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PERFORMANCE COMAPRISON OF METALLIC REFLECTOR AND PRINTED PLANAR ANTENNAS FOR MOBILE INFANTRY RADARS

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Abstract: *The paper analyzes performances of metallic reflector and printed planar antennas aimed for application in modern mobile ground based infantry radars. It is known that metallic reflector antennas might generally have better gain comparing to classical printed planar antenna solutions. The paper however shows that when all major parameters are taken into account for both antenna classes in this kind of application including electrical, mechanical, and economical - conclusion is that printed planar antennas that employ modern technologies and design approaches on one side could realize gain figures that are close to metallic reflector antenna ones while on the other side overall performances push them considerably above metallic reflector antennas and make them better and more effective solution in such applications.*

Keywords: *Sensor, Radar, Infantry radar, Antenna, Printed Antenna, PCB antenna, Reflector antenna.*

1. INTRODUCTION

Surveillance radars now days represent common equipment used by defense forces, various governments security agencies and even for some civil applications as they have various advantages over optical/IR systems and other methods.

Today's trends for portable radars/sensors implicate the following performance requirements:

- Mobility (even handling by a single person)
- Lightweight
- Small size
- Longer detection ranges
- Higher resolution
- Low transmitting power
- Low radio siginture
- Powerfull processing of raw data to achieve:
- intelligent detecion, classification and target activity analysis
- High reliability in various environments.

All these requirements have implication to various elements of the radar system. One of them is antenna that is at common infantry radar frequencies usually largest and block of considerable importance as it establishes several major radar parameters, e.g.: bearing/angular resolution, available S/(N+I) level, sensitivity, maximal target detection range, mass, size, mobility, required output power levels, etc.

This article analyzes performance and compares two antenna classes:

- classical metallic parabolic reflector antenna and
- planar printed antenna arrays

from the perspective of integrability and system performances of infantry surveillance radar IP-15 which design is described [1], [2].

2. CURRENT SOLUTION, REQUIREMENTS OF NEW GENERATION

Origianal version of IP-15 radar uses metallic (parabolic) reflector antenna and it is realized in waveguide technology. On one side its 3d shape do not enable integration (for that - planar structures are required) and on the other side its depth is too big and causes additional difficulties. Also waveguide technology, though it offers low losses, is cumbersome and doesn not enable easy integration of an antenna into a compact system.

So the new solution genaerlly needs planar antenna design as it directly help to improve: size, mass, mobility, and achieve high level of integration of all radar components, improve reliability and achieve cost effective solution. Though planar antenna could be realized in verious technologies – here PCB technology is considered as a most effective one to achieve set goals.

In Table 1 comparison of major parameters are listed for two antenna classes for portable radar/sensor applications: reflector antennas and planar flat panel PCB antenna arrays [3], [4], [5] and [6]. PCB antenna arrays properties listed in the column 3 represent current state of the art without novel technologies and solutions proposed in the paper. Performances that could be achieved with that novel technologies applied to PCB antennas (based on experience and various antanna experiments) are listed in the column 4.

Table 1. Comparison of Reflector and PCB antennas

ANTENNA PROPERTIES			
ELECTRICAL:	**Metallic reflector antenna**	**Flat Panel PCB array, Current SoA 1)**	**Flat Panel PCB array, Novel 2)**
Gain (G)	*High, very High*	*Medium*	***High 3)***
Directivity (D)	*High, very High*	*High, Very High*	*High, Very High*
3dB Beam Width, Azimuth	*Narrow, very Narrow*	*Narrow, Very Narrow*	*Narrow, Very Narrow*
Efficiency (η)	*High, very High*	*Medium*	***High 3)***
Side Lobe Level (SLL)	*Low, very Low*	*Medium*	***Low 3)***
Front / Back (F/B)	*High, very High*	*High, Very High*	*High, Very High*
Return Loss (RL)	*High*	*Medium*	***High***
Frequency (Fc)	*Low, High, very High*	*Low, Medium*	*Low, **High 3)***
MECHANICAL			
Size	*Big*	*Medium, Small*	*Medium, Small*
Depth	*Big*	*Thin, Very Thin*	*Thin, Very Thin*
Technology	*Metallic parabolic reflector W/G/CX port*	*PCB, Planar/ Flat Panel W/G/CX port*	*PCB, Planar/ Flat Panel W/G/CX port*
No. elements	*Single antenna*	*Antenna array (>200 antenna elements)*	*Antenna array (>200 antenna elements)*
Mass	*Bulky, Considerable*	*Lightweight, Compact*	*Lightweight, Compact*
Cost	*Medium, High*	*Low, Medium*	*Low, Medium*
Rigidity, compactness	*Medium, High*	*Low, Medium*	*Medium, **High***

1) current State of the Art (SoA), classical approaches
2) with new technologies and solutions applied by the authors
3) limits are not established

Note: for metallic reflector antennas - parameter ranges that are considered here represent only what is reasonable to fit within portable infantry radar size constraints. It is well known that parabolic reflector antennas could achieve very high levels of directivity and gain with appropriate big reflectors size. However it is obvious that size of the reflector that is in the ranges of 1m and above is completely impractical for these applications.

3. PCB PLANAR ANTENNA SOLUTIONS

3.1. State of the art

General block scheme and various elements of Flat panel PCB antenna for radar applications is show in Fig.1.

Based on Table 1 (column Current State of the Art, SoA) conclusion is that PCB antennas can not compete reflector antennas in sevaral major parameters. As a result PCB antenna arrays have not been used much for these applications though there were some attempts even at lower microwave frequencies (e.g. X band) however without much success. One very promising and advanced approach would be to use Boro arrays [6] (as of their inherent low losses and reduced feeding network) – however up to now no specific project for that have been launched.

Essentially major reason why PCB antenna cannot compete reflector ones is so called "gain saturation effect" combined with some mechanical issues.

As it is known when size of PCB antenna array is increased (to increase aperture of the antenna, directivity and gain) – gain and directivity are also increasing. However at some point (depending on frequency, losses, etc.) – when antenna size increases further - gain initially begin to saturate and by going further it starts even to decrease (while directivity still increases). That "gains saturation effect" is direct consequence of increased losses in feeding network.

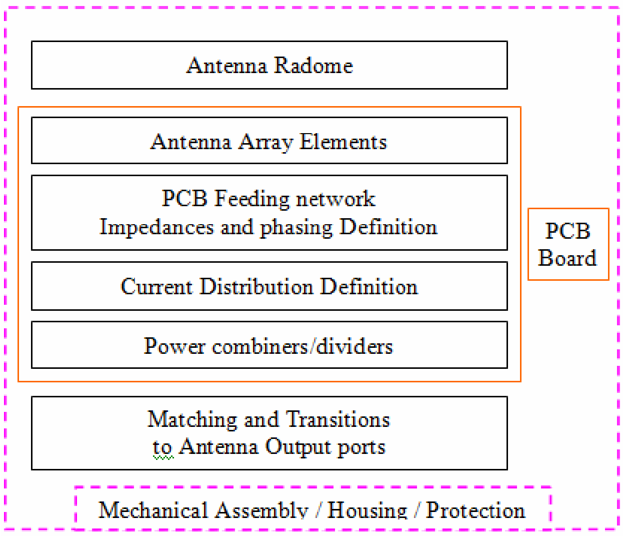

Figure 1. General block diagram of PCB antenna.

As of gain saturation effect - up to now current state of the art has enabled manufacturing of flat panel PCB antennas only with medium gain levels at microwave frequencies however that is not enough for portable radar applications. Generally speaking gain levels above ~25dBi were practically impossible to achieve at microwave frequencies (especially higher ones) with high efficiency and decent antenna size.

3.2. Advanced design approaches

By working extensively on various PCB antenna classes and by analyzing major drawbacks of current state of the art and PCB antenna solutions it has been concluded that considerable advances and breakthrough could be achieved with PCB antennas however with novel concepts and technologies.

In Figure 1 it is shown general block diagram of radar antenna that employs PCB technology. For this application particular attention has to be devoted to rigidity, mechanical construction, radome and environmental protection as equipment is normally deployed in harsh environment. This is also important as it is known that PCB antenna core itself is quite fragile. Major new technological elements and solutions for PCB based antennas that could considerably boost up their performances are:

1. Antenna element design and performances
2. Connection of antenna elements to feeding network
3. Current distribution type
   (currently Uniform and Binomial are generally used, however more efficient ones like Dolph-Chebyshev are not used probably as there were no solutions for implementation of such current distribution scheme)
4. Current distribution implementation
   (i.e. physical definition of amplitudes and phases of required current distribution in chosen technology)
5. Feeding network and losses reduction
6. Solutions less sensitive to production tolerances
7. Power combining of subarrays to ensure high efficiency and reduce losses
8. Implementation of required output ports, interfaces between PCB and Front End block
9. Design of necessary transitions with high efficiency
10. Combining optimal transmission lines in antenna system, etc

Technologies and solution under listed points above are new ones and not previously used and published in open literature (except perhaps couple, however only partially and at basic level without deeper analysis). Extensive research and necessary experiments have been performed to confirm viability and quality of such technologies and solutions. Based on simulation and experimental results it is concluded that approach that includes above listed technologies offers considerable performance improvements and realization of high efficiency PCB antennas. And also major electrical performances (e.g. gain) of such PCB antennas could definitely satisfy requirements for portable radar application and could be comparable to or better than reflector antenna ones.

4. PCB ANTENNA - ADVANCED SOLUTIONS

4.1. Antenna design

Based on the analysis initial task is set to design a PCB antenna for initial feasibility analysis and compare its performances with reflector antenna from IP-15 radar system.

This feasibility model includes only few elements from the previous list with the goal to check general performances i.e., beam width, side lobe levels (SLL), size, mass etc and compare with the reflector antenna. Etc As only few elements (1, 2, 3, and partially 4, 5) of previously listed improvements are applied and also as of production tolerances expectation is that some parameters (e.g. realized gain level) of this breadboard model would not show maximal figures (and get close to reflector antenna), however plan is to tackle maximum gain level in the next step.

Major goal of this prototype is just to asses overall electro-mechanical performances, confirm it has potential to replace reflector antnena and confirm that gain could be further improved considerably at the next step.

The PCB antenna arrays consist of 256 antenna elements with Dolph-Chebyshev current distribution implemented. In Fig. 2 PCB antenna array with reflector plate and some mechanical supporting element is shown. As of clarity radome is not shown.

Simulated model with 3d radiation pattern is shown in Fig.2.

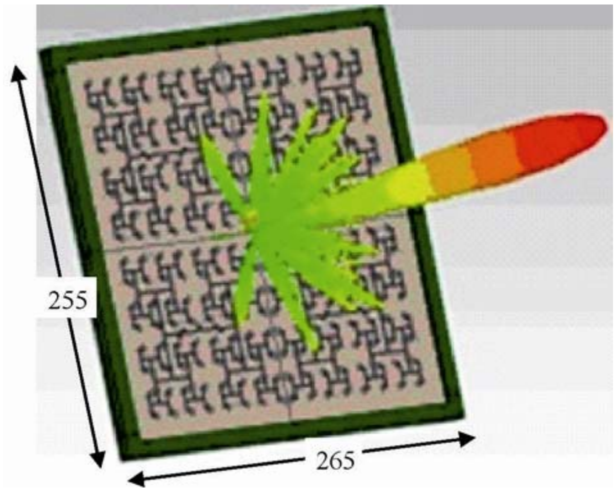

Figure 2. 3d model of prototype antenna (radome is not shown)

Radiation patterns, 2d plots, of the PCB antenna are shown in Fig. 3 (E plane) and in Fig.4 (H plane).

Simulation shows that PCB antenna has high directivity (~30.5dBi) and gain (~28.5dBi) with side lobe level (SLL) ~ 20dB.

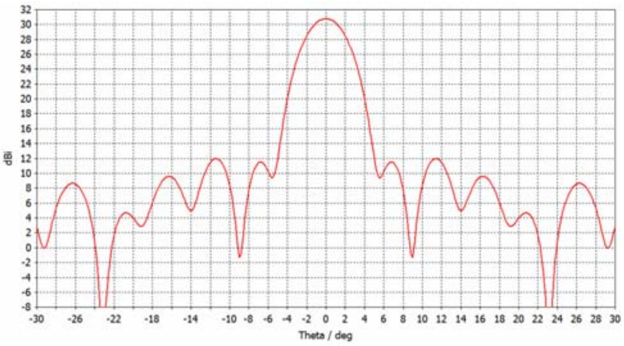

Figure 3. Radiation pattern of the PCB antenna, E plane.

Comparing radiation patterns of both antennas (PCB and reflector) conclusion is that both antennas practically have identical main lob (that could be easily concluded by comparing 3dB beam width of both antennas, see Table 2 as well). In addition maximum side lobe levels are also quite similar (~20dB).

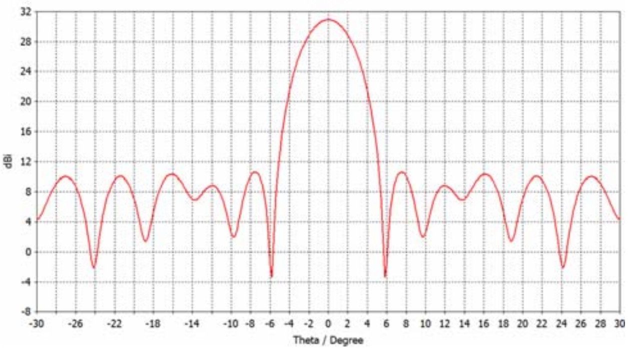

Figure 4. Radiation pattern of the PCB antenna, H plane.

For comparison - radiation pattern of parabolic reflector antenna IP-15 is shown in Fig. 5.

Table 2 also shows that both antennas have similar directivity as well (PCB antenna ~30.5dB).

Simulated gain of the feasibility model is ~2÷2.5dB bellow parabolic antenna reflector antenna. Though smaller this figure is in fact quite good result having in mind smaller size and aperture of the PCB antenna (lateral size ~25% smaller), see Table 2.

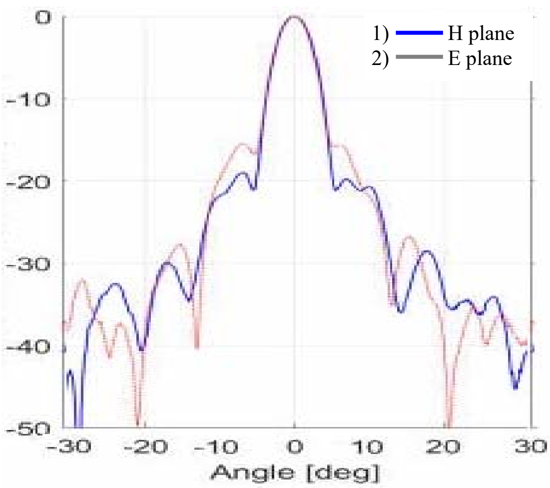

Figure 5. Radiation pattern of the reflector antenna.

PCB antenna gain level is again direct consequence of losses in feeding network and the fact that not all improvements are applied. The goal of this breadboard model is just to asses initial electrical and mechanical performances and see what capacity it has to get electrical parameters close to reflector antenna ones.

Simulated Return Loss of the PCB antenna is shown in Fig. 6. As it can be seen levels between 15-20dB could be achieved in decent band width (~5%) around center frequency of the antenna without additional matching elements.

It is worth to note that active area of PCB antenna (i.e. area occupied by antenna elements without mechanical fixtures) is 17% smaller than aperture of reflector antenna (without fixture elements as well) - so achieved results is considerable breakthrough.

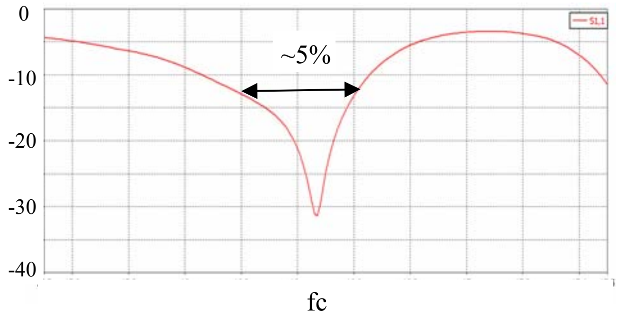

Figure 6. Return loss of the PCB antenna.

On the other side comparing this PCB antenna to current state of the art PCB antenna performances – conclusion is that this novel solution have higher performances and gain saturation issue has been pushed further which gives performances suitable for radar applications.

In the Table 2 performances of realized PCB antenna and reflector antenna are summarized.

Table 2. Comparison of realized performances of novel PCB antena array and original radar reflector antenna

Antenna Parameter:	PCB Flat panel array	Metallic reflector	Unit
Gain (G)	~ 28.5	~ 30.5	dBi
Directivity (D)	~ 30.5	~ 31	dBi
3dB Beam Width, Azimuth	~ 4.85	~ 4.80	°(degrees)
Efficiency (η)	~ 66.5	~ 88.8	%
Side Lobe Level (SLL)	~ 20	~ 20	dB
Front / Back (F/B)	> 35	> 35	dB
Return Loss (RL)	15 - 20	> 20	dB
Frequency (Fc)	Ku band ~15	Ku band ~15	GHz
Size, Lateral	~270	~350	mm
Size, Depth	~30	~180	mm
Mass	~1	~3	kg
Technology	PCB, Planar	Parabolic reflector	
No. elements	256	Single ant	
Note: All parameters include radome, for both antennas			

Overall results show that presented feasibility prototype and proposed approach are viable and such PCB antenna has potential to get electrical performances close to reflector antenna while based on size, mass and geometry it has number of advantages over reflector antenna.

Also novel PCB antenna with presented performances will have enough capacity to cover near and medium ranges for detection. Apart from smaller gain level (which will be improved at prototype stage) PCB and reflector antennas have similar other electrical performances. At the same time PCB antenna is smaller more compact and with reduced profile and mass comparing to original reflector antenna and enables better integration of components.

5. CONCLUSION

Overall performances of novel PCB antenna where apart from electrical we have to consider also integrability and mechanical and economical parameters – show that PCB could be more effective solution and is in line with modern trends of miniaturization of radars with increased mobility and functionality. Novel PCB antenna is ~25% smaller (front profile) and has ~4 times smaller depth than reflector antenna. Directivity is similar to reflector antenna while gain is around 2-2.5 dB smaller than reflector antenna. Smaller gain is result of losses in feeding network and smaller aperture size of PCB antenna. The next step is to assemble and measure the PCB antenna and compare measured results with simulated ones and with reflector antenna ones as well.

Also after measurement of this feasibility model the plan for the future antenna prototypes is to apply few additional (of 1-10) listed technologies. That will aim to realize prototype PCB antenna with all electro-mechanical-environmental features that will have higher gain and closer to the reflector antenna one - so it could completely replace reflector antenna in the radar system.

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