Operational consequences of a non-linearity of the harmonic radar

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The harmonic radar (non-linear junction detector – NLJD) receives waves generated by nonlinear electronic components or by junctions of oxidized surfaces of different metals in IED or in its activating parts.
Propagation model

The amounts of \( D, H_1, \) and \( H_2 \) have been selected in ranges which appeared in \([1]\). The surface roughness \( \Delta h_n \) satisfies a Rayleigh criterion for wavelength \( \lambda_n \), \( \Delta h_n < \lambda_n D/(8(H_1+H_2)) \) and the surface is electrically smooth.

For decimeter wavelengths and the grazing angles \(< \approx 2^\circ\) the reflection coefficient can be approximated by \( r \sim 1 \) for linear vertical and for horizontal polarizations. It was provided that the antenna pattern diagram in the vertical plane was nearly constant \( F(R) \sim F(R1) \sim 1 \) in directions of \( R \) and \( R1 \).

Total amount \( E \) of the resulting electrical field \( E \) is sum of direct \( E_D \) and reflected waves, \( E = E_D(1 + re^{-j\beta H_1H_2/D}) \), \( \beta=2\pi/\lambda \).

The normalised function estimates spatial distribution of the electric fields \( E1(f1), E2(f2), E3(f3) \) modules

\[
|E/(jE_D e^{-j\beta H_1H_2/D})| = |2 \sin(\beta H_1H_2/D)| \tag{5}
\]
Detection range limitations of the harmonic radar

- IED's pseudo non-linear radar cross section $\sigma_n$ at wavelength $\lambda_n$ depends on power density $S_n$ [W/m$^2$] on a target

$$\sigma_n = S_n \sigma_{spec} \quad (1)$$

$\sigma_{spec}$ [m$^4$/W] is specific harmonic radar cross section

- the oscillatory instead of monotonic decay distribution of electric field strength of electromagnetic waves if radar and IED are above ground flat surface.

- Radar received power $P_r$ for harmonic $n$ of a non-linear radar in the free space

$$P_r = \frac{G_m \lambda_n^2 (P_t G_t)^n \sigma_n}{(4\pi)^{n+2} R^{2n+2}} \quad (2)$$

- For second harmonic ($n=2$)

$$P_{r2} = \frac{G_{r2} \lambda_2^2 (P_t G_t)^2 \sigma_2}{(4\pi)^4 R^6} \quad (3)$$

- Linear radar has not above limitation, $\sigma = $ constant, independent of $P G^2$

$$P_r = P G^2 \lambda_r^2 \sigma / (4\pi)^3 R^4 \quad (4)$$

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Loss of detection by harmonic radar
(low heights H1, H2, small distances D)

At the locations marked with * appear minima of field strength, this causes wrong conclusion that there is no target in this direction.

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Threat increases due to oscillatory spatial distribution of E2

The increase of threat for operator. The same type IED on two different distances from radar a) 20 m, b) 13 m and target's orientation. Horizontal axis shows distance from IED to radar.
Manual search and detecting distances

Detecting ranges

gained in [1], can not be applied for other situations

<table>
<thead>
<tr>
<th>Targets</th>
<th>Ground</th>
<th>$H_2 = 1.2, m$</th>
<th>$H_2 = 0, m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toy Car</td>
<td>dry</td>
<td>11.5 m - 18.5 m</td>
<td>11 m - 14 m</td>
</tr>
<tr>
<td>IR sensor</td>
<td>dry</td>
<td>20 m - 30 m</td>
<td>11 m - 23.5 m</td>
</tr>
<tr>
<td>NOKIA1616+El.s.</td>
<td>dry</td>
<td>14 m - 22 m</td>
<td>12.5 m - 17 m</td>
</tr>
<tr>
<td>Meteo station</td>
<td>wet</td>
<td>12 m - 13.5 m</td>
<td>9 m</td>
</tr>
<tr>
<td>Remote Control</td>
<td>wet</td>
<td>18.3 m - 20 m</td>
<td>16.5 m - 17 m</td>
</tr>
<tr>
<td>Nokia5130c</td>
<td>wet</td>
<td>10.5 m - 11 m</td>
<td>7 m</td>
</tr>
<tr>
<td>Mortar shell 120mm</td>
<td>dry</td>
<td>-</td>
<td>2-3 m</td>
</tr>
<tr>
<td>1/2 dipole, balun,</td>
<td>dry</td>
<td>76 m</td>
<td>21 m</td>
</tr>
</tbody>
</table>

Difference of detecting range

due to target orientation changes, [1]

<table>
<thead>
<tr>
<th>Target</th>
<th>$H_2, m$</th>
<th>Difference m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toy car</td>
<td>1,2</td>
<td>4,0</td>
</tr>
<tr>
<td>Infra Red sensor</td>
<td>1,2</td>
<td>10,0</td>
</tr>
<tr>
<td>NOKIA1616 &amp; electric switch</td>
<td>1,2</td>
<td>5,3</td>
</tr>
<tr>
<td>Toy Car</td>
<td>0,5</td>
<td>3,5</td>
</tr>
<tr>
<td>IR sensor</td>
<td>0,5</td>
<td>7,0</td>
</tr>
<tr>
<td>NOKIA1616 &amp; el. switch</td>
<td>0,5</td>
<td>6,0</td>
</tr>
<tr>
<td>Toy Car</td>
<td>0</td>
<td>3,0</td>
</tr>
<tr>
<td>Infra Red sensor</td>
<td>0</td>
<td>3,0</td>
</tr>
<tr>
<td>NOKIA1616 &amp; el. switch</td>
<td>0</td>
<td>2,5</td>
</tr>
</tbody>
</table>
Status of the harmonic radars in March 2018

Manually search with harmonic radar, [1]

Application in Syrian conflict, [3].

Development NATO, [2].

Field testing of new mobile systems designed for detection of improvised explosive devices, Igor Parfentsev (2018), pp. 32-37. Can stop at a safe distance from explosive objects, when moving at a maximum speed of 20 km/h.

Has additionally integrated NLJD (Non-Linear Junction Detector). Transport speed 0-5 km/hour. [DOK-ING Innovative Solutions, MV-4].
Positive consequence of oscillatory spatial fields distribution

Interesting statement was claimed by [Field testing of new mobile systems designed for detection of improvised explosive devices, Igor Parfentsev (2018), pp. 32-37.]

If the harmonic radar is used from remotely controlled ground platform (acceptable risk or no threat for life or injury), the oscillatory field distribution can be used for improvement of IED detection probability.

The level of the signal reflected from standard targets increases when the vehicle is moving, the sum echo signal starts fluctuating strongly, causing increases of the range of their detection.

This statement should be checked and analyzed.
References


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Thank you for attention!

QUESTIONS?