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Shared Aperture Antenna Technology for SAR: A Review of the Theory and Applications

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Abstract

In order to use shared aperture antenna technology for Synthetic aperture radar, communication, Satellite communications, Electronic warfare and all radar applications (e.g., Space borne, aircraft telephony performances, antenna designs, wireless communications, airborne systems), studying the nature and characteristics of the shared aperture antenna technology is important. The purpose of this paper is to review and discuss various techniques aimed to develop the shared aperture antenna subsystem. This paper further focuses on the review of future implementation techniques and performance comparison along with their applications. This review serves as a comparative studies and reference beneficial for shared aperture antenna technology researchers and for future implementation of the technology. This review paper opens a corridor for researchers to perform future studies between different configurations and system models as a reference point for developing more powerful, flexible and efficient applications.

Keywords: Shared aperture antenna (SAA), Synthetic aperture radar (SAR), Space borne, Air borne and Wireless.

1. Motivation and Background

Shared aperture antennas are the becoming an active area of research. As we know the technology plays a pivotal role in the design and development of synthetic aperture radar systems. A good design can ensure that a system will satisfy key requirements in such topics as low mass, small volume, so as to reduce payload weight and size and thus the cost of the machine. So the task is to design and develop an effective SAA with less complexity that will support synthetic aperture radar applications. The above observational and budget constraints can be balanced by adopting antennas capable of working at dual polarization while sharing the same aperture, so as to reduce the overall size and weight of the system. As of now there is no systematic literature review for mapping shared aperture antenna technology.

The literature review aids researcher who is ambitious to contribute in this area, without investing time in doing a dedicated literature survey.

1.1 Introduction to Synthetic aperture radar

Since the advent of SAR technology by Carl A. Wiley, in 1954, it has been used as an important tool for earth observation from airborne as well as space-borne platforms. With the launch of Sea sat SAR in 1978, SAR has emerged as an immensely powerful operational research tool (Holtet et al., 1992; Katsaros and Brown, 1991) and tens of satellite placed in polar sun synchronous orbit. Importantly, SAR can provide quantitative measurement of earth surface features and can also delineate the sub surface level geophysical parameters applying appropriate algorithms. It enables us to focus on a given research area for delineating the greater details with high to moderate resolution and high accuracy. SAR sensors can acquire data in single, double and quad polarization as per requirement of study, and meticulously used to geophysical parameters study using SAR interferometry and polarimetry. Antenna theory tells us that the antenna radiation pattern (i.e. a graphical representation of the intensity of the radiation as a function of the angle from the perpendicular line to the antenna plane) in the far field can be approximated to a Fourier transform of the physical shape of the antenna itself. Figure 1. shows an example of a rectangular antenna, which is the common shape of a SAR antenna, and its radiation pattern. The 3-D shape of the radiation pattern is shown in Figure 1. Which illustrates a typical imaging geometry of side-looking imaging radar. The rectangular SAR antenna is loaded either on an aircraft or on a satellite. As the platform moves along with the antenna, a stream of radar pulses is transmitted from the antenna. The platform's flight direction is called azimuth direction, and the transmission direction of radiated pulses in the main lobe is called range (or slant range) direction. The length of the footprint perpendicular to the azimuth direction is called swath width, and the angle of range from vertical is called look angle. Cumming and Wong, 2004 has provided details of SAR acquisition principle and imaging geometry. Foot print of SAR system depends on antenna design and characteristics and radar signal processing. There unique design of the antenna can help in acquiring images in multimode and multi polarization. Shared aperture antenna technology can be used to design a dual or triple band quad polarization and multi resolution SAR system.

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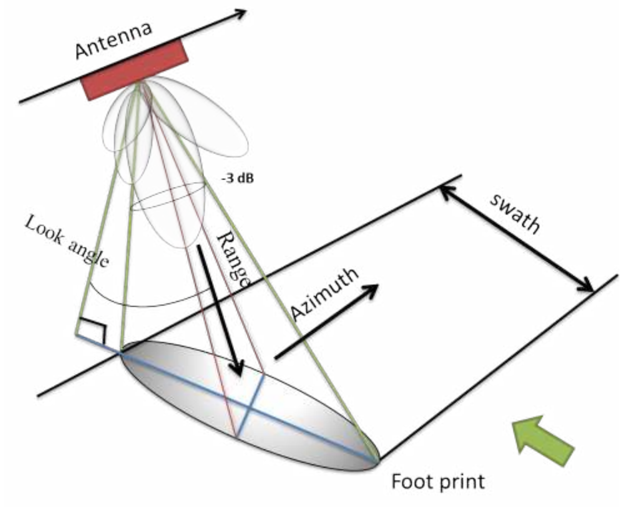


Fig 1. SAR technology

1.2 SAA for SAR applications

Antenna technology using shared aperture antenna (SAA) for dual band operation or using polarization diversity is of immense use in communication, especially in view of gradual increase in demand for communication channels. Such a technology also should help in reducing antenna cost, weight, as well as radar cross section (RCS). By the proper combination of element spacing, addressed in Table-8, amplitude weighting and progressive phase shift, the radiated energy can be concentrated into a main beam in particular scan angel given in Table-8, some minor lobes are called side lobes, are also formed. The input to the array is usually some form of transmission line i.e. coaxial cable. The overall characteristics of the array depend on the choice of the element and choice of the feeder network addressed in Table-9. Shared aperture antennas are the recent trend of antenna technology that integrate the usefulness of several antennas in to one aperture using dual/quad band multiple beamforming technology. The configuration of the SAA technology as shown in Figure 2. An aperture can be shared between systems in various ways. One way is to simply time multiplex the use of the aperture in Figure 2. To reduce the number of associated antenna systems by combining the functions of several systems in to one single aperture (A. T. Axness et al., 1995). Multi-functionality of the antenna system is a key issue in the case of mobile platforms performing simultaneous individual/multiple tasks, such as Radar applications, Synthetic aperture radar (SAR), VSAT, Space craft, 4G LTE, DCS, IEEE &WIMAX and Wireless communication and electronic warfare etc. are addressed in Table-4 and Figure 6. Microstrip patch antenna is usually selected for its low profile and simplicity in fabrication. The trend in radars is to perform simultaneous multiple operations and measurements at dual/multiple frequencies ideally with dual polarization capability. Space borne synthetic aperture radar antennas have many special electrical requirements, such as operation at multiple frequencies with multiple polarization ability, with fairly wideband operation being required at these frequencies. They are also required to be electrically large, giving rise to issues such as low mass, easy and reliable deployability, and low cost and capability of high resolution imaging from airborne or space borne platforms.

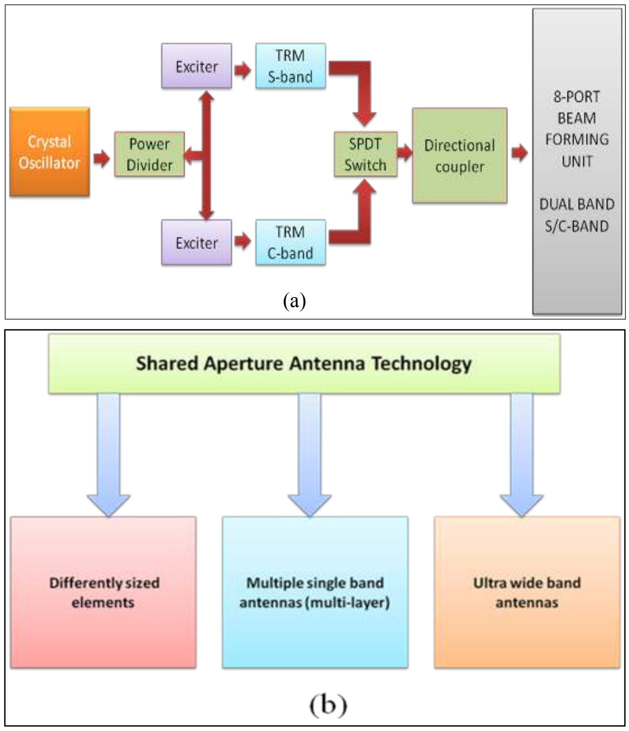


Fig. 2. (a) System configuration (b) SAA technology

A. Operating frequencies are usually widely separated (typically some combination of L/S-, S/C, L/X, P/Ku or P/X-bands), requiring different array element spacings (0.6λ to 0.8λ) to avoid grating lobes (particularly if scanning is required) and are preferred to reduce the number of antenna elements ultimately it leads to minimize cost mentioned in Table-5 in SLR.
B. Due to layout curtailment, a single microstrip feed substrate is limited to two independent feed networks (e.g., dual polarizations or dual frequencies). Thus, at least two/more substrate layers are required (given in Figure 6 & Table 6) for dual polarization dual frequencies of operation.
C. Isolation between frequency bands are not likely to be met unless these feed networks are separated by a ground plane are addressed in Table-11.

This review firstly gives a motivation and back ground, introduction to shared aperture technology with related to synthetic aperture radar brief explanation about SAA. This is followed by highlighting the architectural infrastructure of SAA. Moreover, antenna design perspective based on the frequency range and the different methods have been explained to improve the cross polarization and isolation. The effects of SAA performance and analysis have also been reviewed. Finally, Shared aperture antenna technology have been used in different application ongoing researches.

1.3 Research questions

The main intention of this paper was to find and interpret the published literature related to shared aperture antenna technology for synthetic aperture radar applications to reduce payload weight and size and thus the cost of the machine. This is further detailed in the following research questions:

RQ1 How much activity was carried out in the last decade?

RQ2 what research topics are being addressed?
RQ3What are the frequency bands and polarizations implemented with necessary applications.
RQ4 Software and Substrate used for design with spacing constrains for multi-layer or what are the different tools, technologies that were used?
RQ5 what are the choice of antenna elements (array) specified in SLR
RQ6 what are the type of feeding for antenna elements to improve perfect matching and the type of feeding network used for isolation and cross polarization improvement.
RQ7 what is the inter element spacing required and scan range used in SLR (systematic literature review).
RQ8 How the impedance matching, Return loss / VSWR / Reflection coefficient was improved in SLR
RQ9 How the isolation is achieved with different techniques.
RQ10 what are the configurations implemented for gain enhancement in SLR.

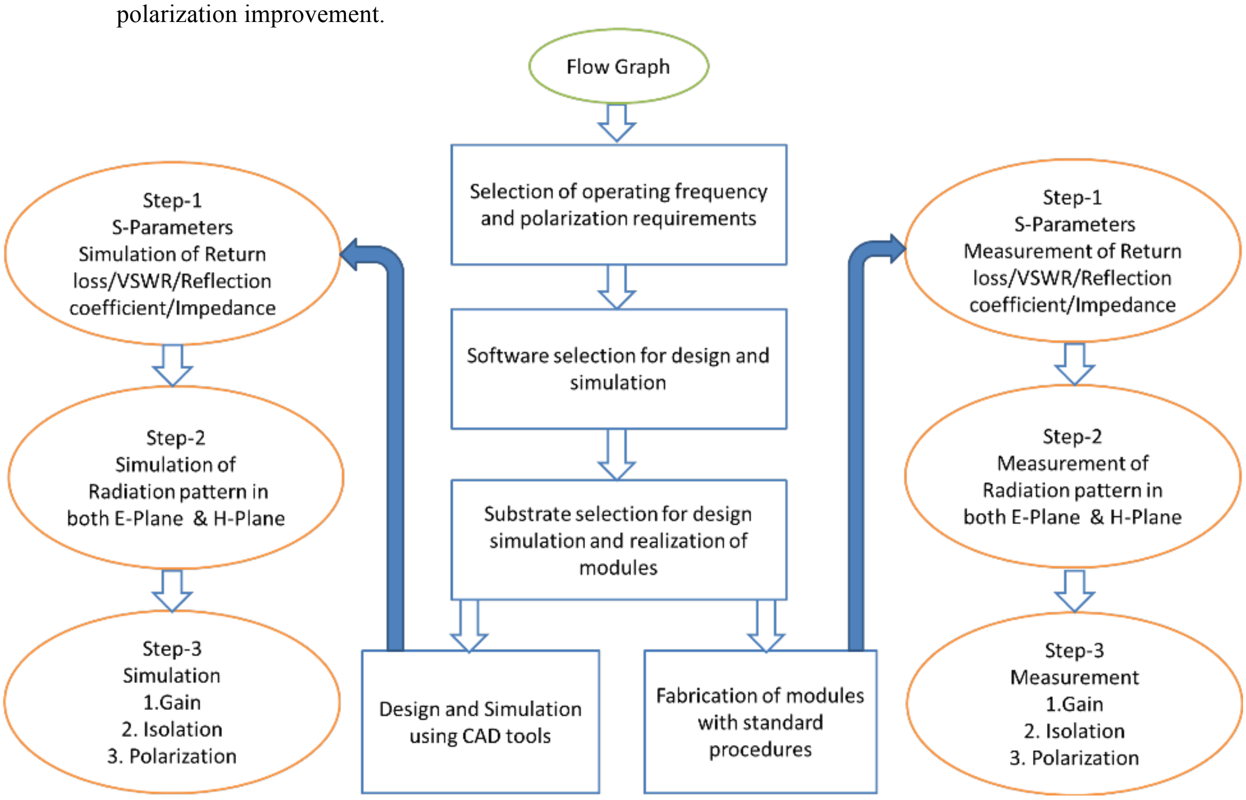


Fig. 3. Flow graph for design steps

1.4 Related work
There are no systematic literature reviews on Shared aperture antenna technology till now. Since then, the number of publications in the domain has not much increased and we focused on a systematic literature review from January 1996 to November 2015 from all locations with search strings only on shared aperture/shared aperture antenna.

2 Search strategy
We performed our search on scientific electronic databases which includes good impact factor conferences, journals and articles. Refer to Table 1 for a list of selected electronic databases.

Table 1. selected electronic databases

Electronics database	*URL*
IEEE	http://ieeexplore.ieee.org
PIERS	www.jpier.org
MOTL/Wiely	www.onlinelibrary.wiley.com
IET	www.theiet.org

2.1 Search string
Search string helps to get all results related to Shared aperture antenna. The reasons for searching with shared aperture and shared aperture antenna as keywords is to ensure all relevant papers are included. The search string used on all databases is: (shared aperture and shared aperture antenna).

2.2 Inclusion criteria
In order to include apropos publications in our review, we defined selection criteria and based on that we performed inclusion of published literature. We selected papers published in peer review journals, conferences and articles from 1/1/1996 to 1/11/2015. We selected papers that are relevant to our research questions. We excluded papers that are not related to shared aperture antenna technology. Table 2 shows our inclusion criteria.

Table 2. Inclusion criteria

Inclusion
Publications from 1/1/1996 on Shared aperture antenna technology related to Radar Applications.
Papers published in journals, conferences and articles.

2.3 Roles and responsibilities

Venkata Kishore Kothapudi (VIT University, research scholar): result classification and detailed analysis for various journals and papers from IEEE, PIERS and Wiely online (MOTL).

Vijay Kumar (VIT University, expert reviewer): assessment of classification and detailed analysis.

2.4 Conference and journal selection process

The process was conducted as follows:

1. The researchers perform the search on each database and save the references in bibliography files
2. The scholar reads all titles and abstracts and checks the inclusion and exclusion criteria for each entry
3. The scholar classifies the conferences and journals ccording to type, topic, and domain. The expert reviewer reassesses the classification and inclusion/exclusion of search results.

2.5 Data analysis

The data is analyzed to show:

1. The databases and number of query results
2. The publications are listed as per databases with respect to authorship, reference, date, publication type, type of content, topic of content and domain
3. The number of relevant publications per year
4. The graph that will show publication of journals and conferences, which are generated from the final results a detailed selection process performed on selected data bases.

3 Results

All results were ordered 'by relevance' as shown by the databases. From these results, we considered the first results of each database in our first repetition of the study. In total we reviewed 35 publications. The following acronyms are used to categorise the results in Tables 4.

Table 3. Number of papers per database

Data base	*Search date*	*Results %*
IEEE	1/10/2015	63.33
PIERS	1/10/2015	6.66
WIELY	15/12/2015	20
IET	1/10/15	3.33
INTECH OPEN SCI	1/10/15	3.33
APL TECH DIGEST	1/10/15	3.33

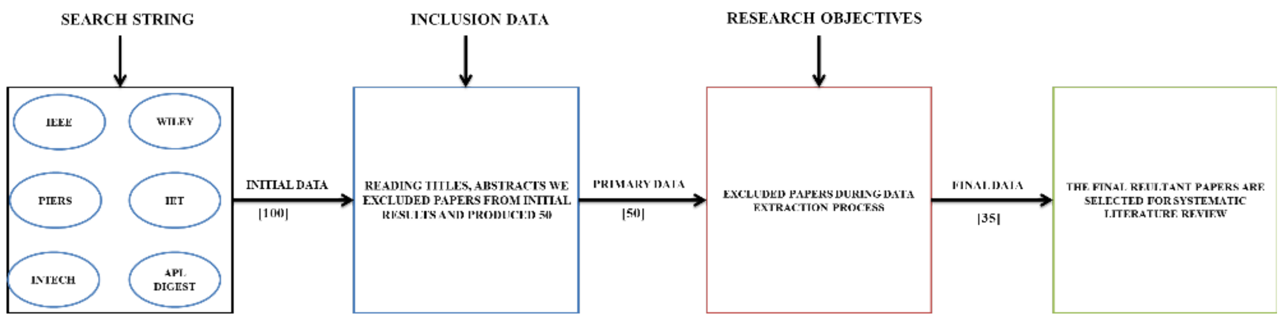
• *Publication:* The included publications classified as journals, conference papers and articles.
• *Type:* What kind of information was presented in the publication, e.g., date, publication, topic, application area. method.
• *Topic:* The exact intention and purpose of the publication.
• *Application area:* We classified publications into different areas, namely: Radar applications, Synthetic aperture radar (SAR), VSAT, Space craft, 4G LTE, DCS, IEEE &WIMAX and Wireless. This will also ensure the publications are relevant to include in the review.

RQ1 How much work was carried out in last decade?

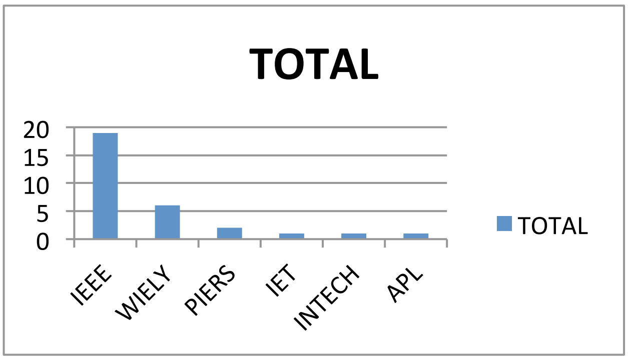
We plotted a number of relevant publications per databases in Figure 2, per publication type in Figure 3 and per year in Figure 4. In the last decade, there was a noteworthy increase in number of publications compared with 2008 to 2015 that shows the significance of the review on shared aperture antenna technology. The first paper on shared aperture antenna technology with complete radar system configuration was published in 1996. Figure 4 shows numbers of papers published from 1996 to 2015 (Note: Search string only shared aperture/shared aperture antenna). We performed searches in October 2015 and December 2015 and all the papers had not been available by that time it might be the reason for less number of papers in 2015. The reviewed papers will help in building up a body of knowledge in shared aperture antenna technology for radar applications.

RQ2 what research topics are being addressed?

To know the research topics that are focused in shared aperture antenna technology, we have generated a table which are derived from topics and applications from year wise analysis are shown in Table 4. The research topics are broadly classified into Radar, Synthetic aperture radar, VSAT, Space craft, 4G LTE, DCS, IEEE &WIMAX and Wireless application domains.



(a)



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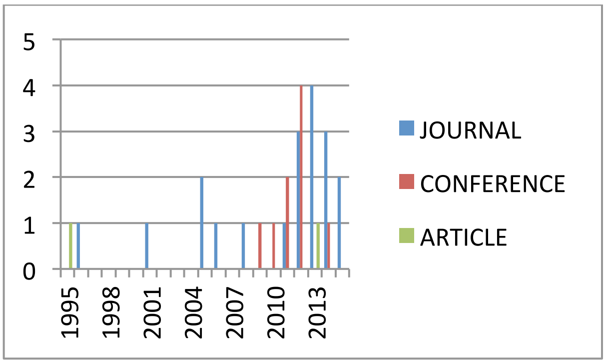

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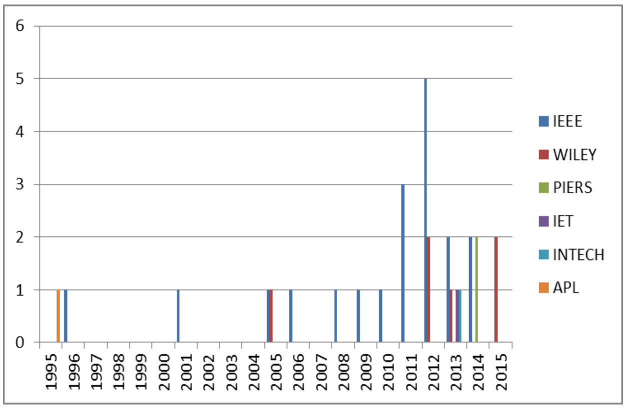

(d)

Fig. 4. (a) Selection process for review (b) Included results per database (c) Included results per publication type (d) Included results per year

RQ3 What are the frequency bands and polarizations implemented with necessary applications.

- Operating frequencies in P (~0.4 GHz), L (~1.3 GHz), S (~2.7 GHz), C (~5.3 GHz), X (~9.6 GHz), or Ku (~17.2 GHz) band - the mostly used bands being L, C and X.
- P-band most suited for biomass monitoring and hydrological mapping.
- S-band best suited for volumetric soil moisture.
- C-band covering the widest range (sea-ice, wave parameters by spectral analysis of image segments,
- Surface soil moisture, snow parameters, glaciers, ground water, etc.).
- X-band providing the best spatial resolution, thus best suited for surveillance.
- Ka-band specifically suited for snow that is semi-transparent at lower frequencies.
- Several combinations of polarizations in transmission and reception possible to be implemented: HH, VV, VV/HH, HH/HV and VV/VH.
- Wide range of applications for every frequency band, with variable effectiveness

Table 4. Specific topic and application area

Author	Ref	Date	Publication	Topic	Application Area
A. T. Axness et al.	[1]	1995	Article	An experimental shared aperture antenna development	COMM &EW
Stephen D. Targonski et al.	[2]	1996	Conference	A prototype S A R array	SAR
D.M. Pozar et al.	[3]	1999	Journal	Dual-band and dual-polarization capability in a shared aperture	SAR
Nemai C. Karmakar et al.	[4]	2001	Journal	A photonic bandgap (PBG)-assisted shared-aperture	VSAT
Vetharatnam, G et al.	[5]	2005	Journal	Combined feed network is proposed for ashared-aperture	SAR
C.I. Coman et al.	[6]	2006	Journal	Differently sized radiating elements	RADAR
Q.-X. Chu et al.	[7]	2008	Journal	Two wideband antennas sharing a common aperture	SAR
M. Meng et al.	[8]	2009	Conference	A multilayer dual-band dual-polarized (DBDP) antenna	SAR
Gao G et al.	[9]	2010	Conference	Shared-aperture Ku/Ka bands microstrip array feeds of parabolic cylindrical reflector antenna	SPACE CRAFT
Giuseppe Colangelo et al.	[10]	2011	Conference	A novel Shared Aperture Dual Band Printed Antenna	SAR
Shun-Shi Zhong et al.	[11]	2011	Conference	Tri-band dual-polarization (TBDP) shared-aperture	SAR
Satyajit chakrabarti et al.	[12]	2011	Journal	Dual feed dual linearly polarized aperture coupled planar microstrip patch antenna	SAR
Zhong, S.-S et al.	[13]	2012	Journal	A tri-band dual-polarization (TBDP) shared-aperture	SAR
Kong, L.-B et al.	[14]	2012	Journal	S/L-band dual-band dual-polarized shared-aperture array	SAR

				antenna	
S.G. Zhou et al.	[15]	2012	Journal	A shared-aperture dual-wideband dual-polarized planar microstrip array	SAR
Zhuo, S. G et al.	[16]	2012	Conference	A design to integrate P-band and Ku-band antenna in a shared compact planar aperture	SAR
Zhuo, S. G et al.	[17]	2012	Conference	a wideband dual polarization L/X-band shared aperture antenna	SAR
Harender Singh Gusain et al.	[18]	2012	Conference	A circularly polarized (CP) printed slot antenna configuration on a shared aperture	SAR
Zhuo, S. G et al.	[19]	2012	Conference	the design of a dual-wideband dual linear polarization shared aperture patch antenna	SAR
Devendra Kumar Sharma et al.	[20]	2013	Journal	a new type of wideband shared aperture dual band dual microstrip polarization patch antenna (MPA) operating at L&S band.	SAR
Shun-shi zhong et al.	[21]	2013	Journal	a shared-aperture MBDP SAR array	SAR
A. B. Smolders et al.	[22]	2013	Journal	array of aperture coupled microstrip antennas (ACMAs) with corresponding feed network	SAR
S.G. Zhou et al.	[23]	2013	Journal	A wideband, low-profile shared aperture antenna	SAR
Krishna Naishadham et al.	[24]	2013	Journal	interleaved printed dipoles spaced to avoid grating lobes	SAR
M. Gulam Nabi Alsath et al.	[25]	2014	Journal	A modified planar inverted-F antenna (PIFA) and a "Y"-shaped monopole sharing a common aperture	4G LTE, DCS, IEEE &WIMAX
Thomas Smith et al.	[26]	2014	Journal	A Ka-band reflect array antenna with a frequency (FSS) ground-plane	SAR
Zhu Sun et al.	[27]	2014	Journal	An L/C dual-band dual-polarized (DBDP) shared aperture array	SAR
Zeyang Tian et al.	[28]	2014	Conference	three-dimensional (3D) substrate integrated waveguide (SIW) technology	WIRELESS
Zhou Shi-Gang et al.	[29]	2015	Journal	a dual-wideband dual-polarized planar shared aperture	SAR
Satyajit Chakrabarti et al.	[30]	2015	Journal	Shared aperture dual configuration antenna with dual linearly/circularly polarized operation at S/Ka-band	SAR

SAR- Synthetic Aperture Radar
DCS-Digital Cellular System
WIMAX- Worldwide Interoperability for Microwave Access
IEEE- Institute of Electrical and Electronics Engineers
LTE- Long Term Evolution

RQ4 Design Software tools and Substrate used for design with spacing constrains for multi-layer modeling.
The software used to model and simulate the antenna was designed using simulation tools addressed in Table. These tools can be used to calculate scattering parameters of antenna and radiation characteristics of the antenna mentioned in flow graph addressed in Figure 3.

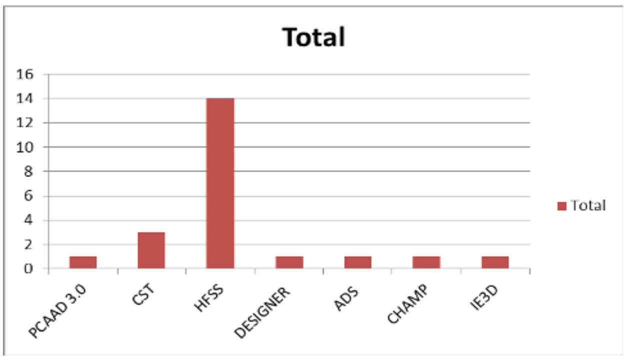

Fig. 5. Tools used for Simulation

The dielectric substrates used in SLR are FR4 Glass Epoxy, RO4003, Taconic TLC and RT Duroid (5870/5880/6002) are addressed in Table 6

FR-4 glass epoxy is a popular and versatile high-pressure thermo set plastic laminate grade with good strength to weight ratios. With near zero water absorption, FR-4 is most commonly used as an electrical insulator possessing considerable mechanical strength.

RO4003 Series High Frequency Circuit Materials are glass reinforced hydrocarbon/ceramic laminates (Not PTFE) designed for performance sensitive, high volume commercial applications. RO4000 laminates are designed to offer superior high frequency performance and low cost circuit fabrication. The result is a low loss material which can be fabricated using standard epoxy/glass (FR4) processes.

Table 5. Operating frequencies and bands

Author	Frequency -Band	P	L	S	C	X	KU	K	KA	W
A. T. Axness et al.	C/X				**7**	**10**				
Stephen D. Targonski et al.	L/X		**1.25**			**9.65**				
D.M. Pozar et al.	L/X		**1.21-1.29**			**9.5-9.8**				

Nemai C. Karmakar et al.	S/C			**3.8**	**6.28**					
Vetharatnam, G et al.	L/C		**1.24**		**5.3**					
C.I. Coman et al.	C/X				**8**	**9**				
Q.-X. Chu et al.	P/L	**110-600**	**0.82-1.2**							
M. Meng et al.	L/C		**1.25**		**5.3**					
Gao G et al.	Ku/Ka						**13.6**		**35.5**	
Giuseppe Colangelo et al.	X/Ka									
Shun-Shi Zhong et al.	L/S/X		**1.25**	**3.5**		**10**				
Satyajitchakrabarti et al.	L		**1.4-1.65**							
Zhong, S.-S et al.	L/S/X									
Kong, L.-B et al.	L/S									
S.G. Zhou et al.	L/X		**1.126-1.217**			**9-10.18**				
Zhuo, S. G et al.	L/X	**325-424**					**14-16**			
Zhuo, S. G et al.	P/Ku		**1.126-1.217**			**9, 9.6, 10**				
Harender Singh Gusain et al.	S/C/X			**3.5**	**4.5, 7.5**	**8.5**				
Zhuo, S. G et al.	L/X		**1.08-1.23**			**8.6-10.2**				
Devendra Kumar Sharma et al.	L/S		**1.25**	**2.5**						
Shun-shizhong et al.	L/S/X		**1.275**	**3**		**9.6**				
A. B. Smolders et al.	C				**4 , 8**					
S.G. Zhou et al.	P/Ku	**330-420**					**14.27-16.2**			
Krishna Naishadham et al.	L		**1-2**							
M. GulamNabiAlsath et al.	L/S		**1.8**	**2.4, 3.5**						
Thomas Smith et al.	L/K/Ka		**1.525-1.661**					**19.7-20.2**	**29.5-30**	
Zhu Sun et al.	L/C		**1.25**		**5.5**					**75**
ZeyangTianet al.	Ka/W								**28**	
Zhou Shi-Gang et al.	L/X		**1.07-1.24**			**8.3-10.3**				
SatyajitChakrabarti et al.	S/Ka		**1.95-2.5**						**27-29**	`

Note:
P-BAND –Units-MHz
L-, S-, C-, X-, Ku-, K-, Ka-, V-, & W-BANDS- Units-GHz

RT/Duroid-6002 microwave material was the first low loss and low dielectric constant laminate to offer superior electrical and mechanical properties essential in designing complex microwave structures which are mechanically reliable and electrically stable. Applications particularly suited to the unique properties of RT/Duroid-6002 material include flat & non-planar structures such as antennas, phased array antennas and beam forming networks.

RT/Duroid-5870 and 5880 glass microfiber reinforced PTFE composites are designed for exacting stripline and microstrip circuit applications. The dielectric constant of RT/Duroid 5870 and 5880 laminates is uniform from panel to panel and is constant over a wide frequency range. Its low dissipation factor extends the usefulness of RT/Duroid 5870 and 5880 laminates to Ku-band and above.

Taconic TLY-5 substrates are specifically designed to meet the low cost objectives for newly emerging commercial RF/microwave applications. These materials exhibit excellent mechanical and thermal stability and cost less than traditional PTFE substrates.

RQ5 what are the choice of antenna elements (array) specified in SLR.

The typical configurations of the shared-aperture DBDP planar arrays include the perforated structure, the interlaced layout and the overlapped layout. The perforated structure mainly Includes perforated-patch/patch, ring/patch and cross-
Patch/patch. The interlaced layout includes interlace patch with dipole/slot and interlaced slot with slot/dipole etc. Both the perforated structure and interlaced layout are commonly adopted in space- or air-borne applications because of their low profile performance. On the other hand, the overlapped layout can provide further improvement in the bandwidths of dual bands, but with larger antenna profile. The different options for selecting lower and higher band elements are addressed in Table-9 in SLR.

RQ6 what are the type of feeding for antenna elements to improve perfect matching and the type of feeding network used for isolation and cross polarization improvement.

The feeding of individual elements has to be designed with respect to perfect impedance matching. The pair-wise anti phase feeding technique and differential feeding technique was implemented to reduce levels of cross polarization levels between the ports and bands mentioned in Table 8 and the cross polarization levels also given in Table-12 in SLR. The perturbation will also raise element cross polarization level; however, it can be suppressed by applying pair-wise anti-phase feeding method in the array scale.

Table 6. Substrate and Software used in SLR

Author	Frequency -Band		SAA	Substrate used	Foam used	Software used
A. T. Axness et al.	C/X	WBDP	Single layer(1)	RT-Duroid	Na	Na
Stephen D. Targonski et al.	L/X	DBDP	Multi-layer(5)	RT-Duroid	Rohacell IG-51	Na
D.M. Pozar et al.	L/X	DBDP	Multi-layer(5)	RT-Duroid	Rohacell IG-51	CAD TOOL PCAAD 3.0
emai C. Karmakar et al.	S/C	DBDP	Multi-layer(3)	RT-Duroid	Rohacell 51HF	Na
Vetharatnam, G et al.	L/C	DBDP	Multi-layer(5)	RT-Duroid	Rohacell 51HF	Na
C.I. Coman et al.	C/X	DBDP	Single layer(1)	RT-Duroid	Na	CST
Q.-X. Chu et al.	P/L	DBDP	Single layer(1)	RT-Duroid	Na	CST
M. Meng et al.	L/C	DBDP	Multi-layer(5)	FR4	Air Honey comb	HFSS
Gao G et al.	Ku/Ka	DBDP	Multi-layer(4)	RT-Duroid	Rohacell 51HF	HFSS
Giuseppe Colangelo et al.	X/Ka	DBDP	Multi-layer(5)	RT-Duroid	Rohacell 51HF	Na
Shun-Shi Zhong et al.	L/S/X	TBDP	Multi-layer(5)	RT-Duroid	Rohacell 51HF	HFSS-10.0
Satyajit chakrabarti et al.	L	DBDP	Single layer(1)	RT-Duroid	Na	IE3D
Zhong, S.-S et al.	L/S/X	TBDP	Multi-layer(5)	RT-Duroid	Rohacell 51HF	HFSS-10.0
Kong, L.-B et al.	L/S	DBDP	Multi-layer(5)	RT-Duroid	Rohacell 51HF	HFSS
S.G. Zhou et al.	L/X	DBDP	Multi-layer(7)	RT-Duroid	Rohacell 51HF	HFSS-12.1
Zhuo, S. G et al.	L/X	DBDP	Multi-layer(7)	FR4	Rohacell 51HF	HFSS-12.1
Zhuo, S. G et al.	P/Ku	DBDP	Multi-layer(7)	RT-Duroid	Rohacell 51HF	HFSS
Harender Singh Gusain et al.	S/C/X	DBDP	Single layer(1)	RT-Duroid	Na	HFSS
Zhuo, S. G et al.	L/X	DBDP	Multi-layer(4)	Arlon DICLAD880, Taconic TLY-5	Rohacell 51HF	ANSOFT DESIGNER V-4.0
Devendra Kumar Sharma et al.	L/S	DBDP	Multi-layer(9)	RT-Duroid	Rohacell 51HF	HFSS-10.0
Shun-shizhong et al.	L/S/X	DBDP	Multi-layer(5)	RT-Duroid	Rohacell 51HF	ADS MOMENTUM
A. B. Smolders et al.	C	DBDP	Multi-layer(Na)	RT-Duroid	Rohacell 51HF	HFSS
S.G. Zhou et al.	P/Ku	DLP/SLP	Multi-layer(5)	FR4, TLY-5	Rohacell 51HF	CST
Krishna Naishadham et al.	L	DBDP	Single layer(1)	Paper substrate	Na	Na
M. Gulam Nabi Alsath et al.	L/S	TBDP	Single layer(1)	FR4	Na	CHAMP
Thomas Smith et al.	L/K/Ka	DBDP	Multi-layer(3)	RT-Duroid	Rohacell 51HF	HFSS-13.0
Zhu Sun et al.	L/C	DBDP	Multi-layer(Na)	RT-Duroid	Rohacell 51HF	HFSS
ZeyangTianet al.	Ka/W	DBDP	Single layer(1)	RT-Duroid	Rohacell 51HF	Na
Zhou Shi-Gang et al.	L/X	DBDP	Multi-layer(Na)	RT-Duroid	Plastic strips on the edge	Na
SatyajitChakrabarti et al.	S/Ka	DBDP	Parabolic			HFSS

Note :
CST- FDTD/FEM based Computer simulation software
HFSS-FDTD/FEM based High Frequency Structure simulator
IE3D- MoM based Integral Equation 3- Dimensional Software
ADS Momentum- MoM based Advance Design System Electromagnetic simulation software

RQ7 what is the inter element spacing required and scan range used in SLR (systematic literature review).

Illumination taper:-
The side lobe requirement of 20dB requires a suitable illumination taper.

Table 7. SLL and Taper efficiency

Type	SLL	Taper efficiency
Uniform	-13dB	100%
Cosine	-23dB	81%
Cosine square	-32dB	66.7%
Cosine squared on pedestal	-25.7dB	88%
Triangular	-26.4dB	75%
Taylor	-20dB	93.3%

	-25dB	86.3%

Taylor distribution has the advantage of high directivity with equal level close-in lower side lobes for a tapered envelope for the far-out side lobes.

Inter-element spacing:-
To keep the grating lobes from entering the visible region we have to select the inter-element spacing for an array according to the equation.

$$\frac{d}{\lambda} \leq \frac{1}{1+\sin\theta}$$

Where θ is the scan angle

Table 8. Scan angle and Element spacing

Scan angle	*Element spacing*
5	0.92 λ
10	0.85 λ
15	0.79 λ
20	0.75 λ
25	0.70 λ
30	0.66 λ
35	0.63 λ
40	0.60 λ
45	0.58 λ
50	0.56 λ

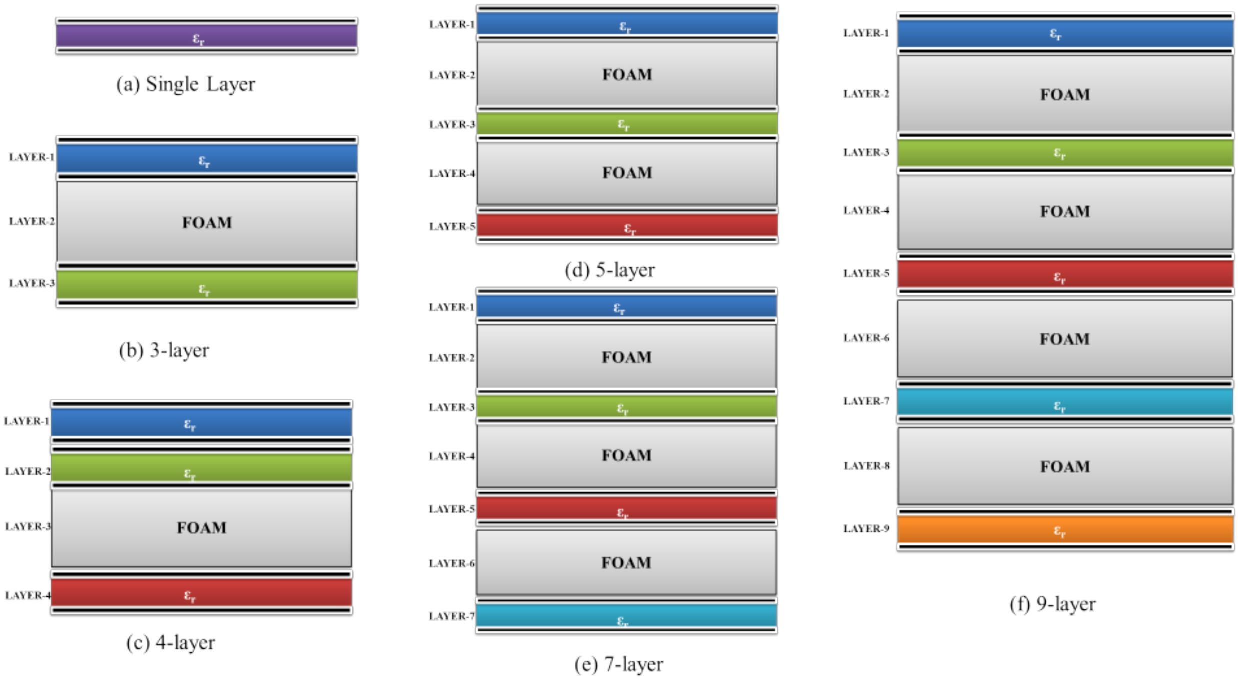

Fig. 6. Single layer and Multi-layer configuration

RQ8 How the impedance matching, Return loss / VSWR / Reflection coefficient was improved in SLR.

Return loss is the difference in dB between the forward and reflected power measured at any given point in the RF system.

The SWR of the antenna is the mathematical relationship between the forward and reflected power measured at the feed point of the antenna. The simulated and measure return loss, VSWR at various frequencies of operation mentioned in Table 10 in SLR. Here again the relationship is linear, not logarithmic, and less reflected power (the better situation), the lower the value of SWR. With return loss, less reflected power means small number of dBm to be subtracted off, resulting in large return loss for better situations. Using our antenna example and the definition of the return loss given above, the return loss (dB) generally measured at the input to the co-axial cable connected to the antenna.

To calculate return loss

1. Convert forward and reflected powers to dB.
2. Subtract reflected power in dB from forward power.

Example 1:- The best case [VSWR=1:1]

Forward power=1500 watts= 61.76dBm
Reflected power= 0 watts=0
Return loss = Forward power - Reflected power
= 61.76dBm – Infinity (dBm)
= Infinity dB

Example 2:- The best case [VSWR=1.05:1]

Forward power=1500 watts= 61.76dBm

Reflected power= 1 watts=30dBm
Return loss = Forward power - Reflected power
Return loss = Forward power - Reflected power
= 61.76dBm – 30dBm
= 31.76dB

Example 3:- The best case [VSWR=1.92:1]

Forward power=100 watts= 50dBm
Reflected power= 10 watts=40dBm
Return loss = Forward power - Reflected power
= 50dBm – 40dBm
= 10dB

Example 4:- The best case [VSWR=infinity: 1]

Forward power=100 watts= 50dBm
Reflected power=100 watts=50dBm
Return loss = Forward power - Reflected power
= 50dBm – 50dBm
=0dB

This situation illustrates a dead short or completely open, with 100% forward power reflected back to the source. Reflection coefficient is the voltage form of return loss and mismatch loss is the amount of power lost due to reflection.

Table 9. Choice of Antenna element and feed network

Author	Date	Publication	Frequency-Band		Antenna element	Element feed & Feed network	
A. T. Axness et al.	1995	Article	C/X	WBDP	Tapered notch radiating element	Probe feed	A
Stephen D. Targonski et al.	1996	Conference	L/X	DBDP	Perforated patch/patch	Aperture coupled	A
D.M. Pozar et al.	1999	Journal	L/X	DBDP	Perforated patch/patch	Aperture coupled	A
Nemai C. Karmakar et al.	2001	Journal	S/C	DBDP	Rectangular patch	Aperture coupled	A
Vetharatnam, G et al.	2005	Journal	L/C	DBDP	Square patch/square perforated patch	Aperture coupled	A
C.I. Coman et al.	2006	Journal	C/X	DBDP	Microstrip patch antenna	Probe feed	B
Q.-X. Chu et al.	2008	Journal	P/L	DBDP	Electrically loaded monopole/electrically loaded inverse L-shape monopole	Microstripline feed	A
M. Meng et al.	2009	Conference	L/C	DBDP	Perforated patch/stacked patch	Transmission line feed/slot coupled	B
Gao G et al.	2010	Conference	Ku/Ka	DBDP	Microstrip crossed slots/ patch	Inversted microstrip line/ microstrip line	A
Giuseppe Colangelo et al.	2011	Conference	X/Ka	DBDP	Planar monopulse printed antenna-Ka slot array/X-slot array	Probe feed	A
Shun-Shi Zhong et al.	2011	Conference	L/S/X	TBDP	Microstrip Dipole/patch/patch	Microstrip line feed/probe feed/probe feed	B
Satyajit chakrabarti et al.	2011	Journal	L	DBDP	Planar microstrip patch	Aperture coupled	A
Zhong, S.-S et al.	2012	Journal	L/S/X	TBDP	Microstrip Dipole/patch/patch	Microstrip line feed/probe feed/probe feed	B
Kong, L.-B et al.	2012	Journal	L/S	DBDP	Stacked patch with crossed slots	Aperture coupled	B
S.G. Zhou et al.	2012	Journal	L/X	DBDP	Microstrip array	Aperture coupled	A
Zhuo, S. G et al.	2012	Conference	L/X	DBDP	Patch/stacked patch	L-probe feed/Aperture coupled	A
Zhuo, S. G et al.	2012	Conference	P/Ku	DBDP	Perforated patch/stacked patch	Microstrip line feed/proximity coupled/aperture coupled	A
Harender Singh Gusain et al.	2012	Conference	S/C/X	DBDP	Patch with dual slot circular polarized element	Microstrip line feed	A
Zhuo, S. G et al.	2012	Conference	L/X	DBDP	Microstrip patch	proximity coupled/aperture coupled	C
Devendra Kumar Sharma et al.	2013	Journal	L/S	DBDP	Square ring shaped element/square shaped patch	L-probe feed	A
Shun-shi zhong et al.	2013	Journal	L/S/X	DBDP	L-dipole	Microstrip line feed/probe feed/probe feed	B
A. B. Smolders et al.	2013	Journal	C	DBDP	Microstrip patch	Aperture coupled	A
S.G. Zhou et al.	2013	Journal	P/Ku	DLP/SLP	Microstrip patch	Aperture coupled	C
Krishna Naishadham et al.	2013	Journal	L	DBDP	Microstrip folded dipole	Microstrip line feed	A
M. Gulam Nabi Alsath et al.	2014	Journal	L/S	TBDP	PIFA/ Y-shaped monopole	Microstrip line feed	A
Thomas Smith et al.	2014	Journal	L/K/Ka	DBDP	Patch/stacked patch	Probe feed	A
Zhu Sun et al.	2014	Journal	L/C	DBDP	Stacked patch	probe feed/	B

						Microstrip line feed	
Zeyang Tian et al.	2014	Conference	Ka/W	DBDP	Diploe/slot antenna	Microstrip line feed	A
Zhou Shi-Gang et al.	2015	Journal	L/X	DBDP	Microstrip patch	proximity coupled/aperture coupled	C
Satyajit Chakrabarti et al.	2015	Journal	S/Ka	DBDP	Parabolic reflector	Cassegrain / primary focus	A

Feeder network mentioned:

A. Corporate binary feeder network
B. Pair-wise anti-phase feeder network
C. Differential feeder network

Table 10. Source to load parameters with transmission line loss is 3dB

	Parameters measured at line input	**Calculated parameters at input to the load**
Forward power	100 W	50.119 W
Reflected power	10 W	19.95 W
Return loss	10 dB	4 dB
% power reflected	10	39.81
VSWR	1.92 : 1	4.42 : 1
Mismatch loss	0.458 dB	2.205 dB
Reflection coefficient	0.32	0.63

RQ9 How the isolation is achieved with different techniques.

Isolation is sometimes referred to as on/off ratio. A minimum amount of isolation is required by the system designer to provide adequate rejection of unwanted signals in a given RF path. Isolation levels are range from 20dB to 70dB or more with value above 90dB achievable but designs to achieve these levels are expense of other parameters. Feed methods, such as probe-feed, aperture-coupled, proximity-coupled, and L-shape feed are proposed to improve the key performances. Besides, balanced-feed and hybrid-feed are also implemented to enhance the port isolation, mentioned in Table 10. Important isolation measurement requirements are

a. Isolation between bands.
b. Isolation between horizontal and vertical polarization ports
c. Isolation between co-pol and cross-pol levels.

Table 11. RL, Scan range, Spacing and Isolation

Author	**Frequency-Band**		**SAA technology**	**Return loss /VSWR/Impedance**	**Scan range**	**Inter-element spacing**	**Isolation (dB)**
A. T. Axness et al.	C/X	WBDP	Single layer(1)	-10dB/<2/50Ω	Na	Na	Na
Stephen D. Targonski et al.	L/X	DBDP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	40
D.M. Pozar et al.	L/X	DBDP	Multi-layer(5)	-20dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	21
Nemai C. Karmakar et al.	S/C	DBDP	Multi-layer(3)	-15dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	30
Vetharatnam, G et al.	L/C	DBDP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	50
C.I. Coman et al.	C/X	DBDP	Single layer(1)	-10dB/<2/50Ω	Na	Na	25
Q.-X. Chu et al.	P/L	DBDP	Single layer(1)	-10dB/<2/50Ω	Na	Na	Na
M. Meng et al.	L/C	DBDP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	Na
Gao G et al.	Ku/Ka	DBDP	Multi-layer(4)	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	Na
Giuseppe Colangelo et al.	X/Ka	DBDP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	Na
Shun-Shi Zhong et al.	L/S/X	TBDP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 27^{0}$	0.6 λ-0.8 λ	37, 45, 43
Satyajit chakrabarti et al.	L	DBDP	Single layer(1)	-10dB/<2/50Ω	Na	Na	30
Zhong, S.-S et al.	L/S/X	TBDP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	37, 45, 43
Kong, L.-B et al.	L/S	DBDP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	45
S.G. Zhou et al.	L/X	DBDP	Multi-layer(7)	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	35
Zhuo, S. G et al.	L/X	DBDP	Multi-	-10dB/<2/50Ω	$\pm 20^{0}$-50^{0}	0.6 λ-0.8 λ	28

			layer(7)				
Zhuo, S. G et al.	P/Ku	DBDP	Multi-layer(7)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	20
Harender Singh Gusain et al.	S/C/X	DBDP	Single layer(1)	-10dB/<2/50Ω	Na	Na	Na
Zhuo, S. G et al.	L/X	DBDP	Multi-layer(4)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	25, 32
Devendra Kumar Sharma et al.	L/S	DBDP	Multi-layer(9)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	
Shun-shi zhong et al.	L/S/X	DBDP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	12, 15
A. B. Smolders et al.	C	DBDP	Multi-layer(Na)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	37, 45, 43
S.G. Zhou et al.	P/Ku	DLP/SLP	Multi-layer(5)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	26
Krishna Naishadham et al.	L	DBDP	Single layer(1)	-10dB/<2/50Ω	Na	Na	17, 25
M. Gulam Nabi Alsath et al.	L/S	TBDP	Single layer(1)	-10dB/<2/50Ω	Na	Na	15
Thomas Smith et al.	L/K/Ka	DBDP	Multi-layer(3)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	Na
Zhu Sun et al.	L/C	DBDP	Multi-layer(Na)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	25
Zeyang Tian et al.	Ka/W	DBDP	Single layer(1)	-10dB/<2/50Ω	Na	Na	Na
Zhou Shi-Gang et al.	L/X	DBDP	Multi-layer(Na)	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	22.5, 29.6
Satyajit Chakrabarti et al.	S/Ka	DBDP	Parabolic	-10dB/<2/50Ω	$\pm 20^0$-50^0	0.6 λ-0.8 λ	19, 20

Note :DBDP: Dual Band Dual Polarization
TBDP: Triple Band Dual Polarization
DLP: Dual Linear Polarization
SLP: Single Linear Polarization

Table 12. Gain, Side lobe level and Polartization

	Vertical and horizontal polarizations with different combinations							
Author	**E-plane**				**H-plane**			
	Gain	**SLL**	**Co-pol**	**X-pol**	**Gain**	**SLL**	**Co-pol**	**X-pol**
A. T. Axness et al.	Na	>-10dB	0 dB	Na	Na	>-10dB	0 dB	Na
Stephen D. Targonski et al.	Na	>-10dB	0 dB	Na	Na	>-10dB	0 dB	Na
D.M. Pozar et al.	26dB	>-10dB	0 dB	-18	26dB	>-10dB	0 dB	Na
Nemai C. Karmakar et al.	5dB	>-10dB	0 dB	Na	5dB	>-10dB	0 dB	Na
Vetharatnam, G et al.	Na	>-10dB	0 dB	-40 & -12	Na	>-10dB	0 dB	Na
C.I. Coman et al.	Na	>-10dB	0 dB	Na	NA	>-10dB	0 dB	Na
Q.-X. Chu et al.	5dBi/21dBi	>-10dB	0 dB	Na	5dBi/21dBi	>-10dB	0 dB	Na
M. Meng et al.	9dBi/9dBi	>-10dB	0 dB	-20&-30	9dBi/9dBi	>-10dB	0 dB	Na
Gao G et al.	Na	-12.5dB	0 dB	-24	Na	-12.5dB	0 dB	Na
Giuseppe Colangelo et al.	Na	-13dB	0 dB	Na	Na	-13dB	0 dB	Na
Shun-Shi Zhong et al.	13.2-22.2dBi	>-10dB	0 dB	-30	13.2-22.2dBi	>-10dB	0 dB	Na
Satyajit chakrabarti et al.	14	-12dB	0 dB	-25	14	-12dB	0 dB	Na
Zhong, S.-S et al.	13.2-22.2dBi	>-10dB	0 dB	-30	13.2-22.2dBi	>-10dB	0 dB	Na
Kong, L.-B et al.	Na	>-10dB	0 dB	-30&-20	Na	>-10dB	0 dB	-28& -20
S.G. Zhou et al.	10-25dBi	>-10dB	0 dB	-26 &-24	10-25dBi	>-10dB	0 dB	Na
Zhuo, S. G et al.	5.4-24.4dBi	>-10dB	0 dB	-18 & -20.4	5.4-24.4dBi	>-10dB	0 dB	Na
Zhuo, S. G et al.	5.8-21.2dBi	>-10dB	0 dB	-20	5.8-21.2dBi	>-10dB	0 dB	Na
Harender Singh Gusain et al.	3.58-4.1dBi	>-10dB	0 dB	Na	3.58-4.1dBi	>-10dB	0 dB	Na
Zhuo, S. G et al.	Na	>-10dB	0 dB	-20 &-25	Na	>-10dB	0 dB	Na
Devendra Kumar Sharma et al.	6.94-7.04dBi	>-10dB	0 dB	12 &15	6.94-7.04dBi	>-10dB	0 dB	12 & 15
Shun-shi zhong et al.	13.2-22.19dBi	>-10dB	0 dB	-30	13.2-22.19dBi	>-10dB	0 dB	Na
A. B. Smolders et al.	5.1-5.4dBi	>-10dB	0 dB	Na	5.1-5.4dBi	>-10dB	0 dB	Na
S.G. Zhou et al.	6.5-23.4dBi	-11dB	0 dB	-20 & -26	6.5-23.4dBi	-11dB	0 dB	Na

Krishna Naishadham et al.	7-8dBi	>-10dB	0 dB	-30 or -22	7-8dBi	>-10dB	0 dB	-26
M. Gulam Nabi Alsath et al.	Na	>-10dB	0 dB	Na	Na	>-10dB	0 dB	Na
Thomas Smith et al.	36.4-38.5dBi	-17dB	0 dB	-23 & -30	36.4-38.5dBi	-17dB	0 dB	Na
Zhu Sun et al.	12.9-26.8dBi	>-10dB	0 dB	-28	12.9-26.8dBi	>-10dB	0 dB	Na
Zeyang Tian et al.	4.8-11.7dBi	>-10dB	0 dB	Na	4.8-11.7dBi	>-10dB	0 dB	Na
Zhou Shi-Gang et al.	6-23.2dBi	>-10dB	0 dB	-17 & -20	6-23.2dBi	>-10dB	0 dB	Na
Satyajit Chakrabarti et al.	28.5-50dBi	>-10dB	0 dB	-25	28.5-50dBi	>-10dB	0 dB	Na

RQ10 what are the configurations implemented for gain enhancement in SLR.

The radiation pattern of the radar has to be carefully designed in order to obtain selectively backscattered signal as compared to interfering external influences like clutter, radio interference and scatter received through antenna side lobes. To achieve a high sensitivity and angular resolution, the antenna gain, addressed in Table 12 in SLR, should be large and beam width small. The main parameter determining the antenna gain and corresponding beam width is the area of the antenna which is called antenna aperture. An optimization of the aperture increases the sensitivity. Suppression of side lobes by tapering attenuates undesired signals but broadens the antenna beam.

The antenna of radar usually consists of either an array of individual elements to form a large antenna array or phase array and a large dish antenna. The aperture of phased array and the transmitter power is used to calculate the power aperture product which defines the sensitivity of the radar. The main antenna specifications which controls the design of phased array using shared aperture antenna technology for synthetic aperture radar are Gain, Beam width, Side lobe level and Beam scanning.

Array gain can be calculated by using

G_A = 10log (Number of elements)
+ Single element antenna gain

4 Results

This section provides a discussion of results and limitations of the study.

4.1 Conclusions on the state of the art

This Systematic Literature Review provides a study of shared aperture antenna for synthetic aperture radar applications. Though the results of reviews are reliable, they have potential threats to validity. The main intention of this review are the predispose in our selection of studies to be included, data extraction and synthesis. In order to reduce potential threats to validity, we define a research protocol, which contains research questions, inclusion criteria and research strategy.

In our search strategies, the main idea was to regain as much as possible of the available literature to avoid any predispose. Shared aperture antennas related to different radar and communication applications in order to cover all and avoid predispose. We searched for common terms (shared aperture and shared aperture antenna) and combined them in our search string, which decreases bias and increases search work.

The research protocol was developed by the first author and was reviewed by the second author, to ensure the review selection process and the search string was derived from research questions. To ensure correctness in data extraction, we summarized basic information which contains consistent and apropos data with respective to search string,inclusion and research questions. In order to mitigate reliability threat several researchers are involved in reviewing the included papers to achieve high validity of the study.

4.2 Conclusions for a body of knowledge

After analyzing the results of SLR, the body of knowledge has areas that represent shared aperture antenna which deals with Radar, Synthetic aperture radar, VSAT, Space craft, 4G LTE, DCS, IEEE &WIMAX and Wireless application domains and various tools and technologies those are used in the study. This is illustrated in Figure 7

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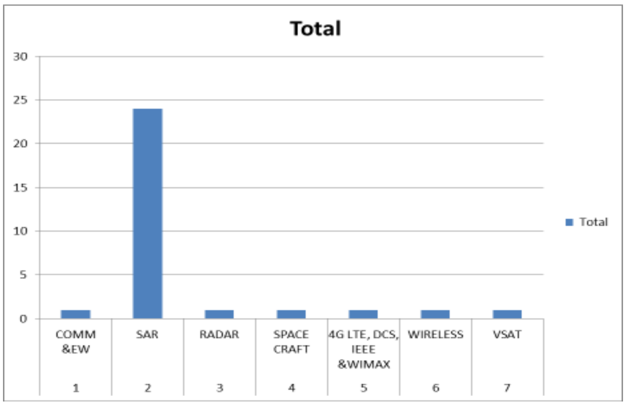

Fig. 7. Application domains for SAA technology

5 Conclusion

Shared aperture antennas has many advantages for future systems including reduced size and weight, easier integration and increased affordability when the cost is considered over multiple systems. The objective of this review was to consolidate existing research on shared aperture antenna technology and associated topics that allow for building up a body of knowledge. We considered 33 out of 100 reviewed publications significant with respect to research protocols, research question and categorized them according to the research area. On that basis, we provided tabulations for representing research areas, application domain, tools and technologies. We identified unexplored areas by synthesizing collected data, making those available for future research. We observed vast interests towards synthetic aperture radar and all radar applications. The field is still in its early stages and in order to mature, microwave and radar engineering researchers should come together by proposing a common research agenda.

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References

1. A. T. Axness, V. R. Coffman, A. B. Kopp, and W. O'Hawer, "Shared aperture technology development," John Hopkins APL Tech. Dig., vol.17, no. 3, pp. 285–294, 1997.
2. Stephen D. Targonski and David M. Pozar "An L/X dual-band dual polarized shared-aperture array for space borne SAR", IEEE Antennas and Propagation Society International Symposium, (1999). (Volume:4) pp.2306-2309
3. D.M. Pozar and S.D. Targonski, A shared-aperture dual-band dual polarized microstrip array, IEEE Trans Antennas Propag 49 (2001), 150–157.
4. Nemai C. Karmakar, Md. N. Mollah, Shantanu K Padhi, and Jeffrey S. Fu PBG-assisted shared-aperture dual-band aperture-coupled patch antenna for satellite communication Microwave and Optical Technology Letters, Jan. (2005). , 16(3), 289-292.
5. Vetharatnam, G., C. B. Kuan, and C. H. Teik, "Combined feed network for a shared-aperture dual-band dual-polarized array," IEEE Antennas Wirel. Propagat. Lett., Vol. 4, 297–299, 2005.
6. C.I. Coman, I. E. Lager and L. Light hart, "The Design of Shared Aperture Antenna Consisting of Differently Sized Elements", IEEE AP-54, February 2006.
7. Q.-X. Chu, M. Han-Qing, and H. Zheng, "Design of shared aperture wideband antennas considering band-notch and radiation pattern control," IEEE Trans. Antennas Propag., vol. 56, no. 11, pp. 3391–3395, Nov. 2008.
8. M. Meng, F. Zhang, X. Ding, K. Ding, and L. Li, "Design of a shared aperture dual-band dual- polarized microstrip antenna," in IEEE AP Symp. Dig., 2009, pp. 680–683.
9. Gao G. , Zhang, Y., Li, A., Zhao, J., &Cheng, H., "Shared-aperture Ku/Ka bands microstrip array feeds for parabolic cylindrical reflector", 2010 International Conference on Microwave and Millimeter Wave Technology (ICMMT),, (2010). , 1028-1030.
10. Giuseppe Colangelo and Roberto Vitiello "Shared aperture dual band printed antenna" in IEEE International Conference on Electromagnetics in Advanced Applications (ICEAA), 2011, pp. 1092–1095.
11. Shun-Shi Zhong , Zhu Sun , Ling-Bing Kong Chu Gao , Wei Wang , and Mou-Ping Jin "Design of tbdp shared-aperture sar array", Asia-Pacific Microwave Conference Proceedings (APMC), 2011, pp. 159–162.
12. Satyajit chakrabarti "Development of shared aperture dual polarized microstrip antenna at L-band" ", IEEE Trans. Antennas Propagat., Jan. (2011)., 59(1).
13. Zhong, S.-S., Sun, Z., Kong, L.- B., Gao, C., Wang ,W., & Jin, M.-P., "Tri-Band Dual Polarization Shared-Aperture Microstrip Array for SAR Applications", IEEE Trans. Antennas Propagat., Sep. (2012)., 60(9).
14. Kong, L.-B., Zhong, S.-S., & Sun, Z., "Broadband microstrip element design of a DBDP shared-aperture SAR array", Microwave and Optical Technology Letters, Jan.(2012). , 54(1), 133-136.
15. S.G. Zhou, T.H. Chio, and J. Lu, A shared-aperture dual-wideband dual-polarized stacked microstrip array, Microwave Opt TechnolLett 54 (2012), 486–491
16. Zhuo, S. G. and T. H. Chio, "A wideband, low profile p- and ku-band dual polarized shared aperture antenna,"Proceedings of ISAP2012, 794–797, Nagoya, Japan, 2012.
17. Zhuo, S. G. and T. H. Chio, "Dual-wideband, dual-polarized shared aperture antenna with high isolation and low cross polarization," Proceedings of ISAP2012, 798–801, Nagoya, Japan, 2012.
18. S.G. Zhouand T.H. Chio, Dual-wideband, dual-polarized shared aperture antenna with high isolation and low cross-polarization, In: The 10th International Symposium on Antennas and Propagation, and EM theory, Xi'an, China, 2012.
19. Harender Singh Gusain, S.Raghavan and P.H.Rao "Shared aperture printed slot antenna"International Conference on Computing Communication & Networking Technologies (ICCCNT), 2012, pp. 1-4.
20. Devendra Kumar Sharma, Sanjeev Kulshrestha, S. B. Chakrabarty, and Rajeev Jyoti Shared aperture dual band dual polarization microstrip patch antenna Microwave Opt Technol Lett 55 (2012), 917–922.
21. Shun-shi zhong ,"Shared-aperture multi-band dual-polarized SAR microstrip array design", Intech.(2013).
22. A. B. Smolders, R. M. C. Mestrom, A. C. F. Reniers, and M. Geurts, "A shared aperture dual-frequency circularly polarized microstrip array antenna", IEEE Antennas Wirel. Propagat. Lett., Vol. 12, 120–123, 2013.
23. Krishna Naishadham, Senior Member, IEEE, RongLin Li, Li Yang, Terrence Wu, Walker Hunsicker, and Manos Tentzeris, "A Shared-Aperture Dual-Band Planar Array With Self-Similar Printed Folded Dipoles", IEEE Trans. Antennas Propagat., Feb. (2013). , 61(2), pp. 606-613.
24. S.G. Zhou, P.K. Tan, and T.H. Chio, A wideband, low profile Pand Ku-band shared aperture antenna with high isolation and low cross-polarization, IET Microwaves Antennas Propag 7 (2013), 223–229.
25. M. Gulam Nabi Alsath and Malathi Kanagasabai, "A shared-aperture multiservice antenna for automotive communications", IEEE Antennas Wirel. Propagat. Lett., Vol. 13, 1417–1420, 2014.
26. Thomas Smith, Ulrich Gothelf,, Oleksiy S. Kim, and Olav Breinbjerg, "An FSS-Backed 20/30 GHz Circularly Polarized Reflect array for a Shared Aperture L- and Ka-Band Satellite Communication Antenna," *IEEE* Transactions on Antennas and Propagation, Feb. 2014, pp.661-668.
27. Zhu Sun, Karu P. Esselle, Shun-Shi Zhong, and Yingjie J. Guo Shared-Aperture Dual-Band Dual-Polarization Array Using Sandwiched Stacked Patch Progress In Electromagnetics Research C, Vol. 52, 183–195, 2014.
28. Zeyang Tian, Jun Ouyang, and Yu Long,"A shared aperture millimeter wave antenna using 3D SIW technology", PIERS Proceedings, Guangzhou, China, August 25–28, 2014.
29. Zhou Shi-Gang, Yang Jiang-Jun and Chio Tan-Huat Design of L/X-band shared aperture antenna array for SAR application Microwave Opt Technol Lett 57 (2015), 2197–2204.
30. Satyajit Chakrabarti, Development of shared aperture dual configuration antenna for S/Ka-band communication Microwave Opt Technol Lett 58 (2015), 139–145.
31. Wiley, C. A. (1954). Pulsed Doppler radar methods and apparatus. United States Patent, No. 3196436, Filed August 1954.
32. Katsaros KB and Brown, RA, (1991), Legacy of the Seasat Mission for the studies of the atmosphere and air-sea-ice interactions, Bull Am Met (Soc) 72(7), 967-981.
33. Cumming IG and Wong, FH (2004) Digital Synthesis of Synthetic Aperture Radar Data: Algorithms and Implementation, Artech House, Norwood.