ROYAL SCHOOL OF ARTILLERY

BASIC SCIENCE & TECHNOLOGY SECTION

Pulse Compression Radar

INTRODUCTION

The pulse length or pulse duration of a radar is the time that the radar takes to transmit the outgoing pulse. This may be between about 0.1 µs and 10 µs, depending on the radar. However, the value chosen has implications on the performance of the radar and some of these are mutually exclusive. For most radars, a short pulse is required to give good range resolution whereas a long pulse is required to give good noise levels, high energy, long range, resistance to jamming, reduced peak power and better Doppler performance.

However, good range resolution is important to enable target tracking, to distinguish between the target and interference such as clutter, rain and chaff. Also, good range resolution enables targets such as groups of adjacent aircraft to be separated into individual craft. Choosing a very short transmitted pulse will achieve good range resolution but will significantly degrade the performance of the radar in other ways.

Fortunately, it is not the the duration of the transmitted pulse that determines the range resolution, but the duration of the pulse that is used in the receiver. Pulse compression techniques are based on the concept that the transmitter can apply a special modulation to a long, outgoing pulse that allows the receiver to process the pulse to reduce its effective length. In this way the radar can achieve high performance in all areas.

RANGE RESOLUTION

The standard formula gives range resolution as being 150 m for each micro-second of pulse duration.

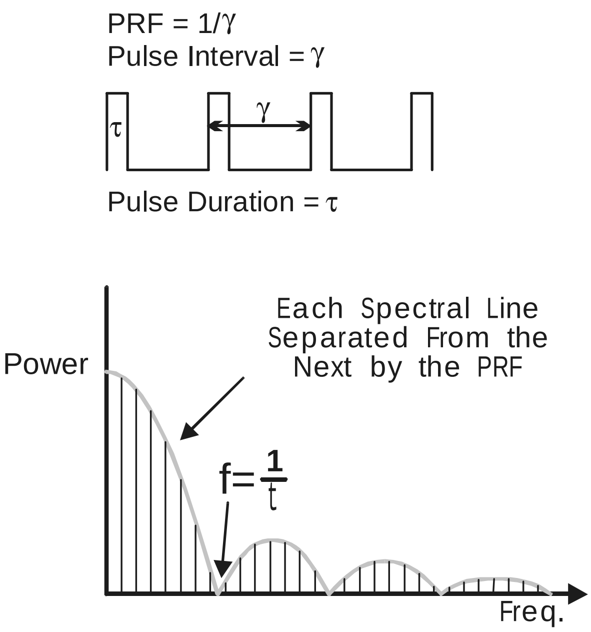

Figure 1: Spectrum of a Pulse-Train

Some doppler radars have pulses of around 10 µs and this would give them a resolution of 1.5 km. They would not be able to distinguish between two targets separated by 1 km, for example. Reducing the pulse length would widen the bandwidth of the transmitted energy and increase the number of harmonics. This would adversely affect the doppler processing.

Furthermore, if a pulse of duration 5 µs and power 10 kW is to be reduced to 2.5 µs then its power must be raised to 20 kW to maintain the same amount of energy in the pulse. This might be beyond the ability of the magnetron (etc.) to provide and, because the electric field in the wave will increase, might also cause arcing within the the transmitter, waveguide or antenna.

The problem, then, is that we might need a pulse of less than 0.5 µs for good range resolution but a pulse of more than 5 µs for the other factors mentioned above. One solution is to use pulse compression - this allows us to get the best of both worlds..

FREQUENCY-CODED PULSE COMPRESSION

The harmonic content of the pulse used to modulate a radar wave is dealt with in another handout (Radar Transmitters). The spectrum of the basic modulating signal is shown in Figure One. It consists of a large number of harmonics.The radar waveform, shown at the top of Figure One is, clearly, not a sine-wave - it is a rectangular wave (not a square wave because the duty-cycle is not 50%).

A mathematical analysis of this rectangular waveform (called a 'pulse-train') reveals that it consists of a large number of sine-waves (harmonics). The harmonics are a series of frequencies, each being a whole-number multiple of the PRF of the pulse-train. For example, if the PRF were 5 kHz then the harmonics would be: Zero Hz (dc), 5 kHz, 10 kHz, 15 kHz, 20 kHz, etc. The list of harmonics is infinite but the amplitude of a harmonic generally reduces with frequency and, beyond a specified limit, the higher harmonics can be ignored. There is a zero harmonic (dc) in this waveform as this represents the average value of the waveform. The average value can be calculated by multiplying the peak value (e.g. 10 V) by the duty cycle (e.g. 8%) to get the average value (e.g. 0.8 V)

The amplitude of the harmonics reduces with frequency in a complex way, as indicated in Figure One. However, there is a 'null' at the harmonic whose frequency is $1/\tau$, where 'τ' is the Pulse Duration. This means that, for example, when the pulse duration is 4 µs then the harmonic at 250 kHz is of zero amplitude (i.e. there isn't a harmonic of 250 kHz). Harmonics beyond this point are generally ignored as they are fairly small in amplitude.

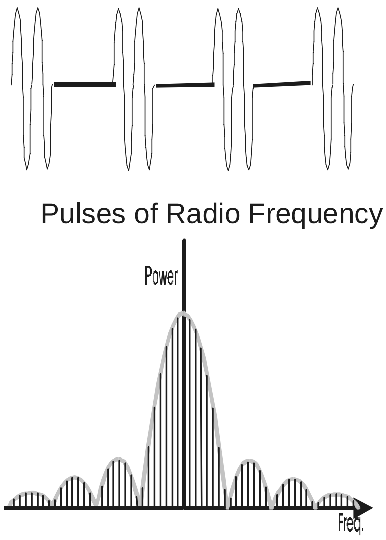

Figure 2: Spectrum of a Carrier Wave Amplitude-Modulated by the Same Pulse-Train

When this pulse is used to modulate the amplitude of a radio carrier wave in the radar transmitter then, as a result of the modulation process, upper and lower side-bands are formed, each of which contains these harmonics, as shown in Figure Two. The central point on the waveform is the carrier frequency of the radar (e.g. 3 GHz) and the harmonics are spread out either side at intervals equal to the PRF. For example, using the values quoted, above, for a PRF of 5 kHz and carrier frqeuency of 3 GHz, the harmonics shown in Figure Two would be 3 GHz, 3.000 005 GHz, 3.000 010 GHz, etc. and 2.999 995 GHz, 2.999 990 Ghz, etc.

The spread of harmonics, either side of the carrier frequency, is governed by the pulse duration. For the example figure of 5 µs, the spread of frequencies is 200 kHz, or ±100 kHz from the centre. Thus, the lowest useful harmonic would be 2.999 9 GHz and the highest would be 3.000 1 GHz and there would be 21 useable harmonics.

When an ordinary short pulse is transmitted then all the harmonics are sent simultaneously to give the short pulse of very high intensity (peak power). The harmonics are not generated individually - it is the process of making a pulse of radar signal that produces the harmonics. Only a single, steady sine-wave - of intinite duration - consists of a single harmonic. All other signals, no matter how they were produced, are comprised of a mixture of harmonics. Clearly, the radar signal is not

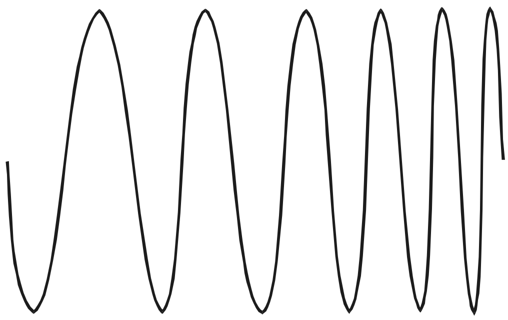

Figure 3: a 'Chirped' Pulse

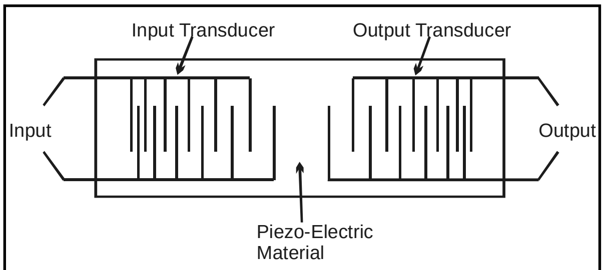

Figure 4: SAW Dispersive Line

a single, steady sine-wave so it naturally contains many harmonics.

When pulse compression is used then the harmonics are separated and sent in sequence, over a longer period of time and, therefore, at a much lower level. The energy in the pulse is the same - but it is now a pulse that lasts for a longer time, at a lower energy level. Typically, sending the harmonics over ten times the time will produce a pulse of one-tenth the intensity.

At the receiver, the various harmonics are re-assembled to generate the original short, high-intensity pulse. The actual pulse that the radar transmits is illustrated in Figure Three. (But note that the amount of frequency change is exaggerated to make it more noticeable.) The frequency of the pulse rises from low to high during the pulse (typically, in about 5 µs) and the pulse is called a 'chirp' because, if you could hear it, it would sound like a bird call. The pulse may also start at the higher frequency and fall in frequency during the chirp - in that case the pulse would be a mirror image of the one shown in Figure Three.

SURFACE ACOUSTIC WAVE DEVICE

The key device, that separates the harmonics in the transmitter and re-assembles them in the receiver, is a Surface Wave Acoustic device (SAW). (The device may be also called a dispersive delay line or a dispersive equaliser.)

This device, which is normally used in matched pairs in pulse-compression radars, is made from a piezo-electric material such as quartz. When this type of material is subjected to an electric field then it responds by changing size. Conversely, if the material changes shape (e.g. it is bent) then an emf is produced. If the material is struck sharply then enough voltage can be produced to cause a spark - and this is used in many gas appliances to ignite the gas. It can also be used in a microphone where the sound pressure causes the piezo-electric material to change shape.

The basic construction of the SAW device is shown in Figure Four. The input transducer consists of a large number of metal 'fingers' that have been evaporated

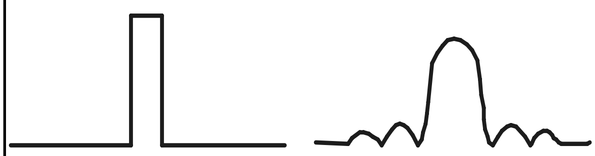

Figure 5: Re-constituted Pulse, with Side-lobes

onto a quartz substrate. (A bit like a printed circuit.) The fingers interlock and the spacing gets wider towards the middle of the device. The output transducer is a mirror-image of the input transducer.

When a very short pulse of radio frequency energy is applied to the input transducer then an electric field is created between the fingers of the input transducer. The short pulse will have a spectrum of frequencies (see Figure Two) and its higher frequencies will cause the quartz to resonate where the spacing between the fingers is narrow whilst the lower frequencies will cause resonance at the wider spaced fingers. The effect of this resonance will be to make a surface compression wave on the quartz crystal. The resonance occurs where the spacing between the fingers is one half of the wavelength of the surface acoustic wave, so the device must be chosen to match the frequencies that are to be used.

This wave has many of the features of a sound wave, although it is far above the frequencies that the human ear can detect. The wave propagates towards the output transducer at the speed of sound in quartz.

At the output transducer, the lowest frequencies will arrive first, because they have a shorter distance to travel. These waves cause resonance where the fingers of the output transducer are close together and an emf is produced. The higher frequency waves arrive later and resonate farther along the output transducer.

Thus, the many frequencies that made up the very short pulse are now stretched out over a much longer period of time. This new waveform is then used as the outgoing radar wave. The wave might be up-converted to produce the final output from the radar transmitter as this will normally be at a much higher frequency than can be used in the SAW. (Up-conversion is a form of processing of a signal so that its frequency is increased, without losing any of the modulated information.)

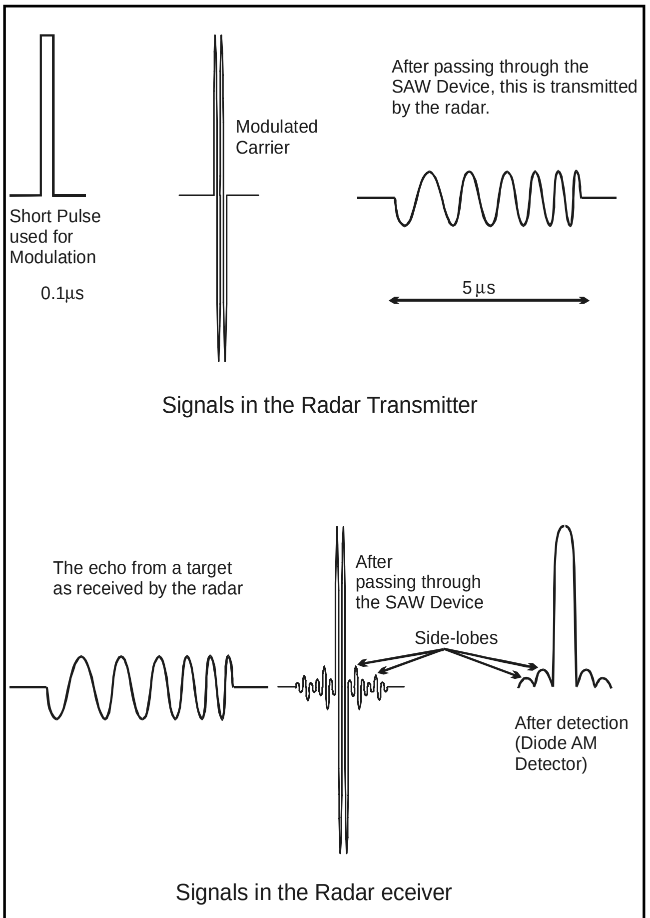

Figure 6: Complete Set of Waveforms

PERFORMANCE IN PRACTISE

The various harmonics that make up the stretched wave are transmitted by the radar and return as an echo. To regenerate the very short pulse needed for range resolution, the harmonics must be put through another SAW device whose properties are the exact opposite of the device used in the transmitter. This is because the harmonics must be re-assembled in the correct phase and amplitude.

However, not all the harmonics are normally used - just those from the central peak of the spectrum (to save bandwidth). The end result is that the re-constituted pulse is not an exact replica of the original - it has a number of little pulses before and after called ‘side-lobes’. This is illustrated in Figure Five. Poor joints in waveguides and cables, through which these signals pass in the radar system, can quite easily cause small changes to some harmonics (e.g. those whose wavelength is related to the size of the gap in the faulty joint). The effect of these changes is to make the side-lobes bigger - this is significant since they could either be mistaken for real targets close to the main target or mask small targets adjacent to larger ones.

Pulse compression reduces the effects of noise and jamming because these signals are essentially random and so, when fed through the SAW device, they do not build into a short, high-intensity pulse. They are just as likely to cancel each other as to re-inforce each other; whereas the components of the real pulse will all re-inforce each other and build into a very intense pulse.

Performance can be improved by varying the spacing of the ‘fingers’ in the SAW device so that the rate of change of frequency in the chirp is more rapid at the beginning and end of the pulse. This is equivalent to using tapered illumination in antennae. Side-lobes can be kept to about 30 - 40 dB below the main peak of the compressed pulse and compressions by a factor of one or two hundred can be achieved. An alternative is to construct the fingers with less overlap between the fingers at the ends of the transducers so that there is less power at either end of the frequency sweep and more in the middle frequencies.

The complete set of waveforms is shown in Figure Six. In this example, a pulse of duration 0.1 µs has been expanded by a factor 50 to 5µs. As the energy remains the same then the power in the wave will have reduced by the same factor. The amplitude will have reduced by a factor $\sqrt{50}$ since power depends on the square of the amplitude of the wave. In practice, due to losses in the SAW device, the output amplitude will be much less than this. (To make the diagram of Figure Six readable, smaller factors have been applied to the waveforms shown. It should also be noted that, at a frequency of 1 GHz, there will be around one hundred cycles of oscillation in the compressed pulse and many more in the

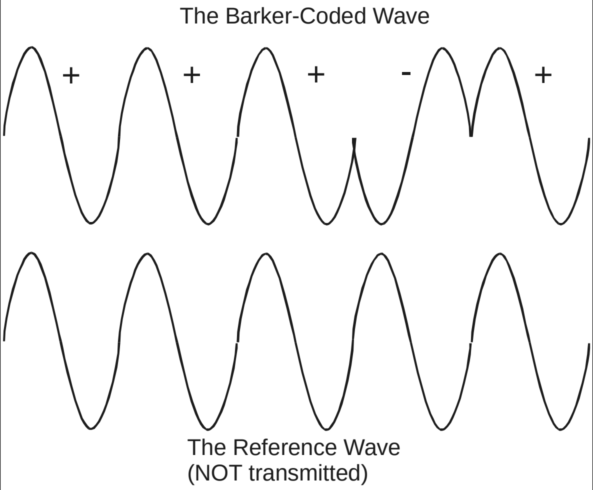

Figure 7: An Example of a Barker-Coded Wave

expanded pulse. The diagram shows far fewer than in order to make visible the individual cycles of oscillation.)

AMOUNT OF FREQUENCY SWEEP

The range of frequencies (or sweep-bandwidth, B) that must be swept through in the chirped pulse is determined from the desired length (τ) of the compressed pulse and is given by the formula B = 1/τ. In the above example, the compressed pulse was of duration 0.1 μs so the sweep bandwidth would be 10 MHz. Using a carrier frequency of 1 GHz then the transmitter's output might sweep from 1.005 GHz to 0.995 GHz.

It is a general rule that a pulse of duration τ has a bandwidth of no less than 1/τ (if a pulse is chirped or encoded then the bandwidth will be greater thatn this). It is also true to say that a pulse of bandwidth B can be compressed to occupy a time no less that 1/B. The SAW device can be used to expand a short pulse into a longer pulse, but some radar oscillators can generate the necessary changes in frequency directly, without using the SAW, by changing some parameter (e.g. a capacitance) in the circuits that generate the microwave signals.

ALTERNATIVE COMPRESSION TECHNIQUE

The SAW device provides a fixed translation between the compressed and uncompressed pulses. This cannot easily be varied, for example, to increase immunity to counter-measures, except by switching-in different SAW devices. An alternative means of compression applies a coded signal to the transmitted pulse and the received echo is compressed when the same code is applied to it in the receiver. One set of codes, called Barker Codes, have the property that the side-lobes are equal and symmetrical about the centre of the compressed pulse. Other codes consist of various arrangements, based on sequences of random binary numbers.

There is only a limited number of known Barker Codes (of length 1, 3, 5 , etc. to 15 elements), but an unlimited number of random, binary codes that can be used. The Barker Codes are much shorter than the binary codes for the same amount of compression.

The codes are used to switch the phase of the transmitted signal between a number of different states. In the example that follows, the there are two phases: zero and 180^{o}. Some codes use four phases and, although the processing is more complex, their basic operation is similar. The compression factor for a Barker Code is equal to the number of elements in the code (equals the number of changes of phase in the radar pulse).

Using a five-digit Barker Code as an example, the following paragraphs will show how a pulse is coded in the transmitter and compressed in the receiver. The code used is + + + - +, where '+' stands for in-phase with the reference and '-' means in anti-phase with the reference. The elements of the code are often referred to as 'chips' so that this is an example of a five-chip code.

The Barker Code is applied in the transmitter to produce a pulse with a waveform like that in Figure Seven.

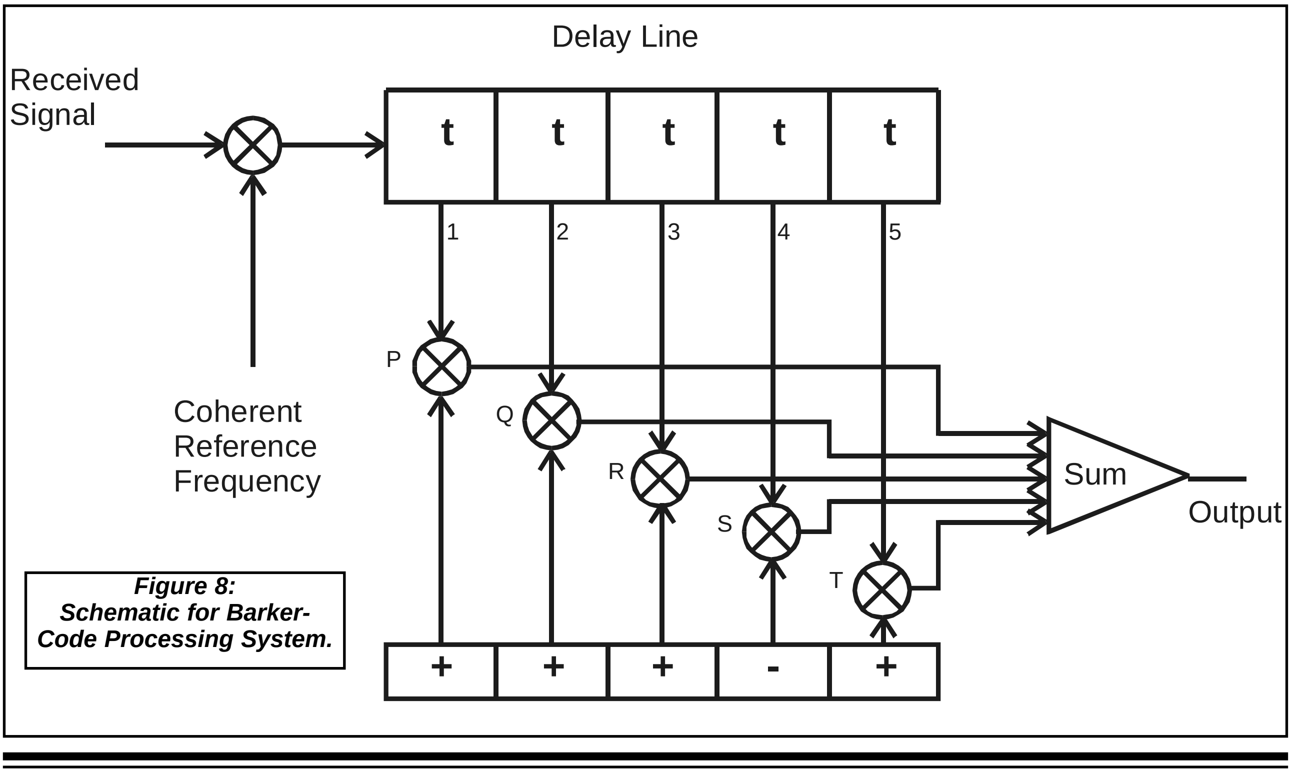

Figure 8: Schematic for Barker-Code Processing System.

Note that only one cycle of each phase is shown for simplicity. In practise, there would be many cycles at each phase. This is the only action that the transmitter needs to take. (There is no expansion of an original pulse as with the SAW.) One important feature of this system is the requirement for a coherent local oscillator (COHO) that will be used by the receiver for the decoding of the received pulses.

DECODING THE BARKER WAVE

The received echo is mixed with the COHO to extract the phase information and the resulting output signal is fed into a delay line with five taps. The time taken to pass along the delay line is equal to the duration of the transmitted radar pulse (e.g. 5 µs.) and the taps are equally-spaced along the line to give delays of 0.5, 1.5, 2.5, 3.5 and 4.5 µs. The output from each tap goes to a multiplier which multiplies the signal by either +1 or -1 - in the same pattern that was used when the Barker Code was applied in the transmitter. Finally, the five multiplied signals are added together to give the output pulse. This is illustrated in Figure Eight. The process is, essentially, one of comparison between the code carried by the echo signal and the code that was transmitted (this can also be called 'correlation'). If the two codes match then when they are multiplied together in the receiver then the output is large. If the two codes differ then the output is small

When the received echo is fed into the delay line, after mixing with the COHO to reduce its frequency, the signal will pass into the delay line. For this example, let us assume that the echo has an amplitude of one, a duration of 5 µs and is comprised of the five-digit, Barker Code '+ + + - +'. As the signal passes along the delay line then it will take 5 µs to enter the line and a further 4 µs to exit. During those 9 µs, which is 2N-1 element lengths, the signals will be as follows:

- **Time = 1 µs**: the first code element is in the line at tap number one. The multiplier 'P' has inputs +1 and +1, giving an output of +1. All other multipliers have a zero input from their delay line taps. The input to the summing amplifier is +1 and the output is +1 (assuming a gain of 1).
- **Time = 2 µs**: the signal has moved further into the delay line so that the first code element is at tap two and the second is at tap 1. Multiplier 'Q' has input +1 and +1, multiplier 'P' has inputs -1 and +1. All other multipliers have a zero input. The input to the summing amplifier is -1 and +1, which is a sum of zero, so there is no output.
- Subsequent times follow the same pattern and the outputs of the multipliers are listed in Table One.

Time	P	Q	R	S	T	Total
0 µs	0	0	0	0	0	0
1 µs	+1	0	0	0	0	1
2 µs	-1	+1	0	0	0	0
3 µs	+1	-1	+1	0	0	+1
4 µs	+1	+1	-1	-1	0	0
5 µs	+1	+1	+1	+1	+1	+5
6 µs	0	+1	+1	-1	-1	0
7 µs	0	0	+1	-1	+1	+1
8 µs	0	0	0	-1	+1	0
9 µs	0	0	0	0	+1	+1
10 µs	0	0	0	0	0	0

Table 1: Compressing a Barker Coded Pulse

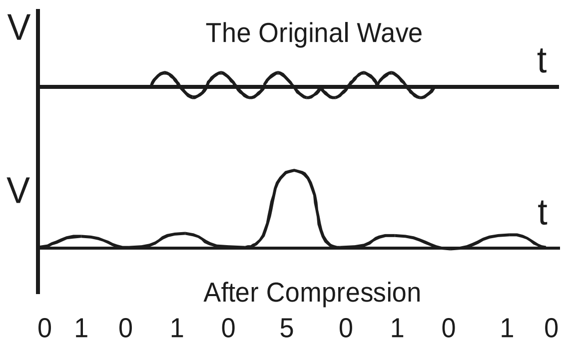

Figure 9: Comparison of Phase-Coded Pulse and its Compressed Version

Note how the output from the system is greatest when the whole code in is the delay line (indicated by an underline). The height of the central peak is five (equal to the number of elements in the code) and its duration equals the duration of one element of the code. The minor peaks, of height one, are side-lobes. Figure Nine shows this graphically.

The Barker Code of length Five has been chosen for illustration so that the computations can be carried out manually. For the longer codes that are used in practice, similar result will be obtained so that, for example, a code sequence of length thirteen elements will give a compressed pulse with a width of one element and a peak height of thirteen. The side-lobes will be of height one. Any noise in the system will also pass through the delay line but, since the noise is random and does not carry the correct code, it will not be magnified by the mulitplication. (In practice, the noise does increase by an amount dependent on the square-root of the number of 'chips' in the code.

OVERLAPPING BARKER CODES

When two targets are sufficiently close together to reflect the phase-coded pulse in such a way that they overlap at the receiver then there is the possibility that two Barker Codes might be in the delay line simultaneously. With a conventional radar, two targets that are closer together in range than the range resolution do not give separate pulses in the receiver - such targets, that might represent two, or more, aeroplanes flying in formation, would be seen as a single target.

For example, for a conventional radar using a pulse length of 5 µs the range resolution is 750 m. When this radar has two targets on the same azimuth that differ in range by 300 m then their two echoes merge into one, with no means of separating them.

When the radar uses phase-coded compression then the two echoes will still arrive back with an overlap and, using the previous example of a five-element Barker Code, the received echo will be the basic code

Time	P	Q	R	S	T	Total
0 µs	0	0	0	0	0	0
1 µs	+1	0	0	0	0	1
2 µs	-1	+1	0	0	0	0
3 µs	+2	-1	+1	0	0	+2
4 µs	0	+2	-1	-1	0	0
5 µs	+2	0	+2	+1	+1	+6
6 µs	+1	+2	0	-2	-1	0
7 µs	+1	+1	+2	0	+2	+6
8 µs	0	+1	+1	-2	0	0
9 µs	0	0	+1	-1	+2	+2
10 µs	0	0	0	-1	+1	0
11µs	0	0	0	0	+1	+1
12 µs	0	0	0	0	0	0

Table 2: Compression of Overlapping Codes

(reflected by the first target) plus a delayed version that is two elements behind (reflected by the second target). The echoes from these two targets will be:

		+1	+1	+1	-1	+1	Tgt A
+1	+1	+1	-1	+1			Tgt B
+1	+1	+2	0	+2	-1	+1	Total

Giving a total length of seven elements to pass through the delay line of Figure Eight. The result is shown in Table Two: the compressed output clearly shown the two peaks - one from each target that a conventional radar would not have been able to resolve.

FEATURES OF PHASE CODED SYSTEMS

For greater compression with Barker Codes, the sequence can be applied twice in succession to the same wave. In this way, using a sequence of length thirteen elements and using this twice on the same wave, it is possible to get a compression ratio of 13^2 or 169 times.

One advantage of these codes is that they can also be applied using a Digital Signal Processor (DSP) chip under computer control to give maximum flexibility in the system.

The process of multiplying the received pattern of phases by the original pattern and then summing the results is called ‘auto-correlation’. It relies on the property of these codes that they have a high degree of autocorrelation and, therefore, give good results using short sequences. To achieve a similar result with a randomly-chosen code might require a sequence ten times as long. It is very difficult to predict which codes will give good results (apart from Barker Codes - but there are only eight known codes) and so computers are used to search for and evaluate many possible codes to find ones that work best.

The noise in the system does not correlate, because it is random in nature. The noise is increased by the compression process, but the amount of increase in the noise power depends on the number of elements in the code whilst the increase in signal power depends on the square of that number. For example, using five elements, the noise power increases by 5 times whilst the signal power increases by 25 times (5^2). In practice, losses in the SAW and noise from other circuits in the radar will result in less noise reduction than that predicted by theory.

GPS SYSTEM

A similar system of codes is used in the GPS System. The satellites do not carry powerful transmitters and, consequently, the signals that GPS receivers pick up are very small. By applying a similar technique to that described for Barker Codes to GPS signals, the receivers can boost the signal strength to usable values. Typically, the GPS signal might be hundreds of times smaller than the noise. The two types of GPS signals are encoded using 1023 chips (acquisition code) and a second code that runs at a chip-rate of 10 MHz for an entire week without repeating.

The technique is also called ‘spread-spectrum’ and is used in many modern communications systems as it offers relative freedom from noise and interference, even when using week signals. Additionally, there is a degree of security because the signals can only be received by applying the same code that was used to transmit them. Unless you know the code then you cannot easily detect the signals - and you certainly cannot decode them. Without the correct code these signals appear to be much smaller than the noise level and are very difficult to detect at all.

SELF TEST QUESTIONS

1. When a radar uses pulse compression then the pulse is actually compressed:

   a. in the radar transmitter.
   b. in the radar receiver.
   c. by the Doppler processing.
   d. by the mixing process of the superhet.

2. A transmitted pulse from a radar has a duration of 4 µs and is compressed by a factor ten in the receiver. The expected range resolution of this radar system, after applying compression, will be:

   a. 600 m.
   b. 6,000 m.
   c. 60 m.
   d. 10 m.

3. When pulse compression is used in a radar then:

   a. maximum range decreases.
   b. transmitted pulses have a shorter duration.
   c. minimum range is not improved.
   d. any radar transmission can be compressed by any radar receiver.

4. A chirped pulse is transmitted from a radar and the echo is to be compressed. To achieve a pulse duration of 0.2 µs ***after*** compression then it will be necessary to:

   a. amplitude modulate the transmitted pulse.
   b. use a sweep bandwidth of 5 MHz.
   c. apply a Barker code in the receiver.
   d. switch-off the receiver 0.2 µs after receiving the echo.

5. When SAW devices are used in a radar system for pulse compression then it is necessary to have:

   a. an SAW device in the transmitter and an identical SAW device in the receiver.
   b. a single SAW device in the receiver only.
   c. a single SAW device in the transmitter only.
   d. an SAW device in the transmitter and matched SAW device, of opposite properties, in the receiver.

6. When a radar system uses pulse compression then it is necessary to:

   a. apply special modulation to the transmitted pulse to prepare it for compression by the receiver.
   b. compress both transmitted and received signals.
   c. compress only the transmitted pulse.
   d. amplitude modulate the received echoes.

7. One disadvantage of using pulse compression in a radar is that it:

   a. decreases maximum range.
   b. decreases minimum range.
   c. reduces transmitter power.
   d. masks small targets adjacent to larger ones.

8. To compress a Barker Coded radar signal the echo is:

   a. multiplied by the original code.
   b. added to the original code.
   c. put through an SAW dispersive filter.
   d. mixed with a chirped wave from the local oscillator.

9. A Barker Code of length seven elements could be used to:

   a. make a chirp with a sweep bandwidth of 7 MHz.
   b. compress a radar echo by a factor seven.
   c. decrease the frequency of a radar echo by a factor seven.
   d. track seven targets simultaneously.

10. When a Barker Code is applied to the pulse from a radar transmitter then it is used to modulate the pulse's:

   a. amplitude.
   b. frequency.
   c. polarisation.
   d. phase.

Answers

1. b	**2. c**	**3. c**	**4. b**	**5. d**
6. a	**7. d**	**8. a**	**9. b**	**10. d**

Teaching Objectives		Comments

H.05.01 Explain the Need for and Benefits of Pulse Compression

H.05.01.01	State that the range resolution is 150 m for each micro-second of pulse.	Need short pulses.
H.05.01.02	State that short pulses are difficult to transmit because they have low energy, high bandwidth, power & electric field.	Need long pulses.
H.05.01.03	State that short pulses cause problems with Doppler processing.	

H.05.02 Describe the Techniques of Frequency Modulated Pulse (Chirp) Compression

H.05.02.01	Describe the frequency spectrum of a modulation envelope and a modulated carrier wave.	All harmonics simultaneously.
H.05.02.02	Relate the ‘chirp’ – sequential harmonics – to the spectrum of the modulated carrier wave.	Sequential harmonics. Include bandwidth and amount of frequency change.
H.05.02.03	Describe the properties of a SAW device (dispersive delay line).	Include diagram
H.05.02.04	Describe how the SAW can be used to reconstitute a pulse from a chirp.	Include waveforms, relate amplitude change to the amount of compression
H.05.02.05	Describe how a matched SAW can be used to generate the chirp.	
H.05.02.06	Describe the limitations of SAW processing and various performance-enhancing methods.	

H.05.03 Describe the Techniques of Phase Coded Pulse Compression

H.05.03.01	State that the phase of the carrier wave is switched according to a pre-determined pattern.	
H.05.03.02	Identify the main features of Barker and pseudo-random techniques.	
H.05.03.04	Relate the phase-coding to the waveform.	
H.05.03.04	Describe how the phase-coded signal is compressed during reception by multiplying the echo by the original code (auto-correlation).	Full description. Can be coded twice, in cascade, to give n^2 compression.
H.05.03.04	Describe how overlapping codes are separated.	

H.05.04 Describe the Advantages and Disadvantages of Pulse Compression

H.05.04.01	Describe how the use of pulse compression reduces the effects of noise on reception.	
H.05.04.02	Describe the effects on minimum range	Not reduced.
H.05.04.03	Describe the effects on range resolution	