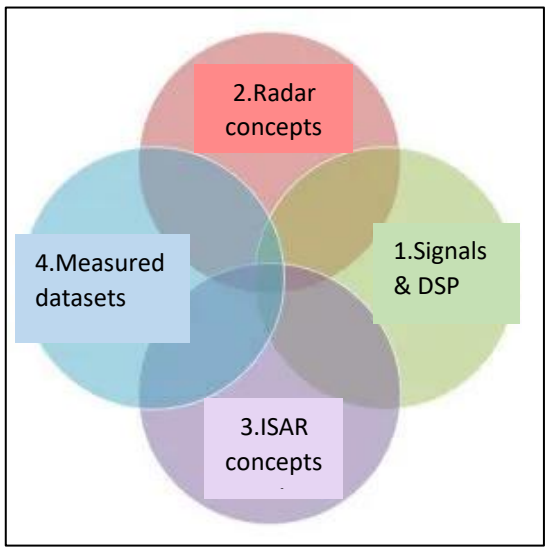
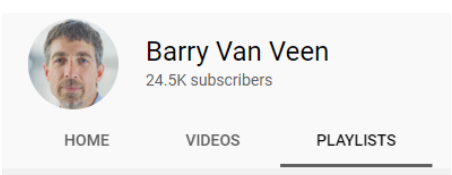
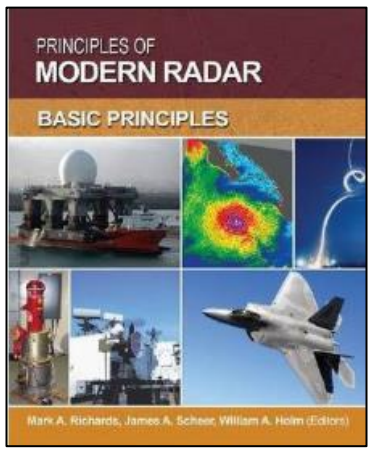
YAG23-05 Quick-look processor for Inverse Synthetic Aperture Radar (ISAR) imaging of sea vessels

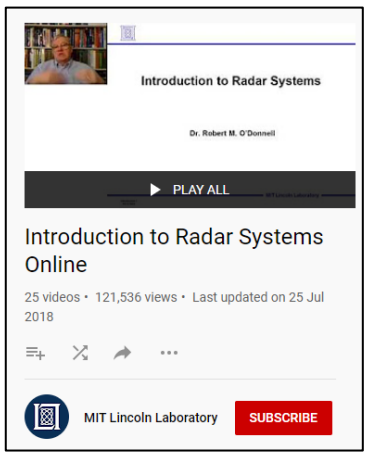


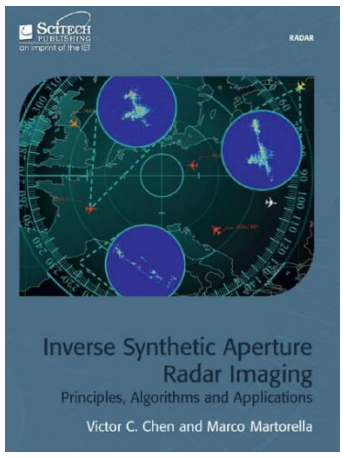
Important learning areas

	Topics	Source used
1	Signals and Digital Signal Processing (DSP)	EEE3092F (Signals and Systems II) – lecture slides EEE4114F (Digital Signal Processing) – course notes YouTube – Professor van Veen
2	Radar concepts	Book - Principles of Modern Radar Lecture video - MIT Lincoln Laboratory. See https://www.youtube.com/playlist?list=PLUJAYadtuizA8RC2Qk8LfmiWA56HZsk9y
3	Radar imaging or Inverse Synthetic Aperture Radar (ISAR) concepts	Book on “Inverse Synthetic Aperture Radar” imaging by Chen and Martorella
4	Measured datasets	Spanish data of the Altera vessel CSIR data of small boats measured in Cape Town
5	Translation motion compensation: Range alignment and autofocus techniques	Algorithms 1. Range alignment algorithm (Haywood) 2. Dominant Scatterer Autofocus (DSA) 3. Multiple Scatterer Autofocus – Yuan autofocus









1. Signals and Systems concepts

<table>
<tr><th></th><th>Topic</th><th>Source</th><th>Tasks to do and questions to answer</th></tr>
<tr><td>1</td><td>Spectrum of a signal</td><td>EEE2047S Signals and Systems course notes/slides
EEE3092F Signals and Systems II course notes/slides
EEE4114F Digital Signal Processing course notes/slides

See Prof Van Veen's youtube video on "The Spectrum: Representing Signals as a Function of Frequency"
https://www.youtube.com/watch?v=xh5pLY3f6H8

See Prof Van Veen's youtube video on "The Spectrum of Sampled Signals"
https://www.youtube.com/watch?v=y794OO606eg

Browse through Principles of Modern Radar textbook.
• Nyquist sampling for real signals and complex signals
• Section 8.3 on the Fourier Transform of a complex signal
• Section 8.4.1 Spectrum of a real sinusoid
• Section 14.4.1 – 14.4.2 Windowing

YouTube video that builds up to the Discrete Fourier Transform
https://www.youtube.com/watch?v=mkGsMWi_j4Q</td><td>Tasks
1. In MATLAB, generate a real sinusoidal signal, y = sin(2*pi*f*t), with the following parameters
• Sampling frequency, fs = 20 Hz
• Frequency of the sinusoid, f = 4 Hz
• Number of samples, N = 16, t = (0:1: (N-1))*1/fs

Plot the signal in the time domain and the frequency domain. Use the fft function to transform the signal from the time domain to the frequency domain. For the time domain plot label the x-axis as time in (ms). For the frequency domain plot, or the spectrum, label the x-axis as frequency in Hz and the y-axis in decibels (dB) and not linear units

2. Repeat task 1,but generate a complex sinusoidal signal, y = exp(j*2*pi*f*t);
3. Generate a complex signal with two sinusoidal signals. One with frequency, f1 = 4 Hz and another at f2 = -6Hz.
4. Generate a complex signal with two sinusoidal signals. One with frequency, f1 = 4 Hz and another at f2 = 10 Hz.

Questions
1. For the real sinusoids in task 1, why are there two peaks in the spectrum? What formula is used to calculate the values along the frequency axis in Hz? [Hint: read up about fftshift]
2. For the complex sinusoid in task 2, why is there one peak in the spectrum? Label the frequency axis with positive and negative frequencies.
3. In task 3, how many peaks are there in the spectrum?
4. In task 4, what are the locations of the peaks? What happened to the signal with a frequency of 10 Hz?
5. Explain what is meant by 'frequency resolution' and how is the value of the frequency resolution related to the coherent processing interval?
6. Explain what is the Nyquist criteria for real signals.</td></tr>
<tr><td></td><td>Spectral estimation techniques</td><td>EEE2047S Signals and Systems course notes/slides
EEE3092F Signals and Systems II course notes/slides
EEE4114F Digital Signal Processing course notes/slides

See Prof Van Veen's youtube video on the Discrete Fourier Transform and short-time Fourier Transform and the spectrogram. See videos
• https://www.youtube.com/watch?v=HUJDpmocv_c
• https://www.youtube.com/watch?v=NA0TwPsECUQ

See Prof Van Veen's youtube videos on "Windowing and the DTFT"
https://www.youtube.com/watch?v=iwLnVKNGxAo</td><td>Tasks
1. In MATLAB, compute the spectrogram of the following signal x = [1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1], where the vector x has 20 elements. Let the sampling frequency fs = 2.

Write code to compute the spectrogram of the signal and plot a signal of frequency versus time. Let the frame length or the window length be 4. Let the overlap between two successive frames be 50%. Assume the window function is w [1 1 1 1]. So, no windowing is applied. So, frame one will involve elements 1 to 4. Frame 2 will involve elements 3 to 6, frame 3 will have 5 to 8, etc.

1a. How many frames are there?
1b. Write a formula to compute the number of frames based on the input parameters (frame length, overlap factor and length of the input vector).
1c. What are the processing steps in computing the spectrogram? Write out the algorithm in pseudocode.
1d. Write MATLAB code to compute the spectrogram and plot the result. Suggestion: use the function imagesc( ) to plot visualise a matrix.

2. In MATLAB, generate a complex chirp signal, with the following parameters:
• Sampling frequency, fs = 192 kHz
• Start frequency of the chirp, f = 20 kHz
• Stop frequency of the chirp, f = 40 kHz
• Duration of the chirp = 1 s

Write code to compute the spectrogram of the signal and plot a signal of frequency versus time. I've deliberately not mentioned all the parameters and parameter values you should use. I'd like you to explore this problem deeper and get to a solution more independently than we did with computing the spectrum of the signal earlier.

Questions
1. Which parameters were deliberately not mentioned in the problem that you had to discover and choose values for?
2. Explain why it is important to apply a window to the time-domain data before applying the fft.</td></tr>
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2. Radar concepts [Link to MIT lecture video playlist: https://www.youtube.com/playlist?list=PLUJAYadtuizA8RC2Qk8LfmiWA56HZsk9y]

	Topic	Source	Tasks to do and questions to answer
1	Real world radar systems	Intro to Radar Systems: • Watch MIT lecture video, Lecture 1: slides 1 – 16	Questions 1. What radar systems do you think we have in Cape Town or in South Africa? What functions are performed by these radar systems?
2	Block diagram of a radar and concept used to estimate range	Read POMR book • Section 1.1 - Section 1.2	Questions 1. Let T = time in seconds for round-trip travel, c = speed of light in meters per second, then express the range to the target in terms of T and c
3	EM waves and spectrum, wavelength, frequency, phase, Radar bands, superposition, intensity, polarisation, radar block diagram, radar equation, SNR, dB	Intro to Radar Systems: • Watch MIT lecture video, Lecture 1: slides 17 – 29 Browse POMR book • Section 1.3	Questions 1. What is the wavelength of EM signal at X-band? Give your answer in centimetres (cm).
4	Radar waveforms, Radar Cross Section (RCS), pulse compression, bandwidth and range resolution, coherent integration, Doppler, Doppler shift, Doppler spectra	Intro to Radar Systems: • Watch MIT lecture video, Lecture 1: slides 30 – 48	Questions 1. Explain the benefits of matched filtering. 2. Why is the bandwidth of the transmit signal important? Or, explain how bandwidth affects the radar's performance. 3. Is a higher bandwidth values desired, or a lower bandwidth value? 4. For moving targets, why information can be gained from the Doppler frequency? 5. What is the mathematical relationship between Doppler frequency and the radial velocity of a target?
5	Radar waveforms – CW and Pulse Doppler Radars	Read POMR book • Section 1.5.1 - Section 1.5.2	Questions 1. Explain what is an 'unambiguous range measurement' and an 'ambiguous range measurement'. Provide an example with values in your explanation. Choose values for PRF, and the range of the target(s). Assume c = speed of light.
6	Range concepts – Range resolution	Read POMR book • Section 20.3	Questions 1. Explain the concept of range resolution 2. What is the formula for range resolution ΔR ?
7	Range concepts – pulse compression or matched filtering [for Pulse-Doppler Radars]	Browse through POMR book (do not study the math is any detail) • Section 20.1 – 20.2.10	Questions 1. Draw the signal before matched filtering and after matched filtering 2. What benefits are gained by performing matched filtering?
8	Range concepts – pulse compression and waveforms [for Pulse-Doppler Radars]	Browse through POMR book (do not study the math is any detail) • Section 20.5 – Pulse compression waveforms • Section 20.6 – Pulse compression gain • Section 20.7 – Linear frequency modulated waveforms Intro to Radar Systems: • Watch MIT lecture video, Lecture 5: slides 25 – 43	Questions 1. Explain what you understand by "pulse compression gain". 2. Explain what you understand by "linear frequency modulated waveforms"
9	Doppler concepts – Introducing the Doppler effect	Intro to Radar Systems: • Watch MIT lecture video, Lecture 1: slides 44 – 48 Read through POMR book • Section 8.1 – 8.2	Questions 1. Is a target is moving towards the radar, is the Doppler frequency positive or negative? 2. If the target's speed increases and is moving towards the radar, does the Doppler frequency increase, decrease or stay the same?
10	Doppler concepts – Doppler, unambiguous Doppler shift measurement, low-medium-high PRF	Read through POMR book • Section 1.5.3	Questions 1. What is the range of Doppler frequencies that can be observed unambiguously? 2. What happens when the target's Doppler frequency is higher than the unambiguous frequency? 3. What parameter must be changed to increase the value of the unambiguous frequency?
11	Doppler concepts – Doppler resolution	Read through POMR book • Section 8.4.7	Questions 1. Explain what you understand by 'Doppler resolution' 2. What parameter must be changed to decrease the value of 'Doppler resolution'?
12	Doppler concepts – Multiple pulses	Read through POMR book • Section 8.5	Questions 1. Why does a Pulse-Doppler and a FMCW radar need to transmit multiple pulses to order to estimate the Doppler frequency of the target?
13	Range and Doppler concepts – Range Doppler map	Read through POMR book • Section 8.8.1 – 8.8.2	Questions 1. What is the x-axis of a Range-Doppler map? 2. What is the y-axis of a Range-Doppler map?

1-2 Radar signal processing concepts

	Topic	Source	Tasks to do and questions to answer
1	Sampling the radar's received signal: I and Q signals	Read through POMR book • Section 8.6.1 – 8.6.2	Questions 1. Why is a coherent detector important for radar signal processing?
2	Range bins	Read through POMR book • Section 8.6.3	Questions 1. What is a range bin? 2. How do you calculate the size of a range bin?
3	Radar data matrix: range, Doppler, receiver channels	Read through POMR book • Section 8.6.4	Questions 1. Explain what you understand by 'fast-time' and 'slow-time' in the 2D radar data matrix
4	Measuring Doppler with multiple pulses; coherent pulses; coherent vs non-coherent pulses	Read through POMR book • Section 8.7	Questions 1. What processing needs to be applied to the baseband received signal, in order to estimate the Doppler frequency of the target? 2. Consider the 2D radar data matrix, which dimension does processing need to be applied to estimate the Doppler frequency: is it the fast-time or the slow time? Motivate your answer with a clear explanation

3 Inverse Synthetic Aperture Radar concepts (Read through selected chapters of Chen and Martorella's book on ISAR radar imaging. Focus more on the concepts and less on the mathematics/equations)

	Topic	Source	Tasks to do and questions to answer
1	Introduction to ISAR	Chapter 1 of Chen and Martorella's book on ISAR radar imaging.	Questions 1. The ISAR image is a 2-D radar image of a rotating object. What is the description of each axis? 2. See Fig 1.8 on page 12. Draw a sketch of the range profiles before range alignment and after range alignment. 3. See Fig 1.8 on page 12. What does Autofocus do? 4. Section 1.4.2 What is meant by cross-range resolution? 5. Read through Chapter 1.5.1, when a ship is travelling directly towards the radar and if it only has pitch motion and no yaw or roll motion, what view of the image will appear in the ISAR image? 6. Read through Chapter 1.5.1, when a ship is travelling directly towards the radar and if it only has yaw motion and no pitch or roll motion, what view of the image will appear in the ISAR image?
2	Waveforms used to obtain high range resolution	Read through Chapter 2.2.3 Stepped Frequency CW waveform. The datasets we will look uses this technique to generate high range resolution profiles. Spend less time on the detail math and more on the concepts	Questions 1. What is a stepped frequency waveform? 2. What processing is done on the received signal to generate a high range resolution profile?
3	ISAR image formation	Chapter 3.1.3 Range alignment Chapter 3.1.4 Phase adjustment or autofocus	Question 1. How is the purpose of range alignment different to phase adjustment?
4	ISAR motion compensation	Chapter 4.1.1. Ignore 4.2	
5	ISAR autofocus algorithms		Questions 1. What are the name of some of the autofocus algorithms mentioned in this chapter? 2. In concept, explain how each of these autofocus algorithms work in a few sentences.
6	Case Study: ground-based ISAR images of a non-cooperative sailing ship	Chapter 12.1 on page 262 Read pages 262 – 267	
7	Effect of Coherent Processing Interval Window Length on ISAR image	Chapter 6.1	Questions 1. How does increasing the CPTWL value affect the ISAR image? 2. How does decreasing the CPTWL value affect the ISAR image?

4. Measured dataset – CSIR dataset of small boats at sea

	Topic	Source	Tasks to do and questions to answer
1	Understanding the radar system used	CSIR summary report	Questions 1. What type of radar system was used? 2. List the important radar parameters
2	Understanding the experiment setup used to take measurements	CSIR summary report	
3	Understanding how to load the data into MATLAB	Code supplied	Tasks 1. Load the data into MATLAB and plot intermediately results
4	Understanding how to interpret the data		Tasks 1. Label the x-axis and the y-axis for any intermediately results

5	Apply range alignment to data- Haywood technique		Tasks 1. Plot the High Range Resolution (HRR) profiles before range alignment and after range alignment
6	Apply autofocus algorithm to measured data to focus the ISAR image		

5. Translation motion compensation

	Topic	**Source**	**Tasks to do and questions to answer**
1	Range algorithm – correlation-based approach	Haywood paper Zyweck's PhD thesis: Appendix A	1.1 Write out the high-level processing steps of the correlation based range alignment algorithm
2	Autofocus - dominant scatterer autofocus	Haywood paper Zyweck's PhD thesis: Appendix A Yuan paper	2.1 Write out the high-level processing steps of the dominant scatterer autofocus algorithm
3	Optimum Coherent Processing Window Length (CPTWL)	Martorella's paper on selection of CPTWL	3.1 How does the value of the Coherent Processing Window Length (CPTWL) affect the ISAR image? 3.2 If the CPTWL is increased from 0.5 seconds to 1.0 seconds, what effect will this have on the ISAR image?

6. Deliverables for review: related to GA tracking form

	Task	**Description**	**Deadline**
1	Learning plan tasks		Week 1 – Week 3/4
2	Develop project plan	Consider adapting generic plan suggested by Dr Abdul Gaffar	Before the end of week 2
3	Complex engineering problem	Clarify the problem statement and 2-3 objectives. Use EEE4022 suggested Latex template.	Before the end of week 3
4	Literature survey – rough draft	Skeleton of the literature survey section: describe section headings. Under each section heading write out the flow of ideas in bullet points.	Before the end of week 6
5	Description of technical work	Flow charts, block diagrams and code	Before the end of week 7
6	Initial/intermediate results	Intermediate/initial results and discussion under each graph in bullet points	Before the end of week 8
7	Outline of final report	Skeleton of report with chapter headings and section headings. If possible, under each section heading, write out the flow of ideas in bullet points	Before the end of week 10