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Spectrum Utilization: Sense and Adapt: Operation on a Noninterference and Nonprotected Basis

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INTRODUCTION

The objective of this article is to outline the sense-and-adapt capabilities of Canada's Third-Generation High Frequency Surface Wave Radar (3rd Gen HFSWR). This system is an evolution of Raytheon's pioneering SWR503 radar.

HF radars depend on the detection of scattered radio waves and are therefore vulnerable to attack by both intentional and unintentional jammers. A couple of defenses have been incorporated into the 3rd Gen System to counter jamming. First, the system uses an active spectrum monitoring system, whereby the radar scans the background radio spectrum and chooses to operate in frequency channels where it does not detect another HF user. In this manner, the system will automatically respond to an in-channel jammer by changing carrier frequency. However, even in the absence of jammers, the radar can be set to change carriers at periodic intervals to help evade detection by jammers as well as minimizing impact on other HF band users.

The 3rd Gen system, previously described in [1], was developed based on Software Definable and Cognitive Radar principles such as sense-and-adapt. This capability is made available by incorporating digital waveform generation and reception. The system is a mono-static pulse Doppler radar. The radar site consists of colocated transmit and receive sites. The radar electronics are based on a software radar design concept and utilizes direct conversion receiver-exciter technology that eliminates much of the analog hardware associated with traditional radar. The 3rd Gen radar incorporates an ultra linear HF power amplifier specifically designed for pulsed operation. The HF power amplifier design results in very low spectral side-lobe levels and consequently minimal spectral leakage that otherwise would result in adjacent channel interference.

The radar operates simultaneously on two independent frequencies in an interleaved pulse mode. The data collected on each frequency thread is processed in multiple parallel paths optimized for different categories of vessels. The data from the two frequencies and multiple processing paths are consolidated prior to the input of the multitarget tracker.

There is no portion of the 3-30 MHz spectrum allocated to radiolocation as a primary service. Therefore, HFSWR's must operate on a Noninterference and Nonprotected Basis (NIB and NPB) with respect to allocated users. Industry Canada is the responsible agency in Canada for the licensing of the radio frequency (RF) spectrum and was actively involved in the development of stringent specifications for the 3rd Gen HFSWR to ensure operation on a NIB/NPB while remaining available 24 hours a day, 7 days a week. Background information related to operational requirements for operating on a NIB/NPB can be found in [2]. The paper details the challenge faced by the radar design engineer as HFSWR technology migrates from experimental to operational status.

These challenges are met in the 3rd Gen HFSWR by the addition of an integrated Proactive Remote Spectrum Management (PRISM) system. The system builds on a cognitive radio *Dynamic Spectrum Access* (DSA) spectrum sharing scheme that allows NIB/NPB users access to portions of the spectrum that are not being utilized by licensed primary users. DSA enables significant improvement in efficient use and maximizes the number of users of the spectrum compared to traditional fixed spectrum access [3].

To meet Industry Canada's requirements, the system had to identify other users of the spectrum that were just above the background noise level. To meet this requirement, it was necessary to implement an impulsive noise detection and removal algorithm in the wideband data channel that was considerably more sensitive than its narrow-band radar counterpart. In developing the algorithm, it was observed that corrupted pulses identified in the wideband data could be readily identified and removed from the narrow band radar data.

SENSE AND ADAPT

The PRISM system, illustrated in Figure 1, continuously monitors the authorized part of the HF spectrum for other users. It generates and maintains a database of historical frequency use of this band. From the database, the system generates a list of open channels and the bandwidths of these channels along with a probability of the channel remaining open. This probability being derived based on the bandwidth and past use of the frequency channel. This list is

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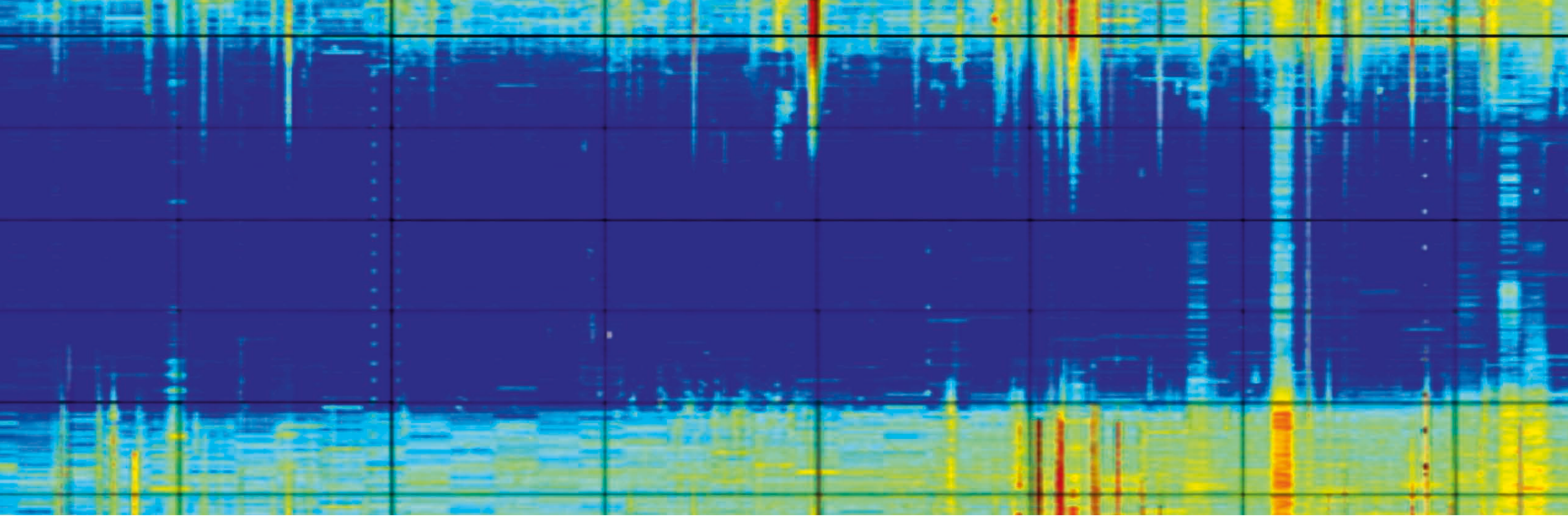

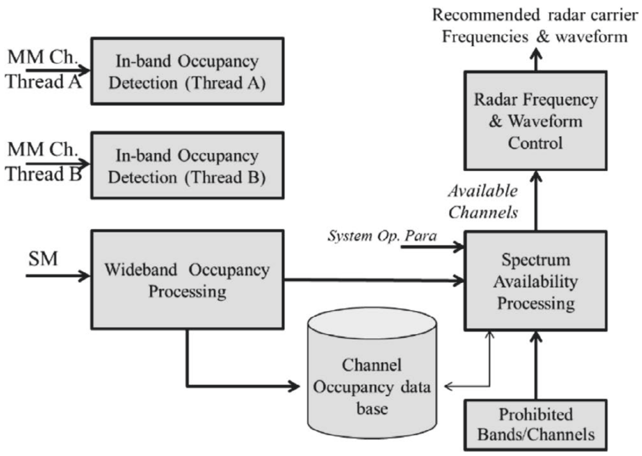

Figure 1.
Proactive Remote Intelligent Spectrum Management System (PRISM).

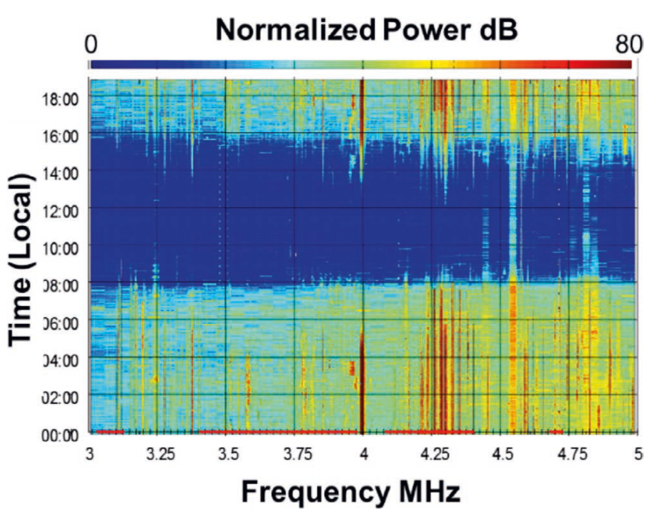

Figure 2.
Spectrum Plot over a 20-hour period showing clear spectrum during daylight hours (08:00–16:00 hours) and congestion during hours of darkness.

continuously updated every few seconds as the wideband monitoring data is processed.

The frequency selection logic has four main constructs: 1) utilize the maximum available bandwidth, 2) minimize the revisit rate to a defined channel, 3) occupy a channel for no more than 20 minutes, and 4) maintain a minimum frequency separation between the two operating frequencies of the radar. Under this mode of operation, spectral use by the radar is spread equally throughout the available band, while maintaining the maximum bandwidth and frequency diversity to maximize radar performance. The utilization of this sense-and-adapt technology allows the radar to optimally perform even in hostile RF environments.

The PRISM system is designed to monitor the two frequency channels on which the radar is currently operating. The in-band occupancy processing utilizes orthogonal waveform codes to remove radar target and clutter energy from the in-band dataset. This process permits reliable detection of users on the same frequency channel which would typically be masked by the dominant radar energy from clutter.

The combination of the in-band occupancy detection with a statistical database of open channels allows the system to react instantly upon detection of an in-band user, by switching to an open channel, thus minimizing radar downtime. In the event that there are no available open channels at suitable bandwidths, the PRISM system can cease transmissions until a suitable channel becomes available or switch to a defined "safe haven" frequency. This mode of operation is consistent with the recommended practices for the operation of HFSWR within the U.S. [3]:

> **"DOD (Department of Defense) expects to increase HF radar use over time, as does the Coast Guard. Since there are no HF allocations for the radiolocation service and new allocations in the HF bands are unlikely, future HF radars must be carefully designed with a dynamic channel occupancy analyzer to minimize harmful interference to other systems."**

An example of a spectrum plot (frequency vs. time) from the PRISM system is presented in Figure 2. It can be observed that, during daylight hours, the spectrum is wide open with few local users of the spectrum being observed. During these times the radar can operate at its maximum bandwidth and at frequencies that are

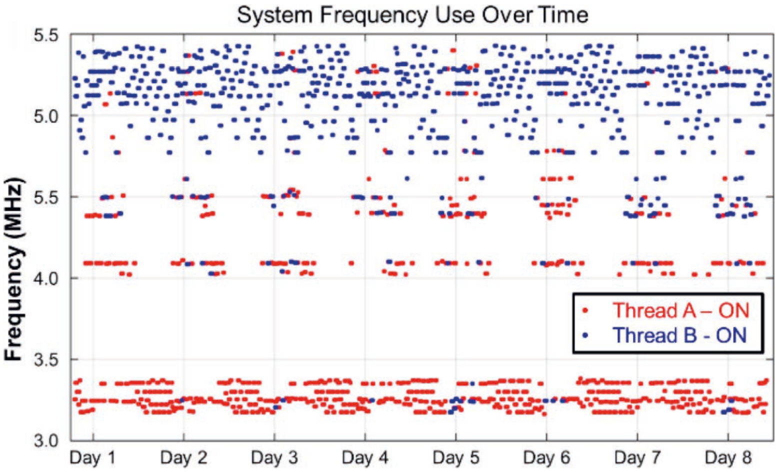

Figure 3.
Plot of radar operating frequencies over an eight-day period for the two operating threads.

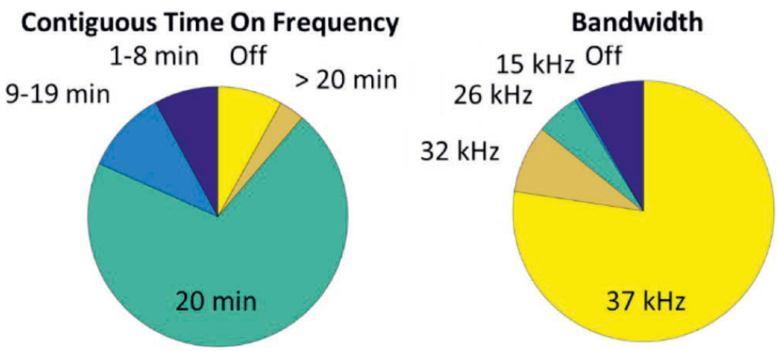

Figure 4.
PRISM—Performance statistics over an eight-day period for both contiguous-time-on-frequency and bandwidth.

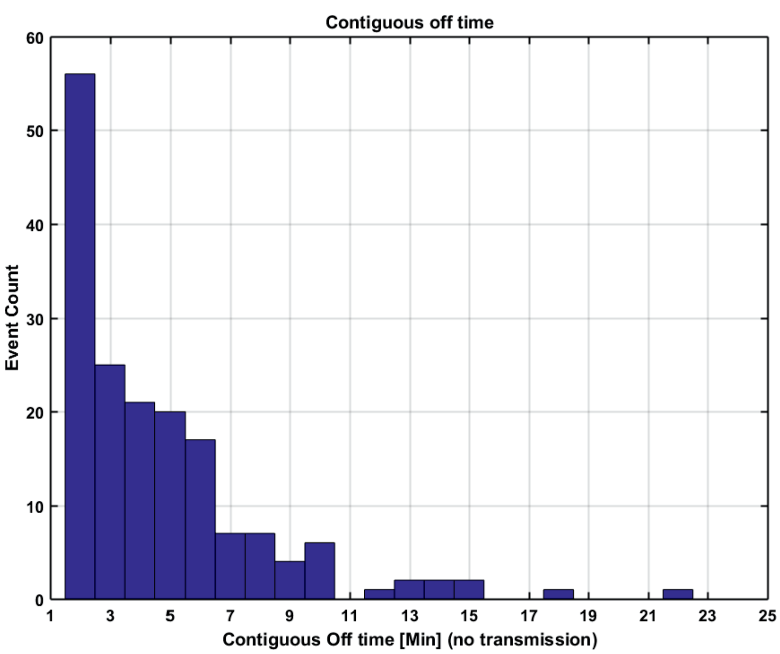

Figure 5.
Analysis of the time-off data.

optimized for the radar mission. During the twilight and the hours of darkness the D-layer, with its absorptive properties, disappears and signals from distant users and natural atmospheric discharges received via sky-wave mode of propagation. Consequently, the night-time noise level increases by 10 to 15 dB and the number of external users increases significantly.

A plot of the operating frequencies utilized by the radar system over an eight-day period in 2015 is presented in Figure 3. The statistics for the eight-day period are presented in Figure 4 for both time-on-frequency and bandwidth of operation. It can be observed that, the majority of the time, the radar remained on the allocated channel for the maximum time of 20 minutes. The rules of operation permitted the radar to operate beyond the 20-minute limit in the event another channel was not available, providing it would change frequency as soon as an alternative became available. There is also a period where the system could not find an available channel and was consequently off or operating at the safe haven frequency. Approximately 15% of the time the radar was forced to move off the allocated channel, thus not completing the 20 minutes. It can also be noted that the system was operating at the maximum bandwidth of 37 kHz for the majority of time.

The pie chart of Figure 4 and the histogram of Figure 5 show minimal downtime of the radar throughout this period. As HFSWR systems have a long integration period (1–4 minutes) associated with each track update, the downtime has minimal impact to the target tracking capability of the system. These figures effectively demonstrate the four constructs of the frequency selection logic and operation of the radar described earlier.

IMPULSIVE NOISE REJECTION

Interference can be a major impediment to the operational performance of radar systems. A common source of interference is impulsive noise which may appear due to regional lighting discharges or local man-made noise sources. Impulsive noise is characterized as having a short duration and therefore may only affect a small portion of the time series. However, for processing techniques that integrates signals and transform to the frequency (Doppler) domain, this will result in elevated noise for the entire Doppler frequency band.

Traditional methods for limiting the signal degradation due to impulsive noise rely on the detection and removal of corrupted pulses to limit frequency leakage into the signal band [6], [7]. These techniques typically rely upon time domain envelope detection methods within the bandwidth of operation. The corrupted pulses are identified though detection of the increased signal power of the envelope. Thus, the received enve-

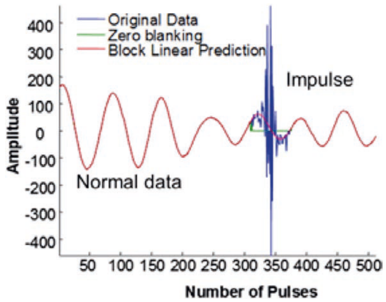

Figure 6.
Example of traditional impulsive noise cancellation techniques. Impulsive noise observed between pulse 310 and 370. Corrupted data is either simply blanked by setting values to zero or values predicted.

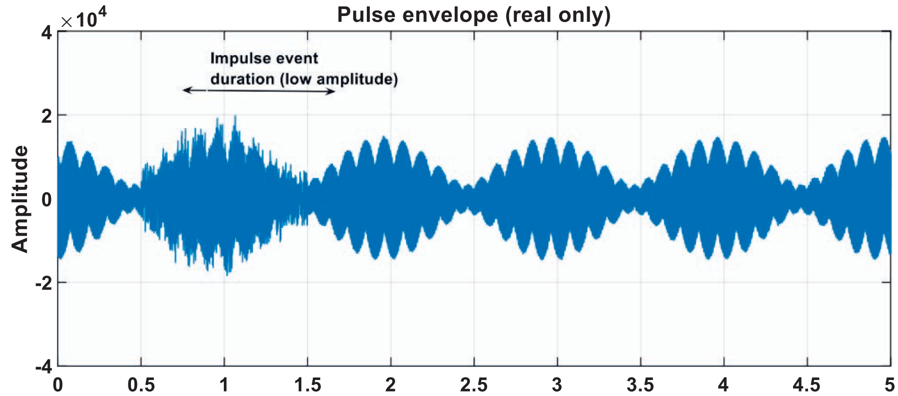

Figure 7.
Pulse envelope (time domain) with low amplitude impulse event.

lope of the signal plus interference must be larger than typical in order to detect within the time segment. A typical example is shown in Figure 6.

Radar systems in the HF band operate in an environment of high clutter and therefore have a large signal envelope in the time domain. Targets of interest may be present in the portion of the frequency (Doppler) domain that is well removed from the clutter, thus are noise floor limited. The effective signal to noise ratio of these targets may be adversely affected in this situation. Figure 7 and Figure 8 demonstrate an example where the time domain envelope is largely unaffected by the low level impulse event however the frequency domain noise floor is elevated by 20 dB, resulting in a significant loss in signal-to-noise ratio (SNR).

The developed approach uses the wideband data as observed on the Spectrum Management system to identify pulses that are corrupted by impulse noise. The impulse event is significantly easier to detect in the wideband frequency domain rather than the time domain. The noise floor increase in the wide band frequency domain from a short duration impulse is shown in Figure 9.

The wideband data collection and the narrowband target processing are time aligned. Thus, a corrupted sweep in the wideband data can be correlated to a specific pulse sequence in the narrowband target data channel. The identified pulse(s) in the narrowband channel can be replaced by zero padding or with interpolated data obtained from adjacent

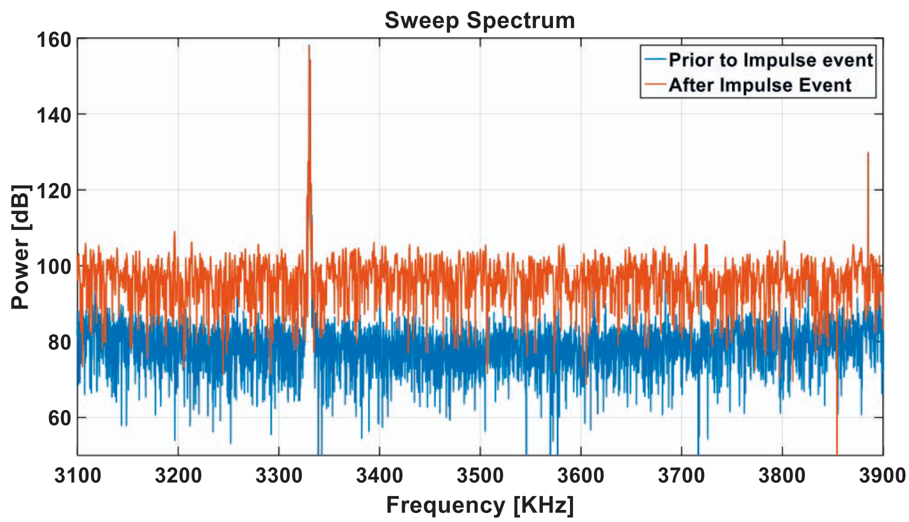

Figure 8.
Frequency domain of signal. Low amplitude impulse resulted in nearly 20 dB increase in noise floor.

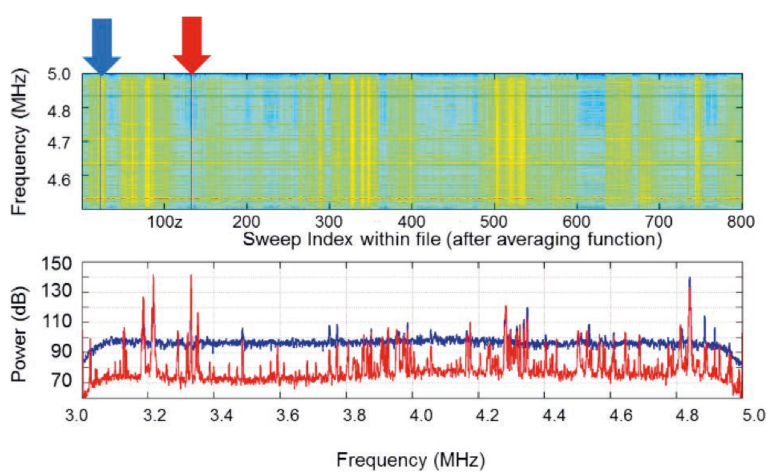

Figure 9.
Wideband noise floor elevation due to impulsive noise events.

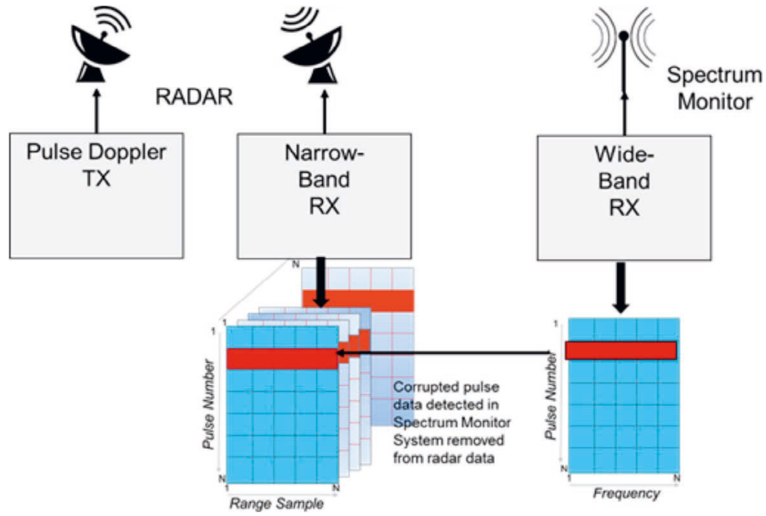

Figure 10.
Wideband detection of impulse events with feedback to narrowband target detection.

noncorrupted pulses [7] prior to Doppler processing thus maintaining the noise floor and SNR of the target channel. This process is depicted in Figure 10.

CONCLUSION

In this article, we have described the basic constructs of the sense and adapt capabilities of the third generation of the HFSWR system developed in conjunction with Defence Research and Development Canada. The system is a significant evolution beyond the previous generations. The PRISM system has demonstrated the capabilities of automated sense and adapt technology applied to spectrum management. This effectively enables operation of HFSWR within a noninterference and nonprotected basis without detriment to HFSWRs detection and tracking capabilities. The wideband impulse noise detection techniques are described and represent another example of sense and adapt capabilities.

The PRISM system and impulse noise rejection functions are carried out automatically without operator input or control. However, both functions are extensively parameterized allowing for customization of the capability. The sense-and-adapt nature of these capabilities is an instantiation of intelligent radar operation. It is evident that Canada's Third Generation HFSWR is a radar with cognitive characteristics. ◆

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