Low-Cost, Programmable, and Accurate Differential Chopping Controller using Digital Signal Processor

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Abstract

This work presents a mixer that receives two signals at different frequencies and produces in its output a signal representing the difference between the frequencies or the sum of the frequencies. Unlike analog circuits that are limited in their ability to separate frequencies and their functionality. A DSP-based digital circuit is presented with excellent separation capability. Since software is used to calculate the output function, the output signal is almost unlimited.

Keywords: Differential Chopper;

**Introduction**

A lock-in amplifier is a type of amplifier that can extract a signal with a known carrier wave from a noisy environment[[1]](#endnote-3), and signals up to six orders smaller than noise components, potentially fairly close in frequency, can still be reliably detected by using the amplifier. Whereas traditional lock-in amplifiers use frequency mixers and RC filters for the demodulation, state-of-the-art instruments have both steps implemented by fast digital signal processors (DSPs) or field programmable gate array (FPGAs). Recovering signals at low signal-to-noise ratios requires a strong, clean reference signal with the same frequency as the received signal. In essence, a lock-in amplifier takes the input signal and multiplies it by the reference signal and then integrates the result over a specified time which is usually on the order of milliseconds to a few seconds. The resulting integration is a DC signal, where the contribution from any signal that is not at the same frequency as the reference signal is attenuated close to zero. The out-of-phase component of the signal that has the same frequency as the reference signal is also attenuated, making a lock-in a phase-sensitive detector. To achieve high sensitivity in a measurement, the reference frequency must be as close as possible to the excitation frequency.

In complex measurements involving nonlinear effects and several interactions, e.g., optical pump terahertz probe spectroscopy[[2]](#endnote-4), there are two reference sources when each source is modulated in its own unique frequency. Suppose that we have an interaction that is modulated in two different frequencies ω1 and ω2. The time dependence of the interaction is Sin(ω1t)\*Sin(ω2t), which is proportional to [Sin[(ω1-ω2)t] - Sin[(ω1+ω2)t]. In order to measure the combined effect of both sources, the frequency difference of the two sources is used as a reference for the lock-in amplifier. Consequently, the two sources are multiplied, and the product is filtered by a low-pass filter (LPF). In cases where the sum and the difference of the frequencies are close in their values, it is difficult to perform the filtering adequately, especially if an analog filter is used. Current DSPs provide a completely different approach to the implementation of the required circuit. By using a DSP, the frequencies of the two sources can be measured, and then a new signal with the required frequency that is a general function of the two sources can be synthesized.

Figure 1 is a block diagram of the electronic circuit. The heart of the circuit is an advanced, Texas Instruments[[3]](#endnote-5) TMS320F28335 150 MHz DSC (There is a 200 MHz model). This controller, in addition to the 512 KB of Flash memory for programming and 68 KB of SRAM for data, has a floating point unit (FPU) and a wide range of peripheral units (16 channels of fast ADC, UART, SPI, TIMERS, I2C, PWM, eCAP and more). To implement the synthesizer by DSC, a 32-bit counters timer device, two 32-bit capture devices, and a 32-bit PWM device are needed. In addition, this architecture uses the TIMER0 module as a 32-bit counters timer, the eCAP3 and eCAP4 modules as 32-bit capture devices, and the eCAP5 module (APWM mode) as a generator. The enhanced capture (eCAP) module is essential in systems where accurate timing or external event is important. Features for capture module include the following:

•Speed measurements of rotating machinery (for example, optical chopper).

•Elapsed time measurements between position sensor pulses.

•Period and duty cycle measurements of pulse train signals.

Figure 2 describes the eCAP module architecture in capture mode. In this mode, the value of the 32-bit counter, which runs free at 150 MHz, is captured in four registers, CAP1–CAP4, at each rising edge of the signal in ECAP pin. The eCAP module was configured to work in DELTA mode, meaning that the registers capture the difference value of the counter. By doing this, the registers (CAP1 - CAP4) captured the inputs wave period at a resolution of 6.7 nanoseconds (1/150MHz). Using the wave period of the two inputs signals, the frequency difference (or any other function) of them was also calculated. This calculation was calculated every 10 milliseconds, which was the time determined by TIMER0. In order to avoid sharp jumps in the produced frequency, the frequency difference was constantly averaged. The averaging method used was a first-order Infinite impulse response (IIR) with a time constant of 0.05. Once the average frequency difference was obtained, the wave periods of the output signals were calculated. To produce the output signal, the eCAP5 module was used in APWM mode using the CAP3 register to determine the period time and the CAP4 register to determine the duty cycle. In our system, the duty cycle is always 50%, so CAP4 = 0.5\*CAP3. Figure 3 shows the C language code that initializes the eCAP modules and produces the signal with different frequencies.

In our system, the input signals come from two optical choppers operating at 500 Hz and 3331/3 Hz, respectively, when the two frequencies are derived from a laser that operates at 1 kHz. The mechanical mechanism in our system requires that the output frequency is synchronized in phase with the inputs. This synchronization is achieved by using the eCAP3 module interrupt handler to reset the eCAP5 counter in every 24th pulse. The USB block is then used to connect the system to the PC. The communication channel was then used to determine the desired phase and the output function. The three transistors Q1–Q3 are used to adjust voltage levels between the system and the processor, and in this configuration, the input voltages can be up to 50 volts, and the output is a standard 5V TTL level.

The Code Composer Studio 6.2 (CCS) 3 environment and ANSI C language were used for the writing of the embedded program (assembly or C++ were also optional). The circuit can be realized on TI's evaluation board - TMDSDOCK28335 Experimenter Kit (150$ at Digikey). Figure 4 shows our controller that is built on the previously mentioned EVB. In our implementation, GPIO9 was used as IN1 (ECAP3), GPIO11 was used as IN2 (ECAP4) and GPIO3 was used as OUT (ECAP5).

To characterize and demonstrate the performance of the controller, several tests were conducted using the testing application. On the first test, the two frequencies from the optical chopper, 500.00 Hz and 333.33 Hz, were supplied at the inputs. Using the Keysight 53220A universal frequency counter, the frequency was measured at the outputs. Figure 5A shows that the output frequency is 166.666 Hz. To test the performance under more stringent conditions, two signals from the Tektronix AFG3022G dual channel pulse generator, 500.00 Hz and 1.00 Hz, were supplied at the inputs. Figure 5B shows that the output frequency in differential mode is 499.000 Hz, and Figure 5C shows that the output frequency in adding mode is 501.000 Hz. Such separation cannot be performed by any analog filter.

In conclusion, a low-cost, programmable, and accurate differential chopping controller using DSP has been demonstrated. This design can be used by all systems that require a new signal be processed from two known signals.

**Figure Captions**

Fig. 1: Electronic circuit block diagram.

Fig. 2: eCAP module architecture in capture mode.

Fig. 3: C language code that initializes the eCAP modules and produces the different frequency signals.

Fig. 4: The controller that is built on the TMDSDOCK28335 Experimenter Kit

Fig. 5: a) The output frequencies in the differential mode when the inputs are 500.00 Hz and 333.33 Hz. b) The output frequencies in the differential mode when the inputs are 500.00 Hz and 490.00 Hz. c) The output frequencies in the adding mode when the inputs are 500.00 Hz and 490.00 Hz.

References

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3. . Texas Instruments: http://www.ti.com [↑](#endnote-ref-5)