Excitation signals for ultrasonic testing

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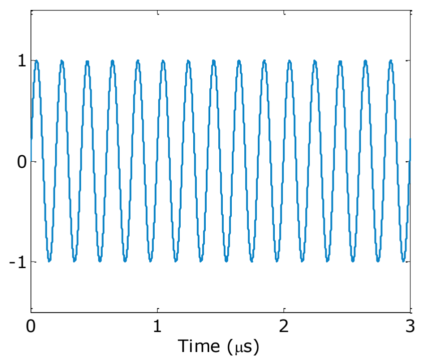
Introduction:

Experiments involving wave propagation are often based on a simple scheme including a wave source, a sample under test and a receiving transducer. One of the decisions that the designer should take is the type of excitation signal emitted by the source. The choice of a specific signal will impact on the complexity of the measurement process, the required equipment and the quality of the results. This note explains some considerations that should be taken into account when choosing the excitation signal. Different types of signals are discussed, showing their advantages and drawbacks and providing some guidelines about environments and equipment where specific signals are more appropriate.

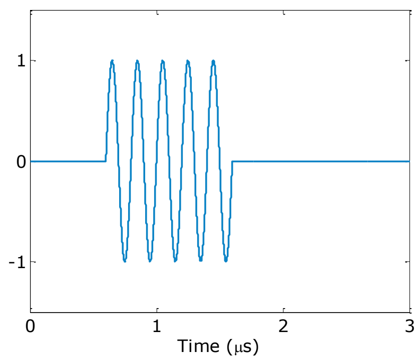
Continuous wave vs pulsed operation:

Continuous operation is based on signals that are not turned off during the measurement procedure. The signal is easily obtainable with a function generator and the processing of the measured data is in principle simple. Since the wave is not turned off, the measurement of times of flight and phases is not obvious, although they could be obtained.

Continuous operation is required in some standardized measures where the excitation is based on noise. In other cases, it is only recommended when a simple experimental setup is intended in environments where wave reflections are not an issue (like anechoic chambers). Note that continuous operation involves the measurement of the sample as well as the surrounding environment, so this type of excitation is discouraged in places where reflections of the waves can occur.

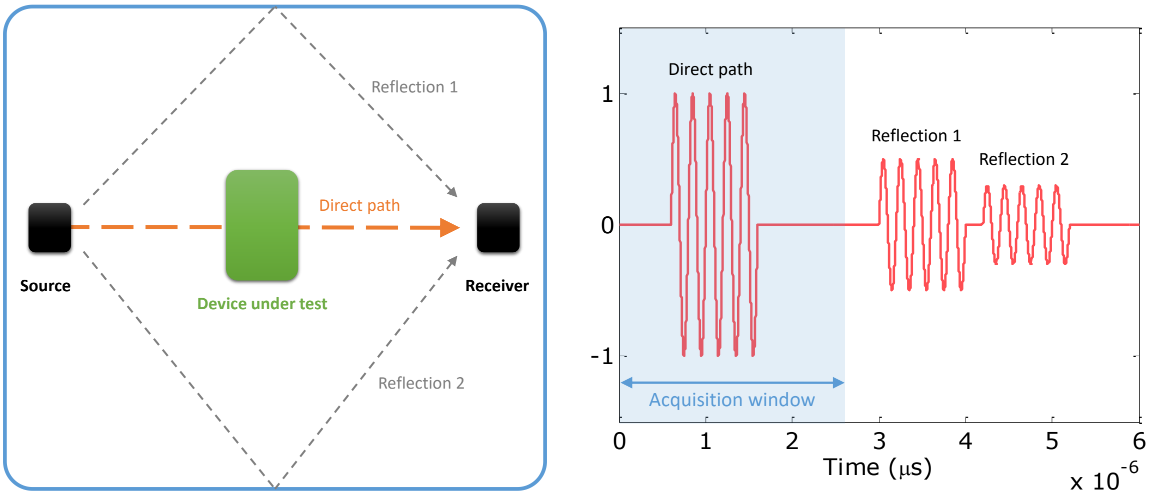


Example of continuous signal: Sine wave



Example of pulsed signal: Tone burst

Pulsed operation consists of sending a short signal and then disable the excitation during a specific time. In this manner the interaction between the wave and the sample can be acquired before the unwanted echoes of the surrounding space arrive to the receiving transducer. This process allows to measure a sample in places where unwanted reflections take place. In addition, times of flight and phases are easily obtainable. Pulsed operation is required in experimental setups scanning a given space (for instance 2D maps) where the receiving transducer acquires the field in several points.

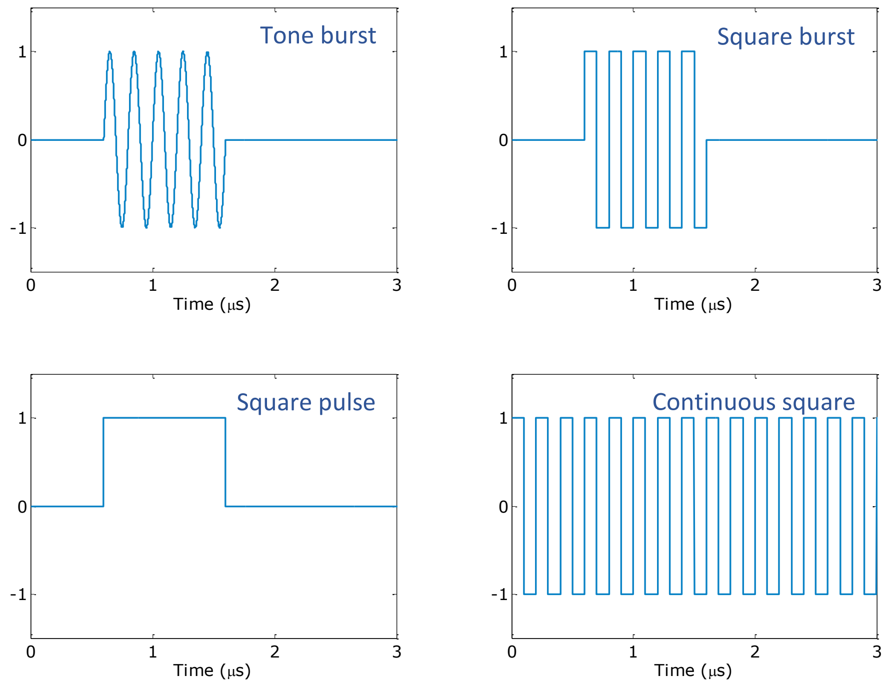


Pulsed operation requires a measurement software capable of discriminating the unwanted echoes that do not come from the sample under test. However, this excitation paves the way for high quality measures that provide excellent results even in non-anechoic environments.

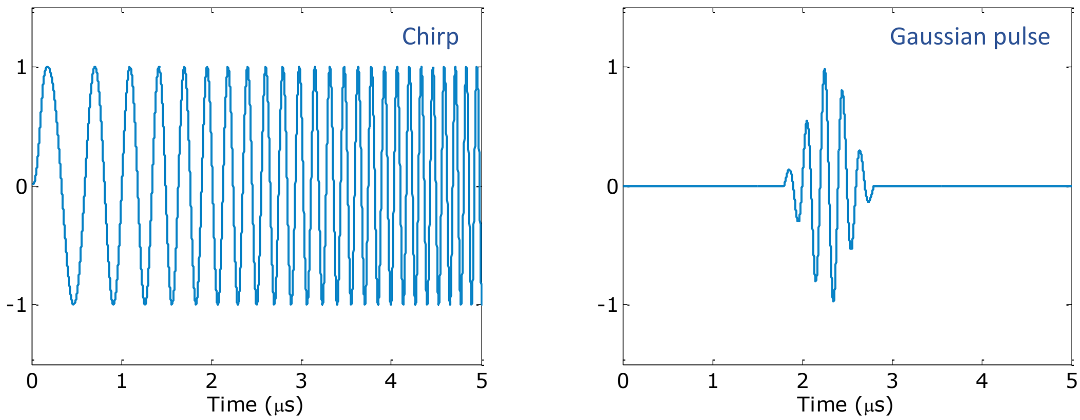
Some amplifiers cannot deliver full power all time due to heating issues. Their output is limited to a maximum time between inactive periods, defining a maximum duty cycle. In these cases, pulsed operation is unavoidable unless a device capable of deliver the required power in continuous mode is employed.

Analog signals vs square waveforms:

In most applications it is required an amplifier to drive the emitter transducer with acceptable levels of power. Power amplifiers can operate in several ways depending on their specific design. For instance, some cheap models simply switch their output from ground to a high but fixed level since the electronic associated to this type of operation is simpler. These devices provide waves based on one or several square pulses. Note that the usage of square pulses may not be recommended in some experiments because of its high content of harmonics. The figure below some examples of square waveforms compared to a tone burst signal:

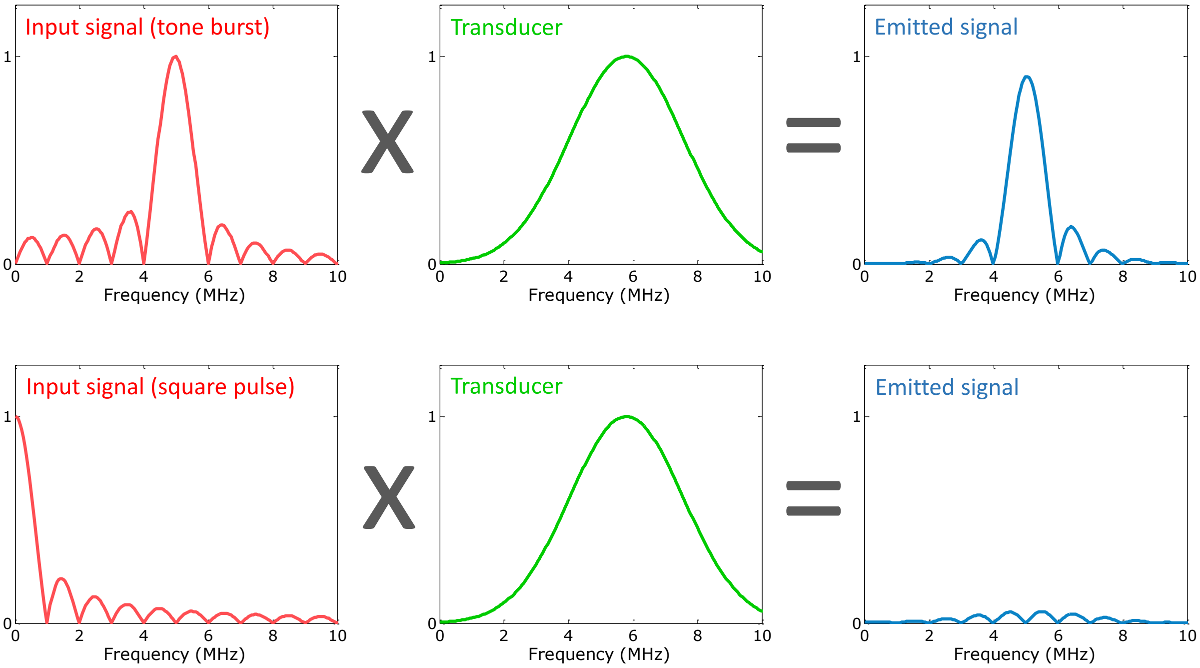


On the other hand, linear amplifiers can amplify signals with any shape. This not only includes sine waves or tone bursts but also noise or more complex waveforms like chirps, Gaussian pulses and other arbitrary signals. The precise control of the emitted waveform allows to efficiently distribute the energy along the target spectrum and analyze broad ranges of frequencies, as will be shown in the next sections. Moreover, complex measurement procedures like the characterization of non-linearities through the Farina method requires specific analog signals that can be only obtained with linear amplifiers.



Frequency response of transducers:

The spectrum of the emitted signal is defined by the product of the spectrum of the electronically synthetized signal and the frequency response of the transducer that converts the electronic signal into a propagating wave. Because of this, an efficient excitation should have a spectrum whose components are located at the same frequencies as the transducer. This is especially important for transducers with narrow band operation such as piezoelectric actuators. The figure below shows two examples of how signals are filtered by a transducer with a Gaussian-like spectrum. The first case represents an efficient excitation, while the second one has a spectrum mismatched with that of the transducer, resulting in a low level emitted signal.



As shown, an appropriate control of the input signal will result in a more efficient excitation. Some devices (especially those delivering single pulses) can offer high amounts of power, although this power is not conveniently exploited since most of the energy is located outside the bandwidth of the transducer. On the other hand, analog signals can be accurately controlled and transfer higher amounts of power to the transducers, even requiring lower power ratings.

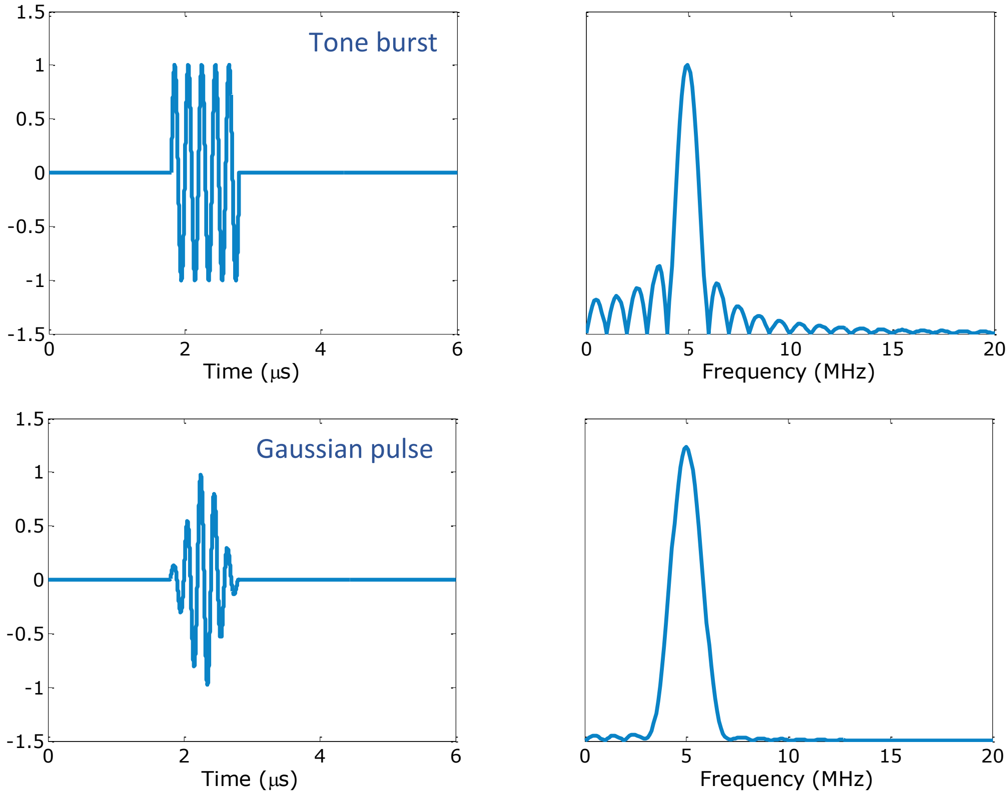
Bandwidth of scan:

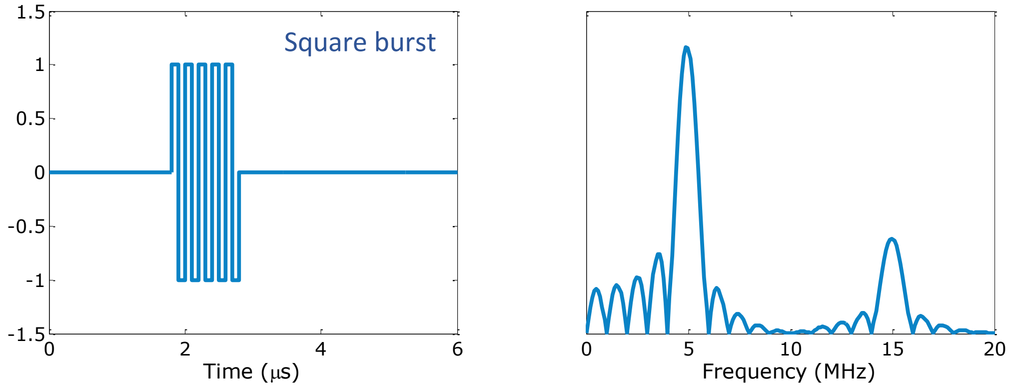
There are two different ways to measure a given range of frequencies:

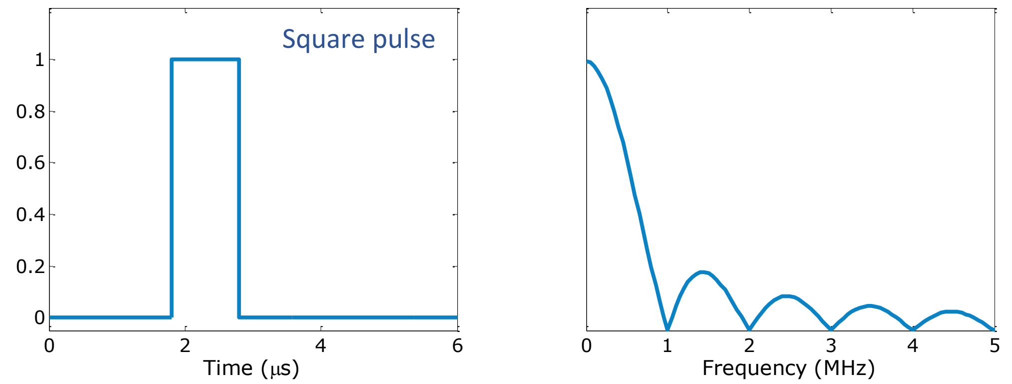
- A pass-band signal (tone burst, train of pulses, pure tone, etc.) is emitted to characterize the sample at a single frequency. The same process is repeated for each target frequency. This sweep has advantages such as the concentration of the energy in a specific frequency at each step, although it results in a slow measurement procedure.
- Apply a broadband signal that covers the frequency range to be measured. Pulses with sharp transitions can be here considered, although their frequency response is poorly controlled, and it is inefficiently distributed. The most advantageous choice is the usage of broadband analog signals like white noise or more complex analog waveforms such as chirps.

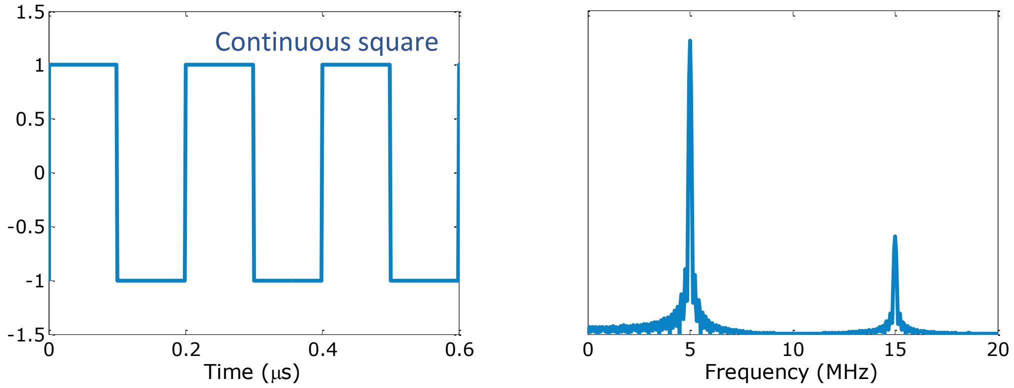
Examples:

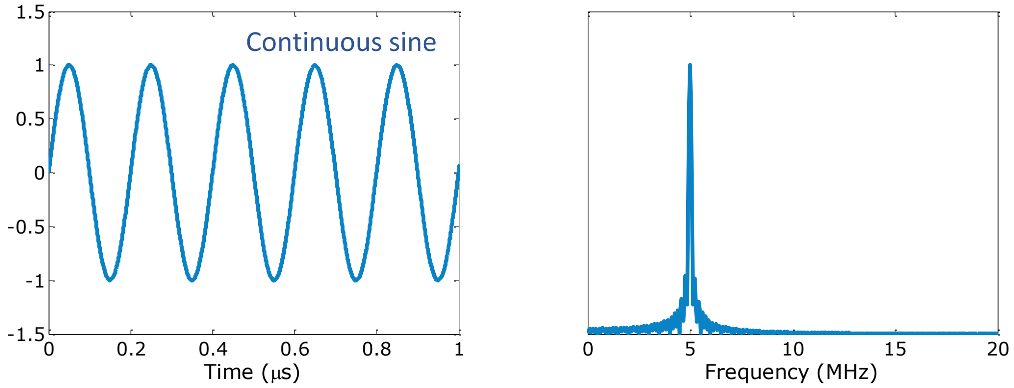
The figures below show the time and frequency response of the most common excitation signals:

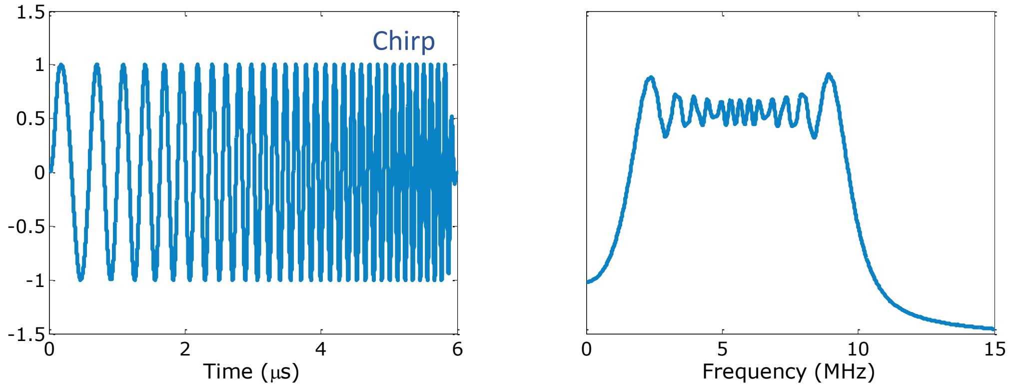



Square burst
1.5
1
0.5
0
-0.5
-1
-1.5
0
2
4
6
Time (μs)
0
5
10
15
20
Frequency (MHz)


Square pulse
1
0.8
0.6
0.4
0.2
0
0
2
4
6
Time (μs)
0
1
2
3
4
5
Frequency (MHz)


Continuous square
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.2
0.4
0.6
Time (μs)
0
5
10
15
20
Frequency (MHz)


Continuous sine
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.2
0.4
0.6
0.8
1
Time (μs)
0
5
10
15
20
Frequency (MHz)



Conclusion:

The waveform employed as excitation in an experiment has a significant impact on the quality of the results obtained. It will also determine the required equipment and the complexity of the measurement system. Because of this, the choice of the waveform should be done by considering the specific conditions of the tests. The presence of unwanted reflections in the experimental setup, the bandwidth of the transducers and the bandwidth intended to measure are factors that must be here considered. The type of signal selected will define the required power amplifier, linear amplifiers being the most versatile devices since they can work with any type of signal.

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