DIGITAL GENERATION OF THE HIGH QUALITY AUDIO SIGNALS WITH THE NeXT COMPUTER

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Digital methods for sinusoidal signal synthesis

A computer - based digital function generator can generate any arbitrary type of signal in the frequency range from 0 Hz to 20,000 Hz, S/N = 95 dB, and with no harmonic or intermodulation distortion (when based on 16-bit, 44.1kHz-sampling rate D/A converter). Frequency stability is determined by a quartz clock in the D/A converter which has an accuracy in the order of $1/10^7$. Generation of sinusoidal waves is of primary importance in digital synthesis, since due to the Fourier theorem any periodic wave may be constructed via additive synthesis (an addition of pure tones with appropriate amplitudes and phases). There are many alternative methods to digitally generate pure tones [1,2,3,7]. Very often real-time synthesis is accomplished by using a sine function look-up table [2,7]. A limitation to this approach is the short length of the sine table (N). In order to synthesize any arbitrary frequency using the look-up table method, one has to synthesize the values of the sine function using an interpolation process [2]. Interpolation between sine samples leads to the generation of harmonic and intermodulation distortion by this algorithm [2,7]. Another problem is that synthesis of more complex signal (combinations of several sinusoids with certain amplitudes and phases) in real time could put too much performance demand on the computer's DSP chip or microprocessor.

Digital Function Generator software for the NeXT computer

A new high precision digital synthesis method has been developed for the generation of the high quality audio signals [7]. This method has been successfully implemented on the NeXT computer and was used with great success in teaching of acoustics, psychoacoustics, electronics and in various research projects. During the course of this research, a software package called **Digital Function Generator (DFG)** was written. At present the DFG software consists of 5 modules. The **Principles of Digital Audio** module (Fig.1) allows synthesis of pure tones and white noise. It can also be used to illustrate concepts of signal amplitude, frequency, phase, interference, coherence, incoherence, signal ramping, additive synthesis, beats, virtual pitch as well as to demonstrate quantization, dithering, aliasing / hard clipping / harmonic / intermodulation distortions, etc. The **Modulation (AM, FM & AFM)** module allows synthesis of pure tones which can be Amplitude Modulated (AM), Frequency Modulated (FM) or Amplitude and Frequency Modulated (AFM). The **Additive Synthesis** module allows very flexible synthesis of complex sounds from their Fourier components. The **Sweep Generator (AS, FS & AFS)** module is a very flexible tool for generating arbitrary amplitude (AS), frequency (FS) or amplitude and frequency (AFS) sweeps. The **Function Generator** module (Fig.2) can be used to synthesize sine, square, triangular, sawtooth, pulse and white noise signals.

RAM-based method for sinusoidal signal synthesis

In order to generate sinusoidal signal in this method, one has to synthesize audio file, which contains appropriate samples in RAM (Random Access Memory) or on the Hard or Optical Disk. Then reading of this file in real time to the D/A converter is performed to generate the desired audio signal [6]. However there is a limit on the duration of this signal due to memory consumption = 88,200 Bytes/sec (for 16-bit, 44.1 kHz D/A converter). In many situations long durations of test signal are required. In this case the most appropriate way to generate sine wave is to construct the audio file in RAM in such a way as to be able to read this file to the D/A converter over and over again (looping) [7].

Generation of frequencies 1Hz, 2Hz, 3Hz......20,000Hz with the NeXT computer

NeXT computer has a 16-bit, 44.1 kHz stereo set of the D/A converters (CD-quality), available 16-bit, 44.1 kHz stereo set of the A/D converters, built in DSP processor (Motorola 56001), from 8 to 256 MBytes of RAM and from 100 MBytes to 5.6 GBytes of internal hard disk storage. This, therefore, is the best computer for audio and acoustical applications available today. With RAM buffer size N=44,100 (176,400 Bytes - which is small by the NeXT standards) the available frequencies for looping are: 1 Hz, 2 Hz, 3 Hz,........20,000 Hz. It takes about 3 sec for Motorola 68040-based NeXT machine to generate a pure tone soundfile of this length. Once generated, this file can be played in loop from RAM indefinitely.

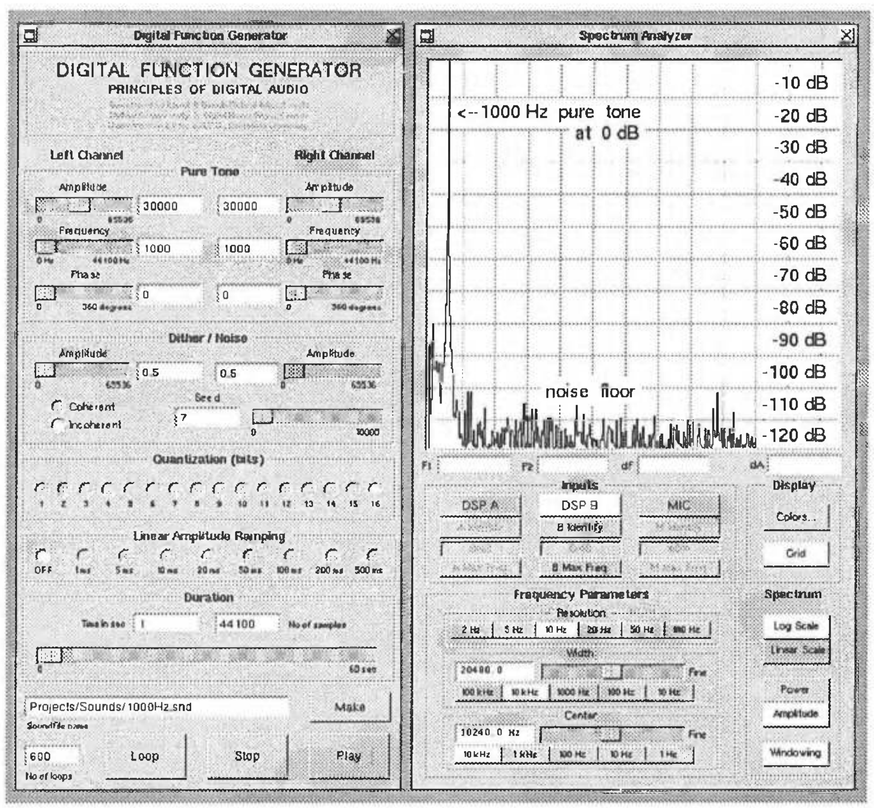

Figure 1. 1000 Hz pure tone generated with the Digital Function Generator (Principles of Digital Audio module) and displayed with the Spectrum Analyzer.

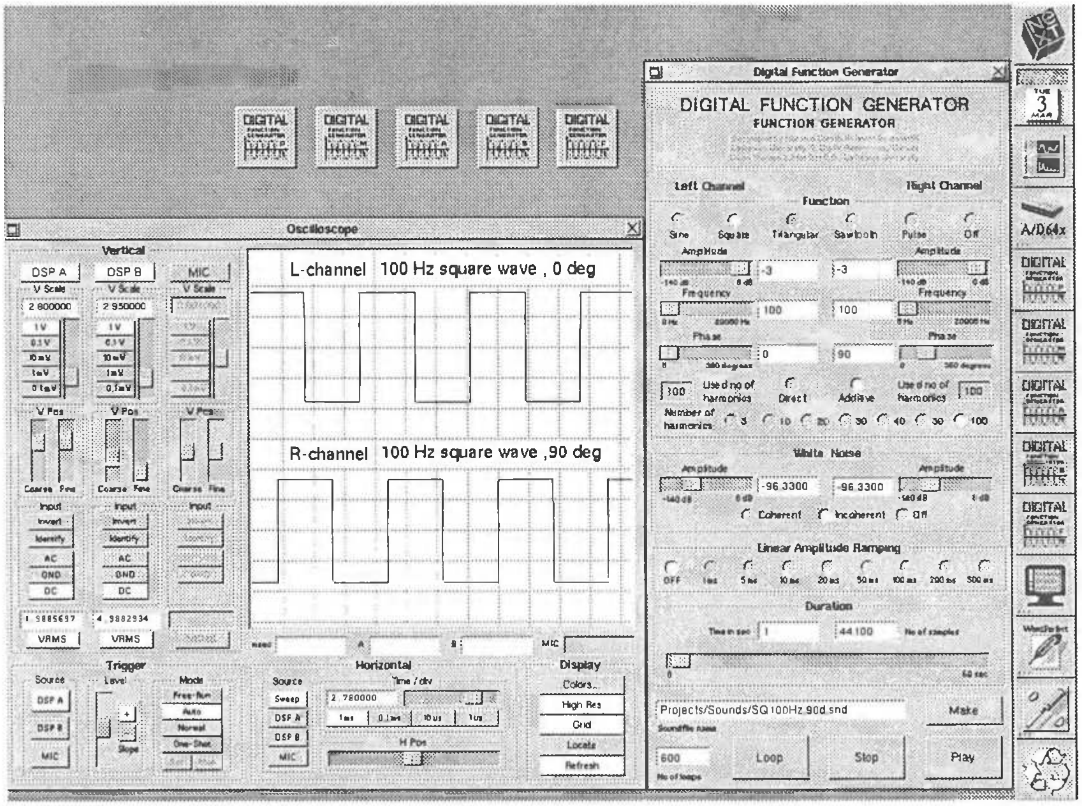

Figure 2. 100 Hz square wave generated with the Digital Function Generator (Function Generator module) and displayed with the Digital Oscilloscope.

With RAM buffer size N=441,000 (1,764,000 Bytes - still small by the NeXT standards), one can generate all frequencies from 0.1 Hz to 20,000 Hz with 0.1 Hz resolution. Precision of these frequencies is determined only by the precision of the D/A converter's clock which is in the order of $1/10^7$, and in the case of a 1000 Hz tone this leads to an expected error in the order of $\pm$ 0.0001 Hz. Generated soundfiles with desired frequencies can be stored on the Hard or Optical Disk and recovered into RAM prior to generation of sine tones.

Improving DFG through the use of Digital Dither

The only harmonic and intermodulation distortion generated by the used algorithm is associated with round-off error of final amplitudes A[n] due to the signal correlated nature of quantization noise [4,5,7]. Elimination of the harmonic and nonharmonic (intermodulation) distortion (which are imposed by the resolution of the D/A converter) may be accomplished by using Digital Dither, with a small white noise penalty (3 dB- for uniform-pdf dither) [5,8], resulting in S/N=95 dB for 16-bit dithered digital generator (theoretical S/N=98.2 dB for undithered 16-bit digital system) [4]. This technique was implemented in the DFG software to improve quality of the generated signals.

Generating stereo signals with NeXT

The procedures outlined in ref [7] were applied for synthesis of stereo waveforms with the NeXT computer. One can generate different or similar waveforms in each channel. Phase relationship between waveforms will be maintained during playback. Since signal phase constants are arbitrary real numbers, arbitrary phase shifts between waveforms can be obtained. This could be important for some audiological and psychoacoustic tests [6,11,12].

Conclusions

The most precise digital-domain method for the generation of arbitrary audio signals was successfully implemented on the NeXT computer. Since NeXT is a multitasking, UNIX operating system-based machine, many software applications can run on it simultaneously. DFG software by-design puts very little demand on the hardware and does not use the built-in Motorola DSP 56001 processor for sound synthesis. This allows running of the Digital Oscilloscope (Fig.2), Spectrum Analyzer (Fig.1) and Sound Recording software simultaneously with DFG. This in turn allows very sophisticated tests and demonstrations in such fields as acoustics, electronics, physics and engineering to be performed on a single NeXT computer.

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