As shown in FIG. 1, the binary digital data stream is generated by a digital waveform generator including, for example, a time-dependent waveform source 12, and a delta-sigma (Δ-Σ) modulator 14. The time-dependent waveform from the source 12 describes an analog signal such as a DC voltage, a pure sinewave, or a band of chirp frequencies, where chirp is meant to include both linear and nonlinear frequency modulated (FM) frequencies which are swept over a predetermined frequency range. This time-dependent signal is converted to a digital pulse train by the Δ-Σmodulator 14 in a well known manner. A current pulse driver 16, which could be realized as a digital pulse pattern generator, is used to current bias the Josephson junction quantizer 10. The output of the Δ-Σmodulator 14 and current pulse driver 16 consists of a binary digital pulse train 18 which includes the frequency spectrum of the desired waveform from the source 12.

While such pulses are adequate for use with digital logic circuits, the amplitude and phase of the digital ONE pulses may not necessarily be uniform. For example, existing digital signal generators typically have voltage and phase noise that is both correlated and uncorrelated to the binary digital code bit density. Such a pulse train, however, when applied to the Josephson quantizer 10 by the current pulse driver 16 produces a corresponding digital output across terminals 22 and 24 which consists of a pulse train 26 where every pulse representing a binary ONE has a quantum mechanically accurate time integral. When the pulse train signal 26 appearing across terminals 22 and 24 is coupled to a low pass filter 28 as shown in FIG. 1, an analog signal 29 which is substantially noise free and which corresponds to the requested time-dependent waveform from the source 12 will be transmitted on circuit lead 30. The analog signal generator provides a high frequency clock signal that controls the current pulse driver 16 via signal lead 33. The foregoing description is sufficient for general applications of the Josephson digital to analog converter, such as metrology applications.

For radar applications, however, the analog signal generator 34 provides a relatively low phase noise clock signal to control the current pulse driver 16 via lead 33. Such a low phase noise signal can be provided by a cryogenic stabilized local oscillator (STALO). This low phase noise signal is additionally fed via lead 36 to signal mixer 32 which also receives the signal on lead 30. The mixer generates a low phase-noise output signal 37 which appears on circuit lead 38 and which can then be used in the generation of RF pulses transmitted by a radar system, not shown.

The foregoing is made by way of preface to the preferred embodiment of the invention as a low phase noise radar signal generator which is shown in FIG. 2. Referring now to FIG. 2, shown there at is apparatus including a digital to analog converter for generating low phase-noise analog X-band signals utilizing a Josephson junction array 10 which is excited by the digital ONE amplitudes of a digital data stream 18 which includes a spectrum of chirp signals.

The digital data stream 18 is now generated by a digital waveform generator 39 comprised of a set of random access memories (RAMs) $40_1 \ldots 40^n$ which are programmed with a desired binary sequence representative of the chirp signals and which are controlled by an address controller 42. The controller 42 is shown clocked at a rate derived from a clock signal generated by a stabilized oscillator (STALO) 34' which comprises a cryogenically cooled dielectric (sapphire) resonator which generates a fixed RF frequency of 10 GHz. The rate at which the address controller 42 is clocked is a sub-multiple of the clock frequency and is provided by a frequency divider 43. The selected binary outputs from the RAMs $40_1 \ldots 40^n$ are multiplexed into a single data stream by a multiplexer 44, where it is then used to drive the Josephson junction array 10 via a high speed semiconductor digital logic gate 46 also clocked by the STALO 34'.

The output 26 of the Josephson array 10 comprises a corresponding binary waveform sequence wherein each and every digital ONE pulse has an identical quantum mechanically precise time integral, which when fed to a low-pass filter 28 having a pass-band from DC to 20 MHz, provides low phase-noise analog voltage signals corresponding to the output of digital waveform generator 39. Such a configuration can generate an RF chirp output from the mixer 32, which can then be fed to a radar transmitter, not shown, as an IF signal for the generation of chirped radar transmit pulses.

The validity of the subject scheme has been confirmed by two experiments performed at the National Institute of Standards and Technology in Boulder, Colo. In those experiments, 2 nanosecond (2×10^{-9}sec.) current pulses were applied to 512 Josephson junctions connected in series. The layout of the chip had the junctions at the center conductor of a 50-ohm coplanar waveguide structure. Since the voltage-state impedance of each junction was noted to be 4.4 milliohms, the total series impedance of 2 ohms was a small perturbation of the coplanar transmission line. Thus the amplitude of the excitation pulse was substantially the same at the last junction as it was at the first junction. Furthermore, in these experiments, the DC current-voltage characteristic of the Josephson junction array changed with frequency of the applied pulses. At 250 MHz, constant voltage steps were measured which had a spacing of about 250 microvolts. This time-averaged DC voltage corresponds to a single output pulse per junction per excitation pulse, which is expressed as: $V=Nf\phi_0$, where N is the number of junctions, f is the excitation pulse frequency, and ϕ_0 is the single flux quantum voltage pulse having a magnitude of 207 microvolts per GHz.

The basic Δ-Σ function of producing a lower output voltage when the excitation pulses occur less frequently was also confirmed in the NIST experiments. When the 2 nanosecond excitations were applied at 100 MHZ rate, the voltage steps occurred at 106 microvolt intervals, while at 10 MHz pulse rate, the voltage steps occurred at 10.6 microvolt intervals.

Thus what has been shown and described is a digital-to-analog converter based on the quantum mechanical accuracy of Josephson junctions that can be used for generating accurate time-dependent waveforms. This accurate voltage source may be used as a programmable voltage standard for metrology applications. For cryogenic radar systems, it can be combined with the low phase-noise of a cryogenically cooled dielectric (sapphire) resonator acting as a stabilized local oscillator, thereby allowing pulse compression to be implemented so as to improve detection of targets in clutter which would otherwise not be detected.

Thus having shown and described what is at present considered to be the preferred embodiment of the invention, it should be noted that the same has been made by way of illustration and not limitation. Accordingly, all modifications, alterations and changes coming within the spirit and scope of the invention as set forth in the appended claims are herein meant to be included.

We claim:

1. Apparatus for generating an accurately known time dependent signal comprising: