Company and Technology Background

IMSAR LLC has radar technology that is able to track moving targets, image the surface of the earth, create digital elevation maps, assist in search and rescue operations, and detect small changes in a scene, such as the movement of a vehicle. Various branches of the US military, including the Navy, Army, and Air Force, as well as some commercial businesses, have expressed interest in this technology. The size, weight, power, and cost of IMSAR's Synthetic Aperture Radar (SAR) system, known as NanoSAR, are an order of magnitude less than similar systems. The end user of these experimental systems will predominantly be the US Department of Defense. All testing is in accordance with U.S. Government contract #W911QY-14-D-007

IMSAR performs SAR tests from a small aircraft typically flying between 2,000 and 10,000 feet in altitude (above ground level). Directional transmit and receive antennas are nominally pointed toward the earth. Reflected signals are collected and processed to create images of the ground. Transmission is a linear frequency modulated continuous wave (LFM-CW), or a "chirp," with the frequency being swept from the minimum to the maximum frequency 1000 times per second. A chirp signal is illustrated in Figure 1. Because the transmission power is under 15 W ERP and the frequency sweeps are very rapid, the average power at any given frequency is extremely low, as is the likelihood of detection by (i.e., interference to) ground based systems operating in the same frequency range.

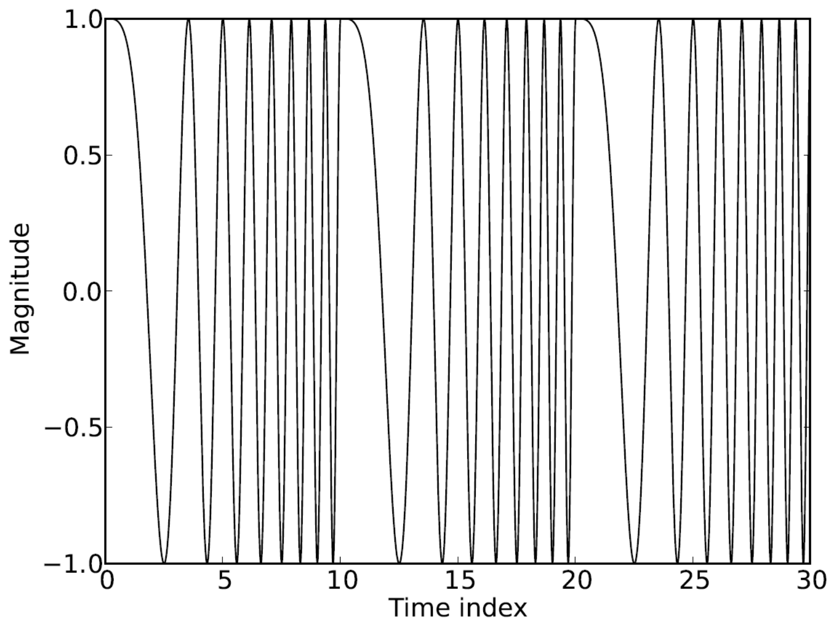

Figure 1. Example LFM chirp signal, increasing in frequency from left to right, then repeating.

UHF frequencies are employed to enable ground penetration and observation of specific targets where UHF reduces the clutter of the background. The transmit signal is directed perpendicular to the direction of travel and towards the ground using a directional antenna. The antenna radiation pattern is approximately 120° in elevation and 70° in azimuth. The back lobes of the antenna are attenuated significantly. The peak of the antenna pattern has a 45° incident angle to the ground. The return signal is received by the same antenna. An example of the geometry of a SAR is shown in Figure 2.

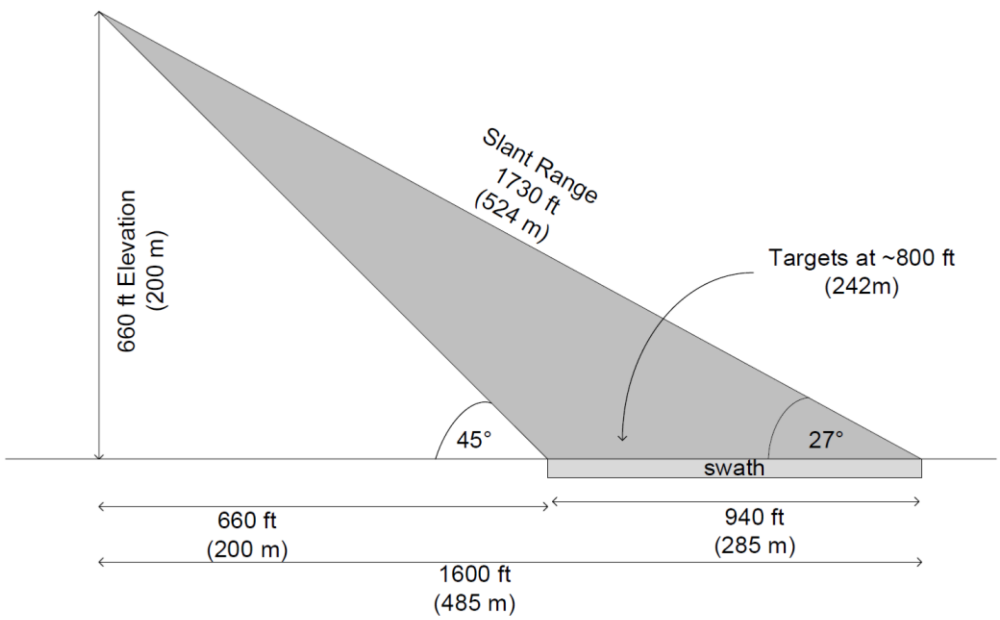

Figure 2. Example SAR geometry, from an airborne platform.

<u>Non-interference – Mathematical</u>

IMSAR's UHF band radar has a very low probability of interfering with other systems operating in the same frequency band, because the low-power signals are transmitted from a considerable range and are spread out over a large bandwidth.

The radar signal is a linear frequency modulated (LFM) "chirp" whose instantaneous frequency increases linearly throughout the duration of the radar pulse, beginning at the smallest frequency and ending at the largest. This is repeated 1000 times per second. Since each individual frequency is only transmitted for a very short duration, the power in each frequency bin is considerably less than it would be with a continuous wave (CW) signal transmitting at that single frequency. This is known as a spread spectrum signal.

As a microwave signal radiates from an antenna it spreads out as the distance from the antenna increases. This is in contrast to a laser beam, which is highly focused and maintains all of its power in the pointed direction. The power density (in units of watts per square meter) of a microwave signal radiated from an isotropic source decreases by a factor of $4\pi R^2$, where R is the distance from the antenna. For a directional antenna, the transmitted power is first multiplied by the gain of the antenna before dividing by the R^2 term. Even still the R^2 term becomes large very quickly and greatly reduces the power incident on the distant target.

The IMSAR UHF radar transmits 6 watts of power through an antenna that has about 6 dBi of gain, currently operates over 560 MHz of bandwidth (from 400-960 MHz), and typically operates at a range of 3000 feet or more from the intended target. So the 6 watts gets spread out over the band and then the power density is reduced by the distance that it must travel before reaching the ground. The end result is that the transmitted radar signal is indistinguishable from noise once it reaches another device or system operating in a sub-band, such as the 11 MHz-wide bands used by the FirstNet emergency responders network (power levels are on the order of picowatts). (IMSAR is able to detect this signal from out of the noise with the use of a broadband receiver and appropriate signal processing techniques.)

Non-interference – Experience

IMSAR has had an FCC experimental license covering portions of the UHF band since November 2008, when the license allowed for transmissions between 405-450 MHz. This was expanded to be 405-650 MHz in September 2010, and expanded further to 405-960 MHz in December 2012. During this time there has not been any reported incident of interference caused by our radar system, while logging many hundreds of hours of operation time in both rural and metropolitan areas.

During 2013 testing was performed near Atlanta, GA, and there was concern that our system would interfere with various broadcast and communication systems in the vicinity of this busy city. As a result, we notified about 40 different agencies to let them know what we were doing and when we were doing it. We told them that we didn't anticipate any problems but for them to call us if they encountered anything at all, and we would immediately shut down our transmitter. We successfully completed our experiments without any complaints from any of the organizations that were notified.

On another occasion, we were flying at just 500 feet above ground level at a military facility. Some members of the military wanted to prove that they could detect our signal. They brought out their expensive RF equipment and pointed it in the direction of our transmitter as it flew by on the aircraft. Even knowing where to look, the band we were transmitting at, and having sensitive equipment, they were unable to distinguish our signal from the noise floor of the equipment.

Calculated Incident Power as a Function of LOS Distance to Receiver

The incident power level decreases with distance between the transmitter and receiver. Figure 3 shows the power level incident at a receiver system as a function of the distance of that system from the IMSAR UHF radar. The vertical line in the plot represents the minimum altitude (AGL) at which the UHF radar can successfully operate. At this "worst case" distance, and for a receiver bandwidth of 10 MHz, the incident power level is estimated to be about -65 dBm, or 320 picowatts. For a system with a smaller receiver bandwidth, the incident power would be even less.

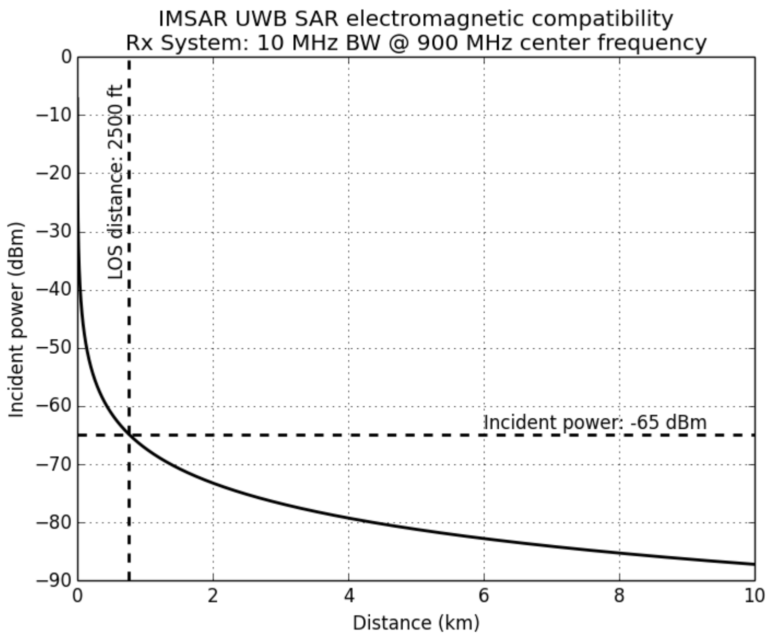

Figure 3. Power incident at a receiver as a function of distance from the UHF radar.

The results of Figure 3 were obtained using the following calculations.

Definitions

rr	ramp rate (Hz/sec)
duty	transmitter duty cycle
B_{Tx}	transmitter bandwidth (Hz)
B_{Rx}	receiver bandwidth (Hz)
P_{Tx}	transmit power (W)
P_{Rx}	receiver power (W)
G_A	transmit antenna gain (linear)
PRF	pulse repetition frequency (Hz)
freq	receiver frequency (Hz)
dist	distance to receiver (m)
FSPL	free space path loss
λ	wavelength (c/freq, where c is speed of light 3e8)

Equations

$$\mathrm{rr} = \frac{\mathrm{B_{Tx}\,PRF}}{\mathrm{duty}}$$

$$\mathrm{FSPL} = \left(\frac{4\pi\,\mathrm{dist}}{\lambda}\right)^2 = 20\log_{10}(\mathrm{dist} * \mathrm{freq}) + 20\log_{10}(4\pi c)$$

$$P_{Rx} = \frac{B_{Rx}\ P_{Tx}\ PRF\ G_A}{16\ rr} \left(\frac{c}{\pi\ dist\ freq} \right)^2$$

<u>Example</u>

duty	0.63
B_{Tx}	560 MHz (covering 400-960 MHz)
P_T	6 W
G_A	4
PRF	1000 Hz

For a receiver with 10 MHz bandwidth centered on 900 MHz, at 762.2 m (2500 ft) from the transmitter, the power level incident at the receiver is calculated to be 320 pW, or -65 dBm.