Radartutorial

Book 7: “Intrapulse Modulation”

This educational endowment is a printable summary of all topics about “Intrapulse Modulation” of the internet representation “Radar Basics” on www.radartutorial.eu , containing a lecture on the principles of radar technology.

Note: This book is an edited and thematically slightly extended excerpt from the book number 4.
If book 7 is used, then you don't need the pages 12,13 and 14 (pulse compression) of the book 4.

Table of Contents

Learning Objectives:

This chapter describes the the so called “chirp radars”. At the end of this chapter the student should be able to:

- know the terms “Intra Pulse Modulation” and “Pulse Compression”;
- note the advantages and disadvantages of the pulse compression;
- know the different kinds of modulation;
- describe the pulse shape of a linear frequency modulated and a symmetric or non-symmetric non-linear frequency-modulated transmitting pulse;
- know the terms “SAW filter”, “amplitude weighting” and “time side lobes” and can assign them to the various modulation techniques in which they have a special significance.

Intrapulse Modulation and Pulse Compression

Pulse compression is a generic term that is used to describe a waveshaping process that is produced as a propagating waveform is modified by the electrical network properties of the transmission line. The pulse is internally modulated in phase or in frequency, which provides a method to further resolve targets which may have overlapping returns (so called **Intrapulse Modulation**). Pulse compression originated with the desire to amplify the transmitted impulse (peak) power by temporal compression. It is a method which combines the high energy of a long pulse width with the high resolution of a short pulse width. The pulse structures are shown in figure 1.

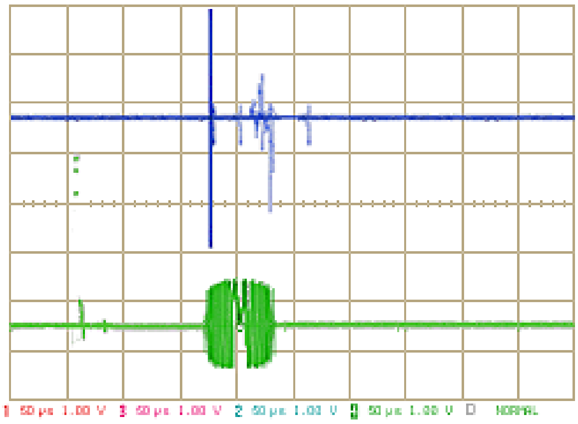

Figure 1: short pulse (blue) of a classic pulsed radar and a long pulse with intrapulse modulation (green channel)

Pulse radar sets of the older keyed on/off modulated type require a high pulse power to achieve the desired range. At the same time the transmission pulse should be as short as possible, because this parameter affects the range resolution. These radars must are able to generate and radiate the total transmit power in just a few micro- or even nanoseconds. For this task have been developed powerful modulator and transmitter vacuum tubes.

In semiconductor technology built high-power transmitters (transmitter in solid-state technology) are not able to produce such high-power pulses due to their limited dielectric strength and its limited working temperature. To radiate the same transmission energy, the transmitting pulse of this radar must therefore be much longer.

In order to improve range resolution of a radar pulse having a relatively large transmitting pulse duration, the pulse is modulated internally. Since each part of the pulse has unique frequency, these returns can be completely separated and integrated into a shorter single output pulse. The echo signal is therefore compressed in its pulse duration in special filters. The procedure for this is called pulse compression. Now it is possible to perform a localization of targets within the transmitted and now received pulse. In pulse compression, the energetic advantages of very long pulses with the benefits of very short pulses are combined. Through the necessary modulation self-oscillating channels can not perform this procedure.

The noise in the receiver is always broadband with a random distribution. The frequency synchronous amount of the received noise is rather low compared to the echo signal. The amount of noise is greatly reduced by the pulse compression filter therefore. Thus, by the pulse compression can be achieved even then an output signal when the input signal is smaller than the noise floor and would be lost for a simple diode demodulation.

Disadvantage of this method is, however, that the minimum measuring distance from the most monostatic radars is very deteriorated. As long as the transmitter is operating, simply nothing can be received because the duplexer locks the receiver during this time. The echo before the pulse compression filter is about as long as the transmitting pulse. It must be received in its entire length, to generate a target character. This decreases from the perspective of the duration of the receiving time calculated unambiguous maximum range.

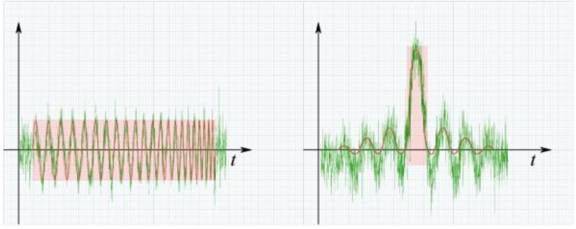

Figure 2: Input signal of a pulse compression filter (linear frequency modulation), and its output signal.

Advantages	Disadvantages
lower possible pulse-power	high wiring effort
higher maximum range	larger radars “blind range”
good range resolution	Time-Sidelobes
better jamming immunity	
difficulter reconnaissance	

This modulation or coding can be either:

- FM (chirp radar) with;
    - linear or
    - non-linear,
        - symetrically or
        - non-symetrically frequency modulation;
    - time-frequency-coded waveform (e.g. Costas code)
- PM (phase modulation) using Barker or Frank code.

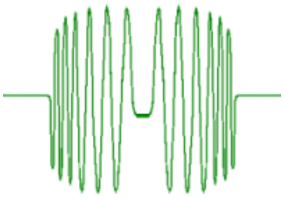

Figure 3: Symmetrical transmitting pulse with intra pulse modulation at the output of waveform generator

Pulse compression with linear FM waveform

In this method, the transmitting pulse is frequency modulated linearly. This has the advantage that the wiring can still be kept relatively simple. However, the linear frequency modulation has the disadvantage that relatively easily interference can be generated by so-called “sweeper”.

Functional principle of pulse compression

In the following example the principle of operation is illustrated by five present in the transmitting pulse different frequencies.

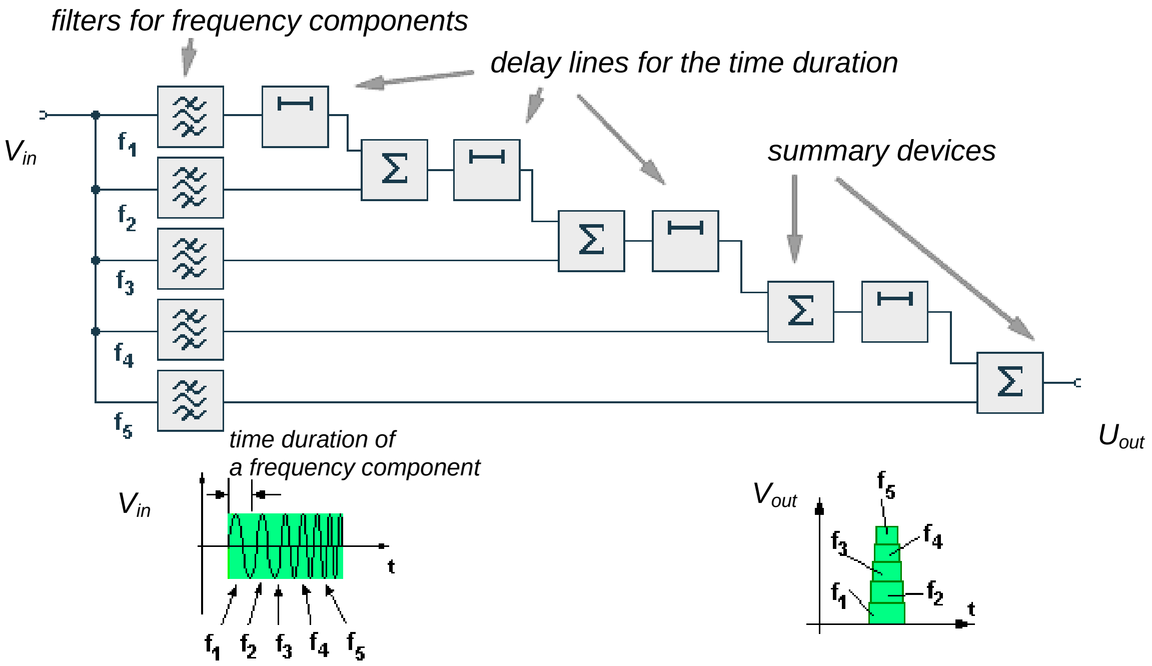

Figure 4: Block diagram of a pulse compression filter

The compression filter are simply dispersive delay lines with a delay, which is a linear function of the frequency. The compression filter allows the end of the pulse to “catch up” to the beginning, and produces a narrower output pulse with a higher amplitude.

As an example of an application of the pulse compression with linear FM waveform can be mentioned the air-defence radar AN/FPS–117.

The high circuit complexity is entirely manageable with today's chip integration ability. Filters for linear FM pulse compression radars are now based on two main types.:

- processor-controlled data processing (after A / D conversion)
- using analogue **SAW**- filters (**S**urface **A**coustic **W**ave devices).

In a processor-controlled data processing, the echo pulse will be distributed initially to lot of memory cells. The processor must also detect this exact memory pattern when in this memory area are superimposed several echo signals.

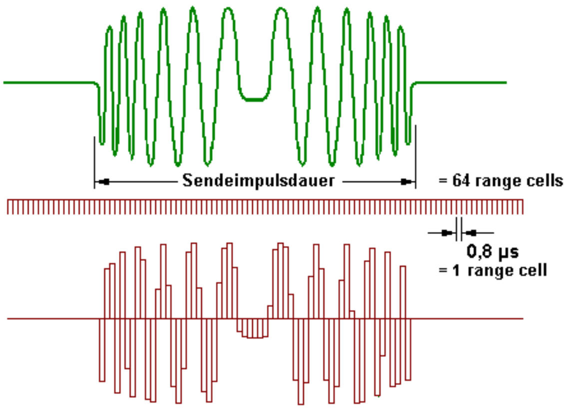

Figure 5: the echo pulse is distributed in the memory in a lot of memory cells.

SAW Filter

The SAW filter compress the frequency-modulated echo signal according to an analogous manner. They work on the piezoelectric principle.

A broadband transducer is vapour-deposited on a piezoelectric crystal, which converts the electrical oscillations into mechanical vibrations in this crystal. However, these mechanical vibrations spread out with much smaller speed than the electrical signals on a line itself. Therefore, relatively high delay times are achieved (in range of microseconds). On the same crystal is deposited a serie of frequency-dependent transducers, which convert the mechanical oscillations back into electrical signals.

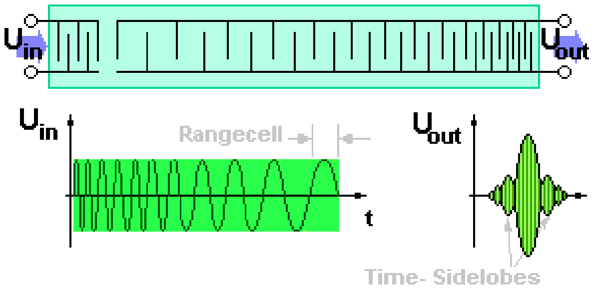

Figure 6: Schematic of a SAW filter with linearly decreasing finger spacing

Due to the different spacing of these various transducers to the feeding system, the different frequency components of the input signal get a different time delay, so that all frequency components of the input signal are shifted in the same range cell. The structure shown in the image is used primarily in a linear frequency modulation. The finger spacing determines the exact resonant frequency. The first frequency in the pulse (left) needs the largest delay. The vapor-deposited on the piezoelectric crystal fingers with precisely this frequency are thus located at the opposite end of the feed.

Time Side Lobes

However, since the frequency-dependent transducers (like any filter!) can also be excited by harmonics, unfortunately arise disturbing sidelobes in addition to the sharp output pulse. These are known as **time** or **range sidelobes**, and have to be compensated by cumbersome procedures often..

These time side lobes are unwanted signals that have an offset from the real target impulse in time (that is, in the distance). The Figure 7 shows these unwanted signals that are shown once as a function of time (on the oscilloscope) and once as a function of distance (on a sector of a PPI-scope).

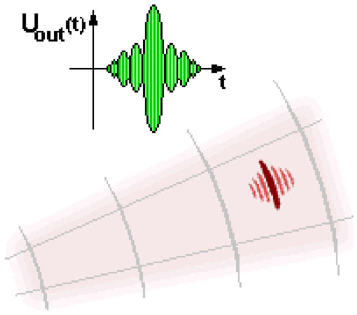

Figure 7: View of the time side lobes: on an oscilloscope and as an analog video on a PPI-screen.

Since both the time intervals and the amplitudes of the time side lobes are constant, these sidelobes can be reduced to an acceptable value with a weighting of the signal amplitudes. If this amplitude weighting is made only on the receive path, but it also causes a deterioration of the filter and reduces the signal-to-noise ratio.

The size of these time side lobes are an important parameter of radar sets using intra pulse modulation and pulse compression and can be lowered by this amplitude weighting to a value in the range of -30 dB. The amplitude weighting is possible with processor controlled signal processing or with a hardware arithmetic logic.

Pulse compression with non-linear frequency modulation

The pulse compression with non-linear frequency modulation has several distinct advantages. E.g. it doesn't need a weighting for the suppression of time side lobes, because the function of the amplitude weighting is achieved by the shape of the non-linear modulation.

It is now possible a filter adjustment with steeper edges by nevertheless low time side lobes. In this way the losses in the signal-to-noise ratio can be avoided that would otherwise occur by the amplitude weighting.

The disadvantages of the pulse compression with non-linear frequency modulation are:

- a more complicated circuit construction, and
- a complex waveform, so that every transmitting pulse gets the same characteristics in compliance with the aforementioned function of the amplitude weighting.

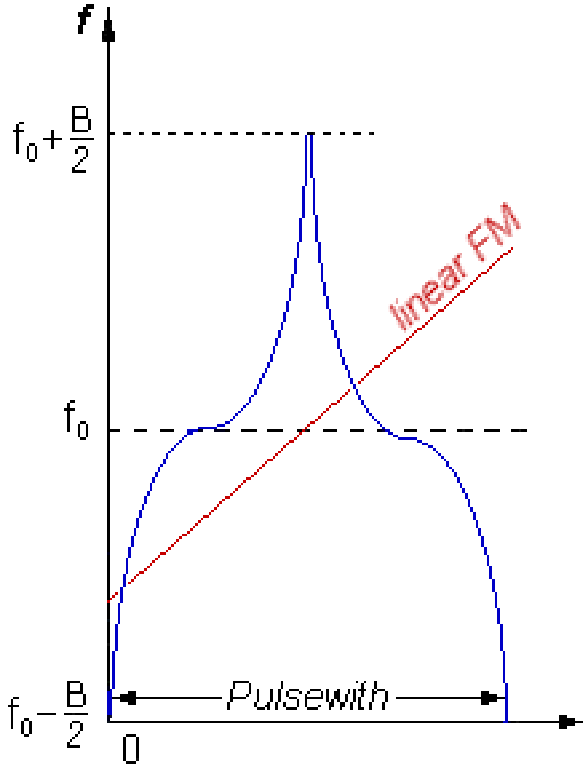

Figure 8: symmetrical shape

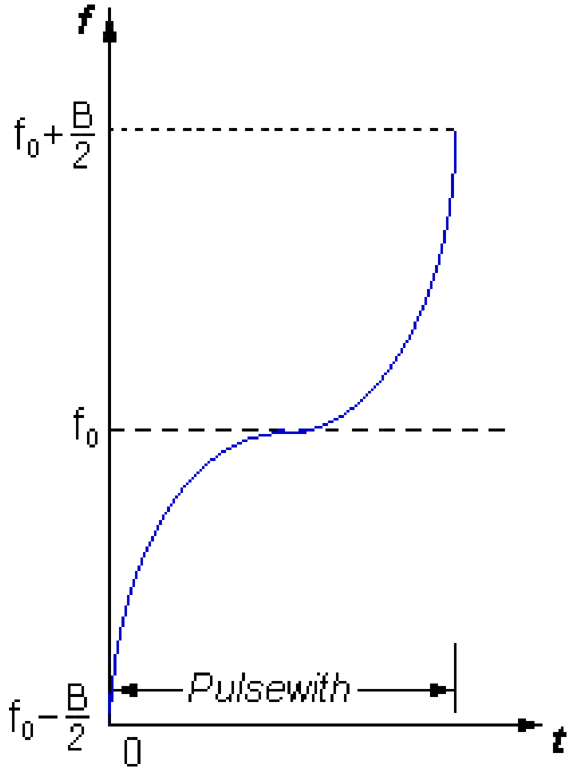

Figure 8: non-symmetrical shape

The symmetrical shape of the modulation uses during the first half of the transmission pulse period a rising (or falling) frequency change, and the in the second half of a falling (or rising now) frequency change. When it is used e.g. only a half of the symmetrical form then obtained a non-symmetrical form of modulation.

Pulse compression by phase modulation

Phase-coded waveforms differ from FM waveforms in that the long pulse is sub-divided into a number of shorter sub pulses. Generally, each sub pulse corresponds with a range bin. The sub pulses are of equal time duration; each is transmitted with a particular phase. The phase of each sub-pulse is selected in accordance with a phase code. The most widely used type of phase coding is binary coding.

The binary code consists of a sequence of either +1 and -1. The phase of the transmitted signal alternates between 0 and 180° in accordance with the sequence of elements, in the phase code, as shown on the figure. Since the transmitted frequency is usually not a multiple of the reciprocal of the sub pulsewidth, the coded signal is generally discontinuous at the phase-reversal points.

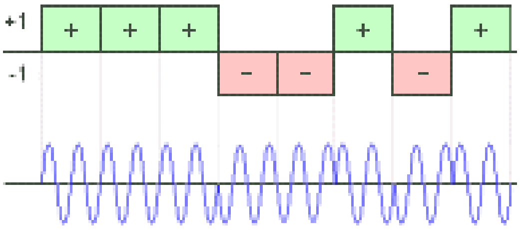

Figure 10: Diagram of phase coded transmitter pulse (here using 8 code elements)

Barker Code

Barker Code is a special class of optimal binary phase-shift keying (BPSK). The selection of the so called random 0 and π phases is in fact critical. They are optimum in the sense that they provide low sidelobes, which are all of equal magnitude. Only a small number of these optimum codes exist. They are shown on the table. A computer based study searched for Barker codes up to 6000 combinations, and obtained only 13 as the maximum value.

It will be noted that there are no larger codes than these 13 which implies a maximum compression ratio of 13, and which is rather low. The maximun time side lobe level is -22.3 db.

Length of the Barker code	Code elements	time side lobe level
2	+-	-6.0 dB
3	++-	-9.5 dB
4	++-+ und +++-	-12.0 dB
5	+++-+	-14.0 dB
7	+++--+-	-16.9 dB
11	+++---++--+-	-20.8 dB
13	+++++--++-+-+	**-22.3** dB

Table 1: Selected Barker codes for pulse compression with phase modulation

Figure 11: The quite elderly AN/TPS-43 took advantage of pulse compression by phase modulation with the length of 13 codes

Radar sets using intra pulse modulation much more difficult to discover. To achieve its maximum range, they require less transmitter power, and its transmission pulse disappears rather in the noise floor than by conventional radars. In this very small signal levels a reconnaissance tool can discover them only when the modulation type and the pulse pattern are well known. Therefore, these radars are also known to as “silent radars”.

Frank Code

The Frank Code is a polyphase code modulation format developed for pulse compression. It use harmonically related phases which are based on certain fundamental phase increments (e.g. for quadrature phase-shift keying, QPSK).

Training questions

Please respond these specific questions about pulse compression. The reasonable time to frame the answers is about 10 minutes. You can use pocket calculator, but the chosen here numerical examples are optimized to perform with mental arithmetic.

(Remember: the questions can have more than one correct answer.)

1. The transmitting pulse using intra pulse modulation has an overall duration of 60 microseconds and is compressed on the receive path to 1 microsecond. A single range cell is 150 m therefore. What is the minimum detection range (“blind range”) of the radar using this waveform?

   ☐ 150 Meters
   ☐ 9000 Meters
   ☐ larger than 9000 Meters

2. The air defense radar AN / FPS-117 uses two different transmitter pulses with a duration of 100 microseconds and 800 microseconds. What restrictions result from this for the minimum and maximum theoretical range of the radar?

   ☐ The maximum unambiguous range is calculated from the receiving time minus 800 microseconds.
   ☐ The receiving time is calculated to 800 µs - 100 µs = 700 µs.
   ☐ The minimum range is determined by the pulse duration of 100 µs.

3. What kind of radars can use the intra pulse modulation and pulse compression?

   ☐ Continuous wave radars with Doppler technology
   ☐ Pulse radar sets
   ☐ Non-coherent radar sets
   ☐ Coherent on receive radar sets
   ☐ Fully coherent radar sets