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Ramp type frequency modulation pulsed radar, with high range resolution

The present invention concerns ramp-based frequency modulated pulsed radar. It applies notably for the improvement of the range resolution of
5 such radar.

Some radar applications need to analyse the targets. As the range from this target to the radar is known beforehand, by known radar methods, the radar analyses the shape of the target, for example, to determine its
10 nature, number or size. For this purpose, pulsed and ramp-based frequency modulation radar is used. In other terms, inside a pulse, the frequency varies linearly in time from a frequency $f_{\min}$ to a frequency $f_{\max}$.

The radar pulses of duration T are thus frequency modulated according to this modulation law with demodulation by a signal of the same
15 law, triggered at an instant that is close to the instant the pulse returns after reflecting off the target, the range from the target to the radar being known. After this demodulation, a signal is obtained whose frequency is proportional to the distance from the target counted relative to the triggering range of the demodulation ramp. When the target range is extended, we obtain a
20 combination of signals where the frequency and start instant are proportional to the range and the amplitude is proportional to the reflectivity of each target element. In general, as we are interested in targets where the length is small compared with the length of the transmitted pulse, it is possible to filter, sample and narrow band encode the obtained signal. The range profile of a
25 target can then be reconstructed by a spectral analysis of the signal thus sampled. For a target that has several elements at different ranges from the radar, each element reflects a signal of different frequency that is proportional to the element's range. Therefore, we can identify the nature of a target.

30 The obtained range resolution r is inversely proportional to the bandwidth of frequencies transmitted B , where B is equal to $f_{\max} - f_{\min}$. This resolution r is given by the following relationship:

$$r = \alpha \frac{c}{2B} \quad (1)$$

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where c represents the phase velocity of light and α is a coefficient that depends on the type of spectral analysis used. If this analysis is a weighted Fourier transform, α is equal to 1. For a Hamming weighting, α is roughly equal to 1.3 while for a high-resolution analysis, α may be less than 1.

For some applications, this resolution r may be insufficient. The relationship (1) shows that it is limited by the modulation band B . As an example, for conventional radar that are capable of passing a band B equal to 50 MHz in a pulse, the resolution given by relationship (1) is in the order of 3 metres.

It is possible to improve this resolution, i.e. to drop below one metre for example, by passing a band B that is distinctly greater than 50 MHz inside a pulse. However, such a solution is costly and complex to implement. It very significantly complicates the radar's transmission and receiving circuits. Another solution to improve the range resolution could be to use "synthetic band" type techniques by sending several narrow band pulses. Nevertheless, range is determined at the cost of a long exposure time that may be incompatible with some applications, for example panoramic watch applications.

One aim of the invention is to compensate for the aforementioned disadvantages by notably economically improving the range resolution. For this purpose, the subject of the invention is a pulsed radar that analyses the range profile of a target from a train of N pulses transmitted to this target, the signal of each pulse being frequency modulated according to a ramp (21, 22, 23), the ramps being frequency-shifted from one pulse to another. Each pulse signal reflected by the target is demodulated by its corresponding ramp, then sampled. The range is analysed by spectral analysis of the signal represented by the series of samples obtained by concatenating the N sampled signals.

The main advantages of the invention are that it can be applied without modifying the hardware of existing radar, it allows the range to be determined almost instantly and it is simple to implement.

Other characteristics and advantages of the invention will be shown in the following description with appended drawings that show:

- figure 1, a frequency modulation ramp applied to a pulsed radar;
- figure 2, frequency modulation ramps applied in a radar according to the invention ;
- 5 - figure 3, through a block diagram, a possible realisation mode of processing means for the signals received in the radar according to the invention;
- figure 4, an illustration of the concatenation function applied to the basic receiving signals sampled.

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Figure 1 shows a frequency modulation ramp 1 applied to pulse radar. The radar transmits a microwave in at least one time interval T . During this pulse, the frequency f of the signal transmitted to a target varies linearly according to the time t from a frequency $f_{\min}$ to a frequency $f_{\max}$. The signal
 15 reflected by the target is demodulated by a signal of the same modulation law. The demodulation is triggered at an instant close to the instant that the pulse returns after reflecting off the target. This instant may be known because the distance from the target to the radar is also known, by means of another radar function but without specific resolution. After this demodulation,
 20 we obtain a signal at the radar receiving circuits, whose frequency is proportional to the distance from the reflection point on the target. The range resolution obtained is given by the relationship (1).

Figure 2 illustrates an example of a waveform transmitted by radar
 25 according to the invention, which notably obtains a better range resolution than the previous one. To determine the range, the wave transmitted by the radar has N consecutive pulses. Each of these pulses is generated in the same way as the one illustrated in figure 1, i.e. with the same duration T . But the centre frequency of the transmitted signal varies from one pulse to
 30 another. Figure 2 shows an example of a case where the number of pulses N is equal to 3. This figure does not show the actual waveform, but its associated frequency modulation represented by ramps 21, 22, 23 that are frequency-shifted. An initial pulse of duration T is sent at an instant t_0 . The frequency of the pulse signal increases from a frequency $f_{0\min}$ to a frequency
 35 $f_{0\max}$. A second pulse of duration T is sent at instant t_1 . The frequency of the

pulse signal increases from a frequency $f_{1\min}$ to a frequency $f_{1\max}$. A third pulse of duration T is sent at instant t_2 . The frequency of the pulse signal increases from a frequency $f_{2\min}$ to a frequency $f_{2\max}$. The modulation bandwidth B for example, is the same for each pulse, thus:

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$$B = f_{0\max} - f_{0\min} = f_{1\max} - f_{1\min} = f_{2\max} - f_{2\min} \quad (2)$$

The centre frequencies of the ramps are for example shifted by a quantity ΔF from one pulse to another. In particular:

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$$\frac{f_{2\max} + f_{2\min}}{2} - \frac{f_{1\max} + f_{1\min}}{2} = \frac{f_{1\max} + f_{1\min}}{2} - \frac{f_{0\max} + f_{0\min}}{2} = \Delta F \quad (3)$$

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On receiving each pulse, the radar treats this pulse as a conventional pulse, each pulse being demodulated by its corresponding ramp. Then the radar stores the samples of each pulse received and demodulated in memory, after encoding. The frequency domain analysis of the target range profile is then carried out on all the samples of N signals after concatenating them, the distance being proportional to the frequency of the global signal represented by all the samples.

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It is possible to be satisfied with narrow band encoding insofar as the range depth of the target is limited. If we analyse a range depth d_p , with a waveform of duration T and bandwidth B , we can sample the signal, after demodulation, at a frequency f_s given by the following relationship:

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$$f_s = \frac{2Bd_p}{cT} \quad (4)$$

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As an example, for a depth of $d_p = 500$ metres, a pulse of duration $T = 100\mu s$ and bandwidth $B = 150$ MHz, the radar can sample the signal at the frequency $f_s = 5$ MHz. In particular, narrow band encoding allows conventional encoders to be used, which do not have specific speed performances.

Once the N pulses sampled have thus been stored in memory, the radar performs a process to determine notably the range.

In order to guarantee the consistency of the signals and the correct operation of the radar in the presence:

- of target movement during transmission of the waveform, i.e. range migration;
- of possible phase shifts from pulse to pulse due to the generation of the radar signals,

there is preferably a certain overlap of the transmitted spectrums.

In other terms, given the example of a wave such as the one shown in figure 2, f_{1min} is less than f_{0max} and f_{2min} is less than f_{1max} . This is expressed by the

following relationship:

$$\Delta F = \beta \cdot B \quad \text{with } \beta < 1 \quad (5)$$

If the target moves, the phase law for the received signal is different from one pulse to another. To ensure the consistency of the signals, this phase variation must therefore be compensated for. This compensation is deduced in a known manner from the knowledge of the speed of the target. The frequency overlap $[f_{1min}, f_{0max}]$, $[f_{2min}, f_{1max}]$ allows this speed to be determined. In particular, the frequency interval $[f_{1min}, f_{0max}]$ belongs to the first and second pulses. In each of these pulses, the radar determines a range spectrum for this interval $[f_{1min}, f_{0max}]$ in a conventional manner, i.e. a set of frequencies that are representative of target element ranges. Given that the signal is the same, the same range profile is obtained, but with a range difference between the responses of both successive pulses. Given that the radar knows the time passed between two pulses, it can then deduce the speed from it. The modulation band overlap is therefore a means of compensating for the phase differences due to the target moving.

The total useable bandwidth B_T is given by the following relationship:

$$B = (1+(N-1)\beta)B = \rho B \quad (6)$$

By keeping the same type of analysis as previously, the corresponding range resolution r_T therefore becomes:

$$r_T = \alpha \frac{c}{2B_T} = \frac{r}{\rho} \quad (7)$$

where r is the resolution as defined by the relationship (1).

As the magnitude ρ is greater than 1, the range resolution is
 5 therefore improved. As an example, for a radar that has the capacity to
 transmit six pulses with a bandwidth $B = 50$ MHz, with $\beta = 0,85$ and an
 analysis with Hamming weighting, the radar can obtain a range resolution r_T
 $= 0.75$ metres instead of a resolution $r = 3.9$ metres.

10 Figure 3 shows an example of processing means to analyse the
 range from the receiving signals that correspond to the same train of pulses.
 The radar analyses the range profile of a target from a train of N pulses.
 Each pulse signal reflected by the target is demodulated by its corresponding
 ramp by conventional receiving means. The ramps are frequency-shifted
 15 from one pulse to another as shown in figure 2. Each basic signal received
 and demodulated, which corresponds to a pulse, is sampled then encoded by
 encoding means. The samples are then stored in memory. The 1, 2, ... N
 pulse samples represented on the input of the processing means in figure 3
 are these sampled and stored signals, which correspond to the first, second
 20 and N^{th} pulse in the train respectively.

The processing means in figure 3 include target movement
 parameter estimation means 31, particularly speed. These estimation means
 31 work for example from target tracking means 32 that are also present in
 the radar. In particular, these tracking means allow the speed of the target to
 25 be determined. The movement parameter estimation means 31 are linked to
 the memory storage means, not shown, for the samples of received signals.
 They therefore take into account the 1, 2, ... N pulse samples. Movement
 correction means 33, 34, 35 are associated to each set of samples of a 1, 2,
 ... N pulse. From the movement parameter estimation means 31, the
 30 movement correction means compensate for the phase differences due to
 the target movements, particularly its speed. For example, this compensation
 is carried out, as indicated previously, by means of modulation band
 overlapping. The correction means 33, 34, 35 modify the value of the
 samples in order to produce the required compensation.

The processing means for example, include phase correction means 36, 37, 38, associated to each set of 1, 2, ...N pulse samples, to correct phase shifts that are not due to the target movements. In particular, even in the absence of target movements, there may be random phase shifts from one pulse to another. The processing means therefore include phase parameter estimation means 39 linked to the sample storage means. The phase correction means 36, 37, 38 for example, are placed after movement correction means 33, 34, 35. From the data supplied by the estimation means for the phase parameters relative to each 1, 2, ...N pulse, they modify the samples, for example from the movement correction means, to compensate for the phase shifts.

The corrected samples are then processed by concatenation means 40. These means sequence the samples to form a global sampled signal that corresponds to the set of N pulses. Figure 4 partially shows the function of these concatenation means 40 applied to sequencing two consecutive basic sampled signals k and k+1. These signals are made up of samples 41. Due to the band overlapping $[f_{1min}, f_{0max}]$, $[f_{2min}, f_{1max}]$, samples 42 are common to the two signals k and k+1. By concatenation, the resulting signal only contains the samples 42 common to the two bands once. The global sampled signal supplied by the concatenation means is then supplied to conventional range analysis means 30.

A particular advantage of the invention is that improves the range resolution of ramp frequency modulated pulsed radar without substantial hardware modification. This improvement costs practically nothing concerning the hardware. The only adaptations concern processing. The invention can therefore be advantageously applied to existing radar without modifying their hardware.

CLAIMS

1. Pulsed radar, characterised by the fact that it analyses the range profile of a target from a train of N pulses transmitted to this target, the signal or each pulse being frequency modulated according to a ramp (21, 22, 23), the ramps being frequency-shifted from one pulse to another, each pulse signal reflected by the target being demodulated by its corresponding ramp then sampled, the range analysis being carried out by the spectral analysis of the signal represented by the series of samples obtained by concatenation (40) of the N sampled signals.

2. Radar according to claim 1, characterised by the fact that the N pulses have the same duration T and their frequency modulation ramps (21, 22, 23) have the same bandwidth.

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3. Radar according to any one of the previous claims, characterised by the fact that the ramps are shifted by the same quantity ΔF from one pulse to another.

20 4. Radar according to any one of the previous claims, characterised by the fact that the modulation bands overlap from one pulse to another ($[f_{1min}, f_{0max}]$, $[f_{2min}, f_{1max}]$).

25 5. Radar according to any one of the previous claims, characterised by the fact that it includes means (31, 33, 34, 35) to compensate for the phase differences from one pulse to another due to movements of the target, these means modifying the value of the samples.

30 6. Radar according to claims 4 and 5, characterised by the fact that the compensation is carried out by means of band overlapping ($[f_{1min}, f_{0max}]$, $[f_{2min}, f_{1max}]$), the radar determining a range spectrum for an overlap interval that is common to two consecutive pulses, the same range profile being obtained for the two pulses with a range difference between the responses, the speed of the target being defined by knowing the time passed

between two pulses, the phase compensation being deduced from the speed of the target.

7. Radar according to any one of the previous claims,
5 characterised by the fact that it includes means (30, 36, 37, 38) to compensate for the random phase differences from one pulse to another, these means modifying the value of the samples.