MULTIRATE ALL-DIGITAL MODEM FOR SUPPORT OF UNIVERSAL MULTIPLEX TRANSPORT LAYER FOR DIGITAL COMPRESSION

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Abstract

With the approaching adoption of digital compression and the supporting development of transport systems to effect the delivery of all-digital television, there is intense activity surrounding the search for low cost but high performance modems for digital signals. This paper discusses recent advances in the state-of-the-art of modulator/demodulator technology for the satellite channel. An all-digital modem implementation is described, yielding benefits of near-theoretical performance, low cost, high reliability and variable rate operation from 1 to 60 Mbps.

INTRODUCTION

Video and audio signals can be compressed to obtain varying levels of quality extending through the progression of SIF, VHS, NTSC, CCIR-601 and HDTV, via successively increasing bit rates. Data streams from a number of video and audio signals (compressed at data rates required for their specified quality) can and will be transported in a number of different ways. They can be merged in a full bandwidth (TDM) data transport which requires a versatile multiplexing scheme or transmitted in a single carrier per channel (SCPC) mode using bandwidths appropriate to each selected data rate.

It would be highly advantageous to have a flexible system modulator/demodulator arrangement such that equipment (especially receivers) could be easily reconfigured to operate across a wide spectrum of data rates. Such an *all-purpose* modem must be capable of operating with transponder signals of full bandwidth as well as with the unique bandwidths of the different SCPC signals which may, during operation, be reassigned to different center frequencies by the satellite carrier in response to changes in transponder loading.

An all-purpose modem required to support delivery of digital video and other services can be characterized by the following requirements:

- capable of rapidly switching and acquiring carrier frequencies,
- capable of (automatically) varying the occupied bandwidths,
- capable of varying the data processing (throughput) rate,
- operate in the presence of multiple adjacent channels,
- operate in the presence of terrestrial interference,
- must yield throughput performance equal to the maximum capacity of present and planned transponders,
- must be low cost.

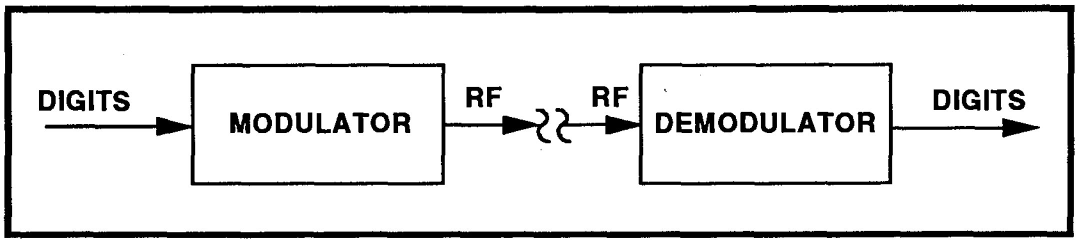

Figure 1
Generic View of Modem

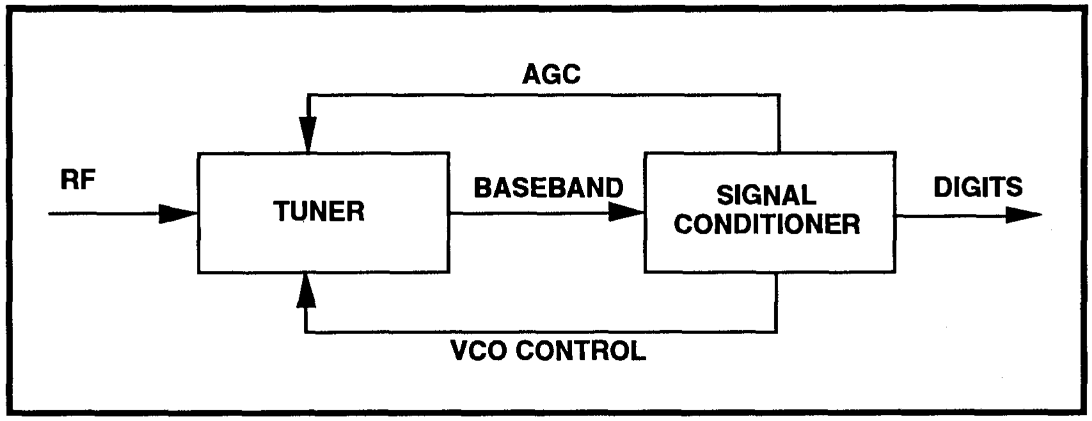

Figure 2
Modem Sub-Block Partition

THE MODEM

From a general perspective, as indicated in Figure 1, modems can be visualized as RF-to-digital transducers operating at the lowest layer of a transport system. This transduction process entails two distinct transformations: RF-to-Baseband and Baseband-to-Digits. To aid in understanding this transduction process it is convenient, as indicated in Figure 2, to partition the modem into two main sub-blocks: a tuner and a baseband "signal conditioner." The tuner isolates and extracts the signal bearing carrier from the channel and performs the RF-to-Baseband transformation.

The baseband signal conditioner processes the analog waveform extracted from the channel (by the tuner) and performs synchronous demodulation with the aid of carrier and timing information derived from the received waveform. The digital output of the baseband signal conditioner is the quantized (soft decision) sample values formed at the output of its matched filters. In developing DSP-based solutions, this second transformation (Baseband-to-Digital) is accomplished by an analog-to-digital converter (ADC) located somewhere in the signal conditioning processing chain.

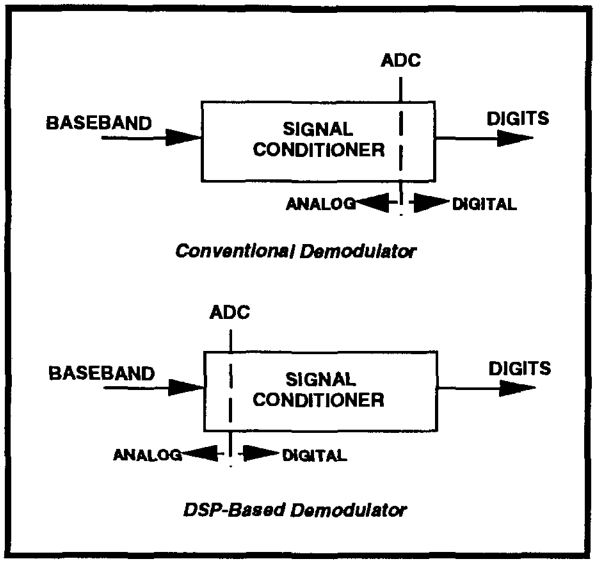

Figure 3
ADC Insertion—Conventional & Modern Modem

The ADC is the boundary between the analog processing and the digital processing performed by the signal conditioner. Traditionally, as shown in Figure 3, this boundary is near the end of the baseband signal conditioning chain. In light of dramatic cost reductions in ADC and digital signal processing technology (alluded to in the next section), there are significant advantages to moving this boundary toward the beginning of the chain. In fact, by placing the ADC at the very beginning of the sequence we have a full DSP-based signal conditioner modem, and solutions to the requirements characterized above in developing an all-purpose demodulator become available as an extra benefit.

THE DSP MODEM

The cost of performing signal conditioning by digital signal processing techniques, measured for instance in *dollars per million integer operations*, has fallen two orders of magnitude in the last five years. This rate of cost reduction appears to be persisting, and we can expect another two orders of magnitude decrease in the next five year period. By comparison, the cost of signal conditioning with traditional analog components, measured in *dollars per MHz*, is changing very slowly (Figure 4).

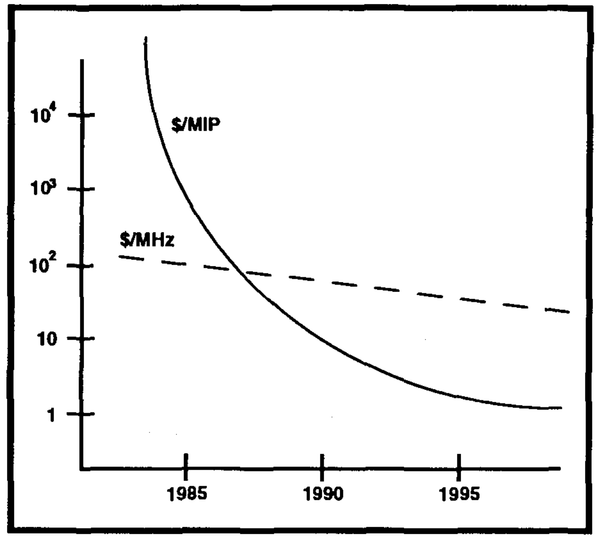

Figure 4
Cost Performance of Analog & Digital Processing Components

The DSP-based modem described herein performs nearly all of the signal conditioning functions of a conventional modem with combinations of application-specific hardware and processor-based software. These functions include:

- automatic gain control,
- timing recovery,
- carrier acquisition,
- bandwidth and sample rate reduction,
- matched filtering,
- soft decision quantization.

The only function not performed via DSP in TV/COM's first generation DSP-based modem is the quadrature down-conversion which uses standard analog mixers with a DAC controlled VCO. A block diagram of the DSP-based modem is presented in Figure 5.

The basebanded I-Q pair is low-pass filtered by analog anti-aliasing filters. The bandwidth and out-of-band attenuation of these filters are selected to avoid spectral aliasing and spectral distortion of the out-of-band and in-band spectral components respectively of the maximum bandwidth signal presented to the modem. The modem's ADCs operate at 60 MHz, the input sample rate corresponding to two samples per input symbol at the current maximum data rate of 60 Mbps.

For signals of lower data rate, hence lower bandwidth, the modem operates in a *multirate resampling mode*. Conceptually, it operates a set of digital resampling filters to reduce the input bandwidth to that of the desired input signal and then resamples to the desired two samples per symbol sample rate. "Resampling" is performed on an ASIC chip automatically according to DSP techniques that allow the actual sampling process to be fixed at 60 MHz, but yield "effective samples" according to selected lower rates.

Samples at the reduced data rate are then processed by a digital matched filter to obtain output samples matched to the transmitter waveforms and bandwidth. In the receiver hardware described here, the bandwidth reducing filters, the resampling and the matched filters are implemented in a proprietary architecture as a polyphase filter process in which resampling and matched filtering are all performed digitally on-chip.

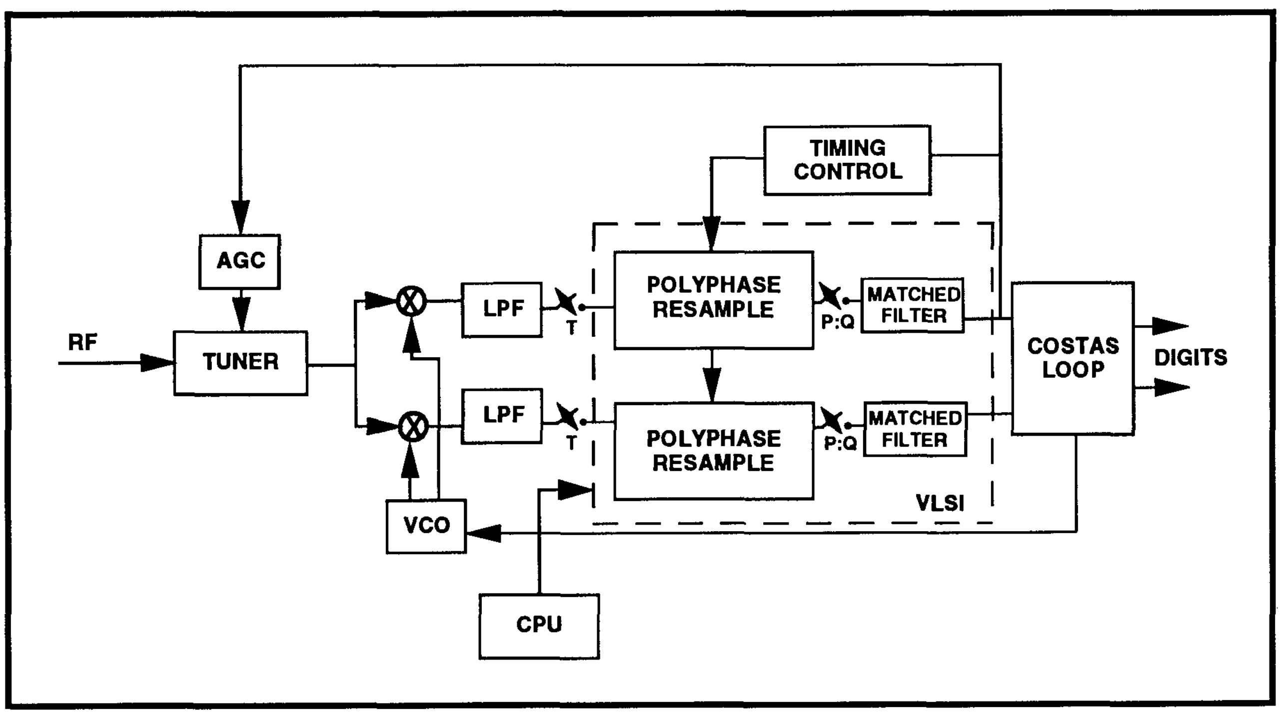

Figure 5
Block Diagram—Multirate All-Digital Demodulator

The polyphase filters are also used in the timing recovery loop. Since phasing of the input time samples is allowed to be *asynchronous* with the input symbol boundaries, a mechanism must be provided for their alignment. A traditional approach would have the timing loop control the VCO sampling clock. Using a VCO to change clock phasing has a significant impact when multiplexing the output of multiple modems which might be required at a head-end for instance.

Polyphase filters capable of down-sampling can also be used for up-sampling. This enables the timing recovery loop to use the polyphase filters to effectively *re-phase* the input sample positions to the desired output positions, again, all on-chip.

As versatile as the DSP filtering process is, it can be made even more so by taking advantage of on-chip design procedures which permit arbitrary gain and phase characteristics. This enables us to imbed the gain and phase corrections required to equalize the analog filters of the demodulator. Thus, through all-digital design, this demodulator simultaneously provides capabilities for bandwidth reduction, resampling, spectral equalization, matched filtering, and time recovery phasing.

As a consequence of architectural structures which yield the versatility identified above, the DSP-based modem is characterized by remarkable flexibility and exhibits performance levels extremely close to theoretical limits.

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** Mr. Wechselberger has held various positions with TV/COM International since 1980. His staff supports all of TV/COM's cable, satellite, and compression engineering initiatives and he is responsible for a number of key patents. Before joining TV/COM, Mr. Wechselberger was with the General Dynamics Electronics Division. He holds B.S. and M.S. degrees in Electrical Engineering and has published and lectured extensively in the fields of TV Signal Security, communications, and encryption.