Reply to comments on Overlapped Phased Array Antenna for Avalanche Radar

Mandana Ardeshir, Paul Brennan

***Abstract*—In this reply, we refer to comments made by a reader on our publication "Overlapped Phased Array Antenna for Avalanche Radar". Authors would like to thank the reader for reading the paper. In this paper authors provided detailed answers to the comments made by the reader.**

***Index Terms*—Phased array, power divider, feed network.**

I. Reply to comments

Authors believe that the technical comments that the reader made on the published are not very accurate and may be misleading other readers.The reader commented that the authors did not cite all the relevant papers discussing the overlapped subarraying techniques. However, in this work overlapping subarraying technique is used to suppress grating lobes without compromising array gain and scan angle [1]. As a result relevant papers which are discussing the techniques to avoid phased array grating lobes were cited in the Introduction section and also throughout the paper. As the reader also mentioned, the fundamentals of overlapping Subarrays have been discussed in several papers and books, however, the references cited by the authors in [1] are the most relevant papers which cover all essential materials for the proposed work. However, papers [2]–[5] suggested by the reader may be useful to those readers who would like to expand their knowledge on overlapping subarrays and phased array feed networks in general. Authors believe that papers which are partly relevant or the papers which do not add enough information to the reader's knowledge should not be randomly cited. For instance, the reader suggested the paper titled "Methods of constructing optimum phased array antennas" [6]. The suggested paper is a survey paper which discusses methods to construct flat-topped phased array element pattern which was not at all relevant to the focus of the proposed work. Moreover, the reader also suggested the paper titled "Some features of the overlapped subarrays built up of beamforming matrices for shaping flat-topped radiation pattern" [7] which authors again do not find it relevant to the proposed work as the main focus of the published work [1] was to suppress phased array grating lobes utilising overlapping subarraying technique with a unique feeding network and not designing a phased array antenna with flat-topped radiation pattern. The reader also suggests a paper titled "Radiation pattern optimisation of Skobelev Networks" [8] which is entirely irrelevant to the work presented [1], since in the published paper [1] by the authors the designed phased array structure and the proposed feed power distribution network is very unique to the application requirements (Imaging snow avalanche). The suggested reference paper by the reader is a conference paper which discusses optimization methods for computing the coupling coefficients of directional couplers constituting Skobelev network and sidelobe level improvement of the subarray which based on above discussions is also irrelevant to the work presented by the authors. Moreover, authors would not cite proceedings as the materials may not have passed through full research cycle. The reader should be careful that if the keywords of the presented work are only included in a paper, it does not necessarily mean that particular paper is relevant and it is required to be cited.

Also, the authors never mentioned throughout the published paper [1] that the overlapping subarraying technique was a novel technique and proposed by them. In the published paper [1] the authors mentioned "Overlapped Subarray: In the overlapped subarray structure, each subarray shares its outer elements with a neighbouring subarray[21]." and this sentence was also referenced properly. The reference number (21) [9] in the published paper [1] titled "The Use of Overlapped Subarray Techniques in Simultaneous Receive Beam Linear Arrays, (Defence Technical Information Center), DTIC, 1984." thoroughly discusses the fundamentals of overlapping subarraying to suppress grating lobes and it is very relevant to the published paper [1]. The reader must not invalidly accuse authors for not providing a valid reference or undermining other researchers work. As authors mentioned, the reference number [21] [9] (in the published paper [1]) was the most relevant to the presented work. The restrictions of the overlapping approach have been also discussed to the point which was necessary based on the opinion of the authors and IEEE transaction reviewers and associate editors who accepted [1] for publication. The published paper [1] is on developing a phased array antenna for a radar system to image the snow avalanche, therefore a very unique phased array antenna is designed to accommodate the application requirements utilising overlapping subarraying and a unique feed network which consists of a novel Two-in Two-out power splitter structure. The published paper [1] is not a review/ survey/history paper on the subject of overlapped subarray structures, therefore citing a "Overlapping subarrays" patent paper which was published in 1974 is out of the context of the published paper [1].

The reader also made inaccurate technical comments. The focus of this paper was to utilise overlapping sub-arrays to avoid grating lobes without compromising scan angle or array gain. The reader commented that "the Authors pay their attention only to additional reduction of the grating lobe level. However, the effect is achieved only at the expense of fast drop of the array gain with beam scanning from the broadside direction" this statement is inaccurate. The reader should pay attention that how by utilising overlapping subarraying technique the grating lobes can be suppressed which was explained in details in [1]. In the published paper [1] by utilising overlapping subarraying technique the array element pattern was used as a spatial ant-alias filter. Also, in order to effectively suppress grating lobes wider antenna aperture was required which was achieved by using overlapping subarraying technique. As a result the array element width exceeded the inter-element spacing which resulted in a narrower beamwidth which was capable of attenuating aliased signals. The reader commented that "the grating lobe reduction is achieved at the expense of fast drop of gain with beam scanning from the broadside direction" which is an inaccurate statement based on above explanations and this means that the reader denies the fact that the overlapping subarraying technique is an effective technique to be used to suppress the grating lobes which is inaccurate. However, the reader in another sentence following above sentence mentioned that "Meanwhile there exist a few other networks of overlapped subarrays allowing not only suppression of the grating lobes but also providing almost non-dropping array gain over the whole sector of scanning as it is often required from radar systems for limited-scan applications." This sentence is in contradictory with the reader's previous discussion, and based on this sentence the reader this time accepts the fact that the overlapping subarraying technique is an effective technique to suppress grating lobes. Also the reader compares the published work to that on sectoral radiation pattern which is not a valid comparison and it is irrelevant. The reader also mentioned that "Moreover, the indicated chess-board network utilizes transmission line sections of identical electrical length unlike the network used in [1] where it is required to adjust the sections of different length carefully for providing correct phase match in radiating elements, and such a situation impose additional restriction on operating bandwidth of the array antenna developed in [1]." and compares the published work with Chess-board network (Skobelev network) which is not again a valid comparison. In the published work [1] the unique power distribution feed network was required to be able to apply amplitude tapering to the overlapping or sharing element to further reduce the sidelobe level. Based on the studies shown in the published paper [1] the 3dB power difference was required between the overlapping and non-overlapping elements to reduce the sidelobe level, therefore, the conventional Skobelev network cannot be used for this work. As a result a power distribution feed network using the novel Two-in Two-out splitter was proposed in the paper to achieve the required amount of power at each phased array element. It should be also mentioned that elements within a subarrays in [1] are in phase by adjusting the transmission line lengths in wavelength.

II. Aim of the Published Paper

The Aim of the published paper was to develop a phased array antenna for an FMCW radar with a novel and unique feeding network and novel power divider. Authors **never** mentioned or claimed in the published paper [1] that overlapping subarraying technique was the contribution of the paper or an invention by the authors and as mentioned relevant papers were cited. As mentioned the contribution of this paper was a novel two-in two-out power divider and a unique feeding network designed a unique and novel avalanche imaging application. The theoretical and mathematical analysis of the proposed power divider and feeding network were thoroughly discussed through out the paper specifically in the Discussion section. However, it is worth repeating those analysis for the readers who may have misunderstood or missed those sections in the published paper.

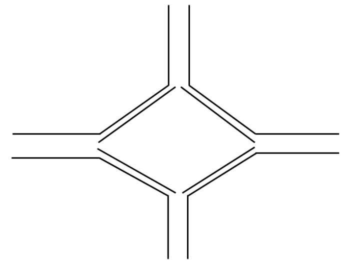

Fig. 1. Diamond Two-in Two-out splitter

A. Proposed Two-in Two-out power splitter

The diamond two-in two-out power splitter is composed of four parallel microstrip transmission lines in series with Z0 characteristic impedance transmission lines in diamond orientation. The diamond two-in two-out power splitter is a microstrip power divider which has four ports and divides quarter of the input power among its four points. Therefore, it can also be called 6-dB power divider. The main advantage of the diamond two-in two-out splitter is that it has a simple structure and resistors are not used in its structure. The Diamond Two-in Two-out splitter Fig.1. behaviour has been mathematically analysed based on transmission line principles. Fig. 2. indicates the equivalent circuit model of the Diamond Two-in Two-out power splitter. Assuming, the power splitter is fed using a single AC power supply at one of the four ends while the other ends are terminated to 50 Ω matched load. Also, for ease of analysis the Z0 characteristic impedance transmission line is considered as two parallel $2Z_0$ and the junction between the transmission lines is considered as node1. The input impedance at node1 (Z_1) is defined as shown in Equation (1, 2 and 3), which is in parallel with Z_0 Thus, the input impedance at the feed point can be determined based on transmission line fundamentals as well as reflection and transmission coefficient, see Equation (4) Moreover, by assuming P_0 and P_1 is the amount of power which travels through port2 and port3 respectively. The S-parameter values can be determined as illustrated by Equation (5), Equation (6) and Equation(7). Utilising the proposed power divider and the designed feed network, the amplitude level of overlapping elements will 3dB less than non-overlapping elements which improves the phased array sidelobe level. The phased array antenna with unique feeding network was successfully deployed at a test site in Alps, Switzerland to image the snow avalanche. The radar image of the snow avalanche which was successfully produced using the developed phased array antenna is shown in Fig. 3. In the following equations β, ℓ, V are phase constant , length and voltage respectively.

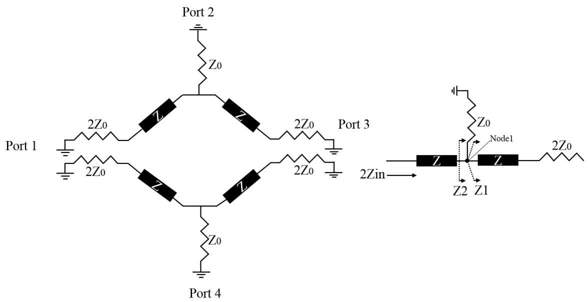

Fig. 2. Equivalent circuit of the diamond two-in two-out power splitter (left). Equivalent circuit of the upper half of the diamond splitter (right)

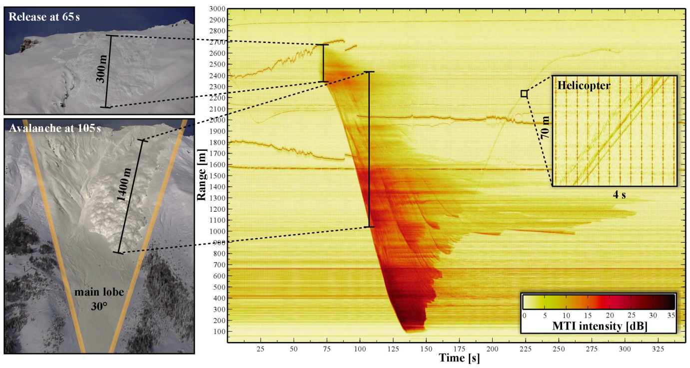

Fig. 3. Radar image of a large powder snow avalanche. Beside this complex, distributed target, a helicopter can be identified.

$$Z_1 = Z(\frac{2Z_0 \cos\beta\ell + jZ \sin\beta\ell}{Z \cos\beta\ell + j2Z_0 \sin\beta\ell}) \tag{1}$$

$$Z_2 = Z_0||Z_1 = \frac{Z_0 Z_1}{Z_0 + Z_1} \tag{2}$$

$$Z_{in} = \frac{Z}{2}(\frac{Z_2 \cos\beta\ell + jZ \sin\beta\ell}{Z \cos\beta\ell + jZ_2 \sin\beta\ell}) \tag{3}$$

$$\Gamma_{in} = \frac{Z_{in} - \bar{Z}_0}{Z_{in} + \bar{Z}_0}, \mid T_{in} \mid^2 = 1 - \mid \Gamma_{in} \mid^2 \tag{4}$$

$$P_0 = \frac{V^2}{Z_0}, P_1 = \frac{V^2 Re(Z_1)}{\mid Z_1 \mid^2} \tag{5}$$

$$\mid S21 \mid^2 = \frac{\mid T_{in} \mid}{2}^2 \times \frac{P_0}{P_0 + P_1} \tag{6}$$

$$\mid S31 \mid^2 = 2\frac{\mid T_{in} \mid}{2}^2 \times \frac{P_1}{P_0 + P_1} \tag{7}$$

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