LOW-COST RESOLUTION IMPROVEMENT TECHNIQUE FOR SHORT DISTANCE MEASUREMENT SYSTEMS

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ABSTRACT: *In this work, a new scheme for short-range distance measurement is presented. It reduces significantly the amount of signal processing needed for frequency-modulated continuous-wave radar or Lidar systems to obtain a good resolution in beat frequency measurement. In this article, a low cost and easy to implement technique is proposed. This resolution improvement is achieved by simple previous processing of the beat signal.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1496–1498, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25243

Key words: *optical communications; Lidar; FMCW; measurement systems*

1. INTRODUCTION

Frequency modulated continuous-wave radar (FMCW) [1–6] is frequently employed in radar systems for distance measurement. In these kind of applications, some meters resolution if good enough for the radar performance, as the range of distances to be measured is of several kilometers.

In this work, a new scheme to be used in laser distance measurement [3], for a distance range from 1 to 50 m, is proposed. It is intended to provide a distance resolution about ±0.5 cm. The use of a Pulsed Chirp technique requires wide bandwidth signals to obtain the required resolution. This implies very complex high-frequency electronics circuits and high-implementation costs [1].

The main parameter of these systems is the slope of the frequency sweep, thus, the variation of frequency along the sweep. The higher the speed, the higher resolution is achieved [3]. With the current frequency synthesizers, the needed bandwidth to achieve the desired sweep slopes is difficult to generate. A first solution consists on the periodical emission of a frequency sweep to obtain several frames for the beat frequency. This solution implies a set of replicas of the same signal for each sweep period, so the counting process, for the beat frequency measurement, gives us the same values for all the sweep periods.

In this work, we propose a new strategy to obtain a continuous beat signal by means of a simple treatment of those replicas of the beat signal. The objective is to simulate a system with longer count times to obtain a higher resolution in the beat frequency estimation avoiding complex signal processing [4].

2. PROPOSED SYSTEM

Let be a FMCW system with a transmitted signal consisting on a linear frequency sweep from 10 MHz (f_1) to 50 MHz (f_2) and whose received signal is mixed with a local generated sweep from 12 MHz (f_1') to 52 MHz (f_2'). Then, the beat frequency (f_b) for nondelay conditions (0 m to target) is 2 MHz (1).

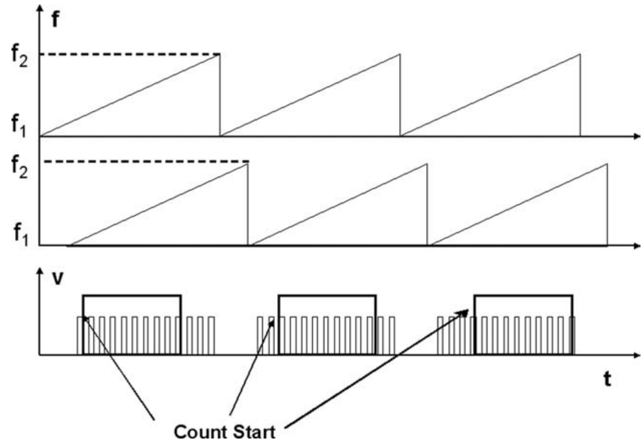

Figure 1 Count window with different starting point each sweep period

$$f_b = \frac{\Delta f}{T_{mod}} \cdot (\Delta t) + f_1' - f_1 \tag{1}$$

The sweep time (T_{mod}) results to be 10 μs and is generated with a DDS with an initial phase for all these frequency sweeps equal to 0°. The result is the generation, at the mixer output, of multiple replicas of the same signal. If the frequency is obtained by a zero crossing counter, we will have the same value for all the frequency sweeps and the count will be always an integer. For the nondelay case, the count obtained is always 20 pulses. For an increment of one pulse at the count (at every sweep), we need to increase the beat frequency in 1 MHz. This frequency variation corresponds to 33.3 ns delay between transmitted and received signal (a distance variation of 5 m), a poor resolution without processing the beat signal. The number of pulses obtained can be expressed as follows:

$$N_{pulses} = \frac{T_{mod}}{T_b} = T_{mod} f_b = \Delta f \cdot (\Delta t) + (f_1' - f_1) T_{mod} \tag{2}$$

where N_{pulses} is estimated by a digital counter and is always an integer. To improve resolution is necessary to perform several count processes and calculate the mean value among them. To avoid obtaining the same count value for all the measures, a pseudorandom delay of the count interval should be added. With such a correction, different number of pulses are obtained at each time. To achieve this, a triggered count is implemented, changing the counting start for each sweep period, as illustrated in Figure 1. Notice that a different number of pulses are obtained within each count interval (count window in advance). Now, calculating the mean value, a more approximated value of the expression (2) can be obtained. The proposed system results to be equivalent to a collection of multiple replicas of the same continuous signal but with different phases. In this way, when $t \rightarrow \infty$, the count process tends to a frequency measurement of a continuous signal employing a simple counter and with the same resolution.

To demonstrate this, we consider that count is performed only over the 40% of the sweep period. The beginning of the count interval is variable following a pseudorandom pattern and its duration is a fixed value. Figure 2 shows an example of the above mentioned example, where N indicates the count result for each window position, T_W is the window duration, T_2 shows the interval of delays for which the count is $N = 2$ and T_3 the interval for a count of 3 for a frequency increment of about 20% (using a zero crossing as measurement method).

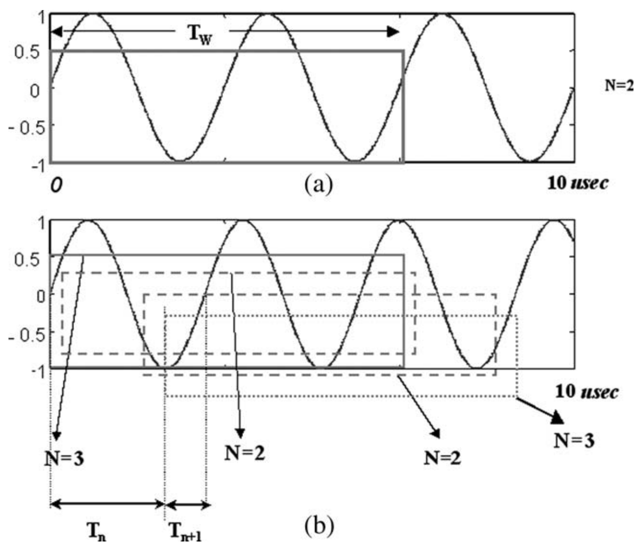

Figure 2 Counting results for different window positions. a) For 3 MHz of beat frequency. b) With a 20% of frequency increment (Different positions for each count window)

Thus, let us consider two signals with periods T_{p1} and T_{p2}, respectively. T_W is an interval with a length equal to a proportional number of times T_{p1}, i.e.,

$$\begin{aligned} T_W &= nT_{p1} \\ T_W &= nT_{p2} + T_{n+1} \end{aligned} \tag{3}$$

The example shown in Figure 2 illustrates how T_{p2} can be divided in two intervals: T_n and T_{n+1}, where as follows:

$$\begin{aligned} T_{n+1} &= T_w - nT_{p2} = nT_{p1} - nT_{p2} \\ T_n &= T_{P2} - T_{n+1} = T_{P2} - nT_{P1} + nT_{P2} = (1+n)T_{P2} - nT_{P1} \end{aligned} \tag{4}$$

We consider that a given time (t) is in T_n if the windows opened in the moment t seconds measures n zero crosses. Similarly, t is in T_{n+1} if the windows opened in t seconds measures $n + 1$ zero crosses.

Let N be a Bernoulli random variable. It denotes the number of zero crosses measured observed in a window of duration T_W. The value of N is equal to n for every window in signal 1. To compute the probability mass function (PMF) of N in signal 2, we compute $P(N = n)$ and $P(N = n + 1)$.

$$P(N = n) = \frac{T_n}{T_{n+1} + T_n} = \frac{T_n}{T_{P2}} = \frac{(1+n)T_{P2} - nT_{P1}}{T_{P2}} \tag{5}$$

$$P(N = n+1) = \frac{T_{n+1}}{T_{n+1} + T_n} = \frac{T_{n+1}}{T_{P2}} = \frac{nT_{p1} - nT_{p2}}{T_{P2}} \tag{6}$$

Notice that the expectation of N can be expressed as an n, T_{p1}, and T_{p2} function as follows:

$$E[N] = n \cdot \Pr[N = n] + (n+1) \cdot \Pr[N = n+1] = \frac{nT_{p1}}{T_{P2}} = \frac{T_W}{T_{P2}} \tag{7}$$

Moreover, the expression (7) can be written as follows:

$$E[N] = \frac{nT_{p1}}{T_{p2}} = \frac{nT_{p2} - n\Delta T_p}{T_{p2}} = n\left(1 - \frac{\Delta T_p}{T_{p2}}\right) \tag{8}$$

where $\Delta T_p = T_{p2} - T_{p1}$

An estimation of ΔT_p is found by the law of large numbers. It estates that,

$$\begin{aligned} &\lim_{i\to\infty} \frac{\sum N_i}{i} = E[N] = n\left(1 - \frac{\Delta T_p}{T_{p2}}\right) \Leftrightarrow \\ &\frac{\sum N_i}{i} \approx n\left(1 - \frac{\Delta T_p}{T_{p2}}\right) = n\frac{f_2}{f_1} \end{aligned} \tag{9}$$

where i is a large number of samples of the random variable N, i.e., the number of windows we have used. Hence,

$$\frac{\sum N_i}{i} \approx n\left(1 - \frac{\Delta T_p}{T_{p2}}\right) \Leftrightarrow \Delta T_p = \left(1 - \frac{\sum N_i}{i \cdot n}\right) T_{p2} \tag{10}$$

where $\Delta T_p = \frac{1}{f_2} - \frac{1}{f_1}$

$$\frac{f_1 - f_2}{f_1 f_2} = \left(1 - \frac{\sum N_i}{i \cdot n}\right)\frac{1}{f_2} \tag{11}$$

For a large number of samples and taking into account expression (9):

$$-\Delta f = f_1\left(1 - \frac{\sum N_i}{i \cdot n}\right) = f_1\left(1 - \frac{f_2}{f_1}\right) = f_1 - f_2 \tag{12}$$

These expressions are valid for any frequency increment.

$$f_2 = \frac{\sum N_i}{i \cdot n} f_1 \tag{13}$$

where n is the count value obtained for a frequency f_1 (nondelay case).

3. SYSTEM EVALUATION

To evaluate the proposed system, the block diagram of Figure 3 is employed for simulation using Matlab. Results have been obtained using Simunlink, replacing optical channel with different time delays. To achieve valid results, a total count time of 1 s has been selected (100,000 samples of random variable N). The trigger generator follows different patterns for the "start of count signal." For the nondelay case, the number of pulses obtained for each period is 20, regardless of the employed pattern. Figure 4 shows the total count versus delay between transmitted and received signals.

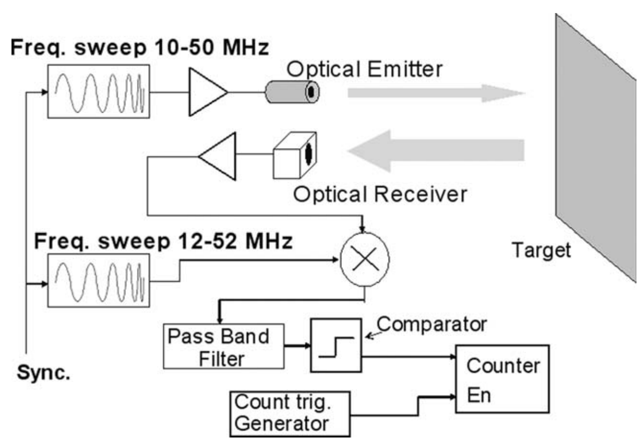

Figure 3 Proposed system block diagram

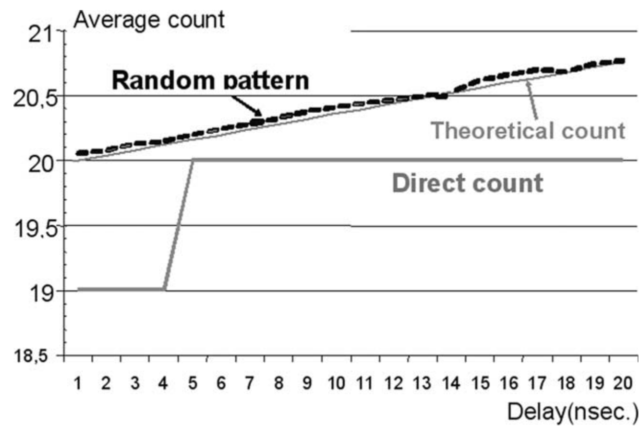

Figure 4 Simulations results for different patterns versus delay

Simulation shown in Figure 4 corresponds to 2000 different positions for the count window, chosen by means of a pseudorandom pattern. As it can be seen, system resolution results highly improved using the pseudorandom pattern.

System performance has been also evaluated employing an arbitrary waveform generator (AWG 520) and a programmable logic circuit using the block diagram shown in Figure 3. To achieve synchronization between the counter and both chirp signals, a ''Start of count signal'' is needed. Circuits corresponding to pseudorandom generation, counter, and synchronism have been implemented using an EPLD programmable device. Figure 5 shows the signals obtained at the scope.

Frequency measurement, using the scope counter, shows a substantial improvement in system resolution compared with the same measurements performed without count window movement.

4. CONCLUSIONS

In this work, we have developed a new low-cost technique for the beat signal frequency measurements in FMCW systems. This technique is suitable for its use in any frequency modulated based radar system, where exact frequency measurement is needed. The proposed system does not need any complex signal process for frequency calculation as in other radar systems. On the other hand, low power requirements and reduced dimensions of the system make it appropriate for portable mobile devices.

We have also test the system for different window movement patterns (lineal, random, and pseudorandom patterns). We have result that convergence time using random and pseudorandom patterns are similar and both better than using linear pattern.

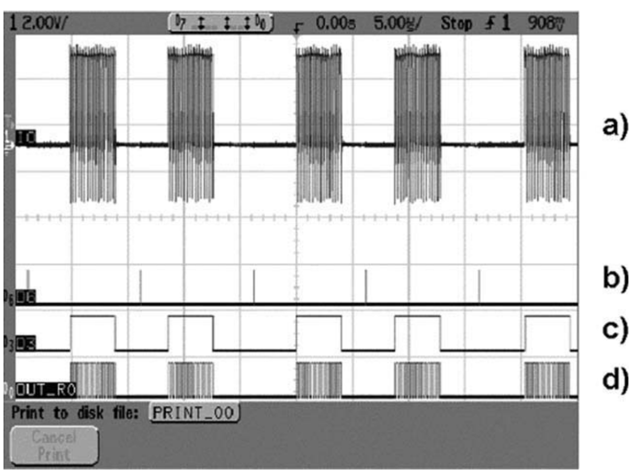

Figure 5 Scope waveforms. a) Beat signal, b) Synchronism signal (Sweep start), c) Counter enabled, d) Pulses at the counter input

REFERENCES

1. D.K. Barton, CW and doppler radar, Norwood/Artech House, Massachusetts, 1978.
2. I.V. Komarov and S.M. Smolskiy, Fundamentals of short-range FM radar, Artech House Radar Library, Norwood, MA.
3. A.V. Jelalian, Laser radar systems, Artech House, Boston, London, 1992.
4. Y. Tokieda, H. Sugawara, S. Niimura, and T. Fujise, High precision waterlevel gauge with an FMCW radar under limited bandwidth, Japan Radio Co., Ltd., Tokyo, Japan.
5. D.G.C. Luck, Frequency modulated radar, McGraw-Hill, New York, 1949.
6. F. Delgado, J. Rufo, J.F. López Hernández, R. Pérez, and J.A. Rabadán, Técnica de Mejora de la Resolución en Sistemas FMCW. Ventana de Cuenta Deslizante, XXI Simpósium Nacional de la Unión Científica Internacional de Radio URSI 2006.

DUAL AND TRIPLE BAND PATCH ANTENNAS FED BY MEANDERING PROBE

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ABSTRACT: *The technique of using U-slots to design dual/triple band patch antennas is applied to patch antennas fed by meandering (M) probes. It is found that the advantage of the M-probe, namely, low cross polarization, is preserved by the use of pairs of face-to-face U-slots.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1498–1504, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25245

Key words: *patch antenna; meandering probe; dual band; triple band*

1. INTRODUCTION

The L-probe fed patch antenna shown in Figure 1 is a popular broadband patch antenna [1]. For air substrate of thickness about

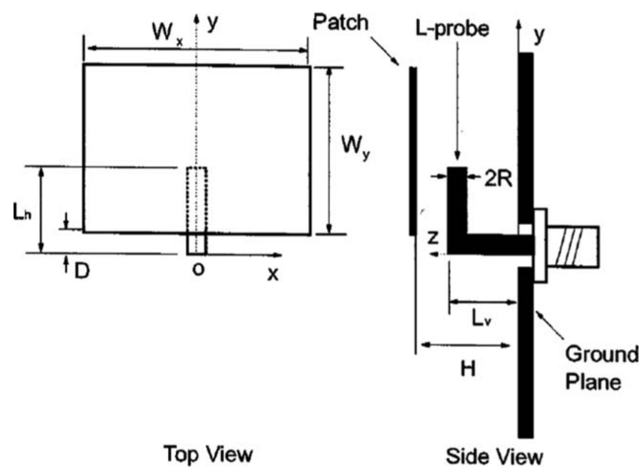

Figure 1 The L-probe fed patch antenna