D1.17B VDES Channel Model - Review of VDES terrestrial test results
Recent Updates and Work In Progress

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VDES Channel Model Development

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- Path loss – large scale and small scale effects (terrestrial)
- Doppler shift analysis from GLA trial
- Channel coherence – definition and measurement
- New data for Tapped Delay Line channel model – rate of change / Power Spectral Density (PSD)

Channel Model – Slow Variation
(or large scale effects)

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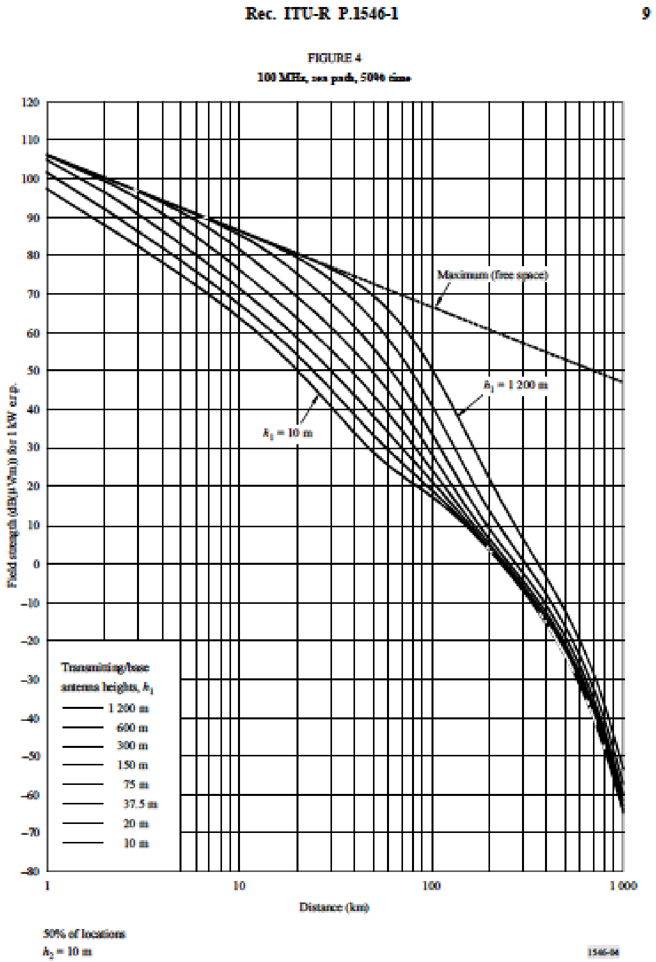
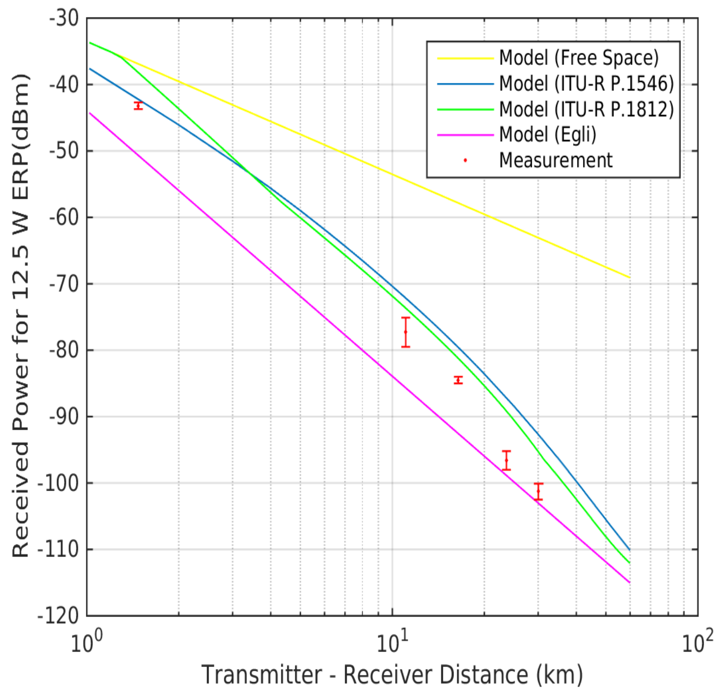
- ITU-R P.1546-5 – median signal level at 100 MHz over sea



- Slow fading provided by ITU-R P.1546-5
- Note: GLA trials show slightly higher losses than P.1546-5



Channel Model – Fast Variation (small scale effects, stationary ship - Harwich Harbour)

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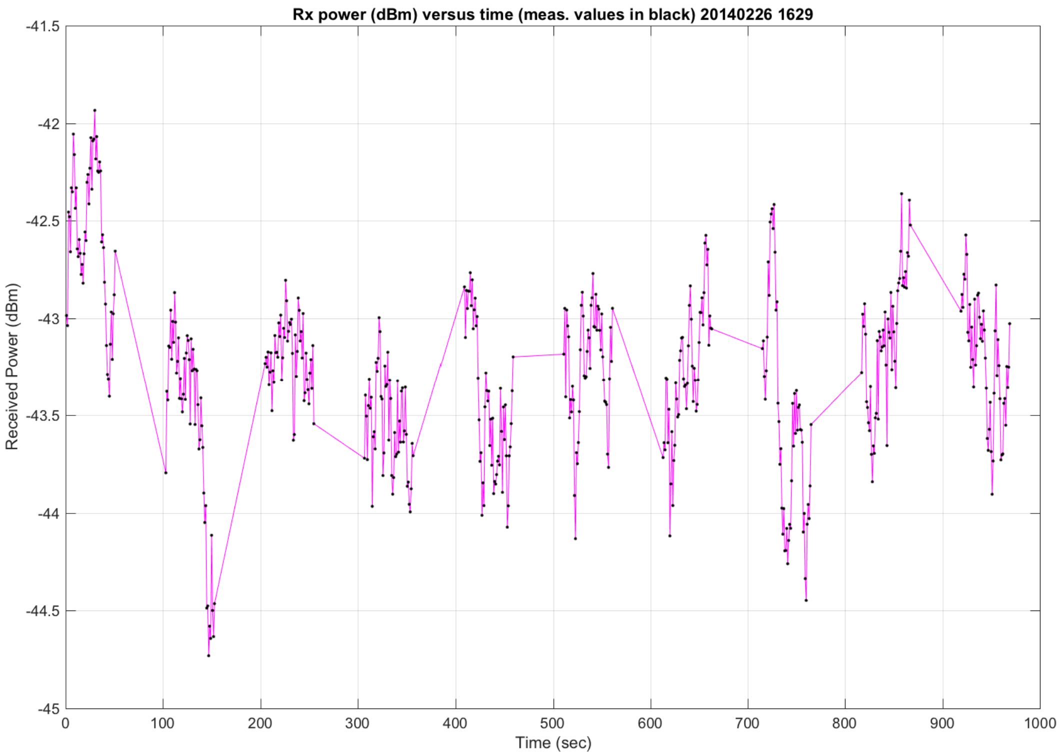
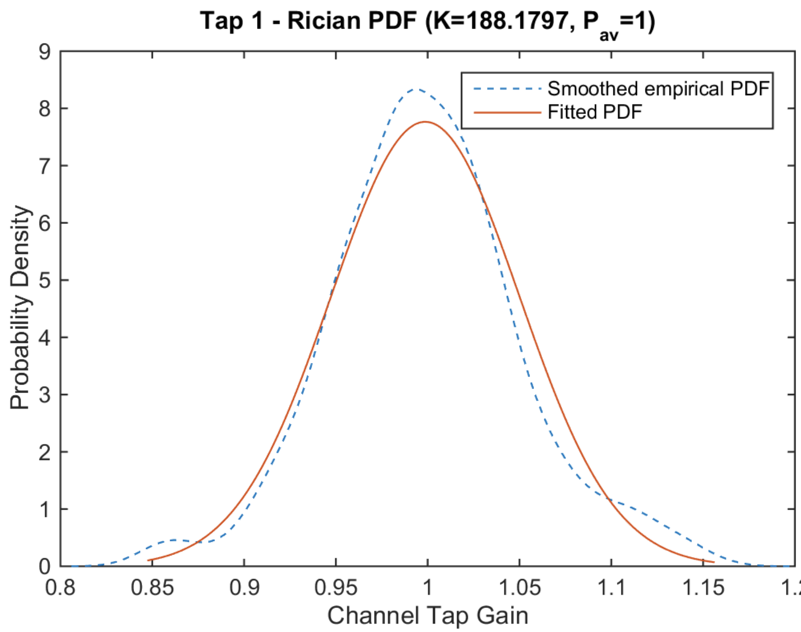
- Fast fades seen are in the range of 2.5 dB over ~15 minutes



- Fast fading follows a Rician distribution with a high K-factor (Trial 1629, 100 kHz channel)
- A fade does not significantly change over 250 milliseconds



Doppler Shift
(Harwich Approach, Moving Ship)

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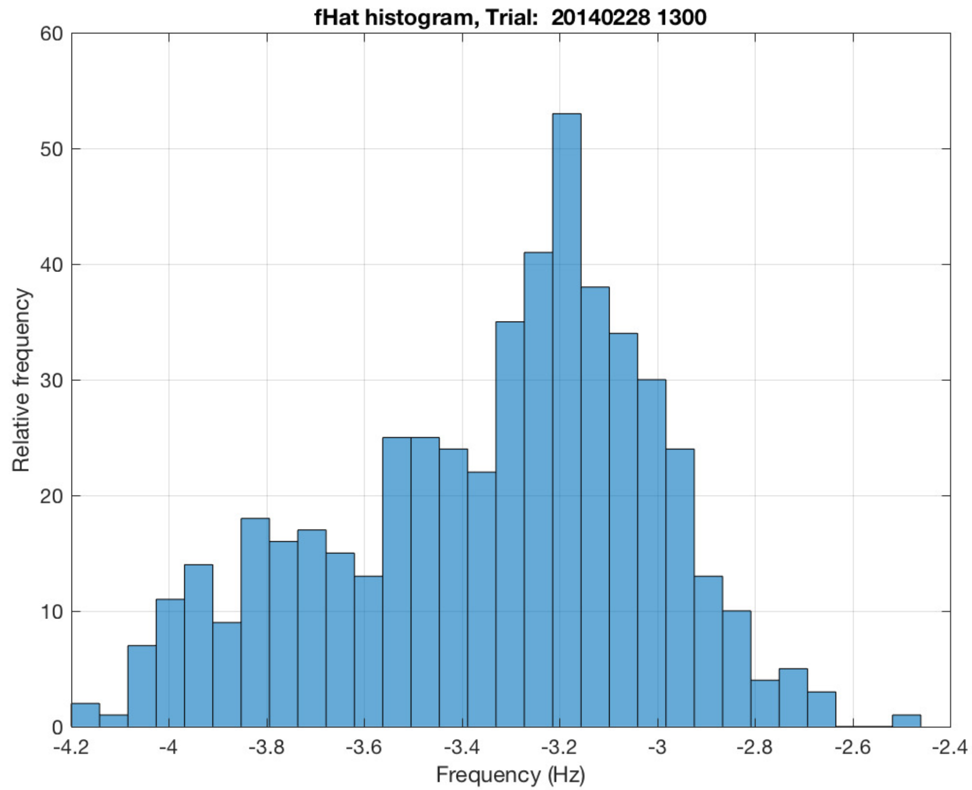
- Frequency shift observed is due to ship relative velocity and swaying motion causing movement of the antenna
- Average velocity approx. 12-14 knots (Trial 1300)
- The maximum frequency measured was -4.2 Hz with a total range of 1.70 Hz (over full trial, about 15 minutes)
- Static cases are ‘zero’ centered with somewhat narrower spread, Harwich Harbour VDE100, 0.5 Hz



Channel Model – Coherence Time

- The stationarity of the channel can be characterized by the *channel coherence time*
- Definition can be based on stability of the channel characteristics
  - such as time correlation of a received waveform– if less than 50% of the peak value, the channel is considered no longer coherent, or
  - width of Doppler frequency spread
- Using reference below, static case (Harwich Approach) had coherence time of about
  - 1.1 seconds based on Doppler spread of 0.3 Hz
- Moving vessel case (Harwich Approach trial 1300) had coherence time of about
  - 0.10 seconds based on max. Doppler of 4.17 Hz
  - For this moving case (only 1 end moving) the coherence time exceeds 3 slot message duration

Ref.: Doppler Spread and Coherence Time, NI white paper, http://www.ni.com/white-paper/14911/en

Tapped Delay Line Model (TDL)
Tap Weights

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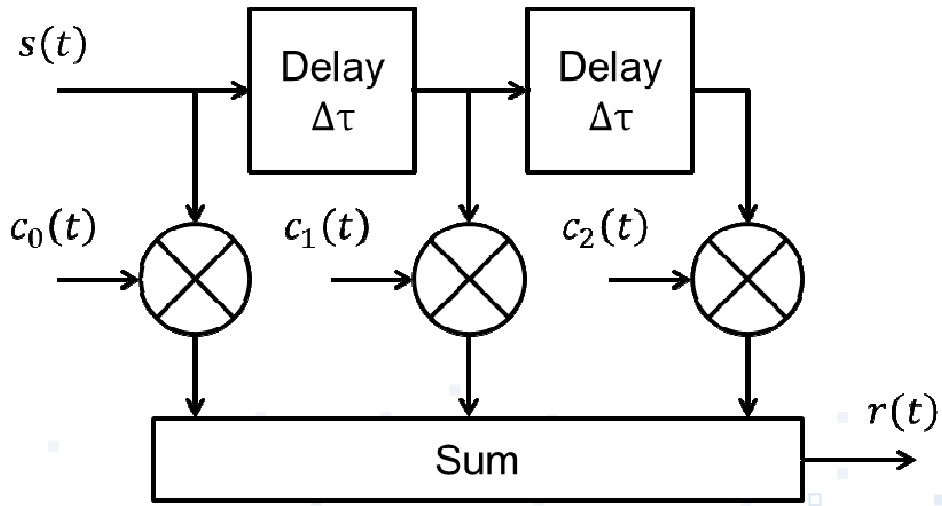
- The TDL model for the direct and scattered multipath components has been described in detail earlier
- For 100 kHz BW, $\Delta\tau = 10$ µs



(ref. VDES draft channel model document)

- Relative tap power level and PDF estimated earlier
- Taps with rel. power < -20 dB considered irrelevant (Rec. ITU-R P.1407-5)

Location	Tap no.	$\widehat{P}_{av,i}$ (dB)	$\widehat{K}_i$ (-)
Harwich Harbour (LOS, static ship)	1	0	188
	2	-19	2
Ipswich (NLOS, static ship)	1	0	9
	2	-13	3
…			

JRC Sounding Trials in Tokyo Bay (Point 4, LOS)

Table 4 Suitable distribution every channel tap (point-4)

Tap number	Relative Time delay (ms)	Suitable distribution	Relative power (dB)	K factor (MLE)	K factor (MM)
1	0	Rice (Rayleigh) with difficulty	0	4.5	5.5
2	0.01	Rice (Rayleigh) with difficulty	-18.1	0 (assuming Rice dist.)	incapable
4	0.03	Rice with difficulty	-17.8	8.3	9.8

In point-4, the strong and stable delay wave which reflected maybe in the Tokyo tower was measured in about 0.03ms delay, relative to the dominant wave. Therefore the 4th tap is stronger than the third one whose relative power is below -20 dB although the delay of the

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RMS delay spread: 9.5 µs (compare to shortest VDES symbol length of 13 µs)

JRC Sounding Trials in Tokyo Bay (Point 6, NLOS)

Table 6 Suitable distribution every channel tap (point-6)

Tap number	Relative Time delay (ms)	Suitable distribution	Relative power (dB)	K factor (MLE)	K factor (MM)
1	0	Rice with difficulty	0	8.3	9.6
2	0.01	Rice (Rayleigh) with difficulty	-9.8	0	incapable
3	0.02	Rice (Rayleigh) with difficulty	-12.0	0	incapable
4	0.03	Log-normal	-17.7	0 (assuming Rice dist.)	incapable

For point-6, the received power was insufficient because the distance between Tx and Rx that was near to our measurement limit. Therefore, the results in point-6 are just for

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RMS delay spread: 9.3 µs (compare to shortest VDES symbol length of 13 µs)

How do the tap weights evolve over time?

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- Analysis of the power spectral density (PSD) of the TDL higher-order taps (2+) provides important channel model behavior of the delayed multipath (diffuse/ scattered) components over time
- The statistics were previously found to be Rician, as for primary received signal (specular, or direct wave)
- A new analysis of the PSD of the relative power between the main (tap 1) component and the delayed components of the tapped delay line model have provided an important insight into the independent variation of the higher-order taps

Higher-order Tap Weight Relative to Tap 1 PSD

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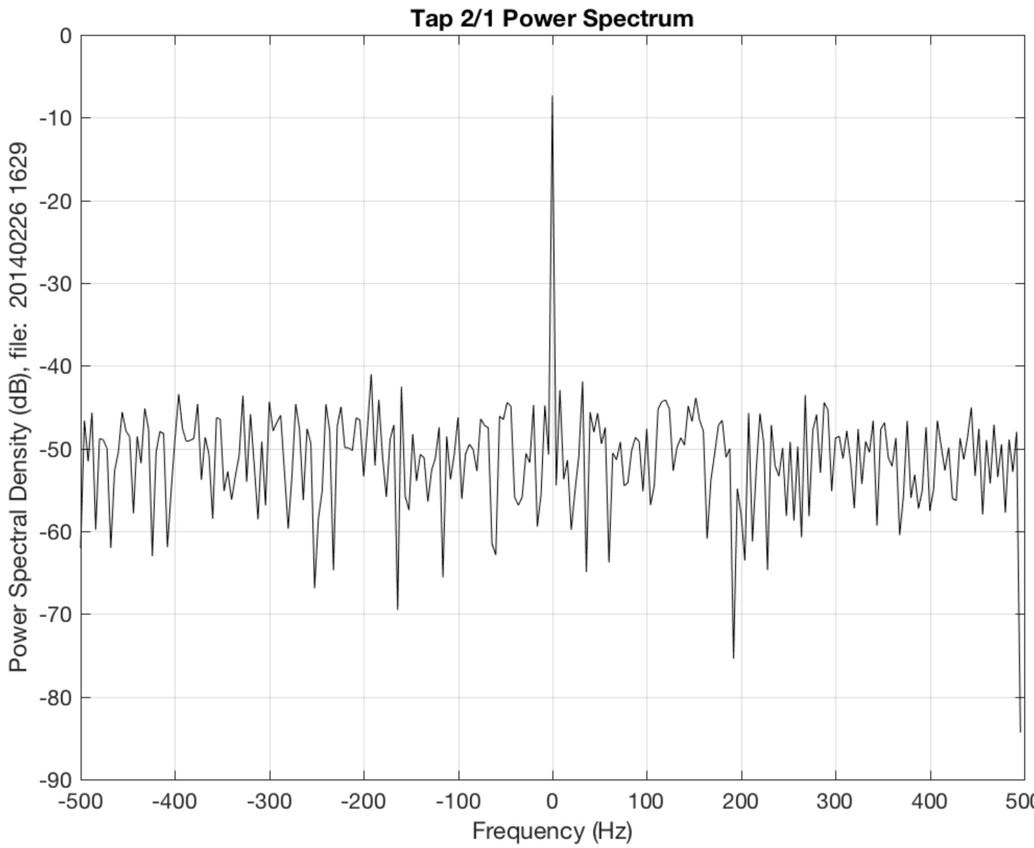
- It was found that the higher-order TDL taps (2, 3, 4 ...) had virtually no change during a packet, nor any significant spread during a trial (< 10 minutes)
- This implies that the **tap weights closely follow the statistics and fading behavior of the main tap, and do not independently vary** over time periods of minutes w.r.t. tap 1
- Analysis is based on data from the GLA sounding campaign and ensemble averaged over all segments (510 over 15 minutes)

- Tap 2 vs 1 shown,
  3 and higher vs 1 are similar



VDES Channel Model
Conclusions and Recommendations

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- VDES channel model update work is progressing well, and several basic models will be created
- The Rician distribution combined with the ITU-R P.1546-5 path loss curves provides a good small scale and large scale amplitude fading characteristics (respectively)
- Fading of higher-order channel taps was found to be highly correlated with the fading of the first tap (analysis based on GLA data)
- Doppler shift is very small for stationary ships, < 0.5 Hz, however those in motion, even at high speed will have negligible Doppler shift (< 15 Hz expected), model to be provided

VDES Channel Model
Conclusions and Recommendations

- Terrestrial channel coherence based on Doppler criteria, and inspection of amplitude and phase stability is generally good for about 1 second, and based on maximum Doppler criteria observed, coherency is calculated at about 0.1 second
  - Leading to recommendation to keep channel model fixed for any given simulated packet (3 slots)
  - Note – based predominantly on **non-moving vessel sounding data**; case of two moving ships, aircraft and satellite will need to be evaluated more closely, considering both spread as well as absolute Doppler offset
- Terrestrial channel models will be completed for next document update and meeting (ENAV 20) in March
- Airborne channel modelling (theory) references have been found, to be assessed before the next meeting

VDES Channel Model
Conclusions and Recommendations

- New higher volume satellite receive data power statistics have been provided by exactEarth last week
  - A satellite channel (fading) model will be created
- The next channel sounding campaign will collect more data on dynamic channels (vessels moving) to refine the channel models

Document Reference

- VDES Channel, Noise and Interference Characteristics Document
- Available for download from Jeffrey's FTP server:
  - ftp://ftpcomms@ftp.e-navigation.nl/201702_intersessional/WORKING_INPUT/Channel_Model/20161104-VDES_Channel_Noise_and_Interference_Characteristics-0v3.docx
  - Password: Merma1d#
- Update expected prior to ENAV20 in March, 2017
- Submission to ITU-R WP5B?