Implementation of Communication Systems

Introduction

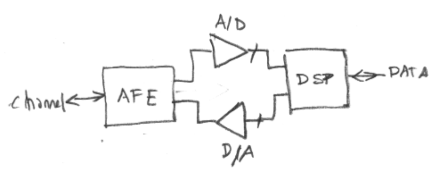
Except for relatively simple devices, modern communication systems are implemented using digital signal processing (DSP) techniques.

The main reason for this is cost. The main cost of an integrated circuit (IC) is the die area. The die area to implement digital logic is decreasing at an exponential rate. Moore's Law states that the density of digital logic doubles every 18 months due to decreases in transistor feature sizes (measured in microns). On the other hand, the die area for analog electronics is typically not a function of feature size and does not decrease over time. Thus the cost of digital implementation is continuing to drop relative to cost of analog implementation.

Exercise 1: If the density doubles every 18 months, how often does the feature size (transistor dimensions) shrink by half?

IC clock rates also increase with smaller feature sizes resulting in constantly increasing clock rates and sampling rates which allow higher-bandwidth systems to be implemented using DSP techniques.

A communication device using DSP is composed of an analog front end (AFE) and a DSP.



The AFE for a receiver provides the following functions:

isolation and protection to protect the device from accidental line power and voltage transients.

down-conversion for RF and wireless systems. These convert the signal at the carrier frequency to baseband or a low IF frequency that is several times the bandwidth (e.g. for a 5 MHz bandwidth the IF could be at 20 MHz).

amplification and filtering to reject signals that are out of band or off-channel. Amplification is required because the signal is usually attenuated by the channel.

digital-to-analog (D/A) conversion (DAC) to sample at more than the Nyquist rate.

Exercise 2: What functions would have to be provided by the AFE for a transmitter?

The remainder of the signal processing is performed using DSP techniques. This typically includes:

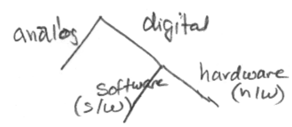
- additional filtering (equalization) to correct for ISI
- demodulation
- FEC decoder

Exercise 3: What are the corresponding DSP functions required by a transmitter?

A DSP-based architecture can also be used with analog modulation techniques. For example, an FM signal can be digitized and demodulated by a digital discriminator.

Software vs Hardware

The DSP portion of a communication device can be implemented in hardware, software or a combination of both.



Hardware implementations are best suited for:

- higher sampling rates because multiple operations can be done in parallel
- lower algorithmic complexity because implementing algorithms in hardware is more difficult than writing software
- low power consumption because there is less overhead for instruction decoding and sequencing
- higher reliability due to relatively poor software development practices

On the other hand, software implementations are best suited for:

- flexibility because it's possible for the software to implement multiple modulation techniques

and the software can be upgraded in the field to track changes to standards and to fix bugs and interoperability issues.
- shorter development time because the ICs don't have to be designed and manufactured which can take several months
- more complex algorithms because implementing algorithms in software is easier
- low hardware costs because the die area is usually smaller

In practice many systems use a combination of hardware and software. A few algorithms that require high throughput such as filters and FEC are implemented in hardware while other functions are implemented in software.

DSP Hardware

DSP Processors

Specialized microprocessor architectures are used for implementing DSP functions. These are often called "DSP"s.

DSP microprocessors include special hardware functions and instructions sets that allow efficient implementation of DSP algorithms. These include:

- Efficient high-bandwidth input and output (I/O) interfaces operating at high speeds and using DMA and sophisticated buffer handling.
- Special-purpose hardware to speed up typical DSP computations such as single-cycle multipliers pipelined with adders for implementing digital filters.
- Special instructions for looping without overhead. For example, a single instruction that decrements a variable, compares it to a limit and and does a conditional branch. This instruction can be executed at the same time as a computation instruction.

DSP Logic Hardware

The ICs used to implement DSP hardware can be either programmable or custom.

Custom ICs require custom masks for the photolithography process involved in IC manufacture. These masks are expensive and so custom ICs are only cost-effective at very high volumes (millions of ICs).

For lower volumes field-programmable gate arrays (FPGAs) are typically used. These are ICs that contain thousands up to hundreds of thousands of simple logic elements. Each logic element is composed of a flip-flop and some programmable combinational logic. The interconnections between logic elements are read from an external memory when the FPGA is powered up. FPGAs have low development costs and are easy to reprogram in the field but are much more expensive than full-custom ICs.

In-between full-custom ICs and FPGAs are various semi-custom IC solutions. These are typically ICs where most of the manufacturing steps are shared between different ICs but the final stage, the interconnection of gates ("gate arrays") or FPGA-like logic elements, is done with a custom mask.

Design

The design of the AFE is analog IC design involving components such as amplifiers, mixers and synthesizers. Different approaches are investigated using circuit simulation programs such as SPICE. Multiple approaches are typically manufactured on the same test die and evaluated before committing to manufacturing. Analog ICs are often made using different processes (Silicon-Germanium (SiGe) or Gallium Arsenide (GaAs)) and larger feature sizes than digital ICs which are typically CMOS. These processes can have power or speed advantages over CMOS.

Consumer communication ICs for very price-sensitive applications are usually mixed-signal ICs that integrate the AFE and DSP functions into the same (CMOS technology) die.

The design of DSP software is done using conventional software development tools; sometimes using special hardware to capture events in real time.

The design of digital logic ICs and FPGAs is done using either hardware description languages (HDLs) or, for simple designs, schematic capture.

HDLs are similar to programming languages but are used to describe processes that happen in parallel, which is a feature of actual logic circuits. The two most popular HDLs are VHDL and Verilog.

Schematic capture is similar to drawing a schematic diagram. The designer adds logic components such as register, adders, memory, logic functions, etc. to a drawing and then interconnects these elements to build a circuit. This type of design tends to be slower and is limited to relatively simple circuits. We will use schematic capture to design some simple communication functions in the final lab.