8.7 Impulse Integration for Increasing the Sensitivity

With all Radar devices, which are not agile from pulse to pulse, several pulses are reflected from a target with each sample instance. One identifies the summation of all pulses from a target as integration. The detection becomes even better the more reflected energy from the target is received and integrated. From the Radar equation possibilities for an apparent energy increase can be seen. They each exist only for only one pulse. In this section the dwell time for a target will also be considered. It results in the hits per scan n_B and depends on the following:

- Pulse repetition rate f_p [Hz],
- Half-power bandwidth of the antenna θ_B [Grad],
- Scan-rate of the antenna $\dot{\Theta}_S$ [Grad/sec].

$$n_B = \frac{\Theta_B f_p}{\dot{\Theta}_S} \tag{8.10}$$

Common by rotating Radar systems:

$$10 < n_B < 15 \tag{8.11}$$

For systems with high PRF (Pulse Doppler for short ranges), values of a few hundred for n_B can be obtained. The integration can always take place at two different places in the signal path:

- IF Integration ⇒ Pre-detection or Coherent integration,
- Video Integration ⇒ Post-detection or Incoherent integration.

Coherent integration (pre-detection) is only seldom used, since it assumes a constant phase between transmission and receiving for the pulses to be integrated. The integration can then, for example, take place through a narrow IF filter, whose bandwidth is inversely proportional to the target dwell time. A sample rate of 360°/sec and a 2° half-power bandwidth result in a dwell time of 1/180 sec. That means that the integration filter has a bandwidth of 180 Hz. The integration effect is obtained by the energy storage in the filter. The quality of the filter determines the integration efficiency. In the following the non-coherent integration will be described in more detail.

8.7.1 Incoherent Integration

For incoherent integration the following considerations apply. If n pulses are summed in an ideal integration, then the S/N ratio at the output of the integrator improves by a factor n. This practically cannot be achieved by incoherent integration, since additional noise develops when rectifying. The improvement, which can be achieved by an operator with a storage tube, is approximately proportional to $\sqrt{n}$. From Marcum [6] the achievable improvement, henceforth identified as integration efficiency, is calculated.

The efficiency for *n* pulses is defined by:

$$E(n) = \frac{(S/N)_1}{n(S/N)_n} \tag{8.12}$$

$(S/N)_1$ = S/N for one pulse.

$(S/N)_n$ = S/N for one pulse of the same probability of detection P_d and false alarm rate P_{fa} with the integration of *n* pulses.

Then one obtains:

$$n \cdot E(n) = I(n) = \frac{(S/N)_1}{(S/N)_n} \tag{8.13}$$

I(n) is the integration factor. Near this factor the power of the Radar can be reduced by the integration in relation to the case, which is not integrated. *I(n)* is represented in Figure 8.14. The probability of detection P_d and the false alarm rate P_{fa} are of minor influence. Often the integration loss (Equation 8.14) is also stated as demonstrated in Figure 8.15.

$$L(n) = 10\log(1/E(n)) \tag{8.14}$$

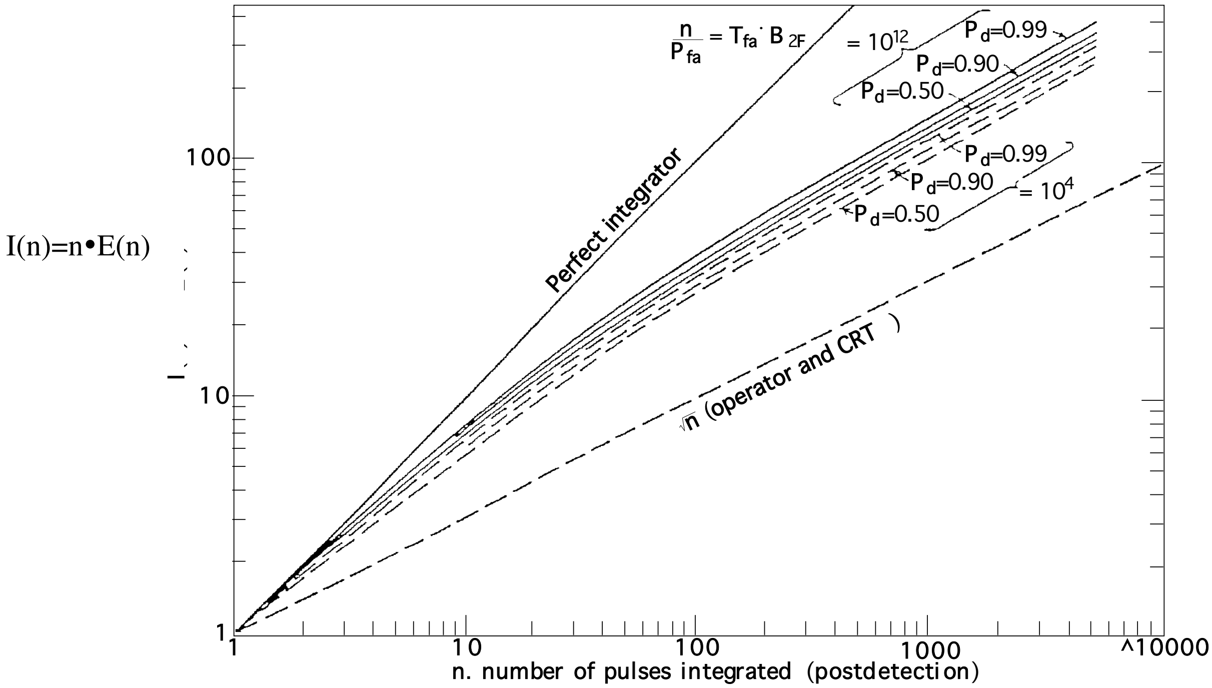

Figure 8.14 Integration factor as a function of the number of the integrated pulses *n* for non-coherent integration.

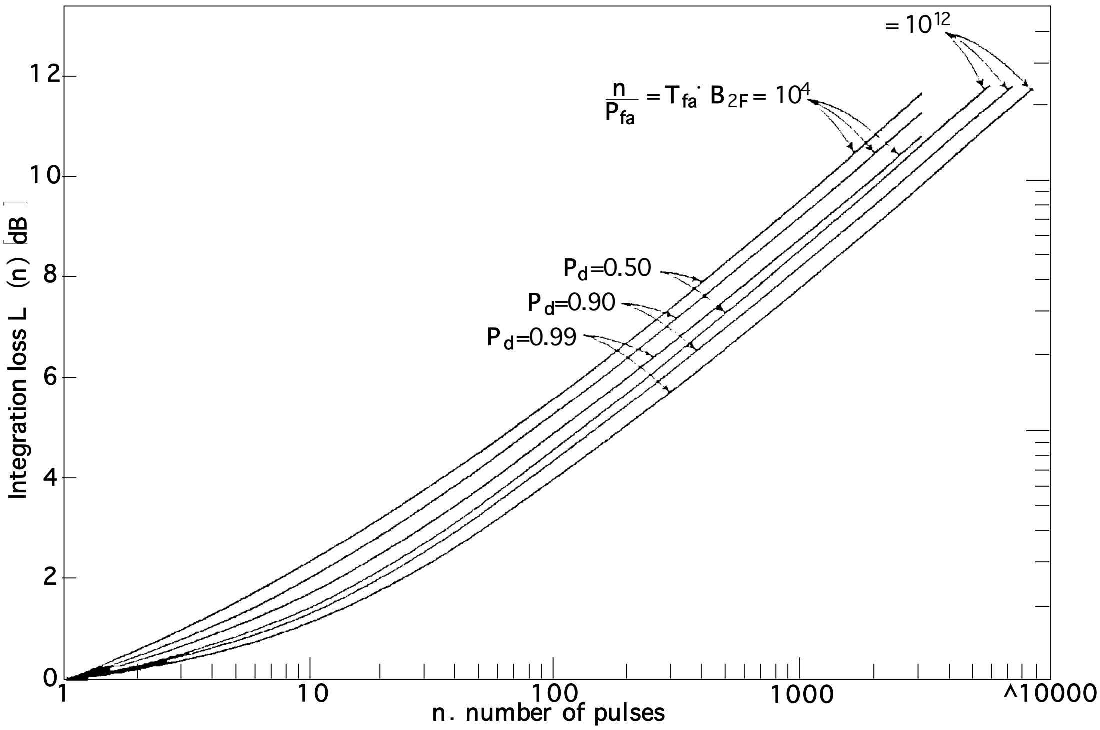

Figure 8.15 Integration loss as a function of the integrated pulses *n* for non-coherent integration.

With a given false alarm rate and detection probability the increase in the range of coverage can be calculated by integration with the modified Radar equation according to equation (3.8) and the integration gain (Figure 8.14 and/or Equation 8.10). In the Radar equation the following is replaced:

$$P_{R_{\min}} = kTB_nL(S/N)_1 \tag{8.15}$$

T = Temperature in Kelvin, $(S/N)_1$ = required signal-to-noise ration for a pulse, B_n = noise bandwidth, L = system losses. Through Equation (3.9), Equation (8.16) results:

$$P_{R_{\min}} = \frac{kTB_nL(S/N)_1}{nE(n)}$$

$$\Rightarrow R_{\max}^4 = \frac{P_S G_S G_E \lambda^2 \sigma}{(4\pi)^3 kTB_nL(S/N)_1} nE(n) \tag{8.16}$$

8.7.2 Examples for Incoherent Integration

Different procedures have been developed for integration, from which three will be quickly presented:

- Tapped delay line integration
- Looped integration

- Binary integration

With tapped delay line integration, according to Figure 8.16, analog or digital signals are fed into a tapped delay line, whose length corresponds to the number of hits per scan n_B. At the output one obtains a maximum if *n* successive echoes are received from a target. The execution of an analog tapped delay line can be realized by RLC bandpass resonators, RC elements, static memory elements or mechanically circulating samplers. Shift registers are used for digital integration. The advantage of the tapped delay line is that any weighting of the taps is possible, for example, in order to strengthen the wanted pulses or weaken the older pulses.

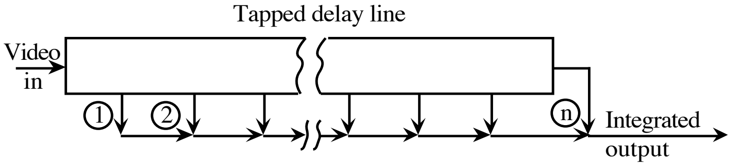

Figure 8.16 Incoherent integrator with a tapped delay line.

The loop integration, as shown in Figure 8.17, as a rule has a poor efficiency as discussed earlier. This is due to the fact that the loop gain k must be smaller than 1 in order to hinder an oscillation. Single-step arrangements make possible a loop gain of up to .9, dual-step up to .98. The loop gain is dependent upon the number of the pulses that must be integrated. A weighting is not possible.

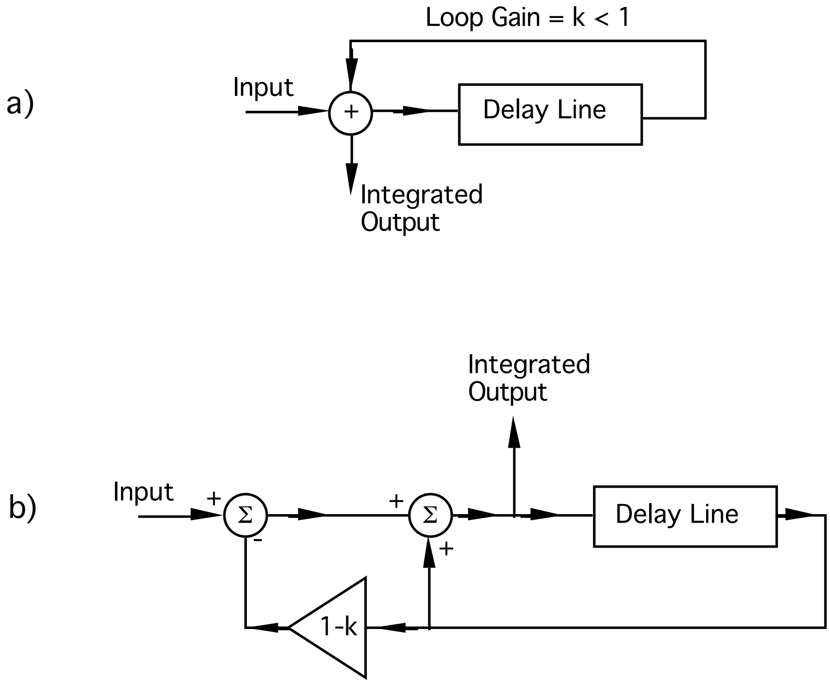

Figure 8.17 Loop integration: a) single-step (k<.9) b) dual-step (k<.98)

The third version of non-coherent integration is binary integration and it digitally analyzes the number of occurrences in a windowed range. Figure 8.18 shows a corresponding arrangement.

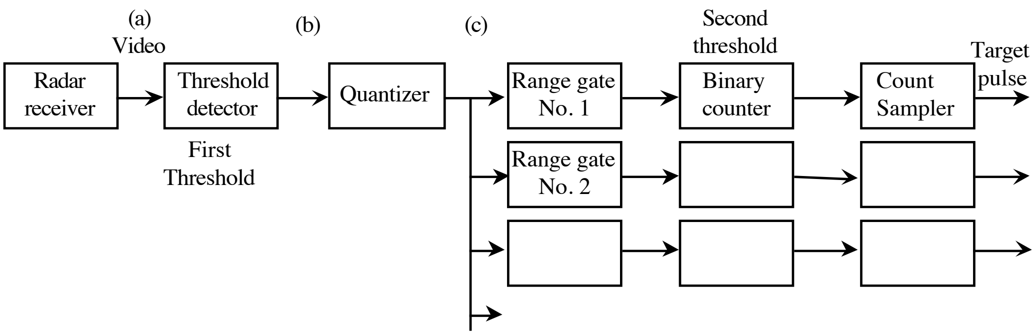

Figure 8.18 Block diagram of a binary integrator.

A target is identified if *m* echoes are counted from a possible number *n*, all within a certain time interval.

8.8 Pulse Compression for Improving the Resolution

As has been already said in the previous section, the range of coverage is determined primarily by the total energy, which is received from a target. There the energy has been increased through the integration of several pulses. The same effect can be achieved by the increase of the pulse duration τ. The precision of the range measurement is independent upon the pulse duration so that there are no given restrictions here. The resolution of two neighbouring targets, as has been shown in section 2.6, is calculated with the autocorrelation function and/or with the cross-correlation. Thus the resolution is directly dependent upon the pulse duration. According to this, the signal at the receiver must be temporally shortened (i.e. compressed) when dealing with longer pulses, this in order to improve the range resolution as well as the precision and the sensitivity. Procedures of this type have been developed in communication theory long before they found use in Radar technology. In order to make possible this compression the transmitting signal must be modulated in the pulse (intra-pulse modulation), again in order to obtain marks within the pulse duration. Digital and analog procedures will be described in the following.

8.8.1 Compression of a frequency modulated pulse (chirp)

One of the first procedures for the realization of pulse compression involved the frequency modulation of the transmitting pulses. The procedure is clearly demonstrated in Figure 8.19. The transmitting pulse, which is represented by a rectangle in Figure 8.19a is, as shown in Figure 8.19b, linearly frequency modulated between f_1 and f_2. Figure 8.19c illustrates the time procedure. The signal re-received over the signal path is fed into a frequency dependent filter, according to Figure 8.19e. The first arriving low frequency f_1 is delayed around t_2, and the later, higher frequencies delayed only around t_1. Through this it is achieved that the entire power of the long transmitting pulses "simultaneously" leave the compression filter within a very short pulse, according to Figure 8.19d.

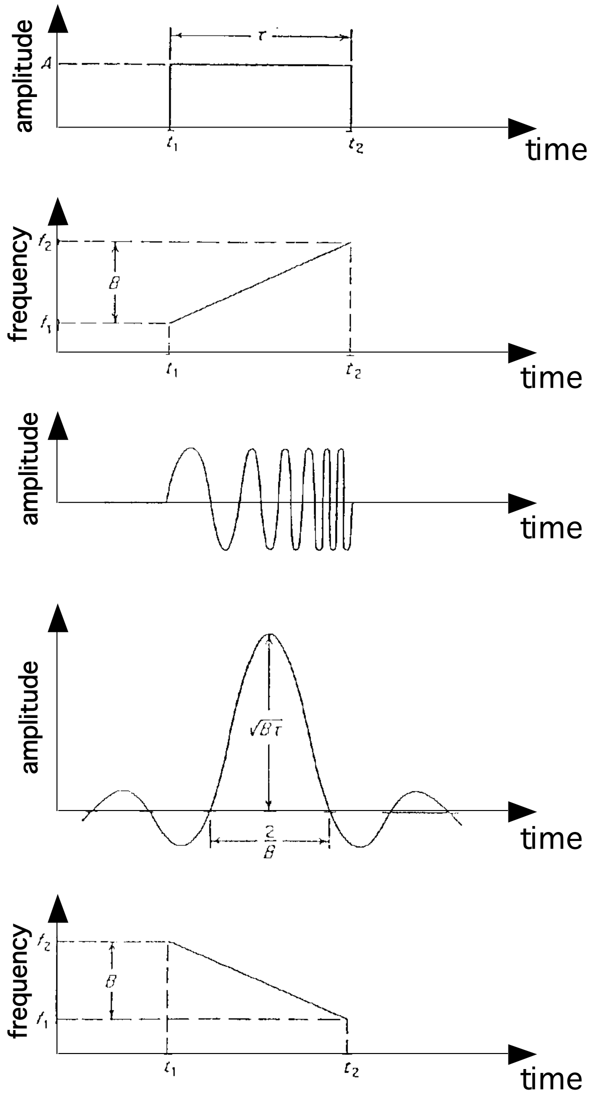

Figure 8.19 Frequency modulated pulse compression.

Figure 8.20 shows how the high resolution is regained. There is no time separation possible before the compression. After the compression the possibility for time separation depends upon the amplitudes of the target echoes and the side lobes of the compressed function.