

Satellite Payloads 2025-2026 - Lesson's log

#	date	time	Topic	Teaching material
COM #01-02	23/09/2025 Room 5	13:00- 15:00	- Introduction to the course, web page, teaching material, "in itinere" tests and final exam structure - The three main payload categories: TLC, Satellite Navigation, and Earth Observation. - Common characteristics, specific orbital requirements, and peculiarities. - Example of Satellite Communication Systems - Geostationary satellites, Sir Clarke, example: the Inmarsat constellation	Slides: 01_Payload_intro https://youtu.be/V6jgJVHagno
	25/09/2025 Room 41	10:00- 12:00	- Lecture postponed	
	25/09/2025 Room 9	12:00- 14:00	- Lecture postponed	
	26/09/2025 Room 10	11:00- 13:00	- Lecture postponed	
COM #03-04	30/09/2025 Room 5	13:00- 15:00	- Global Antenna Beam from GEO, MEO, LEO: Beamwidth and Gain. Beamwidth to Gain relationship for symmetric conical antenna beams. - % of coverage of the Earth surface from the different orbits - Equation for the received density and received power. Impact of the ground receiving antenna equivalent area on the required satellite transmitted power. - Comparison of received power density from GEO, MEO, LEO global beams - Beam persistence from GEO, MEO, LEO - Approximate antenna directivity/gain for rectangular and elliptical antennas - Gain vs Aperture: received power formulation; - EIRP merit figure; - Directional antennas: beam steering/attitude control requirements	Slides: 02_Payload_link_budget_intro https://youtu.be/tdVgyl9S1NQ
COM #05-06	02/10/2025 Room 41	10:00- 12:00	- EIRP, Path Loss, equations for received power - RF Receiver scheme - Filtering needs at RF: reducing global power to be amplified, reduce noise power - Noise Power Spectral Density, - Noise in ideal BPF, noise in generic filter - Equivalent noise bandwidth and evaluation of noise power - Equivalent Base Band transfer function of RF filters - Equivalent noise bandwidth evaluation based on the equivalent BB transfer function - Signal-to noise ratio - Optimizing the Equivalent BB transfer function of the receiver to provide maximum output SNR	Slides: 03_Payload_matched_filter https://youtu.be/q1KUHA6qMtU

GNSS #01-02	02/10/2025 Room 9	12:00- 14:00	- Principles of operation of the global navigation satellite systems - Positioning in 1D, 2D, 3D and the required hypotheses - Pseudorange measurements, clock errors and synchronization problems. 4D solution and PVT estimation	Slides: GNSS_01_2025_principles_v7 https://youtu.be/XHIQnYfhnos
RAD #01-02	03/10/2025 Room 10	11:00- 13:00	- Introduction to space-based radar systems and to the ground-based radar for space surveillance. - Radar principle, - Radar equation, dynamic range; - pulsed vs. CW radar; blind range - The radar detection. And its performance parameters - The power problem for the detection in the far-range and the need to increase SNR / received echo energy	Slides: 21_Payload_2024_Radar_fundamentals https://youtu.be/GZkf3v9gZLE
COM #07-08	07/10/2025 Room 5	13:00- 15:00	- Maximum achievable SNR as energy over Noise power spectral density - Constant envelope signals and maximum energy - Optimizing the filter transfer function of the receiver to provide maximum output SNR - Derivation of the Matched Filter Transfer (MF) function - Interpretation of the resulting $H(f)$ in the frequency domain	Slides: 03_Payload_matched_filter https://youtu.be/FMitgTq9VVc
COM #09-10	09/10/2025 Room 41	10:00- 12:00	- Need of the delay $t_0 \geq$ pulse length to make the MF causal - Signal at the output of the matched filter and of the inverse filter in frequency domain and in time domain - MF output as a translated and scaled waveform autocorrelation - Behaviour of the rect pulse - Compression of pulses with $B \gg$ inverse of duration - BB digital modulator basics - Mapping binary streams into sequence of symbols; symbol rate vs bit rate - Level generation and their distance - Transmit pulse shaping and the possibility of intersymbolic interference	Slides: 03_Payload_matched_filter 05_Payload_ISI https://youtu.be/P4tt4TVxJqA
GNSS #03-04	09/10/2025 Room 9	12:00- 14:00	- Clock scheme and oscillator models - Clock errors: its behavior and its correction - Transferring the required data to the user receivers: predictions, fitting to parametric functions, upload and update every 2 hours. - Estimation of satellite positions and clock errors from the Earth: Reference/Monitor stations, Master Control Station and the inverse GNSS equations. - Global structure of the Ground Segment.	Slides: GNSS_01_2025_principles_v7 https://youtu.be/MSM2WBE5dPs
RAD #03-04	10/10/2025 Room 10	11:00- 13:00	- Use of long pulses is required to improve SNR - SNR improvement using a rect pulse K times longer: Increased SNR interpreted as (i) K times more	Slides: 21_Payload_2024_Radar_fundamentals

			energy, which provides improved Matched filter output $2E/N_0$; (ii) rect pulse has the same received power level, but K times narrower noise bandwidth ($1/\tau_P$); - Increased blind range - the Range resolution: evaluation for a rect pulse - Importance of range resolution in surveillance and imaging sensors. - Ground-range resolution for imaging radar - Need for long compressible pulses to provide at the same time high energy and high range resolution	https://youtu.be/EagisOlj6H4
COM #11-12	14/10/2025 Room 5	13:00-15:00	- Digital transmission using a basic pulse shape: rect pulse, matched filtering and sampling on receive. - Global Transfer function of the TX-Channel-RX - Effect of the global transfer function and the problem of the InterSymbolic Interference (ISI) - Zero ISI condition in time and frequency domain - Symmetric characteristic of the Zero-ISI Transfer Function - Symmetric characteristic of the Zero-ISI Transfer Function - Minimum bandwidth, triangular and trapezoidal shape function - Splitting the raised-cosine shape between TX and RX filter to apply matched filtering	Slides: 03_Payload_matched_filter 05_Payload_ISI 04_Payload_Noise https://youtu.be/f-asW4DWBbc
COM #13-14	16/10/2025 Room 41	10:00-12:00	- Description of the Global digital transmission scheme: Coding – Modulation – Transmission – Demodulation – Decoding - The 3 phases of the Coding (& Decoding): Source Coding; Encryption, Channel Coding with their purposes. - Mapping and demapping: from bit sequences to points in the I&Q constellation plane - Mapping binary streams into sequence of symbols; symbol rate vs bit rate - PSK constellations, QAM constellations - Satellite APSK constellations	Slides: 03_Payload_matched_filter https://youtu.be/3g6ELikHfCl
GNSS #05-06	16/10/2025 Room 9 PL	12:00-14:00	- Keplerian orbits and GNSS ephemeris - Satellite position reconstruction from Keplerian parameters (also with corrections) - The three Segments: Space, Ground and User - Initial idea of global positioning performance - Navigation message structure and timing	Slides: GNSS_01_2025_principles_v7 https://youtu.be/BJUU-8eWWFQ
RAD #05-06	17/10/2025 Room10	11:00-13:00	- At MF output rect becomes a triangle; high resolution requires wide bandwidth waveforms; - Search for long, constant envelope waveforms that provide a high compression ratio - Search for waveforms with high compression ratio: the phase modulation (discrete or analog) and the different ways to obtain a wide band waveform - Phase codes. Example of the Barker codes providing compression - Barker codes: properties of their autocorrelation especially for sidelobes; problems in the presence of Doppler frequency	Slides: 21_Payload_2024_Radar_fundamentals 22_Radar_pulse_compression https://youtu.be/-K-fmT1YEng

COM #15-16	21/10/2025 Room 5	13:00- 15:00	- Satellite APSK constellations - I&Q modulator - I&Q demodulator - Carrier phase shift caused by the propagation delay in the ideal propagation channel - Doppler frequency; its presence in the received signal and its effect on the output of the I&Q demodulator - Need for a phase estimation (Phase Lock Loop) to synchronize the I&Q demodulation - Mapping and demapping: from bit sequences to points in the I&Q constellation plane	Slides: 02_Payload_link_budget_intro 04_Payload_Antenna https://youtu.be/rhyAv4kFj7Y
COM #17-18	23/10/2025 Room 41	10:00- 12:00	- D/A conversion with holding and bandwidth requirements - Pulse shaping & ISI avoidance - Transmission filtering and emission mask - Sample spectral emission mask for DVB-S - Raised-cosine transfer function family and roll-off parameter - Equivalent Base Band transfer function of RF and IF filters - Global receiver Equivalent Base Band transfer function	https://youtu.be/Admsk0cfbiE
GNSS #07-08	23/10/2025 Room 9 PL	12:00- 14:00	- Navigation Solution via Taylor series expansion - Selection of the initial guess - Derivation of matrix H - Iterative algorithm and stopping criterion	Slides: GNSS_02_atmosphere_and_soluti on https://youtu.be/dwpWOxLGoKs
RAD #07-08	24/10/2025 Room 10	11:00- 13:00	- Search for waveforms with high compression ratio: the phase modulation (discrete or analog) - Range resolution as a function of the pulse bandwidth and the different ways to obtain a wide band waveform - Chirp signal to guarantee a desired bandwidth: its frequency and phase characteristic - Spectrum of the Chirp waveform - Ideal compressed chirp waveform: MF output and sidelobes	Slides: 22_Radar_pulse_compression https://youtu.be/vHTyWckTqzE
COM #19-20	28/10/2025 Room 5	13:00- 15:00	- Temporal and spectral characteristics of thermal noise - Equivalent thermal noise level at the receiver input - Thermal noise power and SNR definition Real vs. ideal noiseless receiver; noise contribution from the receiver - Equivalent noise temperature - G/T merit figures; - Noise Figure and SNR degradation - noise figure for cascaded devices - Equivalent noise Temperature for cascaded devices	Slides: 04_Payload_Noise https://youtu.be/PIYnnoaDBCg

COM #21-22	30/10/2025 Room 41	10:00- 12:00	- Antenna Noise temperature as combination of cosmic background, atmosphere, antenna and waveguide - Level of the contributions to the antenna noise from ITU 372 - System noise at different ports of the receiver - Example of System temperature evaluation and improvement with cryogenic receivers - Nonlinear amplifiers, - AM/AM and AM/PM distortion of Power amplifiers and the need of backoff & predistorsions	Slides: 04_Payload_Noise 07_Nonlinear https://youtu.be/M_OHd3Wvr3Y
GNSS #09-10	30/10/2025 Room 9 PL	12:00- 14:00	- Usage of GNSS waveforms for ranging - Requirements for GNSS waveforms: maximum energy and bandwidth - FDMA, TDMA, CDMA - Orthogonality of the waveforms and their separation in the code-domain - MLS codes and their generation with shift registers	Slides: GNSS_03_signal.pdf https://youtu.be/QZt6VIFLdao
RAD #09-10	31/10/2025 Room 10	11:00- 13:00	- Compressed chirp waveform: MF output and sidelobes - Fresnel sidelobes - Sidelobe Control filters and its effects - Spectral windows and their performance - Design with spectral windows - General problems in the presence of Doppler frequency	Slides: 22_Radar_pulse_compression https://youtu.be/cwr7n3_siw0
COM #23-24	04/11/2025 Room 5	13:00- 15:00	- Nonlinear amplifiers, 1dB compression point and AM distortion - Intermodulation caused by the nonlinear devices and spectral contributions - 2nd order and third order intermodulation products and their frequency allocation - In-band contributions to be avoided from odd-order terms	Slides: 07_Nonlinear https://youtu.be/m0ALI0hLP_A
COM #25-26	06/11/2025 Room 41	10:00- 12:00	- Evaluation of the dynamic range: signal to intermodulation ratio as a function of the input level - OIP3 for system of cascaded blocks - Receiver schemes: - Direct I&Q receiver and its properties - Motivation of the filter before LNA in the receive schemes - The heterodyne receiver and its filtering stages - Heterodyne receiver: filtering capability as % of the carrier frequency and the advantages of the 2 or 3 stage down-conversion scheme	Slides: 07_Nonlinear 08_Receiver https://youtu.be/0UILLU3Wg9BU
GNSS #11-12	06/11/2025 Room 9 PL	12:00- 14:00	- Properties of LMS and their cyclic autocorrelation - Difference between autocorrelation and cyclic autocorrelation	Slides: GNSS_03_signal.pdf https://youtu.be/byTteHNtKxw

			- Exercise of the evaluation of the cyclic autocorrelation - Generation of the C/A codes and their properties - Basic principle of the correlation receiver and its ability in discriminating the signals from the different satellites	
RAD #11-12	07/11/2025 Room10	11:00-13:00	- definition and sign of Doppler - I&Q demodulation and residual Doppler - Doppler frequency RADAR measurements and their resolution - single-pulse and sequence Doppler measurement - Frequency resolution - Ambiguity Function: effect of Doppler with examples for rect, barker codes, Chirps	Slides: 21_Payload_2024_Radar_fundamentals https://youtu.be/SKZh9sDTsq8
COM #27-28	11/11/2025 Room 5	13:00-15:00	- the mirror frequency and the image removal filter before the down-conversion mixer - Local oscillator and IF selection; High side and low side injection mixer operation - The bent-pipe transponder scheme and its stages: the DVB-S bent-pipe transponder - Basic mixer implementations: nonlinearity-based and switch circuit-based solutions - Mixer spurious to affect the receive signal and its spur chart - Mixer nonlinearity and OIP3 - Structure of the bent-pipe satellite payload	Slides: 09_Payload_Mixer 10_Payloads_2025_Transponder https://youtu.be/jpK6m9u7TbU
RAD #13-14	11/11/2025 Room DIET09	15:00-17:00	- Sequences of radar pulses can provide: increased SNR and increased Doppler resolution - Sampling return echoes Maximum range and range resolution. - Pulse sequence transform in the absence and presence of Doppler frequency - Filter adapted to pulse sequence - $H(f)$ of the filter adapted to the sequence of pulses - Vector representation of the coherent integration - Sequence-matched filter in the presence of Doppler and its approximate version with single-pulse matched filter implemented at zero Doppler. - Choice of filters at k/NT and bench frequencies	Slides: RADAR_03_coherent_pulse_integration_v2 https://youtu.be/ijEJOBoIURA
COM #29-30	13/11/2025 Room 41	10:00-12:00	- Structure of the bent-pipe satellite payload with multiple separately amplified channels - Organization of the channels - Use of circular right and left- handed polarization - Bent pipe transponder scheme: global amplification, change of frequency - channel separation before amplification - Intermediate frequency selection - Switch matrix for satellites with multiple beams - Typical 4 reflectors, GEO TLC satellite	Slides: 10_Payloads_2025_Transponder https://youtu.be/kfKwBbfi73Y

GNSS #13-14	13/11/2025 Room 9 PL	12:00- 14:00	- Gold codes - GPS carrier generation and frequency allocation - Spectrum of GPS signal - Block diagram of the GPS receiver - Satellite signal search procedure in delay and Doppler frequency - Time To First Fix and number of receiving channels - Assisted GPS	Slides: GNSS_03_signal.pdf https://youtu.be/qIY9Fax-YkU
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COM #31-32	18/11/2025 Room 5	13:00- 15:00	- Applications served by Bent-pipe transponders: broadcast and fixed links (or limited flexibility) - The SNR of up&downlink connection with the bent-pipe transponder - Regenerative transponders scheme with digital demodulation and re-modulation. - Performance of multiple links path with regenerative transponders global BER - Applications served by regenerative transponders, allowing address management and satellite network operation: the LEO satellite mobile communication constellations - The hertzian dipole antenna and its radiation characteristics in the far field - Field linear polarizations: V and H	Slides: 10_Payloads_2025_Transponder 11_Payload_Antenna_v3 https://youtu.be/knG_mj_R3xA
RAD #15-16	18/11/2025 Room DIET09	15:00- 17:00	- Doppler frequency and pulse-to-pulse phase variation - Adapted filter and slow-time/fast-time matrix implementation - Interpretation of the sequence-matched filter in the I&Q plane as a realignment of vectors before the sum - filter bank at k/NT and FFT frequencies - Ambiguity of the Doppler frequency using a sequence with selected PRF	Slides: RADAR_03_coherent_pulse_integration_v2 https://youtu.be/Hw1wrzGpC9Q
COM #33-34	20/11/2025 Room 41	10:00- 12:00	- The hertzian dipole antenna and its radiation characteristics in the far field - Field linear polarizations: V and H - The dipole antenna pattern - Uniform current case and sinc pattern - Aperture of the beam - Half-wavelength dipole - Using the dipole as a basis for 1D and 2D antennas	Slides: 11_Payload_Antenna_v3 https://youtu.be/iUkq_U1tRJc
GNSS #15-16	20/11/2025 Room 9 PL	12:00- 14:00	- Closed loop receiver operation for the accurate estimation of the pseudoranges (discriminator, waveform generator with NCO and loop filter) - Propagation errors and their correction - Effect of the atmosphere on the pseudorange measurements - Analytical expression of the error as a function of the refraction index - Tropospheric effects and compensation - mask angle - Effect of ionosphere on phase propagation	Slides: GNSS_04_receiver GNSS_02_atmosphere_and_solution https://youtu.be/H_fEjRtpzgA

COM #35-36	25/11/2025 Room 5	13:00- 15:00	- Telemetry antennas - Aperture antennas - Reflector antennas - Phased array antennas	Slides: 11_Payload_Antenna_v3
RAD #17-18	25/11/2025 Room DIET09	15:00- 17:00	- Lateral lobes of transverse filters/FFT and dynamics problem in detection - Use of weighing nets for Doppler lobe control - Weighing network effect, selection parameters, worst-case filter intersection loss - Ambiguity in the range-Doppler plane, unambiguous area - - Relationship between cross-range position and Doppler frequency inside the antenna footprint - Exploitation of Doppler resolution to provide cross-range resolution	Slides: RADAR_03_coherent_pulse_integration_v2 RADAR_04_SAR_fundamentals
COM #37-38	27/11/2025 Room 41	10:00- 12:00	- De-mapping operation - Noise at the output of the I&Q demodulator - Joint PDF of the noise components and error probability dependent on the modulus - Minimum distance criterion - Decision regions and their definition - Conceptual evaluation of the symbol error probability by integration of the joint PDF - Probability of symbol error for the most common digital modulations : - BPSK, QPSK & M-PAM by integration of the 2D Gaussian PDF - Probability of symbol error for M-PSK and M-APSK - From symbol error to bit error - Expressions as a function of E_b/N_0 - Communication link sizing starting from BER	Slides: 08_Payload_BER
GNSS #17-18	27/11/2025 Room 9 PL	12:00- 14:00	- correction with navigation message coefficient and exploiting dual-frequency measurements - dispersivity of ionosphere and relationship between phase and group propagation speed and delay. - Error budget for the pseudorange errors - Positioning error vs pseudorange error and the Dilution of Precision (DOP) - Positioning error covariance matrix derivation - Positioning accuracy improvement by reducing the DOP: Geo, pseudolites, doubling constellation, joint use of multiple constellations	Slides: GNSS_02_atmosphere_and_solution GNSS_05_accuracy

COM #39-40	02/12/2025 Room 5	13:00- 15:00	- Single parity bit for error detection - Automatic Retransmission Request in half & full duplex modes: PRO's and CON's - Block codes and their characteristics - Hamming distance between bit sequences - Forward Error Correction exploiting redundancy bits - Error detection and correction as a function of the Hamming distance - Matrix implementation of block coding and decoding and the syndrome - Perfect codes	Slides: 11_Payload_Coding
RAD #19-20	02/12/2025 Room DIET09	15:00- 17:00	- Synthetic Antenna approach, as alternative interpretation of cross-range resolution - Synthetic Antenna aperture length, Synthetic beamwidth and synthetic footprint (cross-range resolution) - Improved Stripmap resolution with smaller antenna length - Maximum integration time and maximum cross-range resolution in STRIP-map mode - Spotlight SAR mode	Slides: RADAR_04_SAR_fundamentals
COM #41-42	04/12/2025 Room 41	10:00- 12:00	- Hamming codes and their ratio - The cyclic code families: BCH and Reed-Solomon with their characteristics - Convolutional codes: coding and decoding approaches - Concatenated codes, Turbo-Codes and LPDC	Slides: 11_Payload_Coding 13_Payload_Shannon
GNSS #19-20	04/12/2025 Aula 9 PL	12:00- 14:00	- Fixed and variable Geometry - Positioning accuracy in 1D - 2D and 3D Gaussian PDF characteristics - 2D and 3D regions with High PDF values - GNSS Positioning accuracy in 2D & CEP - Probability ellipse and its derivation	Slides: GNSS_05_accuracy
COM #43-44	09/12/2025 Room 5	13:00- 15:00	- Evaluation of BER with error correction coding and performance comparison of coding and modulation approaches. - Mention to the Shannon Coding Theorem - Example of the DVB-S standard receiving scheme - Parameters for Global Beam operation in C-Band; Saturated power and transmit backoff, evaluation of EIRP, Free Space Losses (FSL) and received power in clear sky conditions. - CNR in clear-sky conditions and margin - SNR vs E/N_0 vs C/N_0 for the link budget description and relationship to the matched filter optimum output: matched filter gain G. - Discussion of an Example of Link budget evaluation for GEO Global Beam downlink	11_Payload_Coding 13_Payload_Shannon

			- Satellite elevation and coverage limitations when requiring a non-zero elevation - - Global Earth coverage with minimum assigned elevation angle - A look at the Starlink constellation plan for global coverage - Evolution of the GEO DVB-S standards, including variable coding and modulation schemes - Adaptive Coding and ModulationM - LEO Internet Satellites	
RAD #21-22	09/12/2025 Room DIET09	15:00-17:00	- Satellite iso-range and isodops: best antenna pointing strategy & left-right ambiguity - Frequency change for the individual scatterer as a function of slow time and the cross-range chirp - Duration, bandwidth, slope and compression ratio of the slow-time chirp - Compression of the slow-time chirp to focus the SAR image and achievable resolution	Slides: 24_SAR_fundamentals.pdf
COM #45-46	11/12/2025 Room 41	10:00-12:00	-	Slides: 12_Payload_ACM_SatTV_and_Internet
GNSS #21-22	11/12/2025 Room 9	12:00-14:00	- Performance parameters: Accuracy, Availability, Integrity and Continuity - Pseudorange error removal using Local Area Differential approach: SV clock, ionospheric and tropospheric errors - Correction of equivalent error in the ephemeris prediction and its effectiveness - Ground Based Augmentation System (GBAS) scheme - Need for wide area correction for route navigation and problems to extend corrections to a Wide Area - WAAS & EGNOS	Slides: GNSS_06_performance and Diff
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	16/12/2024 Room 5	13:00-15:00		
RAD #23-24	16/12/2024 Room DIET09	15:00-17:00	- Chirp matched filter as a way to compensate the time-varying Doppler of the chirp - Near field antenna interpretation of SAR quadratic phase compensation - Changing slope and aperture inside swath, with constant Doppler Bandwidth - Range cell migration - Range cell migration compensation - Radar PRF: azimuth ambiguity, range ambiguity	Slides: 22_Satellite_RADAR24 25_SAR_quality_parameters 26_SAR_constellations 27_Radar_Altimetry_and_Sounding
	18/12/2025 Room 41	10:00-12:00	-	Slides:
GNSS #23-24	18/12/2025 Room 9 PL	12:00-14:00	- Galileo signals and interoperability with GPS - Galileo offered services - Performance of the offered services - Galileo system architecture for integrity	GNSS_07_Galileo
			- PRF selection diagrams	

			- Bounds for Radar PRF selection and bounds on antenna area and/or information - Range cell migration and its compensation - SAR quality parameters - SAR Constellations - Radar altimetry and Sounding	
			- Range accuracy of surveillance function vs range accuracy of tracking function - Examples where tracking radar require precision (prediction of location and time of impact of re-entry/launcher trajectory prediction) - Angular accuracy of radar measurements (tracking vs surveillance) - High accuracy of angle estimation using antenna scan - Monopulse antenna and its principle of operation - Dependency of range and angular accuracies on SNR	