Volga State University of Technology

URSI GASS 2020

Experimental Study of Single-Mode Propagation Ranges of Short Waves on Mid-Latitude Radio Paths of Various Lengths

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Outline:

I. Background information.

II. Equipment and experimental conditions.

III. Findings of the research into the influence of solar activity, magnetic activity, time of day, path length on single-mode propagation range (SMPR).

IV. Estimation of the probability of the presence of a narrowband (3 kHz) radio channel with a maximum signal-to-noise ratio in the SMPR.

V. Conclusions.

Propagation of radio waves in the ionosphere

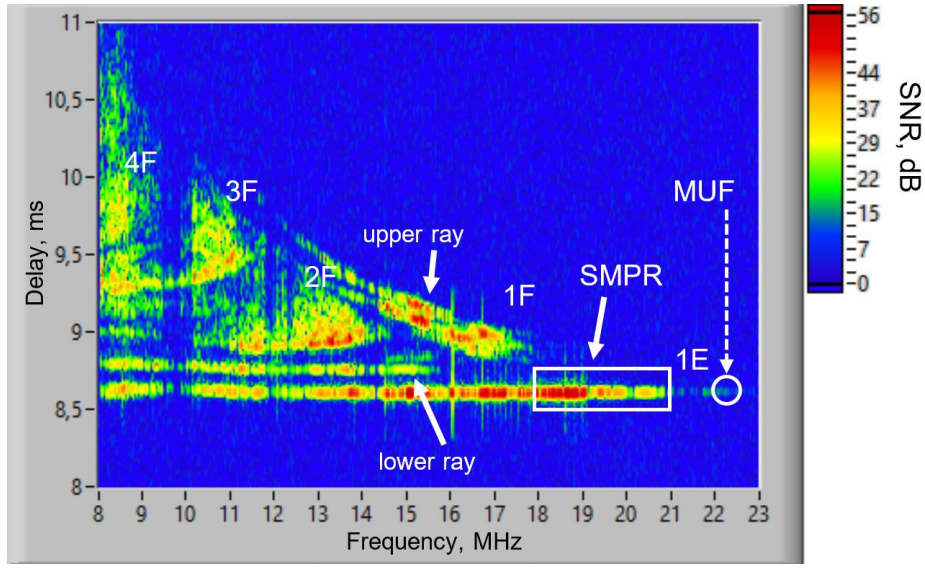
Ionosphere restricts HF skywave communication in several ways:

- multiple propagation modes (1F + 2F, 1E + 2E + 3E, 1F + 1E, 1F + 2E etc.) can exist between two terminals of a path (intermodal multipath);
- earth's magnetic field gives rise to magnetoionic (intramodal) multipath of each propagation mode;
- path delay for each propagation mode depends on frequency (frequency dispersion);
- time-varying properties of the ionosphere cause corresponding variations in the characteristics of radio channels.

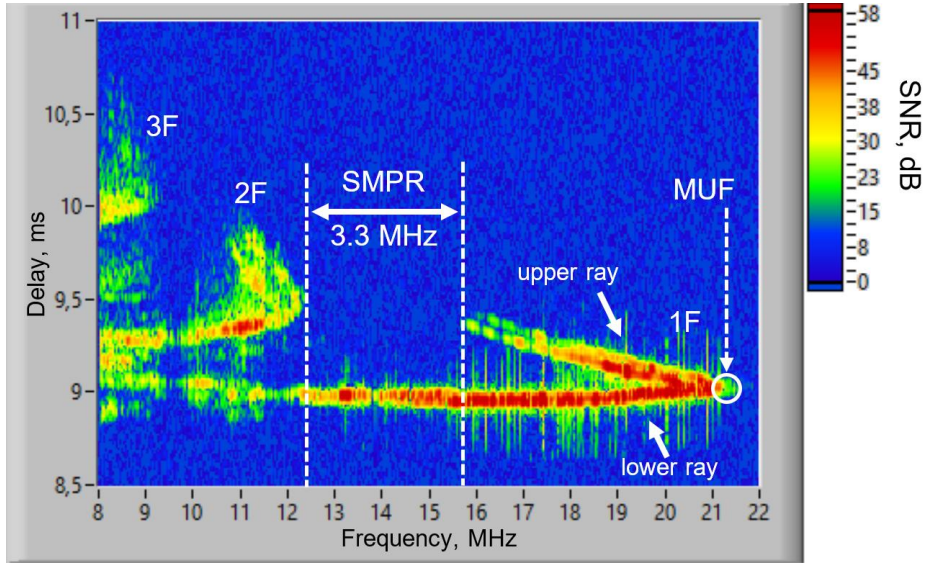
To tackle these problems, it is reasonable to operate over **the single-mode propagation range (SMPR).**

Typically, SMPR lower bound is the maximum usable frequency (MUF_2) of the second-order mode and its upper bound is the lowest usable frequency (LUF_P) of the Pedersen (upper) ray of the main propagation mode, where the lower ray is at least 20 dB up with respect to the Pedersen ray.

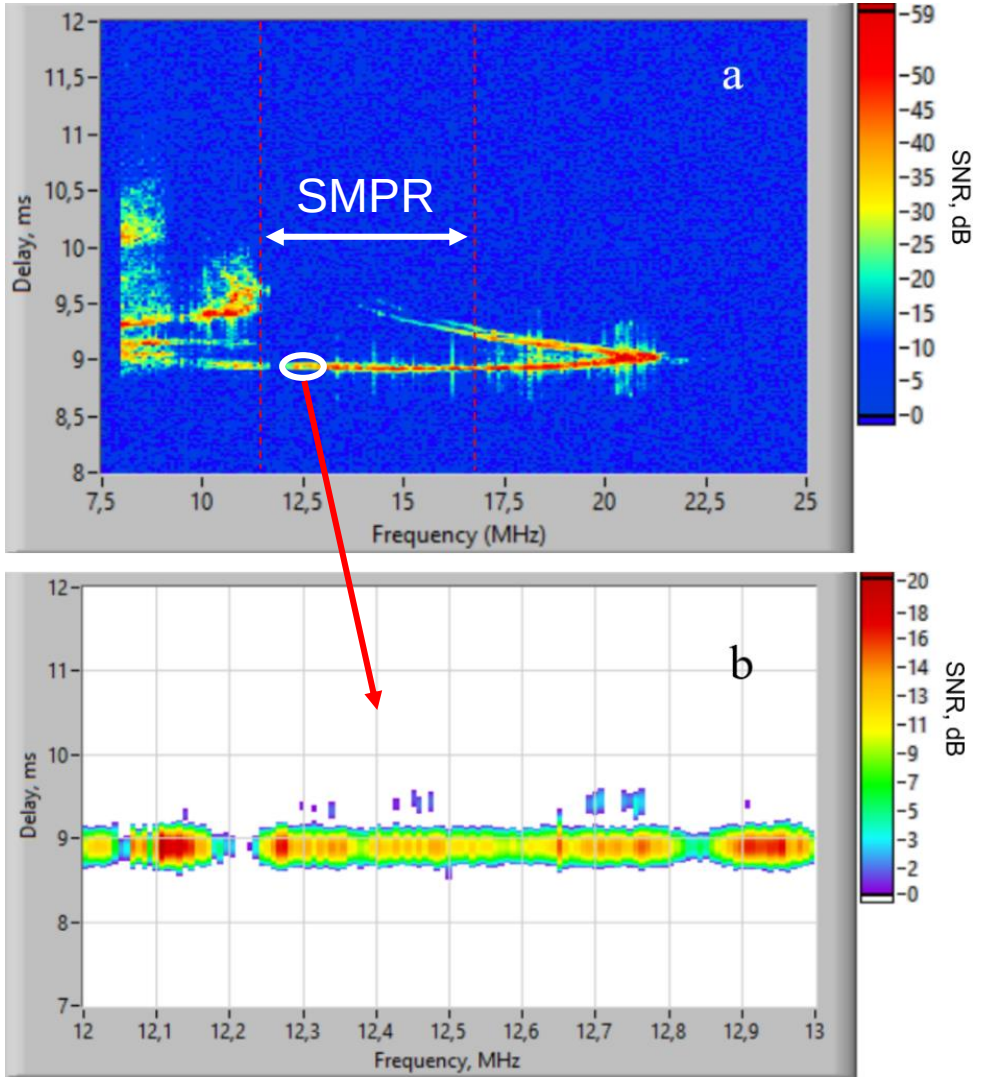
Day



Night



Single-mode propagation range of HF signals



a) oblique-incidence ionogram of radio path of length of 2.6 Mm and SMPR; b) amplitude-frequency response of wideband (1 MHz) channel from SMPR.

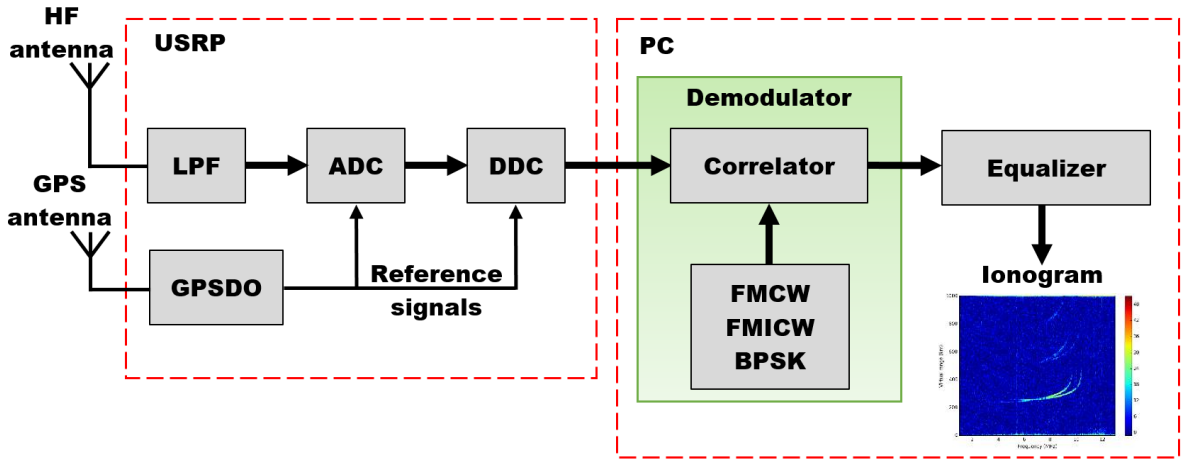
SMPR exhibits the following features:

- interference of magnetoionic rays with path-delay differential of a few mcs on medium and long-haul links;
- variations of amplitude-frequency response of a wideband channel up to 25 dB;
- the slope of the delay characteristic (frequency dependence of the group time delay), related to phase frequency dispersion, limits the coherent bandwidth of the wideband channel up to 50–100 kHz; the effect rises with the increase in the path length.

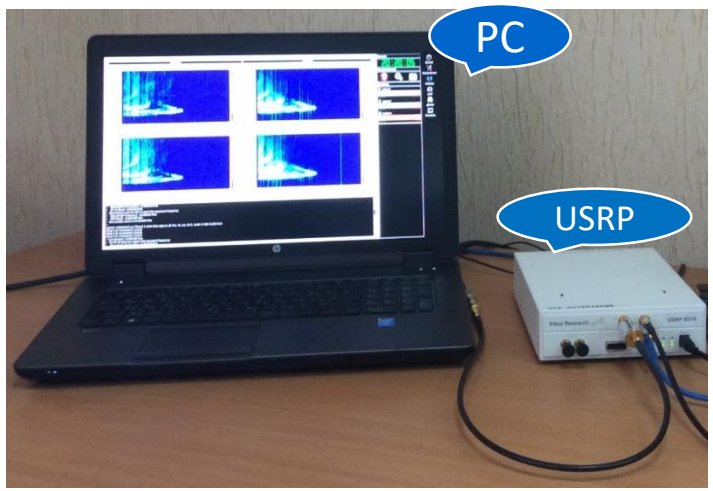
Thus, it is crucial to carry out experimental research into the influence of geophysical factors on SMPR when $\Omega_{ch} / 2\pi \leq SMPR$.

Receive terminal of the universal SDR-ionosonde employed in the research

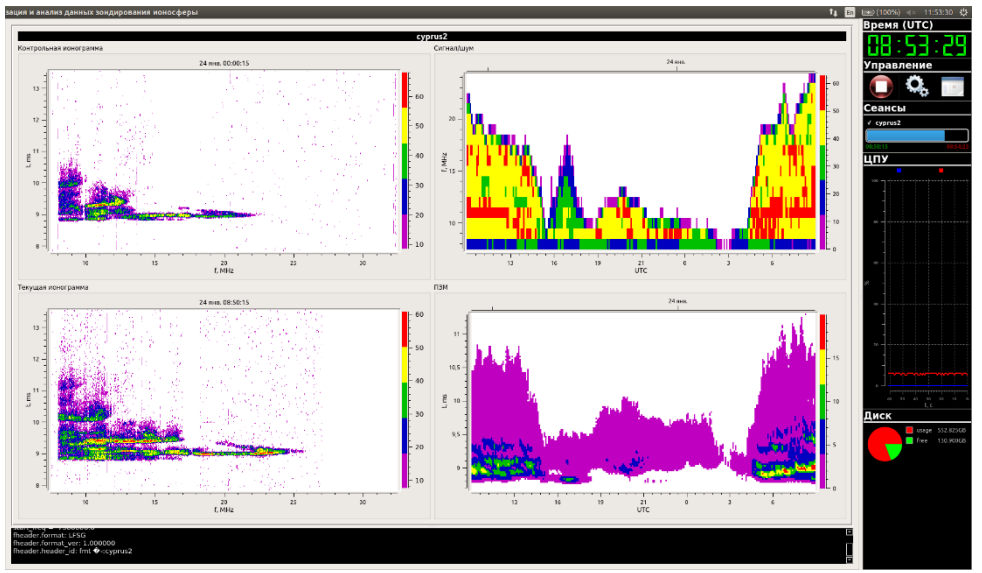
Block scheme of the receive terminal of the universal ionosonde



Universal SDR ionosonde



User interface



Network of employed radio links and experimental conditions

Radio link (transmitter - receiver)	Characteristics of radio links		
	Length, Mm	Main propagation mode	Sounding check point
Khabarovsk – Yoshkar-Ola	5.7	2F2	55-56º N; 58-60º N
San Torcas (Spain) – Yoshkar-Ola	4.1	2F2	44-46º N; 53-55º N
Irkutsk – Yoshkar-Ola	3.6	1F2	57-58º N
Inskip (Great Britain) – Yoshkar-Ola	3.2	1F2	55-57º N
Cyprus – Yoshkar-Ola	2.6	1F2	43-47º N

Conditions for carrying out studies into the influence of the solar activity on SMPR:

- we selected two periods I, II, when the average monthly values of the Wolf numbers were $W_1 \approx 160$, $W_2 \approx 50$; data gathered over the path of the length of 2.6 Mm were used.

Studies into the influence of path length, magnetic activity and time of day on SMPR:

- were carried out for the high solar activity $W_1 \approx 160$; data gathered over the entire paths were used.

Influence of the solar activity on SMPR

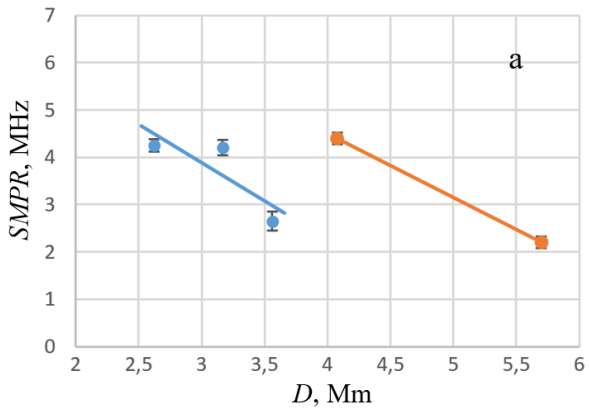
Conditions		SMPR, MHz	LUF_p/MUF	MUF_2/MUF
$W_1 = 160$	day	5.9±0.2	0.87…0.81	0.57…0.68
	night	2.6±0.1		
$W_2 = 50$	day	2.3±1	0.74…0.71	0.57…0.68
	night	1.3±0.2		

Findings allowed to suggest that:

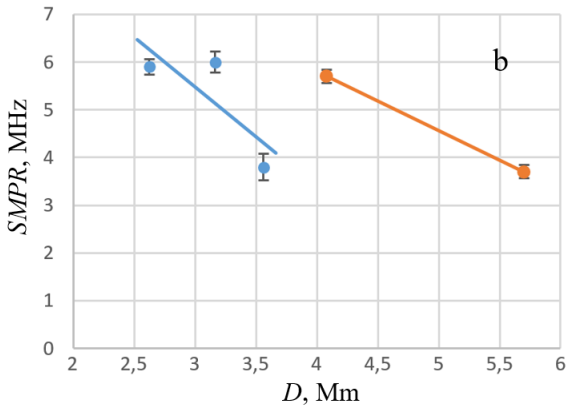
- solar activity changes don't influence SMPR. It primarily depends on the MUF of the radio path and the frequency range of the Pedersen ray, i.e. the upper bound of SMPR;
- SMPR was always observed greater during the day than at night.

Influence of magnetic activity, time of day and path length on SMPR

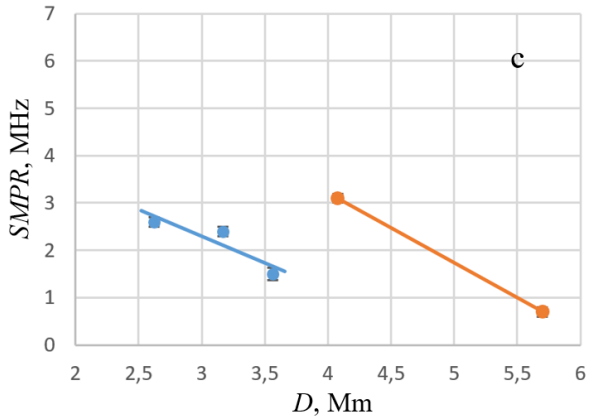
Experimental dependences of SMPR on the path length (standard deviation for all measurements did not exceed 15%)



General statistics



Statistics for the day



Statistics for the night

Single-hop paths:

Time of day	Day	Night
Analytical model *SMPR*(*D*)	$SMPR(D)[MHz] = -2 \cdot D[Mm] + 11.761$	$SMPR(D) = -D + 5.672$

Two-hop paths:

Time of day	Day	Night
Analytical model *SMPR*(*D*)	$SMPR(D) = -D + 10.724$	$SMPR(D) = -D + 9.129$

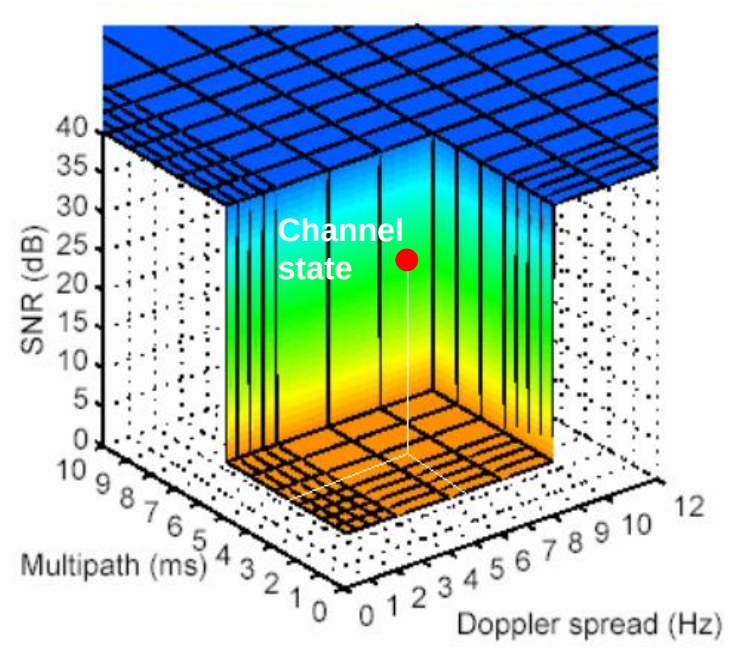
The influence of magnetic activity on SMPR was studied on the basis of a correlation analysis of its variations with the changes in the planetary K-index in the range from 1 to 6 (from quiet to disturbed conditions). It was found no significant correlation between the SMPR value and K-index because:

$$\max CCF \sim 0.32...0.42$$

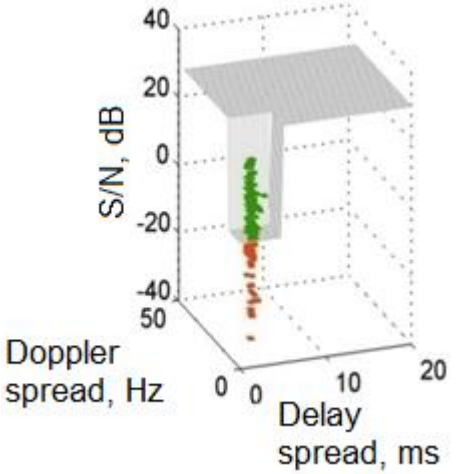
where CCF – cross correlation function.

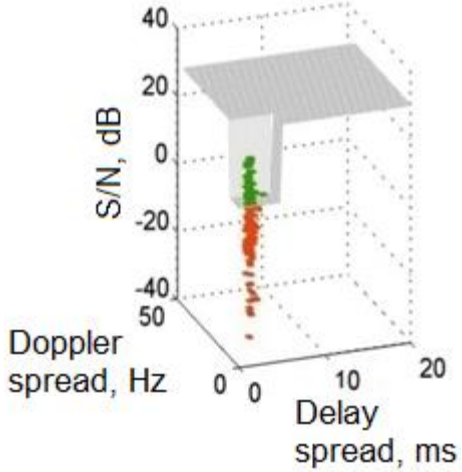
Estimation of the probability of the presence of a narrowband (3 kHz) radio channel with a maximum signal-to-noise ratio in the SMPR

Modem performance surface and point indicating channel conditions



Modem performance surfaces obtained over the path of length of 5.7 Mm





Path length, Mm	Probability
5.7	0.5
4.1	0.6
3.6	0.4
3.2	0.6
2.6	0.7

Conclusions:

- ✓ For the high solar activity($W_1 = 160$) the SMPR average value was (5.9 ± 0.2) MHz at day and (2.6 ± 0.1) MHz at night. During the low solar activity ($W_2 = 50$) SMPR decreased by approximately (2 ... 3) times and was (2.3 ± 1) MHz at day and (1.3 ± 0.2) MHz at night.

- ✓ For the single-hop radio paths (2.5–3.5 Mm), SMPR value decreased from 4.25 MHz to 2.65 MHz with an increase in the path length. For the two-hop radio paths (4.0–5.5 Mm), SMPR value also decreased from 4.4 MHz to 2.2 MHz with an increase in *D*. For the entire studied radio paths, the SMPR value at day was greater than at night by roughly 2 ... 2.5 times for the single-hop paths and by 2 ... 5 times for the two-hop paths.

- ✓ There was no significant correlation between the SMPR and magnetic activity (when K-index changed in the range from 1 to 6).

- ✓ For the entire paths the narrowband 3 kHz channels with the maximum SNR belonged to SMPR only in half of the cases.

Thank you!

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