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A DSP-BASED DIRECTION FINDER

T.B. Vu and G. Jonas
School of Electrical Engineering
University of New South Wales
Sydney, Australia 2033

Abstract

This paper discusses the design of a phased array direction finder based on the TMS320C30, a DSP microdevice with high-speed floating-point capability. The emphasis is on compact design and real-time operation.

Introduction

Existing phased arrays are predominantly microwave-based systems, in the sense that the task of beam scanning and null steering is realized by using microwave digital phase-shifters and attenuators. However, in order to achieve a high precision in pattern control, digital phase-shifters with a large number of phase bits must be used. As a result, the cost and complexity of the system can significantly increase, especially when the number of elements in the array is large. Moreover, these microwave components also introduce unwanted insertion losses which may vary while the antenna beam is being scanned or while the nulls are being steered to different directions. The upshot is that, for many applications, including space-based systems, existing phased arrays may prove to be costly, bulky and/or not flexible enough to meet operational requirements. A more flexible approach is to perform beam scanning, etc. by digitally processing the antenna signals. This paper discusses a phased-array direction finder based on the TMS320C30, a DSP microdevice with high-speed floating-point capability.

Basic Antenna Description

The system being studied is a twenty-element linear array with an interelement spacing of half the wavelength. Figure 1 shows the basic geometry of the antenna.

Generally speaking, in order to track multiple targets in the presence of a large number of jammers or RF interference sources, a non-uniform current distribution must be used [1]. However, for the simple system described in this paper, a uniform linear array will be considered. As a result, the array factor will take the well-known form given below:

$$AF = 1 + e^{j\psi} + e^{j2\psi} + \ldots + e^{j(N-1)\psi} \qquad (1)$$

where

$$\psi = \frac{2\pi d\cos\theta}{\lambda} + \alpha \tag{2}$$

d = interelement spacing = $\lambda/2$
λ = wavelength
α = progressive phase-shift
N = total number of elements in the array

As the array factor will be maximum when $\psi=0$, it is clear from equation(1) that the antenna beam direction can be scanned by changing the progressive phase-shift, α. However, in this case, instead of using conventional microwave digital phase-shifters to scan the beam, the signals received by the twenty array elements will be downconverted to a low intermediate frequency and then processed by the digital section to determine the direction of the source.

Digital Tracking Algorithm

As the downconversion of the carrier to an intermediate frequency (ω_i) does not affect the phase information, the output of the antenna array at the input of the digital section may be expressed as follows:

$$F(\theta) = \sum_{n=1}^{N} e^{jn\alpha} e^{-j(n-1)\pi\cos\theta} = \sum_{n=1}^{N} e^{jn\alpha}(I_n + jQ_n) \tag{3}$$

or
$$F(\theta) = I + jQ \tag{4}$$

where I_n and Q_n are the real and imaginary parts of the signal of the n^{th} channel respectively, and

$$I = I_n \cos[(n-1)\alpha] - Q_n \sin[(n-1)\alpha] \tag{5}$$
$$Q = I_n \sin[(n-1)\alpha] + Q_n \cos[(n-1)\alpha] \tag{6}$$

Therefore the basic function of the TMS320C30 is to increment α, and to compute, for each α, the corresponding $F(\theta)$. From these computations, the processor can find the value α_M that maximizes $F(\theta)$. Finally, from α_M, the direction of the source can be determined by using equation(2) with $\psi=0^o$.

In order to compute $F(\theta)$, the signals from the twenty input channels must be Hilbert transformed to provide the required quadrature signals. Naturally, the in-phase signals must be suitably delayed to compensate for the delay introduced by the Hilbert transformer, which in our case is implemented as a 5-tap FIR digital filter.

Digital Hardware Description

Figure 2 shows the basic components of the digital sub-system hardware. For clarity, the signal conditioner has been omitted. Its role is to minimise unwanted effects caused by DC offset noise, etc. The twenty input channels from the downconverters are simultaneously held by the sample and holds, resulting in the preservation of relative phase information in the channels. High-speed multiplexers are used to select individual channels, one by one for the digital conversion. The A/D converter is the Comlinear CLC922, which can maintain 12-bit accuracy at conversion rates up to 10 MSPS. It requires two control signals, one to effect conversion and the second to enable/disable the digital output buffer. All control signals are derived from the combination logic of the TMS320C30 expansion bus control signals. As a result, the type of sampling, the sampling rate and the channel selection are programmable via the TMS320C30 software control. The heart of the digital system is the TMS320C30, which implements the Hilbert transform of the digital signals from the twenty channels, as well as the tracking algorithm described previously. The total time required to scan the beam from $\theta=0^o$ to $\theta=180^o$ is of the order of a fraction of a millisecond, and is adequate for many practical applications.

Conclusion

The tracking performance of the digital system has been tested for both unmodulated carrier and carrier amplitude modulated by a narrow-band audio signal. In both cases, the intermediate frequency is of the order of 20 KHz. Although the tracking accuracy decreases when the DOA of the source is near to $\theta=0^o$ or $\theta=180^o$, the overall results show that the digital tracking system performs very well in both unmodulated and modulated cases, even when the bandwidth of the modulating signal is equal to 5 KHz, a relatively large fraction of the carrier frequency.

References

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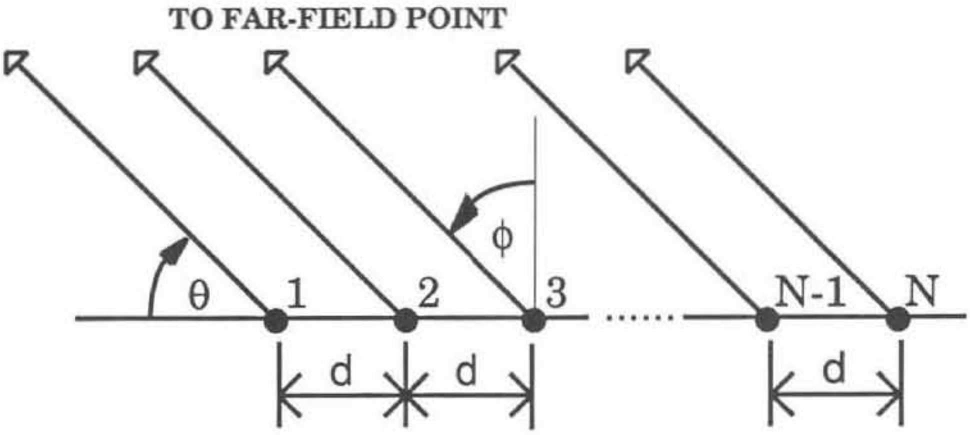

Figure 1 Geometry Of A N Element Array

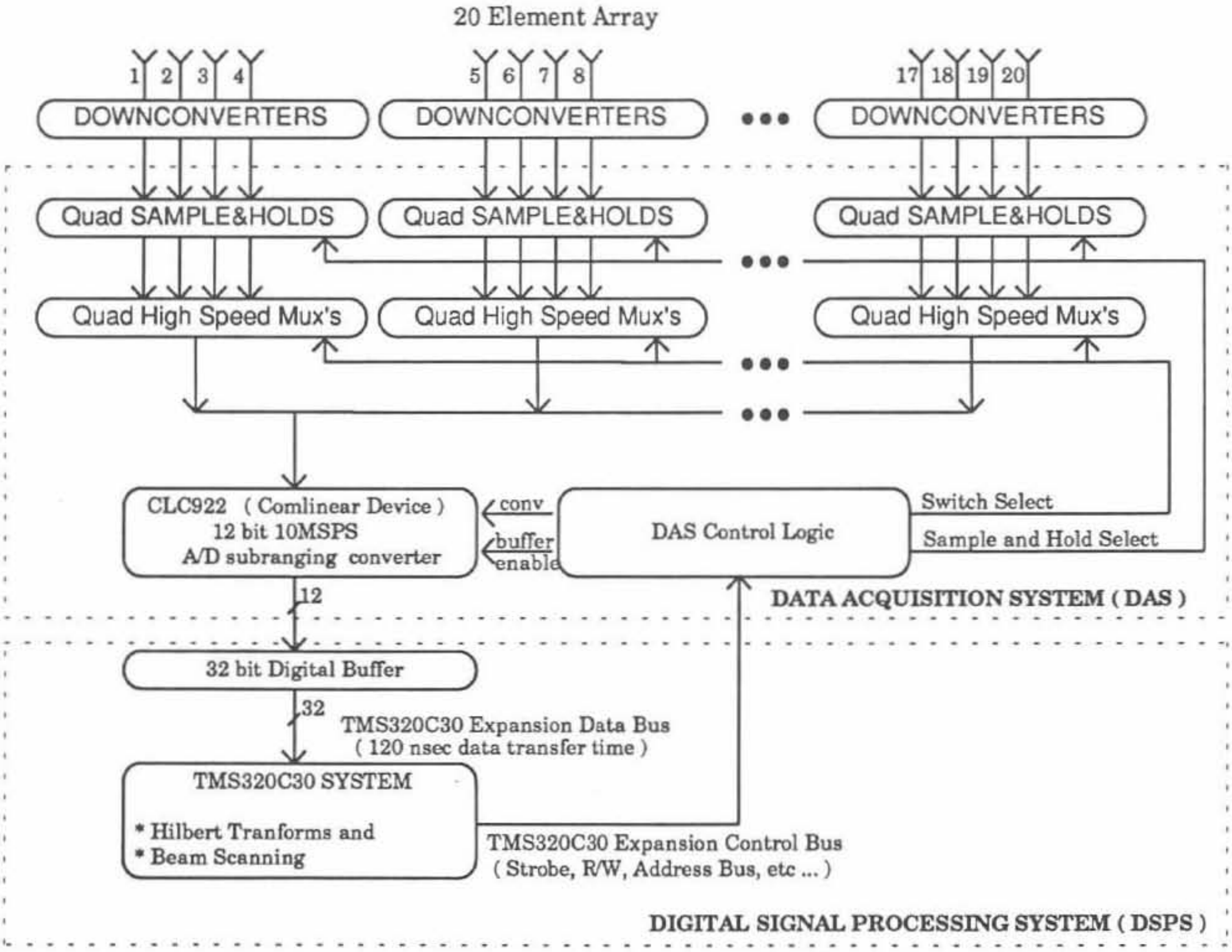

Figure 2 Basic Block Diagram Of Direction Finder Hardware