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Compact Planar Power Divider for Radar Application

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Abstract

In this paper a very compact Wilkinson power divideris developed using Hilbert curve with equal power division. The proposed power divider covers the dualbands from 50 MHz to 240 MHz and from 335 MHz to 480 MHz.This bands are allocated for radiolocation service, airborne early warning radars, battlefield radar systems, position location, surveillance radars and non-military radars such as wind profiling, nuclear safety programs and environmental monitoring.FR4 material with dielectric constant of 4.65, thickness of 1.5 mm and loss tangent of 0.02 is used as a substrate for cost reduction purpose. The proposed structure has a size reduction of 93.54 % relative to conventional one.Good agreement is obtained between simulated and measured results. Also the same power divider is simulated but with an air gap of 3 mm between ground plane and the divider instead of the FR4 substrate. The elimination of the FR4 material is done to avoid any breakdown which may occur due to the applied high power. The proposed simulated air substrate power divider covers thebandwidth from 200 MHz to 450 MHz.

Index Terms— Hilbert curve, Wilkinson power divider

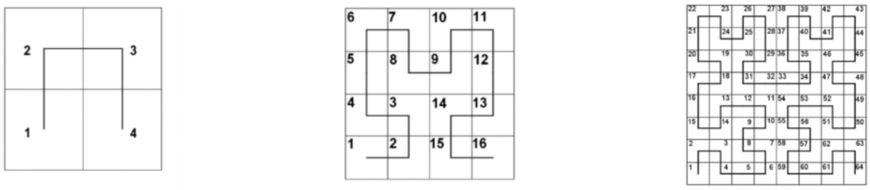
I. INTRODUCTION

Radarsystems have been the subject of much on-going research by both military and commercial. Different frequency bands are allocated for different radar applications. The frequency band from 3–30MHz, normally referred to as the high frequency (HF) band, has only a small portion allocated to the radiolocation service and with only a secondary status. Radars operate in various portions in the HF band on a non-interference basis. Typical radars in this band are referred to as over-the-horizon radars or sky wave radars. The frequency band from 216–225 MHz is allocated on a secondary basis to the radiolocation service and government radiolocation operation is limited to the military services. The frequency band 420–450 MHz is allocated on a primary basis to Federal Government radiolocation service operations in USA. Military radar support includes national air defense radar systems for surveillance of spacecraft and ballistic missiles, service-unique ground and airborne early warning radars, battlefield radar systems for search/surveillance, position location, ship borne long and medium-range air search and surveillance radars, and maritime radio navigation. Non-military radars operations support law enforcement, wind profiling, nuclear safety programs, and environmental monitoring. Also, the frequency band from 890–100000 MHz is divided into many sub bands and are allocated for different radar applications [1]. Power dividers are fundamental components in the GPR radar system and many microwave circuits such as modulators, balanced mixers and antenna array feed networks [2]. Wilkinson power divider is the simplest three-way power divider [3]. Although it provides a match at all ports and high isolation between output ports, a three-way Wilkinson power divider presents serious packaging problems especially in low frequency bands. To overcome these problems, defected ground structures have been used to design compact power divider which showed that a size reduction of 35% and 32% had been achieved using the I and split ring shaped DGS, respectively over conventional power divider without affecting the in band characteristics [4]. A zigzag microstrip structure was used instead of normal microstrip structure and whole size had been reduced by 39% compared to a conventional power divider [5].A zigzag short-ended stub was used instead of normal one and a size reduction of 20 % was obtained compared to a conventional power divider [6]. Coupled lines were used to design a compact Wilkinson power divider and a size reduction of 50% compared to the conventional design was obtained [7].Planar artificial transmission lines were used and the obtained Wilkinson power divider size was reduced to50% of the traditional power divider [8].A π-equivalent shunt stub-based artificial transmission lines was used for a compact planar Wilkinson power divider development. The developed power divider occupies only 14.7% of the circuit size of a conventional one [9]. Many recent researches are interested with dual and ultra wide band, but the obtained structures are comparable with the conventional one [10, 11]. In this paper a very compact Wilkinson power divider which operates in the dual band from 50 MHz to 240 MHz and from 335 MHz to 480 MHz is proposed. FR4 is used for cost reduction purpose. A size reduction of 93.54 % relative to conventional one is obtained. The same power divider is simulated but with an air gap of 3 mm between ground plane and the divider instead of the FR4 substrate. The elimination of the FR4 material is done to avoid any breakdown which may occur due to the applied high power. The proposed simulated air substrate power divider covers thebandwidth from 200 MHz to 450 MHz.Both IE3d and CST simulators are used to simulate the proposed structures.

II. POWER DIVIDER DESIGN

A. Hilbert Filling Space Curve

In 1891 Hilbert defined a space filling curve [12]. The general idea is to divide, at step n, the unit square in 4n equal subsquares each of them containing an equal length part of the curve. The curve so obtained is then depicted by a word of length (4n – 1) which is called the n-th Hilbert word Hn, Fig. 1. A Matlab program was built to draw a Hilbert curve of any order n.



(a) First order **(b) Second order.** **(c) Third order.**

Fig. 1 Hilbert's space filling.

B. ***Conventional Wilkinson Power Divider***

The Wilkinson power divider uses quarter wave transformers to split the input signal to provide two output signals that are in phase with each other. The resistor $2Z_o$ between the two output ports, Fig. 2(a) enables the two outputs to be matched while also providing isolation. For comparison purpose and based on [13, 14], a conventional Wilkinson power divider was designed and simulated for the range from 1 MHz to 250 MHz using FR4 substrate with dielectric constant of 4.65, loss tangent of 0.02 and thickness of 1.5 mm. The characteristic impedance Z_o is chosen to be 50 Ω, the guided wavelength λ_g is calculated at 135 MHz and it is found to be 1221.62 mm, the radius R is 97.21 mm, $\sqrt{2}Z_o$ sector width is 1.43 mm and the Z_o line width is 2.74 mm, Fig. 2(a).The power division ratio varies over the range from -3.6 dB at 1 MHz, -3.8 dB at 250 MHz and -3.3 dB at 135 MHz, Fig. 2(b). Also, the bandwidth extends from 250 MHz to 500 MHz with power division ratio varies from -3.5 dB to -3.9 dB, respectively. The phase performance is almost the same for port 2 and 3, Fig. 2(c). Isolation of -28 dB between ports 2 and 3 is obtained at 135 MHz.

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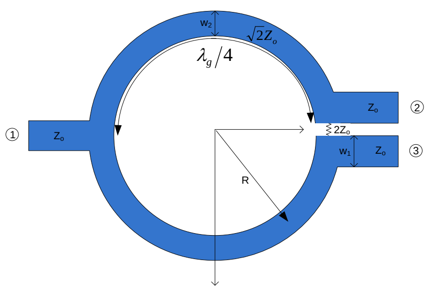

Fig. 2(a) Conventional Wilkinson Power divider.

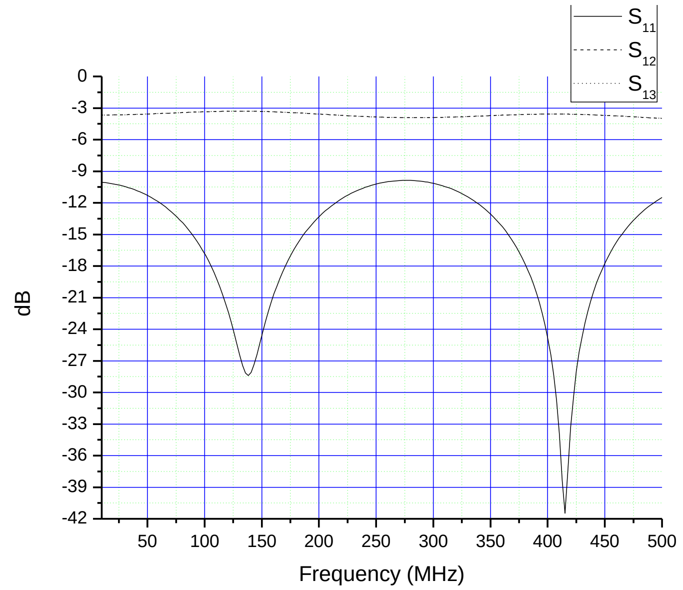

Fig. 2(b) Conventional Wilkinson Power divider simulated |S| parameters versus frequency using IE3D.

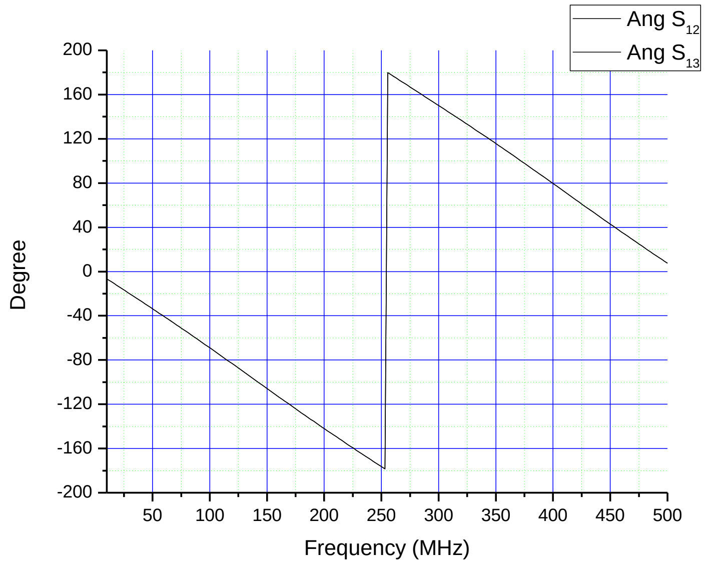

Fig. 2(c) Conventional Wilkinson Power divider simulated |S| parameters phase versus frequency using IE3D.

C. ***Proposed Hilbert Wilkinson Power Divider***

Hilbert space filling curve of order 4 is used to miniaturize the conventional power divider, Fig. 3(a). The proposed structure has 44.5 mm width and 43.1 mm length on FR4 material. A size reduction of 93.54 % is obtained compared with the conventional one. The power division ratiovaries over the range from -3.6 dB at 1 MHz, -3.9 dB at 240 MHz and -3.3 dB at 135 MHz, Fig. 3(b). Also, the bandwidth extends from 315 MHz to 490 MHz and the power division ratio varies from -3.9 dB at 315 MHz to -4 dB at 490 MHz. The phase performance is almost the same for ports 2 and 3, Fig. 3(c).The isolation between ports 2 and 3 reaches -23.5 dB at 135 MHz.

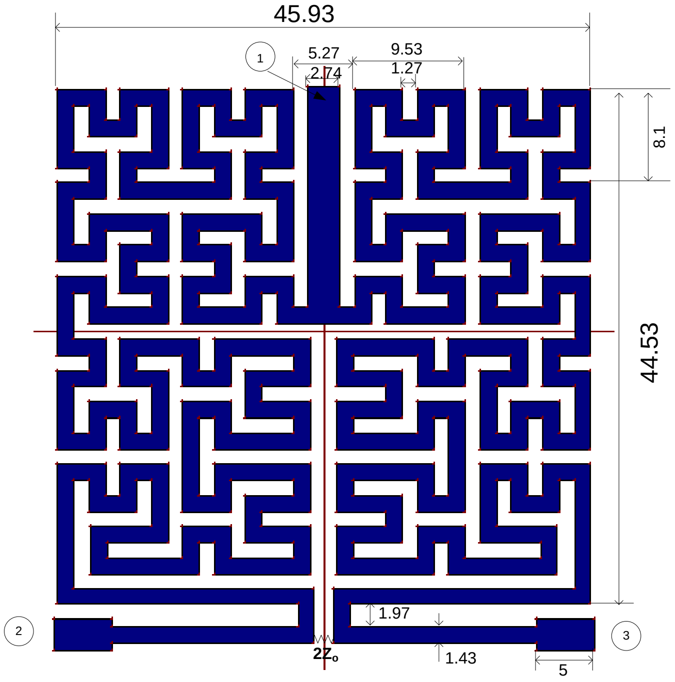

Fig. 3(a) Proposed Hilbert Wilkinson power divider.

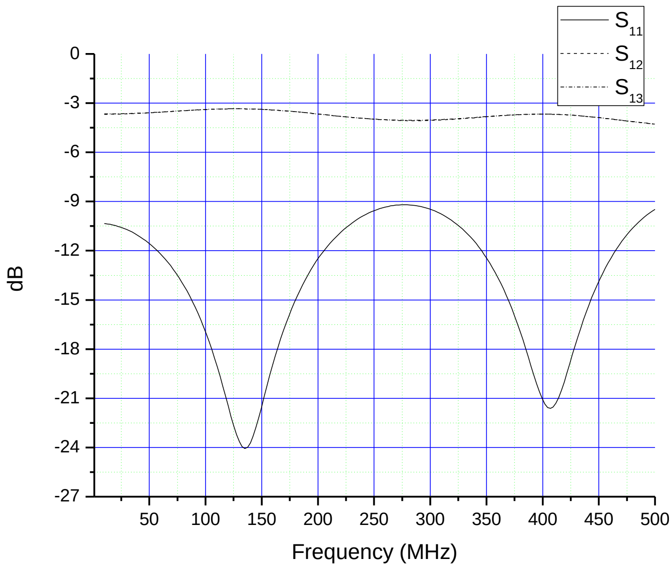

Fig. 3(b) Proposed Hilbert Wilkinson power divider simulated |S| parameters versus frequency using IE3D.

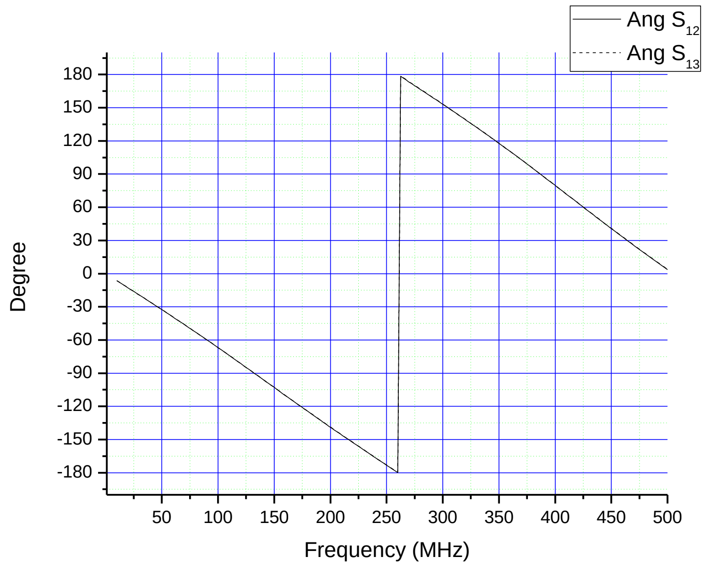

Fig. 3(c) Proposed Hilbert Wilkinson power divider simulated |S| parameters phase versus frequency using IE3D.

D. Proposed air substrate Hilbert Wilkinson Power Divider

Same geometry of the aforementioned Hilbert Wilkinson power divider is used but with an air layer of thickness 3 mm instead of FR4 substrate, Fig 3(e). The elimination of the FR4 material is done to avoid any breakdown which may occur due to the applied high power.The power division ratio varies over the range from -3.3 dB at 200 MHz, -3.25 dB at 240 MHz and -3.5 dB at 450 MHz, Fig. 3(f). The isolation between ports 2 and 3 reaches -21.5 dB at 350 MHz.

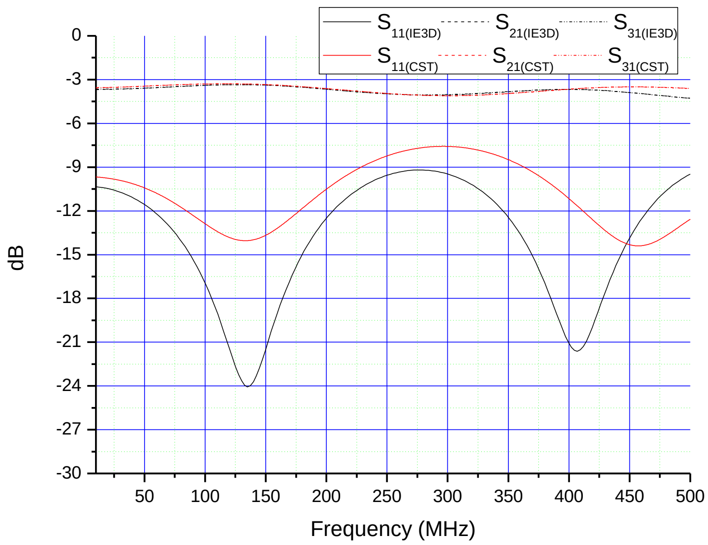

Fig. 3(d) Proposed Hilbert Wilkinson power divider simulated |S| parameters versus frequency using CST.

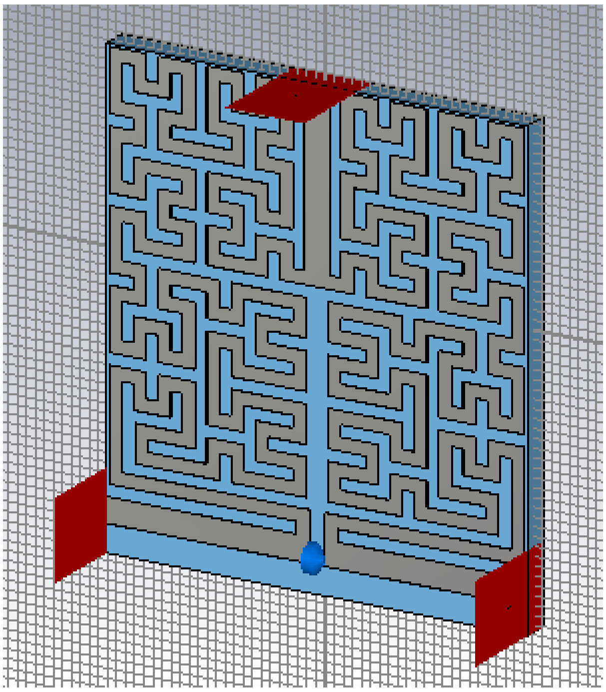

Fig. 3(e) Proposed Hilbert Wilkinson power divider with air substrate.

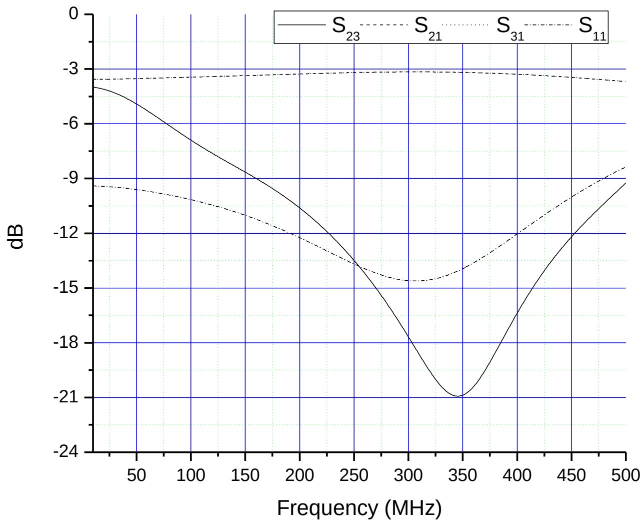

Fig. 3(f) Proposed air substrate Hilbert Wilkinson power divider simulated |S| parameters versus frequency using CST.

III. FABRICATION OF THE PROPOSED POWER DIVIDER

The proposed Hilbert power divider using FR4 material with dielectric constant of 4.65, loss tangent of 0.02 and thickness of 1.5 mmis only fabricated for cost reduction and concept verification. Photolithography process is used as a fabrication method in the Electronics Research Institute Laboratory in Egypt, Fig. 4(a). The measurement setup is shown in Fig. 4(b) where HP 8757 D scalar network analyzer is used for S parameters measurements. Fig. 4(d) shows a comparison between measured and simulated S parameters. The measured frequency band extends from 50 MHz to 240 MHz where the power division ratio varies over this band from -3.1 dB at 50 MHz, -3.1 dB at 240 MHz and -2.8 dB at 135 MHz, Fig. 4(c). Also, the measured frequency band extends from 335 MHz to 480 MHz where the power division ratio varies over the range from -3.1 dB at 335 MHz and -2.83 dB at 480 MHz, Fig. 4(c).The measured isolation between port 2 and port 3 reaches -15.6at 142.3 MHz. The resonant frequency shift from 135 MHz to 142.3 MHz has occurred between IE3D simulated and measured value, respectively. Fig. 4(d) shows the CST results which are agree very much with measured one than IE3D results. The tolerance between measured and simulated results may be referred to fabrication tolerances and soldering the SMA connectors.

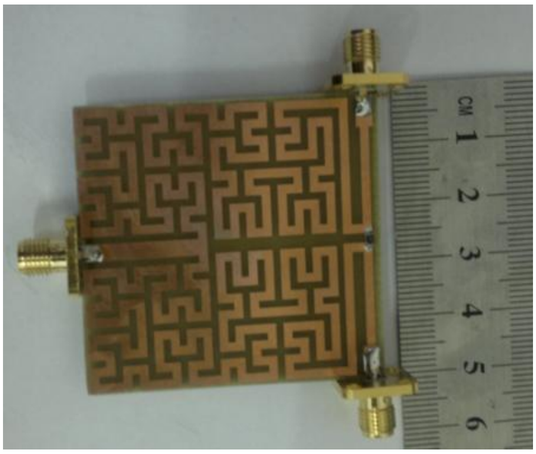

Fig. 4(a) A photo of the fabricated proposed Hilbert Wilkinson power divider.

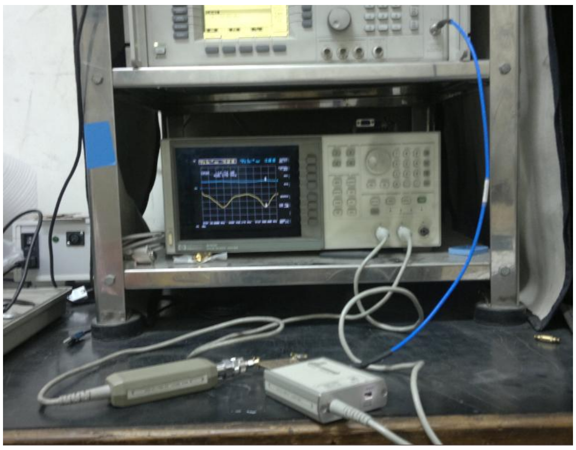

Fig. 4(b) Measurment setup of the proposed fabricated Hilbert Wilkinson power divider.

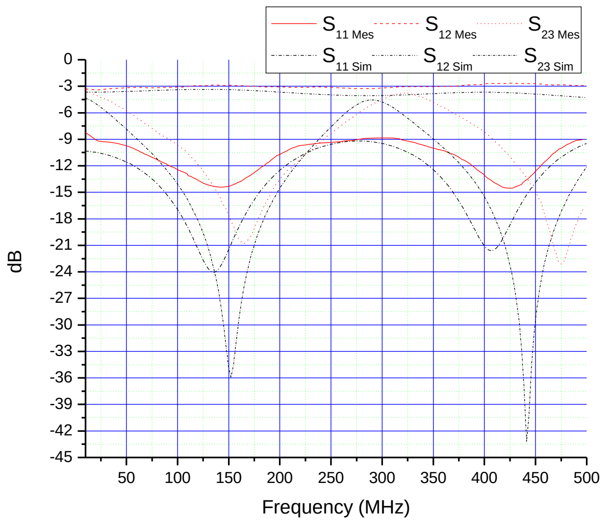

Fig. 4(c) Proposed Hilbert Wilkinson power divider measured and simulated |S| parameters versus frequency using IE3D.

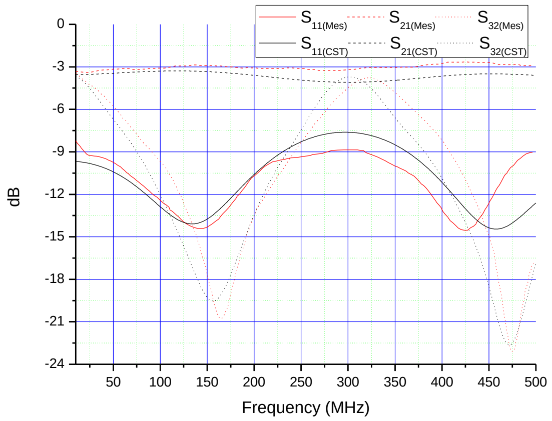

Fig. 4(d) Proposed Hilbert Wilkinson power divider measured and simulated |S| parameters versus frequency using CST.

IV. CONCULSIONS

A very compact power divider was proposed for the radarapplication. A size reduction of 93.54 % is obtained compared with the conventional one. The proposed structure was fabricated using FR4 material so, cost reduction was also achieved.When high power application is a main requirement. The FR4 substrate could be removed and the same power divider structure could be used and a frequency band from 200 MHz to 450 MHz was achieved. This frequency band is enough for radiolocation service, airborne early warning radars, battlefield radar systems, position location, ship borne long, surveillance radars and non-military radars such as wind profiling, nuclear safety programs and environmental monitoring applications.

V. REFERENCES

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