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A.	A. Madjar, et al., "A novel DDS based 94 GHz high linearity FMCW RW front end" 26th European Microwave Conference, 1996 (Volume: 1), September 9-12, 1996.
B.	Z. Galani and R.A. Campbell, "An overview of frequency synthesizers for radars" IEEE Transactions on Microwave Theory and Techniques Vol. 39, Issue 5, May 1991.

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11. A. Madjar, et al., "A novel DDS based 94 GHz high linearity FMCW RW front end" was published as part of the 26th European Microwave Conference, 1996 (Volume: 1). The 26th European Microwave Conference, 1996 (Volume: 1) was held from September 9-12, 1996. Attendees of the conference were provided copies of the publication no later than the last day of the conference. The article is currently available for public download from the IEEE digital library, IEEE Xplore.

12. Z. Galani and R.A. Campbell, "An overview of frequency synthesizers for radars" was published as part of IEEE Transactions on Microwave Theory and Techniques Vol. 39, Issue 5. IEEE Transactions on Microwave Theory and Techniques Vol. 39, Issue 5 was published in May 1991. Copies of this publication were made available no later than the last day of the stated publication month. The article is currently available for public download from the IEEE digital library, IEEE Xplore.

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EXHIBIT A

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A novel DDS based 94 GHz high linearity FMCW RF front end

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Abstract

FMCW millimeter wave sensors are very useful for both military and civilian applications, due to their low cost, simplicity and low transmitted power. In this paper we present a novel approach to the realization of linear FMCW chirp at a frequency of 94 GHz based on a DDS (Direct Digital Synthesizer). This is a much superior method compared to the common approach using a VCO with a linearization loop, the linearity of which is limited. Our approach enables realization of a relatively low cost, small size sensor with an extremely good linearity. We demonstrated an excellent range resolution of better than 0.5 meter at a range of 1 kilometer.

Introduction

In recent years millimeter wave sensors have become very useful for both military and commercial applications (seekers, collision avoidance, traffic control, etc.). Many applications already exist and many more are emerging shortly. The FMCW sensor is becoming more and more popular due to its low cost, low power and simplicity compared to other types (i. e. pulsed radar). In FMCW sensors a linear FM chirp is generated and transmitted toward a target. A sample of the transmitted signal is used as the LO for the receiver mixer. The signal reflected from the target is received and routed to the mixer, where it mixes with the transmitted signal. Due to the delay between the transmitted and received signals there is a frequency difference. Thus, the IF frequency is proportional to the target range.

The implementation of an FMCW sensor is relatively simple, except for the linear FM chirp generator. The linearity of the chirp is the single most important parameter of the FMCW sensor, which determines the range resolution. Any nonlinearity in the frequency vs. time curve causes the IF frequency to fluctuate, and thus causes uncertainty in the range measurement. For many applications moderate linearity is sufficient (~0.5%), and the chirp can be realized by a MM wave VCO and a linearization loop with a linear sawtooth voltage ramp as the reference.

In many applications very high linearity is needed to ensure good range resolution even at large distances (1

different approach. In this paper we demonstrate the realization of a very linear FM chirp at 94 GHz by using a DDS and an optimal combination of up-conversion and frequency multiplication. To our knowledge, this is the frst source of this type at this frequency with excellent linearity, potentially low cost and small size.

Block Diagram

The principle of operation of a Direct Digital Synthesizer is well known and has been described in numerous papers and tutorials (i.e. [1]). Basically, the DDS consists of a clock controlled phase accumulator (counter) that simulates the instantaneous phase, a lookup table containing a sine wave (converting phase mto amplitude), a DAC (digital to analog converter) and a filter. The waveform is generated digitally with an almost absolute accuracy (frequency accuracy depends on the clock, which is crystal controlled). A linear chirp can be generated easily by linearly stepping the frequency at the digital frequency control port, as explained in [2]. Present day DDS can operate using clock in excess of 1 GHz. as described in [3]. Thus DDS can be used to generate signals in the VHF and UHF ranges.

A block diagram of the novel RF front end is depicted in Fig. 1. The subsystem contains the following blocks: a DDS unit with its linear chirp control circuit, an L band assembly, an S band DRO, a Ku band assembly, a W band assembly and the receiver assembly. The DDS is a Sciteq ADS-43 1-000 unit, which can be clocked up to a frequency of 1600 MHz. The DDS control circuit is a digital circuit which generates a stream of binary frequency control words representing a linear sawtooth, which makes the DDS sweep over a bandwidth of 80 MHz. This unit was developed by us using standard digital components. The DDS is clocked by a signal at around 900 MHz, which is supplied by the L band assembly.

The Components

The DRO is a low noise dielectric resonator oscillator operating at S-band. The DRO drives the L band assembly and serves as the system reference. The L band assembly is used to up-convert the DDS output signal to L-band. The DRO signal is used for three purposes: LO for the Ku unit (via the L band unit), LO for the L- band mixer and a clock for the DDS. The last two tasks are achieved by a frequency divider in the L band unit. The DDS signal output in the VHF band is upconverted by a mixer to L band.

The Ku unit contains two components: a x4 subharmonic mixer, using the DRO as the LO, and a power amplifier. The mixer converts the L band signal to Ku band, and exhibits a 10db conversion loss. The amplifier amplifies the chirped signal up to a level of around 2 watt. The W band unit is basically a x6 frequency multiplier, which converts the signal into 94 GHz. This frequency multiplication is the only one in our system. We have avoided excessive frequency multiplication to prevent the increase of spurious signals and noise (20log(n) rule) - most of the frequency upconversion is performed by frequency

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circulator to separate between the transmitted and received signals, a coupler to sample the transmitted signal for mixer LO, a mixer and an IF filter/amplifier. The power is transmitted via a reflector antenna, and the IF signal is processed by an FFT processor, which displays the spectrum of the received down converted signal. The IF frequency is proportional to the target range and is in the MHz band.

Performance

An experimental system was built for performance evaluation by using available components and without consideration to physical size. A photograph of this system is depicted in Fig. 2, which shows also the reflector antenna used in the experiment. The level of transmitted power at 94 GHz is +12.5dbm. The LO power at 94 GHz reaching the receive mixer is +4.5dbm. This power level is low, and a "normal" mixer would have large conversion loss; thus we have used a mixer with bias, which was developed by us specifically for this system. The mixer exhibits a conversion loss of 8db at that LO power level.

We have experimented with the above system and were able to detect targets up to 1 km away. The range resolution was limited by the IF FFT processor (512 sampling points), which was available for the experiment, to around 0.5 meter. This is not an inherent limitation of the system, and can be improved by using a better FFT processor. We were able to distinguish between 2 target separated by 0.5 m at a range of 1 km, as depicted in Fig. 3. The DDS generated chirp has an absolute linearity, however, dispersion of the upconversion chain may degrade the linearity. Experiment shows that in our system dispersion effects are negligible, and the superb linearity was fully exploited.

Presently we are designing the engineering prototype of the above system. Our estimate is that the production cost of the umit in quantities of 1000 is around $3500, and the volume of the unit is around 500 cm³.

References

[1] Henry Eisenson, "Frequency Synthesis Using DDS/NCO Technology-a Tutorial", Electro International Conference, April 16-18, 1991, Javits Convention Center, New York, NY.

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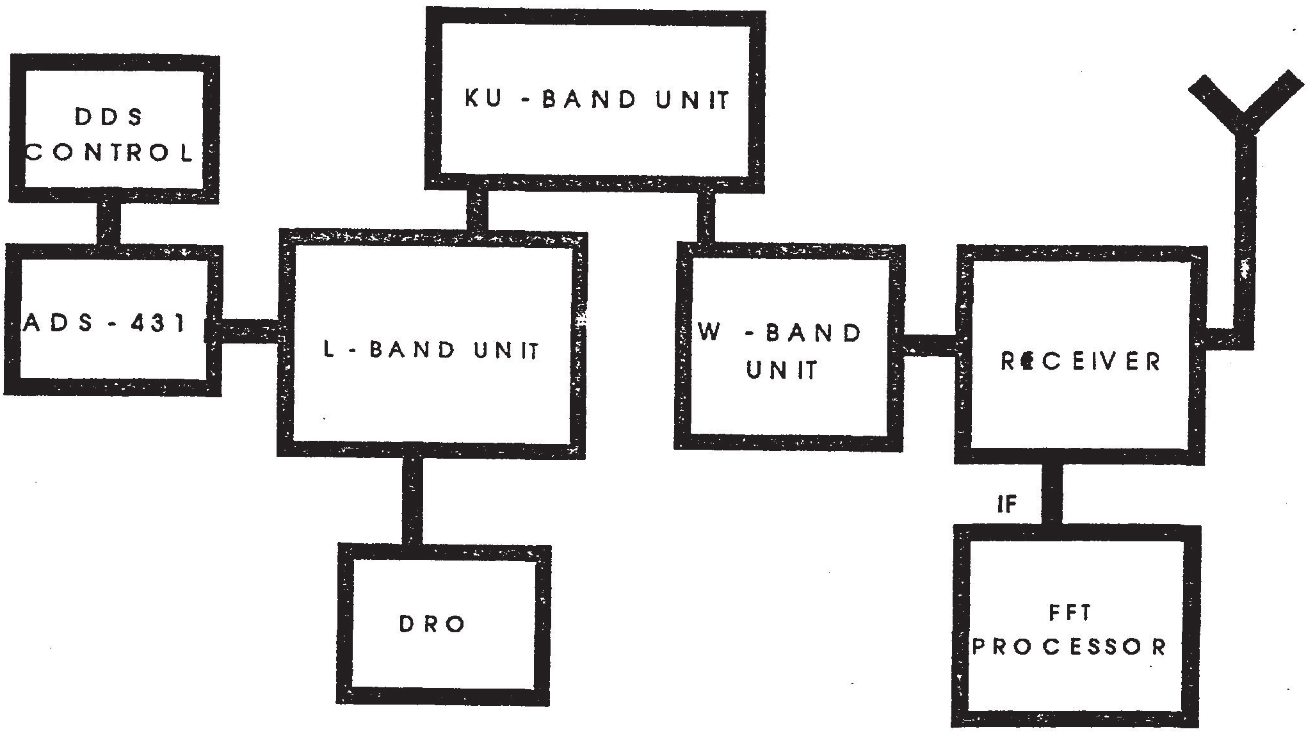

Fig. 1 Block Diagram of the novel RF Front-end

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