BAK - Bakalářská práce

poznámky

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Obsah

1 FMCW radary **1**

1. FMCW radary

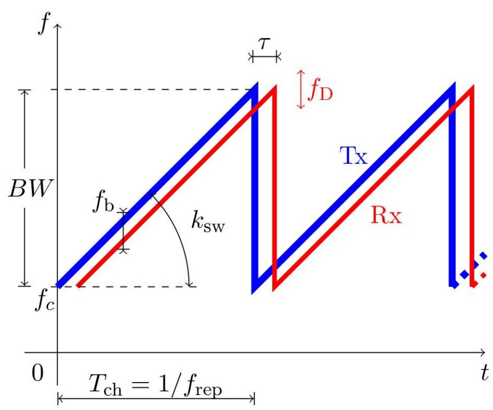
- CW - continuous wave
  - transmits a continuous wave on a single frequency
  - detects targets via a harmonic beat signal with a Doppler frequency of $f_D = \frac{2v_r}{\lambda_c} = \frac{2v_r f_c}{c_0}$ where λ_c/f_c is the wavelength or frequency of the transmitted signal
  - only information about presence of the target and his radial velocity (part of velocity vector that is pointing towards source of signal) can be gathered
- FMCW - frequency modulated continuous wave
  - transmits a continuous wave with a frequency that is modulated by a linear function (frequency periodically increases or decreases)
  - one frequency sweep is called a chirp/frame
  - detects round-trip delay vai frequency of a beat signal
  - received power is determined by radar equation

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4}$$

    where σ is the radar cross section of the target, λ is the wavelength of the transmitted signal, R is the distance to the target, P_t is the transmitted power, G_t is the gain of the transmitting antenna, G_r is the gain of the receiving antenna
  - achievable radar parameters

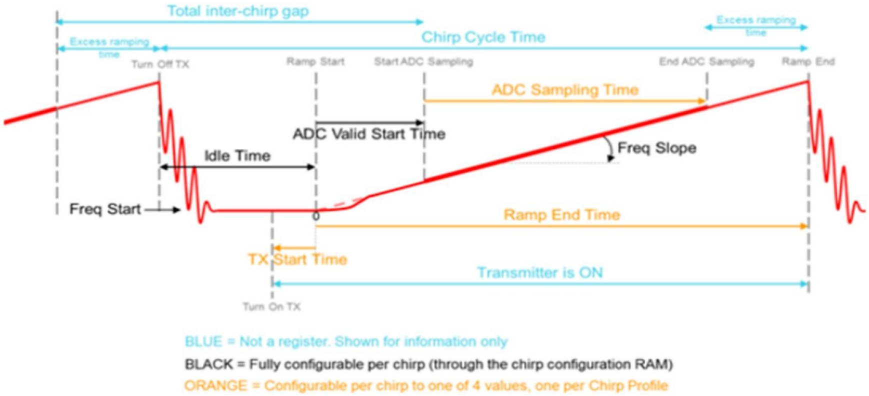
Radar	f_c (GHz)	BW (MHz)	T_{ch} (μs)	f_{rep} (kHz)	k_{sw} (MHz/μs)	R_{tmax} (m)	ΔR_t (m)	v_{rmax} (m/s)	Δv_r (m/s)
24 GHz	24.0	250	1500	0.6	0.17	4500	0.60	2.1	0.03
76 GHz	76.0	400	85	11.0	4.7	160	0.38	11.6	0.18
77 GHz	77.0	4000	40	25.0	100	7.5	0.038	24.3	0.38

- transmitted signal



  - τ – time delay between transmitted signal on T_X and received signal on R_X
  - f_c – carrier frequency that is modulated, usually in tens of GHz
  - BW – bandwidth of the chirp, from roughly 100MHz to 6GHz
  - T_{ch} – duration of the chirp

  - $k_{sw} = T_{ch}/BW$ – chirp slope (how fast we sweep the frequency across the bandwidth)
  - f_D – Doppler frequency of moving target
  - form of a real transmitted signal



- beat signal
  - in FMCW radars we use so called filtered harmonic beat that is defined as $f_{beat}(t) = f_{Tx}(t) f_{Rx}(t)$
  - transmitted signal is changing its frequency within the chirp as $f_{Tx}(t) = f_c + k_{sw}t$, thus it transcription can be written as $s_{Tx}(t) = A_c \cos(2\pi f_c t + \pi k_{sw} t^2)$
  - signal on receiver is delayed by τ thus $s_{Rx}(t) = s_{Tx}(t-\tau) = A_c \cos(2\pi f_c(t-\tau) + \pi k_{sw}(t-\tau)^2)$
  - combining these two signals in a mixer we get our output

$$s_{out}(t) = \frac{A_c^2}{2}(\cos((2\omega_c - 2\pi k_{sw}\tau)t + 2\pi k_{sw}t^2 + (\pi k_{sw}\tau^2 - \omega_c\tau)) \times \cos(2\pi k_{sw}\tau t + (\omega_c\tau - \pi k_{sw}\tau^2)))$$

    * first cosine term describes a linearly increasing FM signal at roughly twice the carrier frequency with a phase shift that is proportional to the delay τ
    * generally no usefully information can be gathered from the first term and is usually filtered out, that can be done simply with a low-pass filter given its higher frequency
    * second cosine term describes a beat signal at a fixed frequency that can be calculated with derivation of the phase shift

$$f_b = \frac{1}{2\pi}\frac{d}{dt}(2\pi k_{sw}\tau t + (\omega_c\tau + \pi k_{sw}\tau^2)) = k_{sw}\tau$$

    * we can see that the frequency is proportional to the delay and chirp slope

- estimating range with a FMCW radar
  - relation between beat signal frequency and distance can be derived as $f_{beat} = \frac{2R_t}{c_0}\frac{BW}{T_{ch}} = \tau k_{sv}$
  - for signal transmitted in air ve can defined relation $\tau = \frac{2R}{c} \Rightarrow f_b = k_{sw}\frac{2R}{c}$
  - thus we can estimate the range as

$$R_t = \frac{f_b c_0}{2k_{sw}}$$

  - in real applications maximal beat frequency detectable is determined by the sampling frequency we use
$$f_{beat,max} = f_s/2$$
    * between number of samples and sampling frequency there is relation $N_s = T_{ch} f_s$
    * ideally we have at least $N_s + 1$ samples
    * we can use both real or IQ sampling
    * negative frequencies enables us to do a estimation of noise flow
  - FT of the beat signal returns N_s-sample complex frequency spectrum with width of f_s, that gives us a resolution of $\delta f_b = f_s/N_s \sim \frac{1}{T_{ch}}$
    * to get a range resolution we can easily substitute frequency with frequency resolution
$$\delta R = \frac{c_0 k_{sw}}{2} \delta f_b \sim \frac{c_0}{2BW}$$
    * we can see that range resolution is determined by the bandwidth and does not depend on the sampling frequency
    * unfortunately given dependence on k_{sw} if the chirp slope is not linear then the range resolution will not be constant (degrades with a derivation of the chirp slope)
  - improving the range resolution
    * most often resolution can be improved by linearsing the chirp slope most often done with a pre-programmed look up table
    * however more complicated circuits (most notably delay-line discriminator) can also be used to achieve the same effect
    * often superposition of neighboring chirps is also used to increase the resolution
  - effect of transmitted signal reaching the receiver via the PCB
    * single antenna or event a dual antenna configuration results in a significant power leaking into the receiver
    * as we are transmitting and receiving at the same time this poses a significant problem
    * this noise must be mitigated primarly with physical design of the radar otherwise if the leakage signal is too high it cal bias the mixer resulting in a significant error
  - effects of phase noise
    * any transmitter will exhibit a certain amount of phase noise, that can be added to our s_{out} equation in following way
$$s_{out}(t) = \frac{A_c^2}{2}(\cos(2\pi k_{sw}\tau t + (\omega_c \tau - \pi k_{sw}\tau^2) + \phi(t) + \phi(t) - \phi(t-\tau))$$

- estimating speed with FMCW radar
  - it is impossible to determine speed of the target from a single chirp
  - estimation of speed is not as precise as estimation of range
  - to get any useful estimation $\frac{2R_t k_{sw}}{c_0} \gg \frac{2v_r f_c}{c_0}$
  - doppler shift causes as phase shift in the beat signal
  - to get estimation of f_D we rely on FT of the beat signals
  - speed resolution $\Delta v_t = \frac{c_0}{2T_{ch}N_{ch}f_c}$
  - speed limit $v_{r,max} = \pm\frac{f_{rep}c_0}{4f_c}$ where $f_{rep} = \frac{1}{T_{ch}}$ and $f_{d,max} = \pm\frac{f_{rep}}{2}$