converter might be used as well as the clock for a sampled comparator-sampler Fig. 4, which can replace the standard comparator.

Another easy control mechanism is given by the use of V_{ref}.

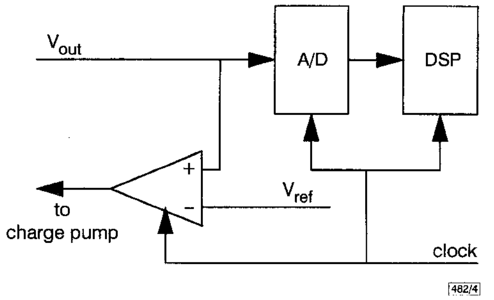

Fig. 4 *Sampler control circuit*

Simulations: All the blocks presented in Figs. 1–4 have been implemented in 0.5µm BiCMOS, and consume 4mA from 3V, for an output voltage of +–350mVp/4 pf load. Measurements were made for F_{IF} = 45MHz. The dynamic range of the AGC is 54dB, with an error of < 0.5dB for corner variations, and the input third-order intercept point (IIP3) is 0dBm, into 50Ω load. The noise figure (NF) for the maximum gain is < 8.5dB. The transient response of the circuit for an input power step is presented in Fig. 5.

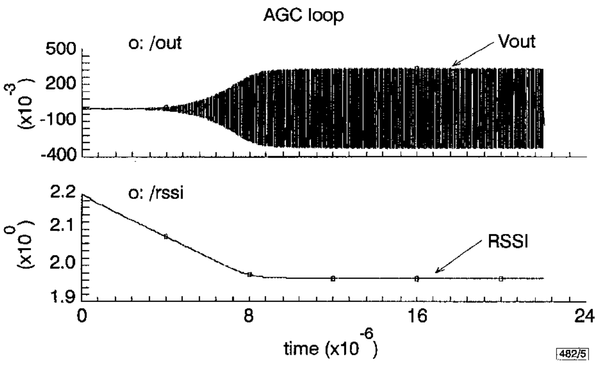

Fig. 5 *SPICE simulated transient response of AGC closed loop*

A similar architecture has been verified to be viable in a global positioning system (GPS) receiver developed for portable applications [8].

Conclusion: A new architecture for AGC has been proposed. The functionality of the proposed circuits has been confirmed by SPICE simulation and the architecture has been proven to work in a global positioning system (GPS) receiver. These circuits are well suited for low power portable wireless products.

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References

1 LARSON, L.E.: 'Integrated circuit technology options for RFIC's-present status and future directions', *IEEE J. Solid-State Circuits*, 1998, **SC-33**, (3), pp. 387–399

2 European Digital Cellular Telecommunications System (Phase 2), European Telecommunications Standard Institute, 1992

3 PCS 1900 Air Interface Specification, Telecommunication Industry Association, 1994

4 CROLS, J., and STEYAERT, M.: 'CMOS wireless transceiver design' (Kluwer Academic Publisher, 1997), pp. 105–133

5 FENK, J., and SEHRING, P.: 'Low-noise, low-voltage, low-power IF gain controlled amplifiers for wireless communications' *in* SANSEN, W., RUIJSING, J.H., and VAN DE PLASSCHE, R.J. (Eds.): 'Analog Circuit Design' (Kluwer Academic Publisher, 1995), pp. 27–44

6 GILBERT, B.: 'Technique for RMS-DC conversion based on the difference of squares', *Electron. Lett.*, 1975, **17**, pp. 181–182

7 WASSENAAR, R., SEEVINCK, E., VAN LEEUWEN, M., SPEELMAN, C., and HOLLE, E.: 'New techniques for high-frequency RMS-to-DC conversion based on a multifunctional V-to-I convertor', *IEEE J. Solid-State Circuits*, 1988, **SC-23**, (3), pp. 802–814

8 PHILSAR ELECTRONICS, : 'An integrated GPS receiver RF front end', *Microw. J.*, 1998, **MJ-41**, pp. 146–148

Time-stretched analogue-to-digital conversion

A.S. Bhushan, F. Coppinger and B. Jalali

A new concept for analogue-to-digital (ADC) conversion is proposed and demonstrated. The analogue signal is stretched in time prior to sampling and quantisation. Time stretching increases the input bandwidth and sampling rate of the ADC and is best implemented using optoelectronic techniques.

The continual proliferation of digital signal processing (DSP) in high performance systems underscores the need for major advances in analogue-to-digital (A/D) converter technology. One example of systems whose needs far exceed the performance of current A/D converters (ADCs) is the digital receiver. In such systems the A/D conversion is performed at IF or RF frequencies, placing stringent requirements on the sampling frequency and input bandwidth of the A/D. While the electronic A/D performance continues to improve, the rate of improvement is too slow to satisfy the requirements of advanced systems in the foreseeable tuture. Hence it is widely recognised that new concepts leading to major advances in A/D technology are a priority. In this Letter, we propose a new A/D converter based on time-stretching the analogue signal prior to sampling and quantisation. By reducing the signal bandwidth, the new concept alleviates problems associated with the limited input bandwidth of ADCs.

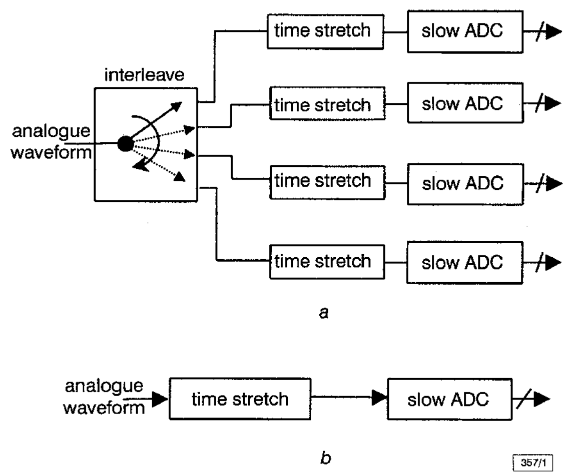

Fig. 1 *Block diagram for time stretch A/D system*

a Input signal continuous
b Input signal non-continuous, e.g. received signal in pulsed radar

Fig. 1*a* shows a block diagram of the proposed system. The analogue signal is segmented and interleaved into *M* parallel channels. Each segment is time-stretched with a magnification factor *M* prior to entering a slow ADC. Time-stretching (or compression) is a well established process in radar technology [1] and is discussed below. The proposed architecture offers the following advantages compared to a conventional ADC. First, it achieves an effective sampling rate of $M.f_s$, where f_s is the sampling rate of individual ADCs (this property is similar to that of the interleaved ADC [2]). Second, the effective input bandwidth is increased to $M.f_{in}$, where f_{in} is the input bandwidth of individual ADCs. In situations where the analogue signal consists of waveforms occurring over a finite time, such as pulsed radar, the simpler architecture shown in Fig. 1*b* can be used.

A signal can be stretched (or compressed) in time by subjecting it to the following sequential steps: (i) dispersion, (ii) linear chirp, and (iii) dispersion [3]. For an amplitude modulated (AM) signal, the modulation waveform is scaled in time by the factor D_2/D_1, while the carrier becomes chirped. Here D_1 and D_2 are the total dispersion in the first and second dispersion stages, respectively. Therefore, the signal can be either stretched ($D_2 > D_1$) or compressed ($D_2 < D_1$).

Time-stretching can also be practiced in the optical domain [4]. Optical implementation is attractive since extremely broadband dispersion and ultrahigh chirp rates are available [5]. Here an optical carrier is intensity modulated by the electrical RF signal, and dispersion and chirping functions are performed in the optical domain. Both the electrical carrier and its modulation are slowed down in time. The optical carrier is chirped; however, this is of no consequence, as optical field oscillations are filtered out by the photodetector. If the chirp bandwidth is much greater than the input signal bandwidth, then the first dispersion stage can be avoided with minor penalty in the signal-to-noise ratio [5]. The ability to slow down the microwave carrier and its modulation is of paramount importance in digital receivers wherein the ADC must capture the received signal before down-conversion.

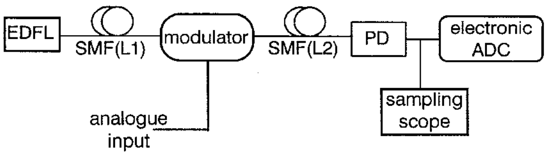

Fig. 2 *Experimental setup*

Fig. 2 shows a block diagram of our experimental setup. To stretch the analogue signal in time, we employ an optoelectronic technique in which a dispersed optical pulse is used to impose an ultra wideband (7.5THz) chirp on the analogue signal. A 160fs pulse from a mode-locked Erbium-doped fibre ring laser (ML-FRL) is dispersed in length L_1 = 1.1km of single mode fibre (SMF) generating a linearly chirped optical signal. The pulse has bandwidth = 60nm (7.5THz). The chirped signal is intensity modulated by the analogue waveform in an electro-optic ($LiNbO_3$) modulator, producing an optically chirped copy of the analogue waveform. The latter is linearly stretched in time by a second dispersion stage consisting of L_2 = 7.6km of SMF. The stretch factor is given approximately by $M \sim (L_1 + L_2)/L_1$ [5]. The stretched waveform is digitised by a 1Gs/s electronic ADC. For comparison, the waveform is also recorded with a high speed sampling oscilloscope. An arbitrary analogue waveform was generated by biasing the modulator at $V\pi$ and applying a pulse to it. The solid line in Fig. 3 shows the analogue time stretched waveform captured by the sampling oscilloscope and the data points, spaced 1ns apart, represent the digitised output of the ADC. The inset shows the waveform prior to time stretching. The bandwidth of the analogue waveform has been reduced by the stretch factor, $M \sim 7.9$, allowing it to be captured by the ADC. The effective sampling rate of the 1Gs/s electronic ADC has been increased to 7.9Gs/s.

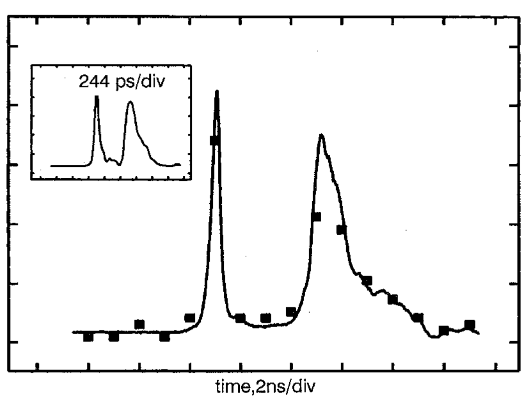

Fig. 3 *Experimental data*

——— time stretched waveform measured on sampling oscilloscope
■ digitised samples of 1 Gsps electronic A/D
Inset shows analogue input prior to time stretch

Time stretching can, in principle, mitigate the sampling jitter noise in ADCs. To study this effect, we simulate the system of Fig. 1*a* assuming a noiseless time stretching. Each ADC is assumed to be a Nyquist converter (as opposed to an oversampling Σ–Δ converter) consisting of a sample-and-hold stage followed by an ideal quantiser. A 10bit resolution and 4Gs/s sampling rate is assumed for each converter, although the values chosen are immaterial. A 1 ps jitter is introduced in the sampling clock. Fig. 4 shows the signal-to-noise ratio (SNR) and the effective number of bits, N_{eff} = (SNR – 1.76dB)/6.02, as a function of the input signal frequency, for different time-stretch factors, *M*. At low frequency, the ADC is limited by the quantisation noise. This region is unchanged, indicating that time-stretching has no effect on the quantisation noise of a Nyquist ADC. The noise due to sampling clock jitter is proportional to the slew rate of the analogue signal and reduces the SNR at high frequencies. In this regime, ADC resolution improves by 1 bit for every octave of time stretch (see inset of Fig. 4 for f_{in} = 1.8GHz). Alternatively, for a given SNR, the maximum resolvable input frequency improves linearly with the stretch factor.

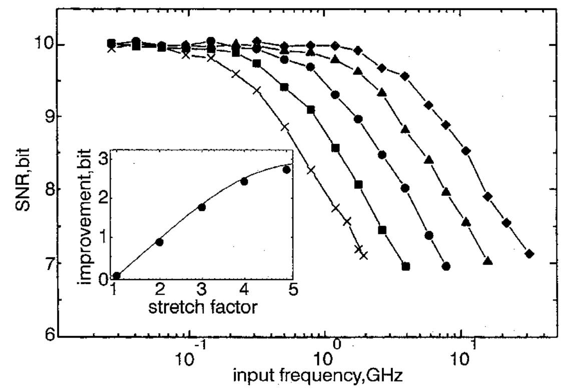

Fig. 4 *Simulation results: Effective resolution of time stretched analogue-to-digital converter as function of input frequency for different stretch factors, M*

1ps sampling jitter clock is assumed
× *M* = ×1
■ *M* = ×2
● *M* = ×4
▲ *M* = ×8
◆ *M* = ×16

Simulations shown in Fig. 4 were performed assuming that no jitter noise is introduced in the segmentation stage of Fig. 1*a*. It is critical to minimise the jitter introduced by this stage as it diminishes the improvements gained by time-stretching. In general, time-stretching is more effective and simpler to implement in ADC applications wherein the input signal is non-continuous, and hence no segmentation is necessary. An important example of such applications, and one in which time-stretching can have a significant impact, is the pulsed radar.

In summary, we have proposed and demonstrated an A/D system wherein the input analogue signal is stretched in time prior to sampling and quantisation. This system can potentially mitigate the A/D bottleneck in the digital receiver.

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References

1 SKOLNIK, M.I.: 'Introduction to radar systems' (McGraw-Hill, New York, 1980), 2nd edn.
2 BLACK, W.C., and HODGES, D.A.: 'Time interleaved converter arrays', *IEEE J. Solid-State Circuits*, 1980, **SC-15**, (6), pp. 1022–1029
3 CAPUTI, W.J.: 'Stretch: a time-transformation technique', *IEEE Trans. Aerosp. Electron. Syst.*, 1971, **AES-7**, pp. 269–278

4 BENNET, C.V., SCOTT, E.P., and KOLNER, B.H.: 'Temporal magnification and reversal of 100Gb/s optical data with an up-conversion time microscope', *Appl. Phys. Lett.*, 1994, **65**, (20), pp. 2513–2515

5 COPPINGER, F., BHUSHAN, A.S., and JALALI, B.: 'Time magnification of electrical signal using chirped optical pulse', *Electron. Lett.*, 1998, **34**, (4), pp. 399–400

ABR performance in presence of bursty TCP traffic

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The available bit rate (ABR) service class is a solution for the integration of data traffic in asynchronous transfer mode networks. Many algorithms have been proposed to implement ABR services. The authors present simulation results showing poor performance by a common ABR algorithm when supporting TCP bursty traffic. As a solution to this problem, the authors propose time averaging of the parameters calculated by the ABR algorithms.

Introduction: Asynchronous transfer mode (ATM) is the generally accepted switching technology for the support of broadband integrated services digital networks. One of the services to be integrated is data service, which conveys random and bursty traffic. To efficiently manage data traffic in ATM networks, the ATM Forum has proposed two service categories: UBR (unspecified bit rate) and ABR (available bit rate) [1]. ABR is currently considered the most promising solution because of its ability to share the changing available network bandwidth with a low cell loss rate. Nevertheless, it is not proven that ABR is the best choice for data applications because it has not yet been tested in completely realistic environments.

ABR performs congestion control by means of a closed loop of resource management (RM) cells. This loop starts at the source, goes forward to the destination along the virtual connection path, and returns to the source. Returning RM cells collect information about the network state. Depending on this information, the source must limit its cell rate emission, according to a standard protocol. Several algorithms have been proposed to compute the information to be written into the RM cells for the switches [2]. ABR performance has been evaluated under different conditions, including persistent and modulated sources, as well as TCP sources [3].

For every traffic burst, an ABR connection operates in two phases: open loop and closed loop. The loop is open from the start of transmission until the first RM cell arrives at the source. From this moment, the connection is in closed loop. ABR algorithms are designed and tested to operate in closed loop, but the assumption that ABR connections will remain in closed loop most of the time is not always realistic. If an ABR connection conveys traffic bursts with a shorter transmission time than the connection round trip time (RTT), then it will operate in open loop. With this kind of traffic, ABR algorithm behaviour may be very different from that seen in closed loop, with its performance worse, as we show below.

ABR with TCP traffic: The bursty profile of data traffic can be caused not only by the application demand patterns, but also by congestion control mechanisms in the upper layer protocols running in most legacy nets. In particular, TCP can cause this bursty traffic, leading the ABR connection to operate mostly in open loop.

TCP uses a window mechanism to control flow and avoid congestion. It does not use the network state information from lower layers, but obtains an estimation of the network state from ACK messages. Thus, network congestion is perceived by TCP only when packets are lost, which means a delay of at least one RTT. To cope with this uncertainty about the current network state, TCP implements a number of preventive mechanisms. The most important of these from the point of view of ABR, is the slow start mechanism. Slow start closes the transmission window when a loss segment is detected, and opens it gradually after the reception of new ACKs. In the slow start phase, TCP generates short traffic bursts with RTT millisecond periodicity.

ABR instability: During the open loop phase, an ABR source has no information about the network state. Thus, if some connections operate for a long time in open loop, the ABR algorithm can become unstable. This situation arises when sources emit bursty traffic, as TCP sources do during the slow start phase. If the bursts are shorter than RTT, then when a source receives RM cells, the burst has already ended. According to the ABR source behaviour, however, this information can be used erroneously in the next burst. This is what causes instability, because this information does not refer to the present state of the network.

This instability can be observed in the simulation results shown below. They correspond to a configuration of two switches, connected by a 100km trunk link at 150Mbit/s, and five terminals connected to each switch by 100km links. At the terminals, TCP is running and using ABR connections. There is a TCP connection between each pair of terminals on one side and the other. All of these connections convey unidirectional data traffic. The TCP transmission window is set to equal the product delay bandwidth, so the transmission rate is limited only by the link rate.

In the switch, ABR is implemented by the ERICA algorithm [4]. This algorithm computes the arrival cell rate to each output port (*IR*), measuring the arriving time of 60 cells, and counts the number of active connections *N*. A target rate *TR* of 90% of available bandwidth is defined. For each port, it calculates an 'overload factor' $of = IR/TR$, and a 'fair cell rate' $CR_f = TR/N$. When a backward RM cell arrives, then its explicit rate information is clipped to the maximum of CCR/of and CR_f. *CCR* is the connection current cell rate, carried by the forward RM cells. This algorithm leads, in most situations, to an accurate fair sharing of the target rate between the active connections.

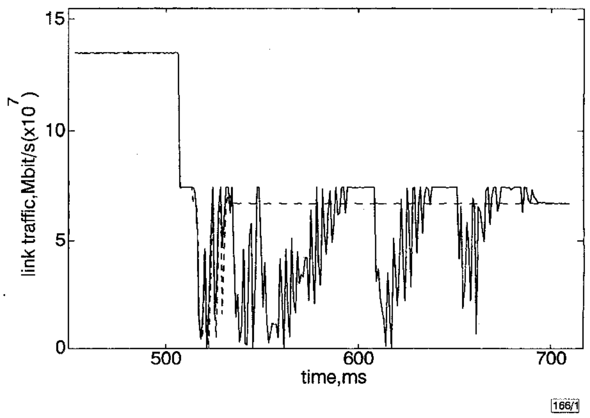

Fig. 1 *Link cell rate*

——— filtering without parameters
– – – – filteringwith parameters

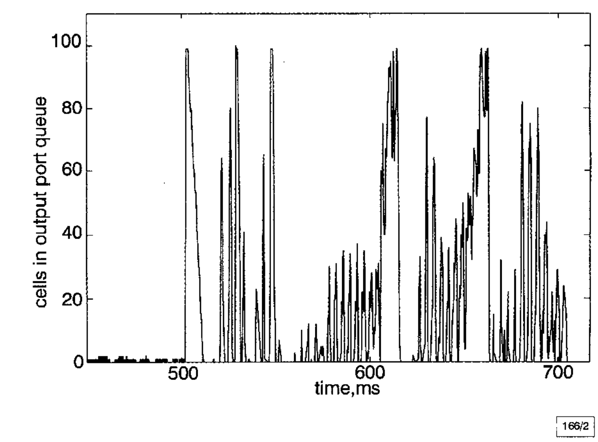

Fig. 2 *Number of cells in output port queue*

In the simulations shown, the five connections sharing the link are in steady state until $t = 500$ms. At this time, the link capacity is reduced to one half, as seen in Fig. 1. This causes a transitory in