DSP Research Project: DSP Function Generator

I. DSP device requirements

You will design and construct a basic DSP function generator with the base specifications listed below. Any improvements on these specifications are welcome, but not necessary.

Analog Output Signals

The function generator will have two analog function outputs (see part II: Theory of Operation for additional details).

Number of independent analog outputs: 2

Functions: sinusoid, triangle wave, and square wave.

Output frequency: 0 to 100 kHz.

Frequency stability (0° C to 50° C): 100 ppm or better.

Amplitudes (AC): 0 to 5 V (adjustable).

Amplitude resolution: equivalent to 8-bit or better.

DC offsets: -5 V to +5 V (adjustable).

Phase control of output 2 with respect to output 1: 0 to 360° with a resolution of at least 3.6°. You must be able to shift the phase by exactly 90°. The phase must be stable to better than 1% of its resolution.

Spurious 2nd harmonic: -20 dB (i.e. 100 times smaller than the main output) or less.

Output impedance: 50 Ω.

TTL Output

The function generator will have a single TTL output which has the frequency of output 1 and is at a fixed phase with respect to output signal 1.

Output impedance: standard TTL output impedance.

Inputs

The function generator will have a single input for an optional external clock, which can be used instead of the internal clock.

Input impedance: standard TTL input impedance.

II. Theory of Operation

The function generator is similar in operation to the one you use in the electronics lab with two important exceptions;

1. Two phase-locked analog outputs: The function generator outputs two signals of the same frequency but with a different phase between them. In other words, one of the two signals is delayed with respect to the other. Implementing a stable phase delay is difficult with analog circuitry, but relatively simple on an FPGA. This feature can be improved with little effort (not necessary for project) to include the option of outputting the second signal at an integer multiple of the frequency of the first signal.

2. External clock input: While your DSP function generator should have an internal clock for its operations, it should also include the option of using an external clock. This feature becomes useful if you want to operate several similar function generators with the same clock: when done carefully, the outputs of the independent function generators will be phase-locked.

III. Why would anybody want a function generator with two phase coherent outputs?

A dual output function generator is often used for producing rotating fields. Here are a few two examples:

1. Rotating magnetic fields and TOP traps: One can generate a rotating magnetic field with two pairs of identical coils, which are arranged perpendicularly to each other. Each coil pair is driven by a current which generates a magnetic field. Both of these magnetic fields are equal and perpendicular to each other. If the two current are sinusoid but 90° out of phase, then the resulting total magnetic field will be of constant magnitude, but with a rotating direction. This type of rotating magnetic field was used to generate a special type of magnetic trap called a Time Orbiting Potential Trap, or TOP trap. A TOP trap was used to generate the first Bose-Einstein condensates of ultra-cold atoms with $T_c \approx 10\text{-}100$ nK in 1995.

2. Circularly polarized electro-magnetic waves: An oscillating electric or magnetic dipole will generate linearly polarized electromagnetic waves. One way of generating circularly polarized electromagnetic waves is to use two oscillating dipoles perpendicular to each other but 90° out of phase. The circularly polarization means that the direction of the electric and magnetic fields rotate around the propagation axis as the wave travels. Circularly polarized electromagnetic waves carry angular momentum as well as linear momentum.

3. Phased-array radar: You have probably seen the big parabolic dish radar antennas at airports that constantly rotate around searching for aircraft. An alternative to these large cumbersome mechanical devices is the phased-array radar antenna which consists of many tiny antennas arranged in a 2-d array. Each mini antenna generates electromagnetic radiation at the same frequency but slightly out of phase from its neighbor. The array of mini-antennas produces a narrow beam of electromagnetic radiation whose direction is determined by the phase gradient, in much the same way that Bragg reflection of X-rays in crystals works. With this technology, you can direct the radar search beam in any direction by adjusting the phase gradient electronically: there is no longer any need for cumbersome mechanical rotation, so one can point the radar beam very quickly and accurately. Modern fighter aircraft use phased-array radars to rapidly scan the sky for other aircraft and quickly pin point their locations.