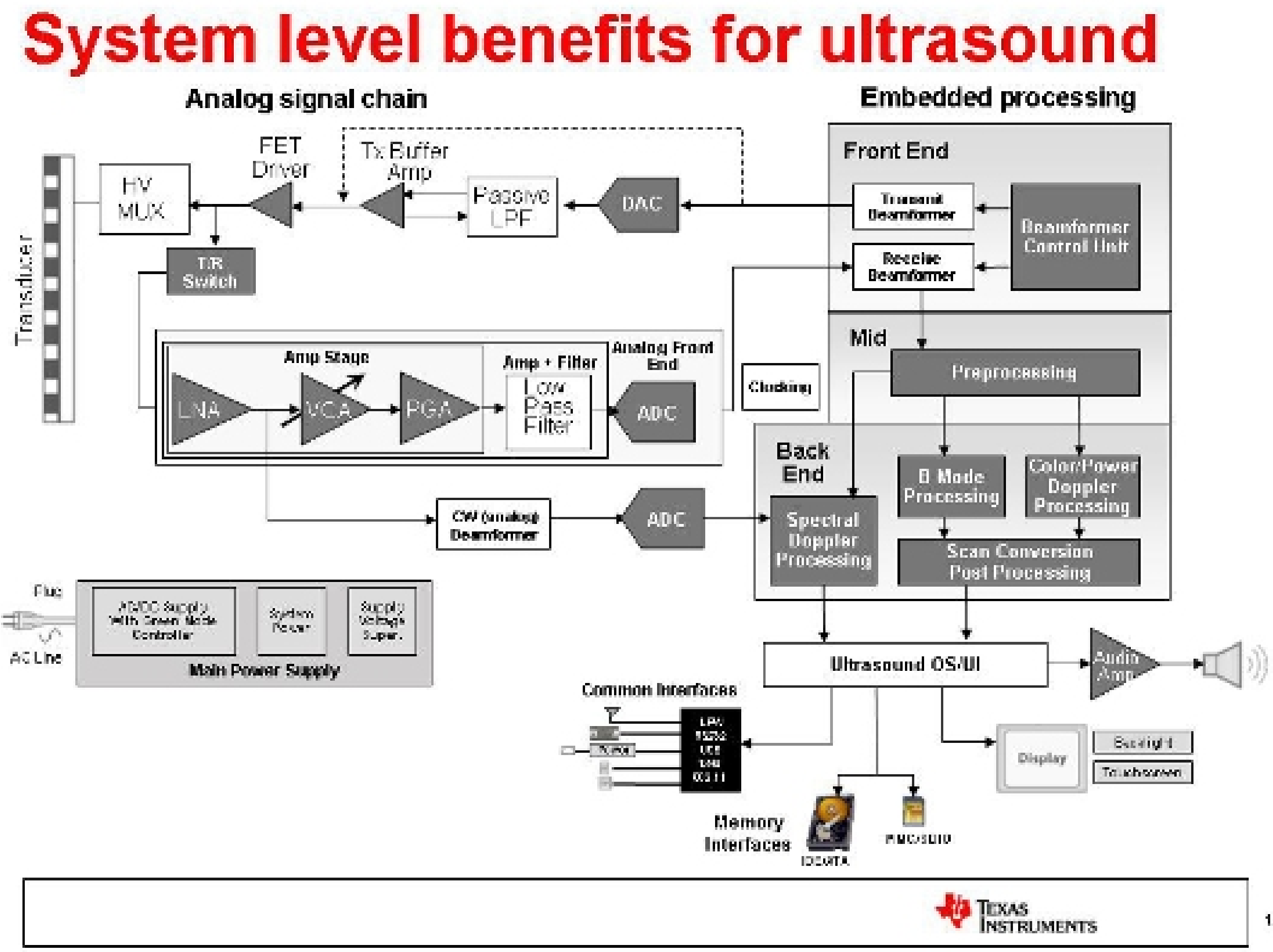
Image acquisition in ultrasound begins when a high-voltage pulser and multiplexer excite a transducer of multiple piezoelectric elements with high frequency, time-delayed pulses. As a result, the transducer transmits acoustic waves that propagate through structures of varying densities and acoustic impedances in the target (e.g. heart, liver). The difference in impedance at structural boundaries dictates the intensity of waves reflected/further transmitted. Through a transmit-and-receive switch like TI's TX810, the transducer is toggled into receive mode and converts the acoustic energy into an analog signal.

Clinical end-use and form factor are key considerations in transducer design. The number of elements in systems today typically varies from eight to 512, with more channels translating to higher image quality but also higher power consumption. Portable systems trade channel density for greater battery life. The transducer's center frequency varies in the 1 to 15 MHz range where higher frequency waves achieve higher resolution images but trade-off penetration depth, since acoustic waves attenuate at about 1 dB/cm/MHz. Lower operating frequencies are therefore more pertinent for applications like abdominal imaging, while a transducer at, for example, 10 MHz is useful for imaging superficial areas. The clinical application also influences the shape of the transducer, where a curved transducer allows better resolution and a broader field of view in applications like abdominal imaging, a sector transducer is good for cardiac imaging and a linear transducer useful for shallow depth imaging.

Next in the signal chain is the analog front end (AFE) which improves sensitivity and dynamic range, performs time gain compensation to account for signal attenuation, enhances the signal-to-noise ratio (SNR) and converts the signal into the digital domain. To achieve this, the AFE typically incorporates a low-noise amplifier, voltage controlled attenuator, programmable gain amplifier, anti-aliasing filter and analog-to-digital converter. For example, TI offers a broad range of fully integrated AFEs like the AFE58xx range of pin-to-pin compatible devices that offer system developers various feature sets to choose from, including tradeoffs between SNR and power consumption.



Once in the digital domain, the received echoes from the transducer elements are delayed and summed based on the time delays used during acquisition along a given line of sight or scan line. This process is known as beamforming, with multiple scan lines forming an entire image frame. B-mode data is interpreted to create a grayscale image that displays structural details. For color flow data, which is associated with blood flow, each color line is formed as a result of a number of pulses, also known as the ensemble length. Next, beamformed data undergoes IQ demodulation, where it is down converted to baseband through downmixing, is low pass filtered to eliminate side lobes and then decimated. The decimated B-mode data additionally undergoes envelope detection and logarithmic compression. The decimated color flow data undergoes ensemble aggregation, followed by wall filter processing where a high-pass filter reduces high-amplitude, low-velocity echoes from vessel walls, and then color flow estimation that calculates the velocity, direction, turbulence and power. Finally, the processed data is used to construct an image through scan conversion, which interpolates data from the acquiring co-ordinate system to Cartesian co-ordinate system corresponding to the display size on an LCD screen.



Deterministic execution, reliability, and low latency play a key role in guaranteeing real-time processing, which is essential in any ultrasound system design. In addition, software programmability allows designers to reuse code through their portable to high-end product range. The availability of specific peripherals and interfaces can also influence processor choices. For example, a direct memory access can be very useful to perform data movement between external memory/interfaces and internal memory, thus allowing the CPU to focus on processing tasks.

Table 2

Segment	Embedded	Signal Chain	Power Mgt	Comm
Consumer	MSP430	ADS1192	TPS	CC243
	TMS320C55xx	ADS1292		CC2541
	OMAP35			CC2560
				DM37x
				Stellaris
Monitoring	OMAP35x	TLV320IAC3254	TPS	CC2541
	DM37x			CC2560
				AM35xx

Imaging/ Instruments	C6455 C6446 C6472 C6678	DDC118/232/264 AFE064/0256/5805	TPS HPAS1218

Ultrasound system designers look for the right balance between performance, power, and cost based on product requirements like form factor, data sizes, and functionality. Along with these considerations, it is essential that ultrasound system designers bring their products quickly to market and have the right set of tools and software components to evaluate platforms and kick start development. Availability of software libraries, a comprehensive software framework that allows easy plug-and-play of algorithms, key APIs for tasks like inter-processor communication, and a real-time operating system, ensure that ultrasound system designers spend most of their time innovating and developing their secret sauce and less time in addressing system-level issues. In addition, software libraries and system implementation examples can provide a quick way for developers to evaluate the performance of ultrasound-specific algorithms on various platforms and can also eliminate the need to code these common building blocks.

Conclusion
Understanding the need, defining the product specifications based on this need, and then choosing and integrating the right set of hardware and software components are key steps in designing medical products. As the ultrasound example illustrates, technology vendors can offer technical expertise, collateral, knowledge, and a broad portfolio of solutions in analog, power, and embedded processing with long lifetimes that can be leveraged to design systems, from portable to high-end. System designers have a thorough understanding of their application domain and the need they are trying to meet. Working together, designers and their partners can find the "right" pieces of the puzzle that form the "right" system that solves the "right" clinical needs.

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