Measurement and modelling of HF channel directional spread characteristics for northerly paths

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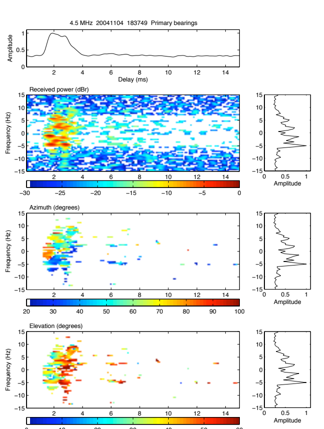
The northerly ionosphere is a dynamic propagation medium that causes HF signals reflected from this region to exhibit delay and Doppler shifts and spreads which significantly exceed those observed over mid-latitude paths. Since the ionosphere is not perfectly horizontally stratified, the signals associated with each propagation mode may arrive at the receiver over a range of angles in both azimuth and elevation. Such large directional spreads may have severe impact on radio systems employing multi-element antenna arrays and associated signal processing techniques since the signal environment is not comprised of a small number of specular components often assumed by the processing algorithms. In order to better understand the directional characteristics of HF signals reflected from the northerly ionosphere, prolonged measurements have recently been made over two paths: (a) from Svalbard to Kiruna, Sweden, and (b) from Kirkenes, Norway to Kiruna. The directional characteristics are summarised, and consideration given to modelling the propagation effects in the form of a channel simulator suitable for the testing of new equipment and processing algorithms.

Map showing the Svalbard – Kiruna and Kirkenes – Kiruna paths.



4.455 MHz signal transmitted at Kirkenes and received at Kiruna, 4 November 2004, at 1837 UT. Panels (top to bottom) are, power received as a function of azimuth and elevation, power as a function of azimuth and power as a function of elevation. The azimuth spread is 41° and the elevation spread 26°.

Measured median, upper quartile, upper decile and 95% values of azimuth spread (in °) for the Kirkenes-Kiruna path at 4.455 MHz. Note that the transmission schedule changed in December 2004, hence the marked increase in the number of cases.

	Cases	50%	75%	90%	95%
2004, March	373	3	6	11	20
April	671	3	6	12	18
May	652	3	6	13	22
June	815	3	4	8	13
July	349	3	6	13	18
August	512	3	7	17	28
September	744	3	6	14	22
October	947	3	6	17	25
November	292	3	7	15	22
December	3075	3	6	13	22
2005, January	2335	3	6	13	22
February	4285	3	6	14	22
March	4659	3	5	11	18
April	4795	3	7	17	27
May	2173	3	6	13	20

Measured values of azimuth, multipath and Doppler spreads at the 95% level for peak-to-mean power ratios of greater than 3.5.

Frequency (MHz)	Svalbard-Kiruna 2003	Svalbard-Kiruna 2004	Svalbard-Kiruna 2005	Kirkenes-Kiruna 2003	Kirkenes-Kiruna 2004	Kirkenes-Kiruna 2005
			Azimuth spread (°)			
4.5	4	18	16	16	21	22
5.8	12	15	–	18	12	–
6.8	9	12	11	18	15	21
9.0	6	9	4	19	11	12
9.9	4	6	–	21	–	–
11.2	5	7	–	25	21	–
14.4	5	4	–	–	–	–
20.0	3	–	–	–	–	–
			Multipath spread (ms)			
4.5	7.7	6.9	5.1	4.6	5.2	5.0
5.8	12.0	7.3	–	4.6	6.1	–
6.8	11.6	5.3	4.9	4.2	4.4	4.8
9.0	5.0	10.2	8.1	4.6	4.2	6.2
9.9	12.3	9.6	–	13.0	–	–
11.2	11.7	5.8	–	7.3	5.9	–
14.4	11.5	3.8	–	6.7	5.5	–
20.0	1.2	–	–	–	5.3	–
			Doppler spread (Hz)			
4.5	1	3.1	2.6	1.5	1.5	2
5.8	2	3.5	–	2	1.1	–
6.8	2	2.5	2.5	2.5	2.6	3.7
9.0	2	3.6	1.5	6.4	5.8	9.4
9.9	2	1.6	–	8.1	–	–
11.2	2	2.5	–	13.8	12.4	–
14.4	2.5	3.6	–	29.8	28.2	–
20.0	1.5	–	–	–	39.2	–

Modelling

The diffuse directional characteristics of the high latitude HF channel may be modelled as one or more grids of point sources distributed in both azimuth and elevation, each grid corresponding to a particular time of flight. The separation of the sources in the grid is not particularly critical (a separation of 0.1° has been employed by the authors) but should be chosen so as to be sufficiently small that the individual components would not be resolved by subsequent processing algorithms. An unnecessarily small a spacing results in increased computation times.

Each grid is specified in terms of spreads in azimuth and elevation spread, with the time varying nature of the diffuse reflections accounted for by angular dependent Doppler shifts separately specified as Doppler spreads in azimuth and elevation. The spatial power distribution is represented as a raised cosine amplitude distribution with the peak at the nominal direction of arrival. Imposition of directionally dependent Doppler shifts is also a way of ensuring that the signals from different directions are incoherent (such incoherence is undoubtedly the case in practice as the individual scatterers are short lived and random in nature).

The overall channel dispersion can be modelled as a number of the above grids with appropriate amplitude weighting, one (or more) grids associated with each propagation delay. Since the grids are essentially delta functions in terms of delay, a filter may be applied to give each grid a time-delay spread. Additionally, such a filter can merge several grids with different, but closely separated, delays into a single time-spread mode. Such a function may, in effect, arise due to the presence of a filter associated with the receiver and it may not be necessary to have two filter functions in the simulation. The channel simulation is then achieved through the convolution of the data signal with the channel dispersion function defined above. It is important to note that the transmitter and receiver bandwidths are likely to have a significant effect on the signal and that appropriate filtering must therefore be included.

The propagation model may be further complicated by noting that, particularly if wider bandwidths are considered, the propagation delay may also be a function of angle since the off-great circle components will have travelled further than the specularly reflected component.

A number of test cases have been selected from the examination of a large number of individual soundings. These are representative of the characteristics of the received signals over both the Svalbard-Kiruna and Kirkenes-Kiruna paths.