Ambiguity function of Iridium signal for radar application

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The Iridium L band downlink signals from a radar viewpoint are studied. The signal is modelled and its ambiguity function is analysed and the ambiguity function with that of the real recorded signal is compared. It is shown that the spectrum and ambiguity diagram of the Iridium signal are independent of the signal content, making it a very suitable signal of opportunity for passive radar. The interference floor of the ambiguity function of a single Iridium burst with a length of 8.28 ms is about 22 dB lower than the main peak.

Introduction: As suggested in [1] modern communication satellites are good candidates as illuminators for passive radars. Cristallini et al. [1] has shown that such systems have wide area coverage, high availability and high power densities at the ground, the latter being driven by the need for wide-bandwidth communication with ground stations which use small antennas. Modern satellite communication (Satcom) systems also use noise-like waveforms to optimise efficiency [2]. Such waveforms lend themselves to radar use because they have acceptable ambiguity functions (AF). The principal limitation in the use of Satcom transmissions for radar is the limited resolution, since their bandwidths are usually still significantly less than typical radar signals. Thus it is necessary to investigate the AF of a communication signal before it is used for radar purpose. As a representative satellite communication system, Iridium signal has particularly high power densities at the ground and a constellation of Iridium satellites provide a global coverage of the Earth surface including the Polar Regions. Thus it is good to discuss the suitability of Iridium as an illuminator of opportunity. This Letter therefore examines the ambiguity of the Iridium signals as radar illuminators.

Ambiguity function: The universal characteristics of a radar signal are defined by its ambiguity function given as:

$$\chi(\tau, f_d) = \left| \int s(t)e^{-j2\pi f_d \tau} dt \right|^2$$

where \(s(t)\) is the complex envelope of the transmitted signal, \(\tau\) is the time delay and \(f_d\) is the Doppler frequency. As is well known the cut of this function along the range axis, i.e. \(\chi(\tau, 0)\) represents the autocorrelation function of the signal. \(\chi(0, f_d)\) is the Doppler profile of the AF at zero delay.

Signal model: Iridium satellite communication system uses time division duplexing, hence it can have the same frequency band i.e. 1616–1626.5 MHz for both uplink and downlink transmissions [3]. This spectrum is divided into 240 channels each with a nominal bandwidth of 41.67 kHz. In each frequency channel, a time division multiplexing frame with a length of 90 ms is transmitted, as is shown in Fig. 1. The frame starts off with a simple time slot (20.32 ms), followed by four uplink time slots and four downlink time slots. Each downlink time slot transmits a signal burst with a length of 8.28 ms. The burst utilises the differentially encoded-QPSK modulation scheme and is shaped by a 0.4 root raised cosine filter. The overall symbol rate of the burst is 25 ksym/b.

![Fig. 1 Iridium frame](image)

Due to the time division duplexing nature of the Iridium satellite communication system, the signals we receive in a single frequency channel are pulse-like and each pulse consists of at most four signal bursts at the downlink time slots. How many downlink time slots are transmitting signal bursts depends on the user traffic which is not known a priori. Since there are gaps between the downlink time slots, it is easy to extract the signal burst from each time slot in the time domain. Therefore, a general way to examine the AF of the Iridium signal is on the basis of a single burst having a length of 8.28 ms and occupying a channel bandwidth of 41.667 kHz.

![Fig. 2 PSD of Iridium burst](image)

![Fig. 3 AFs of the modelled and real recorded signals](image)

![Fig. 4 Delay and Doppler cuts of diagram in Fig. 3](image)

The power spectral density (PSD) of a modelled Iridium burst is shown in Fig. 2. Fig. 2 also shows the PSD of a real recorded Iridium burst. It should be noted that we used random bits to model the Iridium burst. We used a digital programmable receiver, NI USRP-2950R, and a helical antenna with a gain of 16 dB to record the actual Iridium signal. The carrier frequency of the real signal was 1619.506 MHz and it was down converted to the baseband as shown in Fig. 2. It can be seen that the PSD of our modelled burst is close to that of the real recorded burst. This also confirms that the signal is noise-like, independent of channel content waveform.
Experimental ambiguity function: Now we can compute the AF of the modelled Iridium burst and that of the real recorded burst. The AFs are shown in Fig. 3 demonstrating high similarity between modelling and real signals. It also shows that both have apparent random sidelobes, which reflect the fact of the noise-like nature of signals. The average interference floor of both AFs is about –22 dB, which is expected taking into account the limited time bandwidth product defining the processing gain in case of a single Iridium burst. The delay and Doppler cuts of both AFs are shown in Fig. 4. We can estimate the delay resolution from the delay cut and it gives 39.3 µs for the modelled signal which corresponds to a range resolution of 11.8 km and 37 µs for the real recorded signal which corresponds to a range resolution of 11.1 km. Similarly the Doppler frequency resolution are estimated from the Doppler cut and it gives 121 Hz Doppler resolution for both the cases as expected from the signal length.

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The random sidelobes in the AF can be lowered down by averaging the AFs over multiple bursts, which is similar to the incoherent pulse integration in the pulse radar. In the following we average the AFs over multiple bursts, and the results are shown in Fig. 5. It is noted that for the modelled case we average the AFs over 100 bursts to get the result in Fig. 5a, which indicates a converged result as the number of bursts increases. For the real case, we extract one second of signal length of eight adjacent frequency channels and they are assigned simultaneously, which means that combining them together we can increase the effective bandwidth. The Doppler resolution can be improved by using long integration time. It should be noted that the Iridium downlink signals are pulse-like with a repetition time of 90 ms in a single frequency channel. Each pulse consists of at most four bursts with a length of 33.12 ms, corresponding to a Doppler resolution of 30.2 Hz. If we integrate multiple pulses coherently, the Doppler resolution is determined by the length of the overall signal. However, there exists Doppler ambiguity in this case and the maximum unambiguous Doppler frequency is 1/90 ms = 11.1 Hz. Another issue relates to the fact that the Iridium satellites have a large orbiting velocity with respect to the Earth, leading to a great Doppler shift on the signals impinging the earth surface, which needs to be compensated. Such compensation is part of further work.

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Conclusion: The Iridium L-band downlink signals have high power densities at the ground and provide true global coverage of the earth surface including the Polar Regions. In this Letter we take an analysis of Iridium signal from the radar point of view. Without loss of generality, we examine the Iridium signal on the basis of single burst with a length of 8.28 ms occupying a channel bandwidth of 41.667 kHz. The burst has an ambiguity diagram independent of the signal content. We have shown that averaging the AFs over multiple bursts, which is equivalent to incoherent pulse integration in this signal, reduces the level of random sidelobes. It is also stressed that due to large orbiting velocity of Iridium satellites with respect to the Earth, the Doppler effect induced by the motion of the satellites should be compensated.

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Submitted: 21 April 2016  E-first: 26 May 2016
doi: 10.1049/el.2016.1404

One or more of the Figures in this Letter are available in colour online.

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