RADIOLOCATION

DOPPLER BASED RADARS

CW Radar – Pulse Doppler Radar – Moving Target Indicator – FMCW

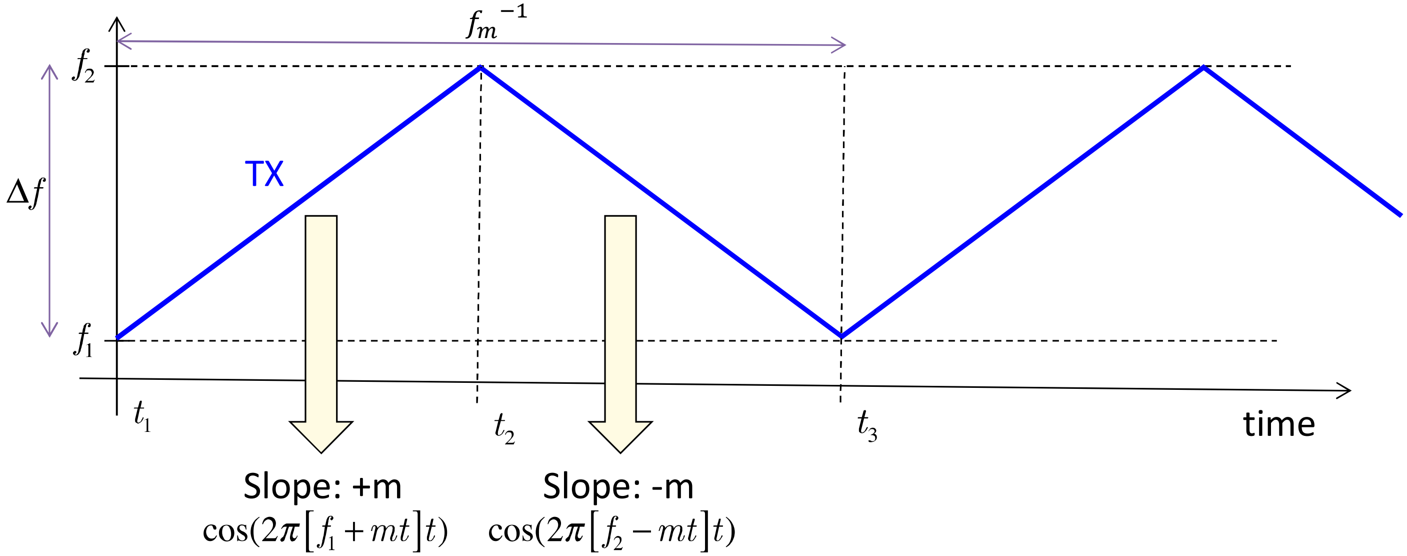
Jordi Mateu – Jordi Berenguer

FM-CW RADAR

RADIOLOCATION

FM-CW Radar

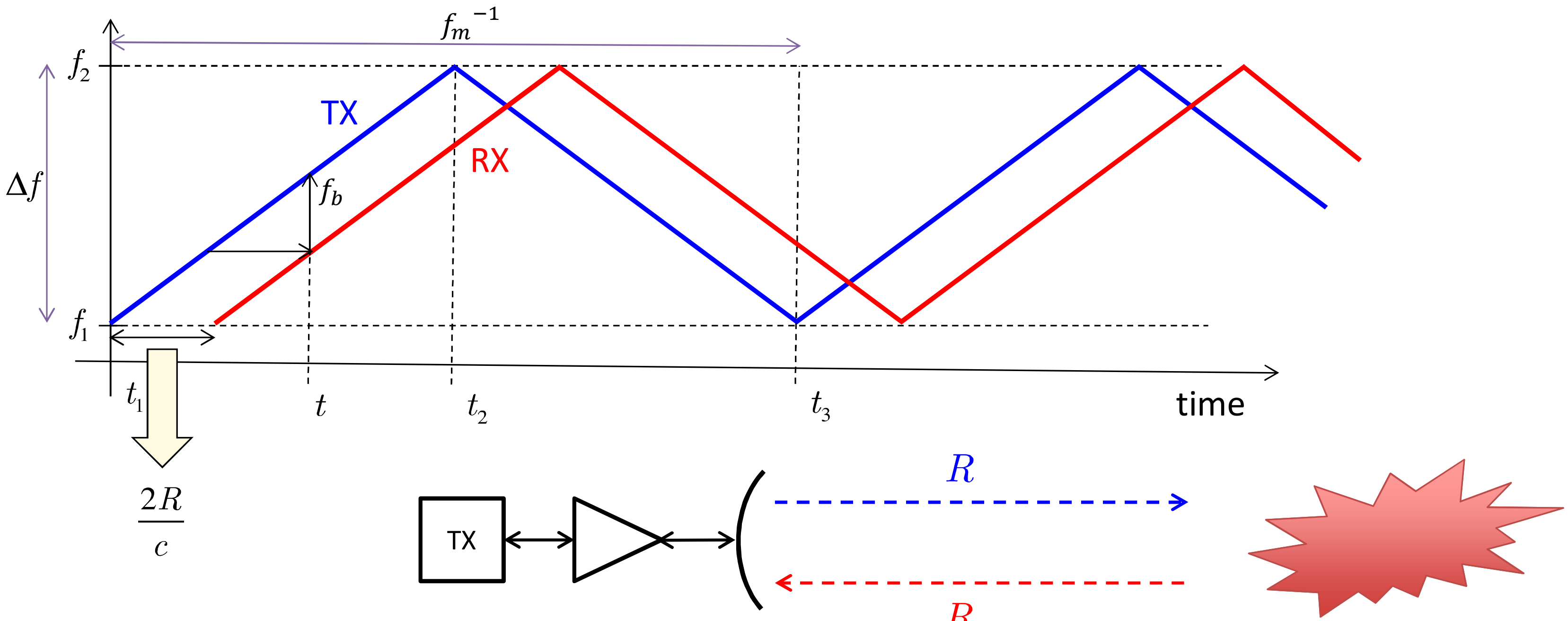
- Frequency modulate a CW signal



$$m = \frac{\Delta f}{(f_m)^{-1}/2} = 2 f_m \Delta f$$

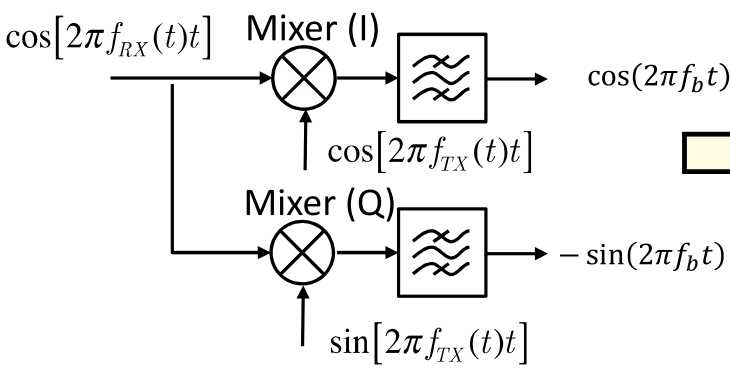
FM-CW Radar

Stationary target at Range ‘R’



$$m = \frac{f_b}{2R/c} = \frac{f_b c}{2R} \Longrightarrow \qquad R = \frac{f_b c}{2m} = \frac{f_b c}{4 f_m \Delta f}$$

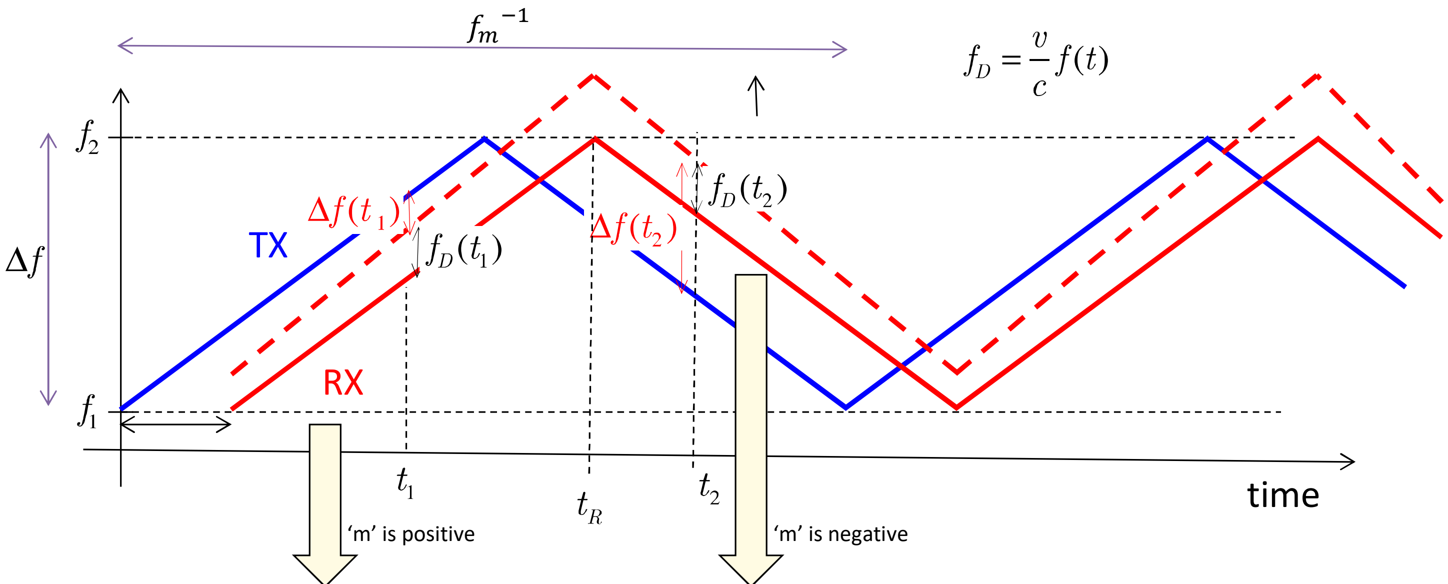
FM-CW Radar



$$f_b = \tan^{-1}\left(\frac{Q}{I}\right)$$

$$R = \frac{f_b c}{4 f_m \Delta f}$$

FM-CW Radar - **Moving** target at Range 'R'



$$f_{m+} = \Delta f(t_1) + f_D(t_1) = m\frac{2R}{c} \qquad f_{m-} = \Delta f(t_2) - f_D(t_2) = m\frac{2R}{c}$$

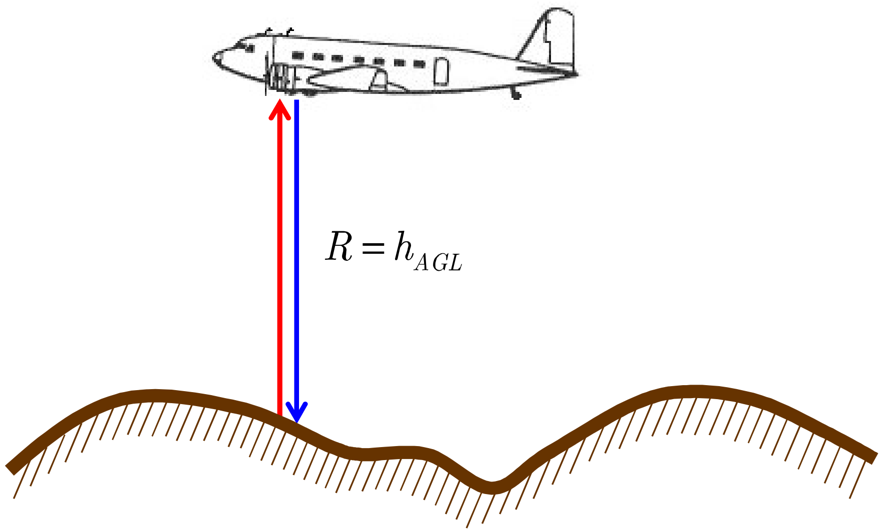
If t_1 and t_2 are chosen symmetric with respect to t_R and the target velocity is constant over that interval:

$$f_D(t_1) = f_D(t_2) = f_D \Rightarrow f_D = \Delta f(t_2) - \Delta f(t_1) \text{ and } R = \frac{c\left[\Delta f(t_2) - \Delta f(t_1)\right]}{4m}$$

FM-CW RADAR ALTIMETER

Application: the Radar Altimeter

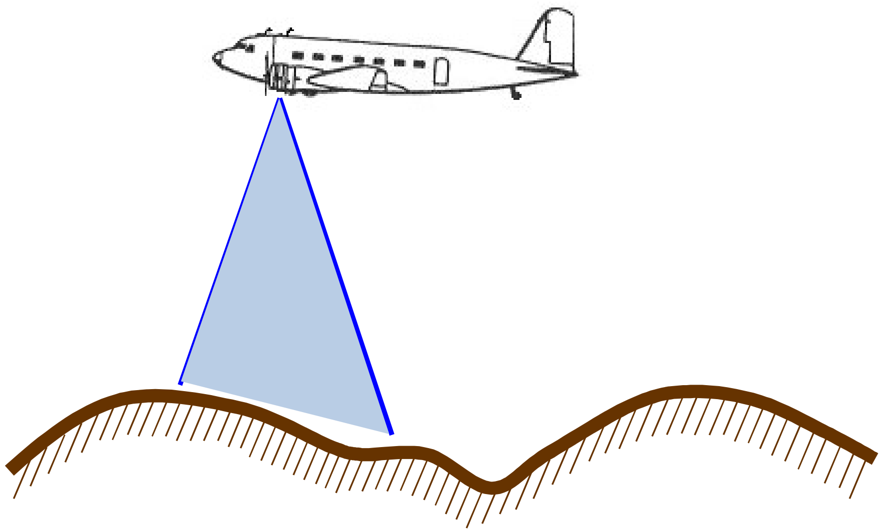
- Measures height ***Above Ground Level (AGL)***



Frequency of operation: 4,2 to 4,4 GHz.

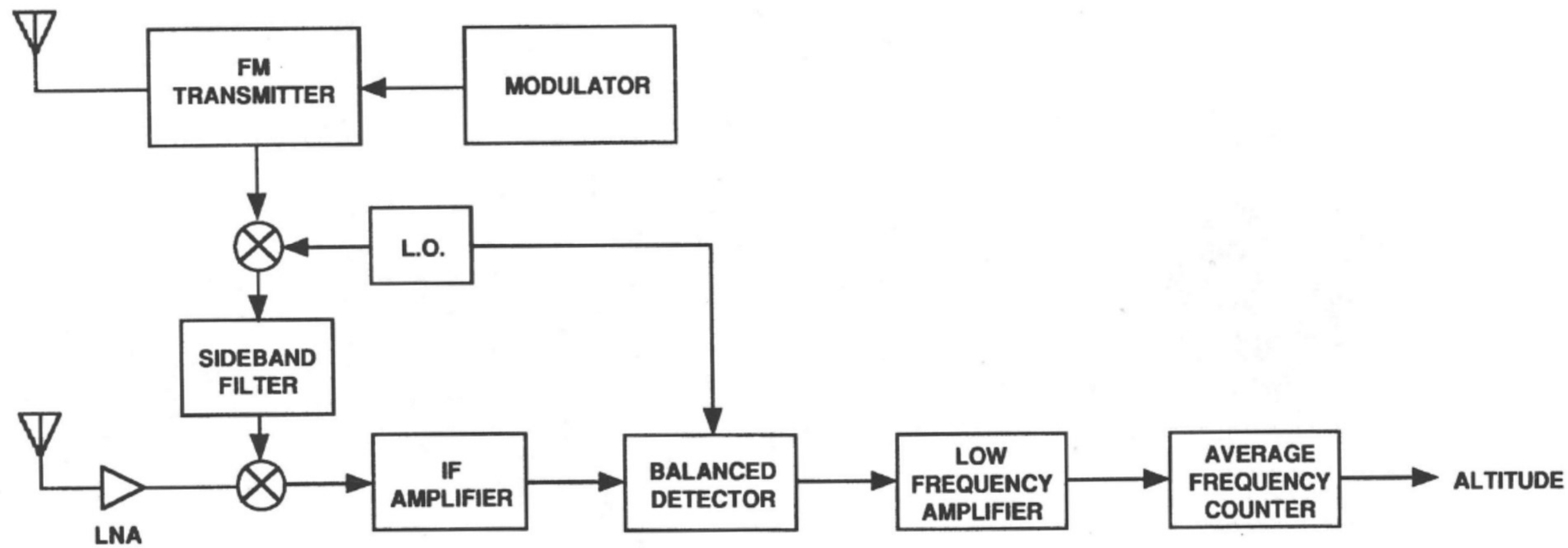
Radar Altimeter – Effect of Beam-width

- The beam illuminates an area rather than a single point



Frequency of operation: 4,2 to 4,4 GHz.

FM-CW Radar Altimeter Block Diagram



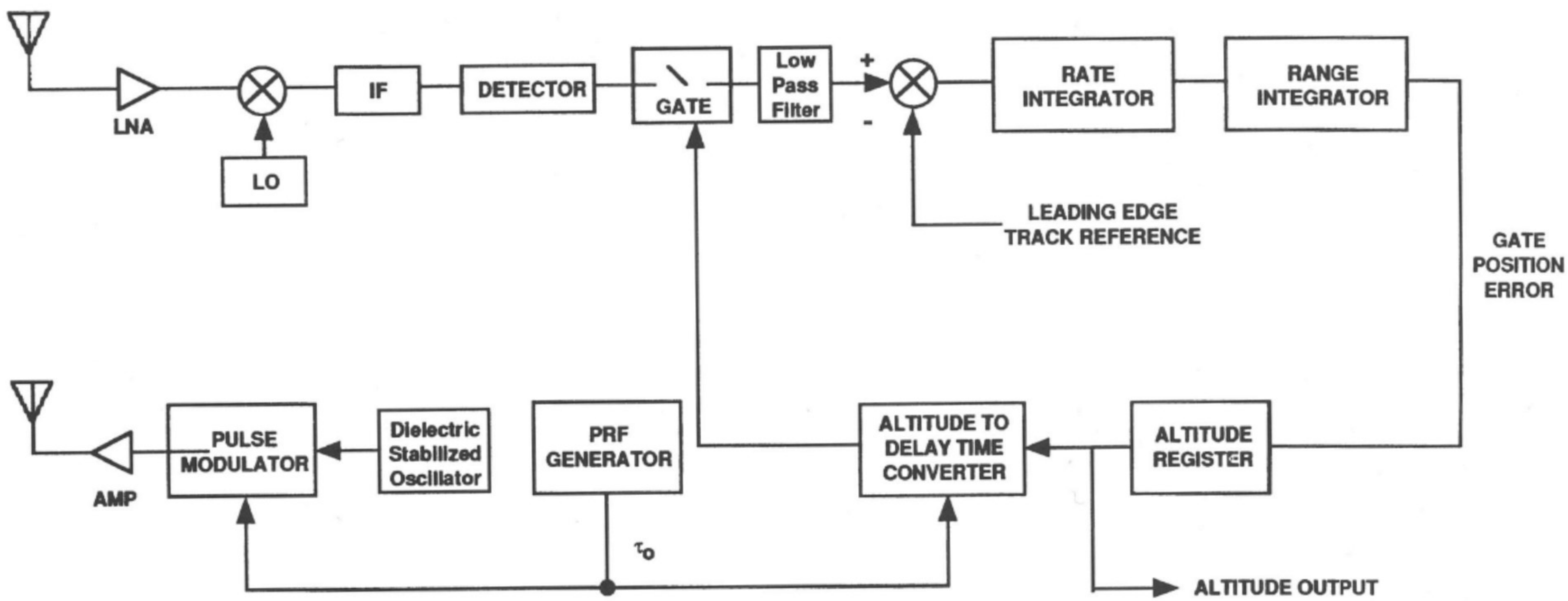
Frequency of operation: 4,2 to 4,4 GHz.

Honeywell KRA-405B FM-CW Radar Altimeter

- The KRA-405B radar altimeter (RADALT) is a lightweight, solid-state, airborne altimeter that provides accurate altitude measurements above terrain during various portions of flight. With more than 10,000 produced and sold to date and more than four million service hours, the KRA-405B RADALT has proven to be one of the most reliable and industry proven radar altimeters available.
  - Size: 3.00"W x 3.50"H x 11."L
  - Weight: 3.06 lbs. (unit); 5.36 lbs (system)
  - TSO Compliance: C87/ETSO-2C87
  - Primary Power: 27.5 VDC ±20% at 850 mA (nom); 18 VDC @ 1.2 Amps (max)
  - Temperature: -55 to +70C
  - Altitude range:
    - Tracked: -20 to 2,500 feet (-6.1 to 762.0 m)
    - Accuracy: 3 ft. or +-3% at 0-500 ft. and +-5% at 500-2500 ft.
  - **Output: 160 mW nominal, FMCW**
  - Frequency: 4300 +- 15 MHz
  - Modulation Frequency: 100 Hz nominal

PULSED RADAR ALTIMETER

PULSED Radar Altimeter Block Diagram



Frequency of operation: 4,2 to 4,4 GHz.

Honeywell HG8500 PULSED Radar Altimeter

Specifications

Input Power:	+28±4.0 VDC, 16 W max
Altitude Range:	0 to 8000 ft
Accuracy:	± (3 ft + 3%) Analog ± (3 ft + 1%) Digital
Frequency:	4300 ± 10 MHz
Track Rate:	> 2000 ft/sec
Sensitivity:	126 dB
Analog Output:	0 to -10 VDC
Digital Output:	16-BIT, Serial
Rel Signal:	+ 5.0 VDC (TTL)
Size:	50 in.^{3} 3.4 in. (W) x 3.4 in. (H) x 5.6 in. (L)
Weight:	3.0 lb
Transmit Power:	5.0-W peak
Pulse Width:	30/225 ns
PRF:	25 kHz
Qual Status:	Mil-Std-810D Environmental; Mil-Std-461C EMI

LG81T Microstrip Antennas

Frequency:	4.3 GHz nominal
Impedance:	50 ohms
Polarization:	Linear
Beamwidth:	50 degrees E-plane 50 degrees H-plane
Gain:	9.5 dB
Isolation:	85 dB minimum at 18-in.
Weight:	spacing
Dimension:	2.0 oz 3.5 in. x 3.5 in.

Caracteristicas técnicas de altímetros

	Radioaltímetro A1	Radioaltímetro A2	Radioaltímetro A3	Radioaltímetro A4	Radioaltímetro A5	Radioaltímetro A6	Unidades
TRANSMISOR							
Frecuencia central nominal	4 300	4 300	4 300	4 300	4 300	4 300	MHz
Potencia de transmisión	0,600	1	0,1 a 0,25	100	5	40	W (cresta)
Modulación (FMCW o impulso)	FMCW	FMCW	FMCW	Impulso	Impulso	Impulso	
Ancho de banda del impulso modulado, excluida la deriva de temperatura	104	132,8	133	No aplicable	No aplicable	No aplicable	MHz
Gama de altitud indicada	−4,6 a + 2 500 (−15 a +8 200)	−6 a +2 438 (−20 a +8 000)	−6 a +6 000 (−20 a +19 685)	+1 524 (5 000)	+1 524 (5 000)	+457 (1 500)	Metros/(pies)
Altitud operativa	12	12	20	12	12	12	km
Gama de temperatura operativa	−40° a +70°	−55° a +70°	−40° a +71°	−55° a +70°	−55° a +70°	−55° a +70°	Celsius
Estabilidad en frecuencia	100	Sin referencia cristal	Sin referencia cristal	No aplicable	No aplicable	No aplicable	ppm/°C
Deriva en frecuencia máxima dentro de la gama de temperatura operativa	±15	±15	±20	No aplicable	No aplicable	No aplicable	MHz
Número típico de altímetros instalados en una aeronave	Hasta 3	Hasta 3	Hasta 3	Hasta 3	Hasta 3	Hasta 3	Por aeronave

Rec. UIT-R M.2059-0

$P_{T,RF}$

Caracteristicas técnicas de altímetros

	Radioaltímetro A1	Radioaltímetro A2	Radioaltímetro A3	Radioaltímetro A4	Radioaltímetro A5	Radioaltímetro A6	Unidades
Desplazamiento de la frecuencia central entre cada uno de los sistemas de radioaltímetro	5	5	0	No aplicable	No aplicable	No aplicable	MHz
Frecuencia de repetición de la forma de onda	49 a 51 Hz	150 Hz	12 Hz a 1 623 Hz	10 000 pps	20 000 pps	6 000 pps	Hz o pps (impulso por segundo)
Ancho de impulso	No aplicable	No aplicable	No aplicable	130	200	75	ns
Ancho de banda de emisión de 3 dB	110	162,8	171	8	7	15	MHz
Ancho de banda de emisión de 20 dB	120	170	181	44	29	51	MHz
Ancho de banda de emisión de 40 dB	180	180	191	130	108	131	MHz

RECEPTOR							
Sensibilidad*	–120	< –113	≤ –120	–95	–95	–95	dBm
Cifra de ruido	10	6	6	10	10	10	dB
Sobrecarga del umbral de potencia de entrada del receptor	–30	–53	–56	–40	–40	–40	dBm
Ancho de banda de frecuencia intermedia (IF) a –3 dB	2	0,25	0,025 a 2	9,2	6,0	16	MHz

Rec. UIT-R M.2059-0

$P_{T,RF}$

Caracteristicas técnicas de altímetros

	Radioaltímetro A1	Radioaltímetro A2	Radioaltímetro A3	Radioaltímetro A4	Radioaltímetro A5	Radioaltímetro A6	Unidades
ANTENA							
Ganancia de antena	10	10 (típica), 9,5 (mínima)	10 (típica), pero puede utilizarse una antena distinta	13	11	11	dBi
Pérdida del cable (trayecto único)	6	6	2 a 7	6	6	6	dB
Ancho de haz de –3 dB	40 a 60	55	45 a 60	35	45	45	Grados

Para algunos de los radioaltímetros enumerados, el nivel de potencia de ruido del receptor, calculado en función del ancho de banda de la IF y de la cifra de ruido, es superior al nivel de sensibilidad del receptor. En tal caso, el ancho de banda del detector del radioaltímetro, que suele ser inferior al ancho de banda de la IF, determina el nivel de sensibilidad del receptor.

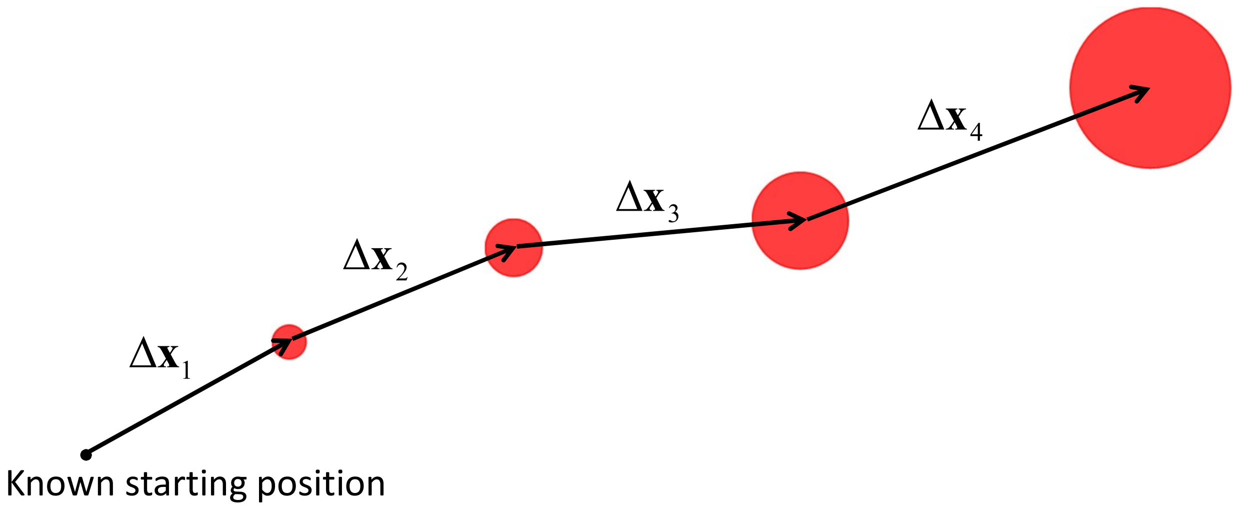
Rec. UIT-R M.2059-0

DOPPLER NAVIGATION (DEAD RECKONING)

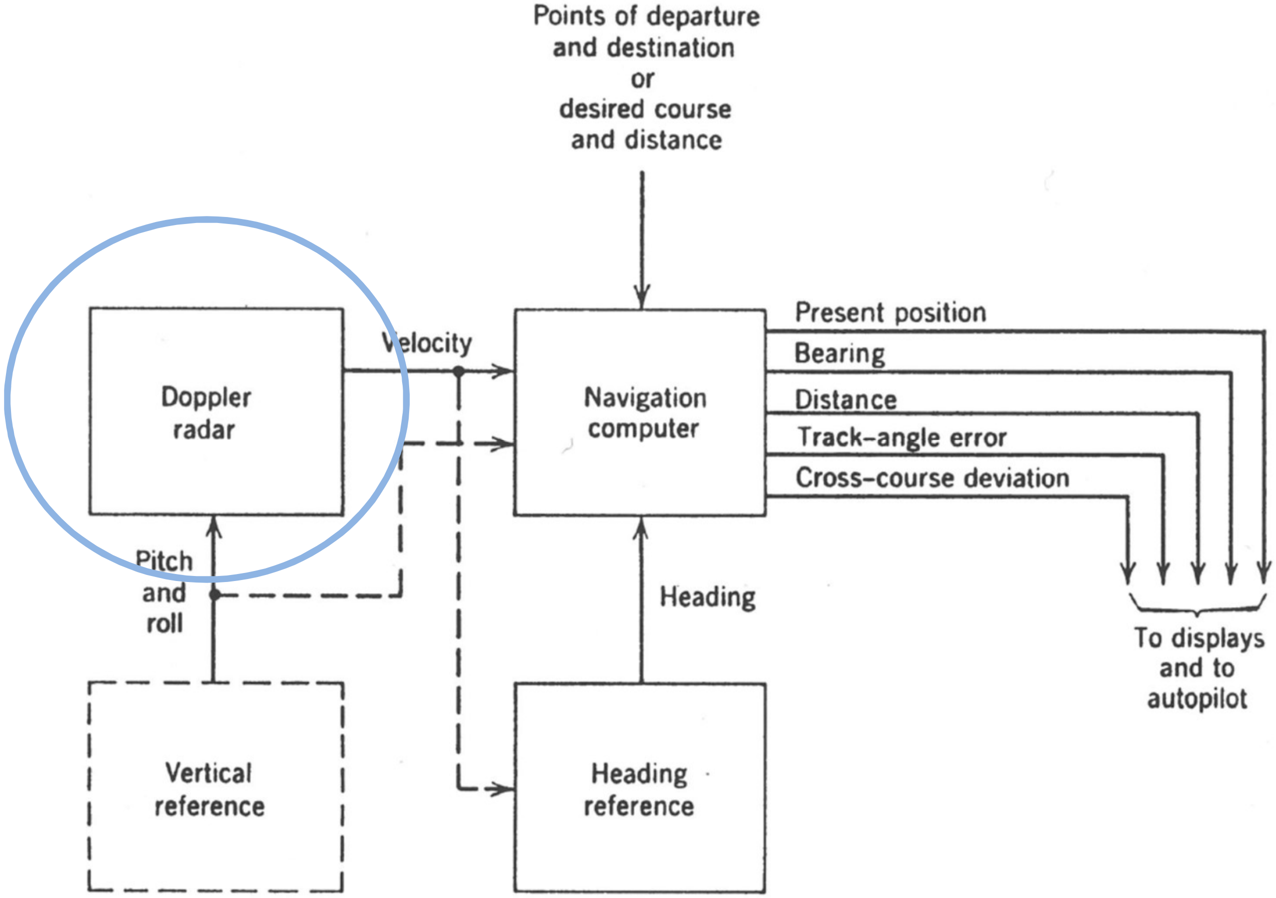
RADIOLOCATION

Dead-reckoning Methods

- Dead-reckoning measures *change in position* or measures the *velocity and integrates* it.
- Position uncertainty grows over time as the error is accumulated.

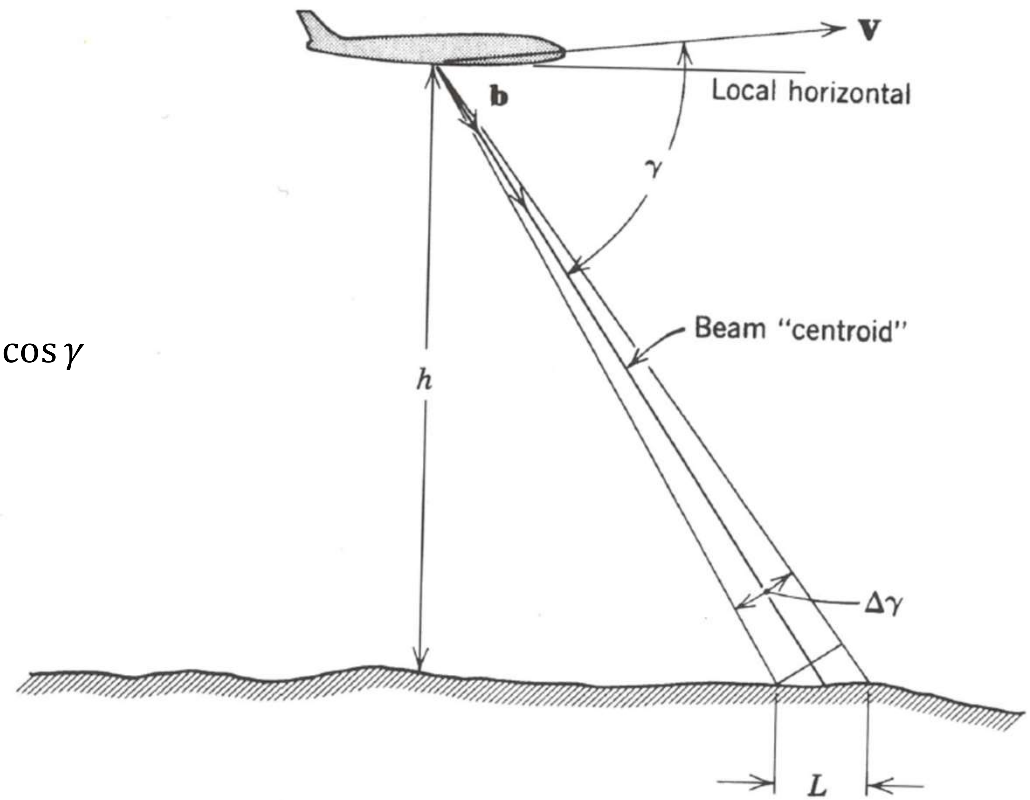


Doppler navigation systems



Basic Doppler radar beam geometry

$$f_D = \frac{2vf_0}{c}\cos\gamma = \frac{2v}{\lambda_0}\cos\gamma$$



JANUS Configuration  (3 antenna beams)

$$f_{D1} = \frac{2}{\lambda_0}(-V'_H \cos\gamma_H + V'_D \cos\gamma_D + V'_V \cos\gamma_V)$$
$$f_{D2} = \frac{2}{\lambda_0}(V'_H \cos\gamma_H + V'_D \cos\gamma_D + V'_V \cos\gamma_V)$$
$$f_{D3} = \frac{2}{\lambda_0}(V'_H \cos\gamma_H - V'_D \cos\gamma_D + V'_V \cos\gamma_V)$$

Where,

$$\cos\gamma_H = \cos\alpha_0 \cos\theta_0$$
$$\cos\gamma_D = \cos\alpha_0 \sin\theta_0$$
$$\cos\gamma_V = \sin\alpha_0$$

And

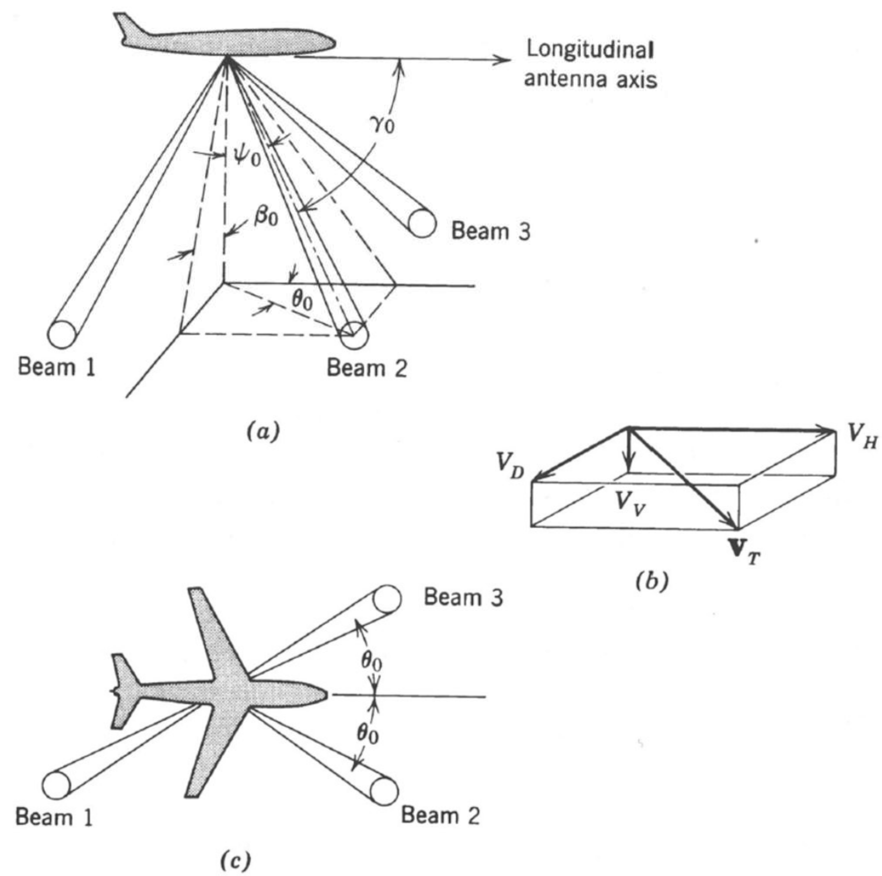
$$V'_H = \frac{(f_{D2} - f_{D1})\lambda_0}{4\cos\alpha_0 \cos\theta_0}$$

$$V'_D = \frac{(f_{D2} - f_{D3})\lambda_0}{4\cos\alpha_0 \sin\theta_0}$$

$$V'_V = \frac{(f_{D1} + f_{D3})\lambda_0}{4\sin\alpha_0}$$

Being, in aircraft coordinates:

- V'_H: The along-heading velocity component
- V'_D: The cross-heading (drift) velocity component
- V'_V: The vertical velocity component



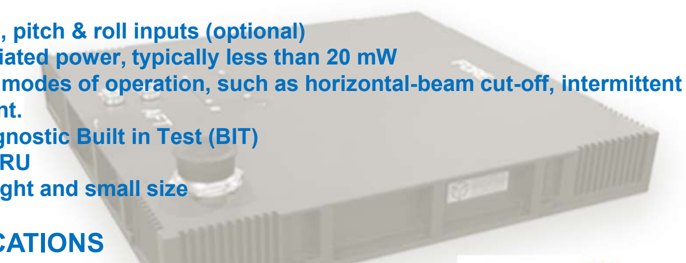
OPERATION FREQUENCIES

- Since 1996, the navigation radars operate at 13,325 GHz, within the reserved band from 13,25 GHz to 13,4 GHz.
- A good trade off is obtained between the antenna size (linear polarized) and the sensitivity for low speeds, and the effects produced by the rain and other atmospheric phenomena.
- The homodyne configuration is the most simple, but the isolation between the emitter and the receiver is poor due to the circulator isolation (usually 30 dB). It can be increased by making use of two different antennas and by introducing a sinusoidal FM modulation, in a similar way as the FM-CW altimeters.

CMA-2012 Doppler Velocity Sensor and Navigation System

FEATURES

- **13.325 GHz Frequency Modulation/Continuous Wave (FM/CW) at 20 mW**
- **Four-beam Janus configuration, together with FM/CW and large, effective antenna aperture**
- **Digital Signal Processing (DSP) for continuous spectrum analysis of signal returns**
- **Dynamic carrier breakthrough circuit**
- **Attitude rate range of up to 60 deg/sec in pitch and roll, and 100 deg/sec in azimuth**
- **Heading, pitch & roll inputs (optional)**
- **Low radiated power, typically less than 20 mW**
- **Tactical modes of operation, such as horizontal-beam cut-off, intermittent track, and silent.**
- **Full-diagnostic Built in Test (BIT)**
- **Single LRU**
- **Low weight and small size**



SPECIFICATIONS

- **Accuracy (2 Sigma) Component Sea (Bft 1) Land**
- **Vx** 0.30% Vt + 0.2 kt 0.25% Vt + 0.2 kt
- **Vy** 0.30% Vt + 0.2 kt 0.25% Vt + 0.2 kt
- **Vz** 0.20% Vt + 0.2 fpm 0.20% Vt + 0.2 fpm

Esterline CMC Electronics
MONTREAL • OTTAWA • CHICAGO • www.cmcelectronics.ca

- **Resolution** Better than 0.1 kt
- **Acquisition** Fully automatic; typically 40 msec
- **Weight** < 11 lb (5 kg)
- **Size** W 13.60” (343.5 mm) x H 14.67” (372.6 mm) x D 1.95” (49.5 mm), excluding connectors
- **Electrical Interface** MIL-STD-1553B; ARINC 429; digital and/or analog discretes
- **Power** 45 W (maximum) @ 28 VDC; 35 W typical
- **Environment** MIL-STD-810
- **EMI/EMC** MIL-STD-461/462 (HIRF to 200 V per meter); lightning to DO-160C
- **Reliability** 10,000 hr. MTBF, ARW environment

AMBIGUITY FUNCTION

RADIOLOCATION

AMBIGUITY FUNCTION

- Is a representation of the matched filter response, in terms of the target echo return time and the Doppler shift.
- Allows the evaluation of the performances and restrictions of the different radar waveforms.

The matched filter output y_{out} is the **cross-correlation function** of the transmitted signal $s(t)$ with the received signal $s_r(t)$:

$$y_{out}(t) = \int_{-\infty}^{+\infty} s_r(t) \cdot s^*(t - T_R')dt$$

Being T_R' the estimated time delay

AMBIGUITY FUNCTION

Assuming that the transmitted signal can be expressed as:

$$s(t) = u(t)\exp(j2\pi f_0 t)$$

Being $u(t)$ the signal envelope, and f_0 the transmission frequency.

The received signal will be:

$$s_r(t) = u(t - T_0)\exp[(j2\pi(f_0 + f_D)(t - T_0)]$$

Being T_0 the delay introduced, and f_D the Doppler shift.

Then, the matched filter output will be:

$$y_{out}(t) = \int_{-\infty}^{+\infty} u(t - T_0)\exp[(j2\pi(f_0 + f_D)(t - T_0)] \cdot u^*(t - T_R')\exp[-j2\pi f_0(t - T_R')]\,dt =$$

$$= \int_{-\infty}^{+\infty} u(t - T_0)u^*(t - T_R')\exp[j2\pi(f_D(t - T_0) + f_0(T_R' - T_0)]\,dt$$

AMBIGUITY FUNCTION

If we consider that is irrelevant the information about the transmission frequency f_0 and the delay time T_0, and we take the origin to be the true time delay and the transmitted frequency, then:

$$f_0 = 0; \;\; T_0 = 0$$

And then $T_0 - T'_R = -T'_R = T_R$

Then, the matched filter output will be:

$$y_{out}(t) = \int_{-\infty}^{+\infty} u(t) u^*(t + T_R) \exp[j2\pi f_D t] \, dt = \chi(T_R, f_D)$$

$T_R > 0$, implies a target beyond the true time delay T_0
$f_D > 0$, implies an approaching target

AMBIGUITY FUNCTION

The **ambiguity function** is the squared magnitude of $\chi(T_R, f_D)$:

$$|\chi(T_R, f_D)|^2 = \left| \int_{-\infty}^{+\infty} u(t) u^*(t + T_R) \exp[j2\pi f_D t] \, dt \right|^2$$

$T_R > 0$, implies a target beyond the true time delay T_0
$f_D > 0$, implies an approaching target

AMBIGUITY FUNCTION PROPIETIES

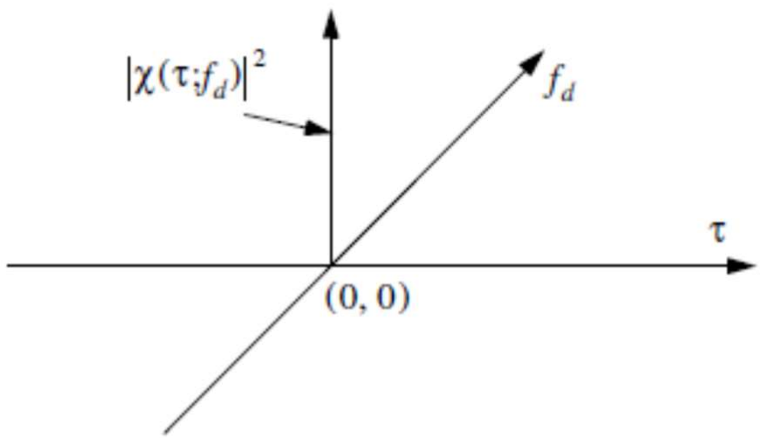
$$|\chi(T_R, f_D)|^2 = \left|\int_{-\infty}^{+\infty} u(t)u^*(t+T_R)\exp[j2\pi f_D t]\, dt\right|^2$$

$T_R > 0$, implies a target beyond the true time delay T_0
$f_D > 0$, implies an approaching target

1. Its maximum value equals the **pulse energy**:
$$|\chi(T_R, f_D)|^2{}_{max} = |\chi(0{,}0)|^2 = (2E)^2$$
2. Is a **symmetric function**:
$$|\chi(-T_R, -f_D)|^2 = |\chi(T_R, f_D)|^2$$
3. The **behavior on T_R axis**, equals the **cross correlation** function of $u(t)$
$$|\chi(T_R, 0\,)|^2 = \left|\int_{-\infty}^{+\infty} u(t)u^*(t+T_R)dt\right|^2$$
4. The **behavior on f_D axis**, equals the **signal frequency spectrum** of $u(t)$
$$|\chi(0, f_D)|^2 = \left|\int_{-\infty}^{+\infty} u^2(t)\exp[j2\pi f_D t]\, dt\right|^2$$
5. It's a **function of constant volume**
$$\iint |\chi(T_R, f_D)|^2 dT_R\, df_D = (2E)^2$$

IDEAL AMBIGUITY FUNCTION PROPIETIES

$$|\chi(T_R, f_D)|^2 = \delta(0,0)$$



AMBIGUITY FUNCTION OF DIFFERENT WAVEFORMS

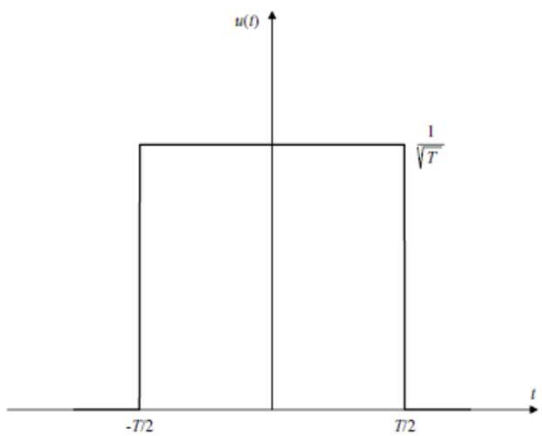


FIGURE 4.1 Complex envelope of a constant-frequency pulse.

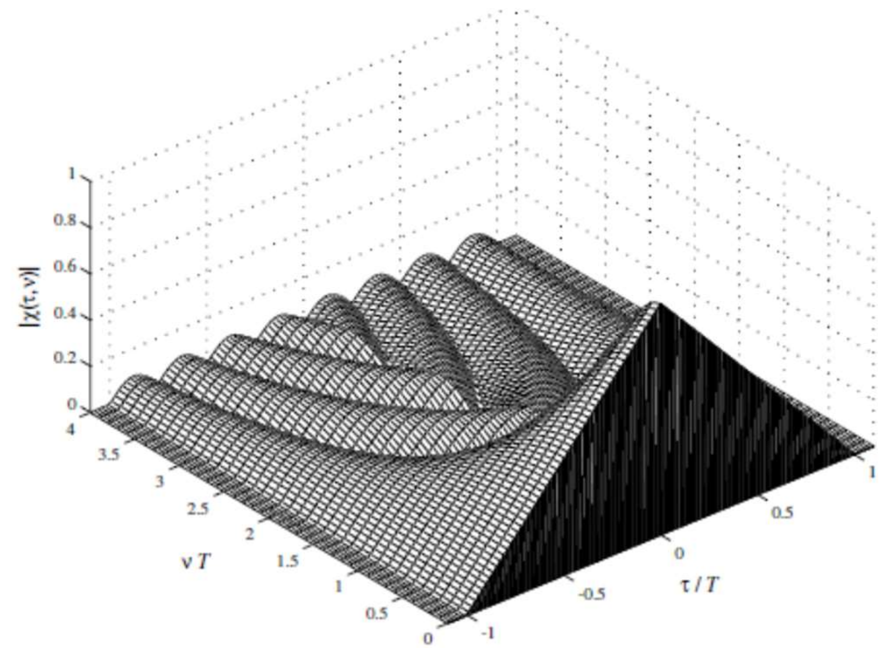


FIGURE 4.2 Partial ambiguity function of a constant-frequency pulse of length T.

AMBIGUITY FUNCTION OF DIFFERENT WAVEFORMS

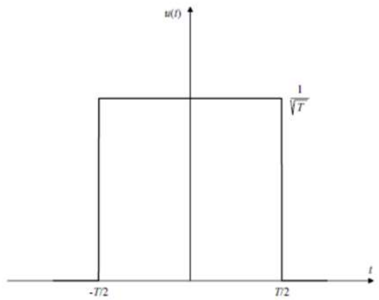


FIGURE 4.1 Complex envelope of a constant-frequency pulse.

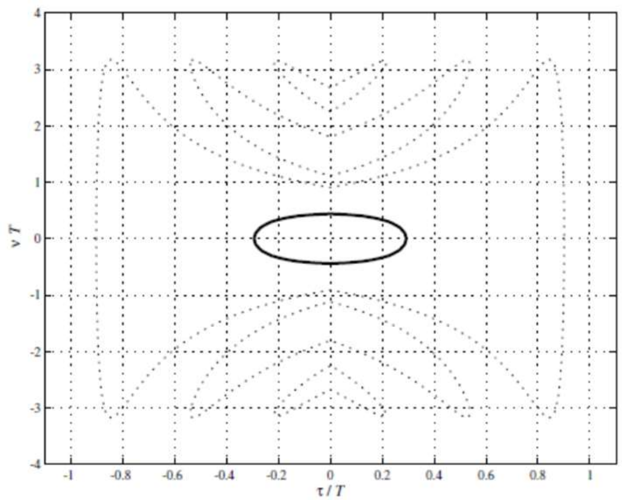


FIGURE 4.3 Contours 0.1 (dotted) and 0.707 (solid) of the AF of a pulse.

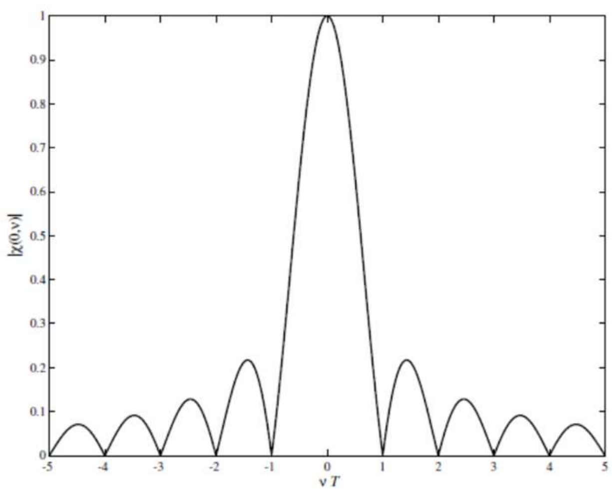


FIGURE 4.4 Zero-delay cut of the AF of a pulse.

AMBIGUITY FUNCTION OF DIFFERENT WAVEFORMS

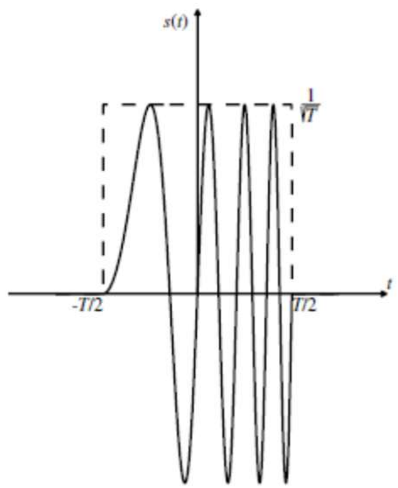


FIGURE 4.5 Linear-FM signal.

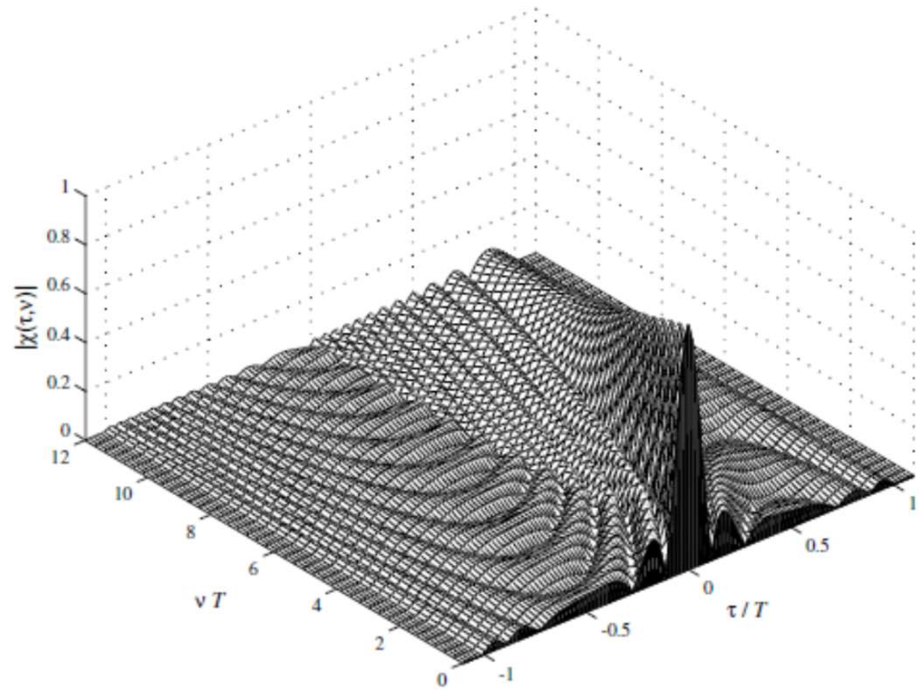


FIGURE 4.6 Partial ambiguity function of linear-FM pulse ($BT = 10$).

AMBIGUITY FUNCTION OF DIFFERENT WAVEFORMS

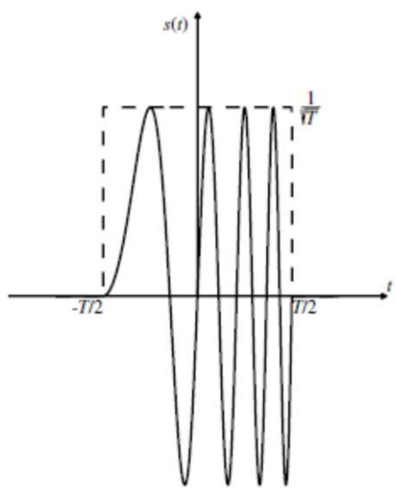


FIGURE 4.5 Linear-FM signal.

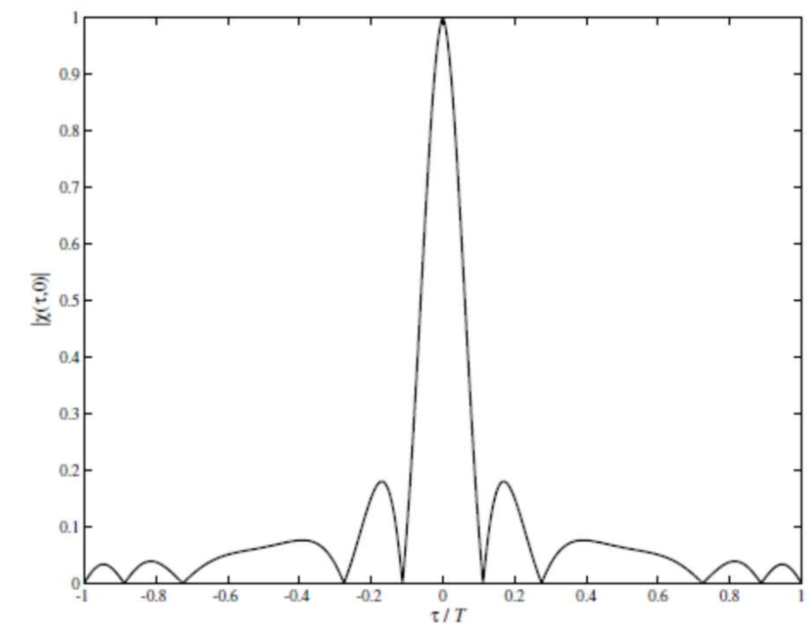


FIGURE 4.8 Zero-Doppler cut of the AF of LFM pulse with a time–bandwidth product of 10.