

DESIGN AND ANALYSIS OF A MICROSTRIP PATCH ANTENNA AT 7.5 GHz FOR X-BAND VSAT APPLICATION

SARAH YASMIN MOHAMAD^{1*}, NORALYA FATIN MUZAMIL¹,
NORUN FARIHAH ABDUL MALEK¹, S.M.A. MOTAKABBER¹, RAFIDAH ABD
MALIK² AND NURAIN IZZATI SHUHAIMI³

¹Department of Electrical and Computer Engineering, Faculty of Engineering,
International Islamic University Malaysia,
Jalan Gombak, 53100 Kuala Lumpur, Malaysia.

²Department of Instrumentation & Electronics Technology, The Science & Technology Research
Institute for Defence (STRIDE) Malaysia.

³Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam,
Selangor Darul Ehsan, Malaysia.

*Corresponding author: smohamad@iium.edu.my

(Received: 12th December 2020; Accepted: 16th April 2021; Published on-line: 4th January 2022)

ABSTRACT: In this paper, a microstrip patch antenna is designed to be used for X-band VSAT application at 7.5 GHz. The antenna is proposed to replace the massive and commonly used parabolic reflector antennas (46.0 inch × 29.3 inch × 13.5 inch (116.84 cm × 74.42 cm × 34.29 cm) with weight of 66.2 kg) in terms of portability due to its compact and lightweight features, with overall dimensions of 19.00 mm × 30.55 mm. The 7.5 GHz frequency is chosen based on the X-band frequency used in Malaysia, as reported by STRIDE. The microstrip patch antenna is first designed and simulated using CST Microwave Studio (CST MWS) and exhibits a good return loss (S_{11}) of -42.09 dB, a bandwidth of 399 MHz, directivity of 7.63 dB and gain of 7.18 dB. The antenna is then fabricated using RT/duroid® High Frequency 5880 substrate with a dielectric constant of $\epsilon_r = 2.2$, loss tangent of $\delta = 0.0009$ and thickness of $t = 1.574$ mm. Next, the return loss and radiation pattern measurements are carried out to confirm the simulated results. The measurement of the antenna prototype provides a return loss S_{11} of -30.53 dB, bandwidth of 455 MHz, directivity of 5.51 dB and gain of 3.88 dB.

ABSTRAK: Di dalam kajian ini, antena jalur mikro dicadangkan untuk tujuan aplikasi jalur-X VSAT pada 7.5 GHz. Antena jalur mikro ini dicadangkan untuk menggantikan antena reflektor parabola yang besar dan biasa digunakan (46.0 inci × 29.3 inci × 13.5 inci (116.84cm × 74.42cm × 34.29cm) dengan berat 66.2kg), kerana cirinya yang mudah alih dengan fizikalnya yang kecil dan ringan, dan dimensi keseluruhan 19.00 mm × 30.55 mm. Frekuensi 7.5 GHz dipilih berdasarkan frekuensi jalur-X yang digunakan di Malaysia, seperti yang dilaporkan oleh STRIDE. Antena jalur mikro ini direka dan disimulasi menggunakan perisian CST Studio Gelombang Mikro (CST MWS) dan menghasilkan kehilangan pulangan yang baik S_{11} -42.09 dB, lebar jalur 399 MHz, keterarahan 7.63 dB dan gandaan 7.18 dB. Antena jalur mikro ini kemudiannya direalisasikan dengan menggunakan substrat RT / duroid® Frekuensi Tinggi 5880 dengan pemalar dielektrik $\epsilon_r = 2.2$, tangen kehilangan $\delta = 0.0009$ dan ketebalan $t = 1.574$ mm. Seterusnya, pengukuran kehilangan pulangan dan corak radiasi dilakukan untuk mengesahkan keputusan simulasi. Pengukuran prototaip antena jalur mikro menunjukkan kehilangan pulangan S_{11} -30.53 dB, lebar jalur 455 MHz, keterarahan 5.51 dB dan gandaan 3.88 dB.

KEYWORDS: *microstrip patch antenna; VSAT application; X-band communication*

1. INTRODUCTION

As technology evolves at a very fast pace, antennas have become extremely important in the world of communication technology. Antennas play a major role in transmitting and/or receiving electromagnetic waves with respect to their specific direction and properties for the intended application [1]. There are various forms of antennas available in the market for instances wires, apertures, arrays, parabolic reflectors, lenses, and microstrip patches. The microstrip patch antenna is one of the most used antennas nowadays due to its excellent properties such as having a low profile and lightweight structure, having low cost, ease of fabrication and ease of integration with circuits [1]. A compact and lightweight antenna is always opted for VSAT, very small aperture terminal [2,3], satellite applications so that it can be easily carried around or accommodated on moving stations, especially for military communication services [4,5].

Generally, the frequency of military communication lies in the X-band range of 8-12 GHz [6-10]. However, according to the Science & Technology Research Institute for Defence (STRIDE), the range of X-band frequency used in Malaysia started at 7 GHz [11]. The common antennas used for this specific application are array and parabolic reflectors. The common dimensions of the parabolic reflectors that were used for X-band operation can reach up to 116.84 cm × 74.42 cm × 34.29 cm, with a load of 66.2 kg [11]. Also, this already omits the positioned case that can reach an additional load of 40 kg, which is compulsory to be used together with the parabolic reflectors. The evolution of military technologies nowadays requires an antenna that is not hefty, portable, and easy to carry around or accommodate on moving stations [4,5]. Hence, a microstrip patch antenna is proposed in this paper to fulfil this requirement where it can provide the advantages of having a lightweight, low profile and compact structure compared to the parabolic reflectors which are more massive, bulkier, and difficult to use on a moving vehicle. The microstrip patch antenna is designed to be working at 7.5 GHz which lies in the frequency range of X-band services in Malaysia [11].

2. DESIGN OF THE MICROSTRIP PATCH ANTENNA

The theoretical dimensions of the microstrip patch antenna proposed in this paper are determined using equations (1) to (5);

$$\text{Patch Width} = \frac{v_o}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

$$\text{Patch Length} = L_{eff} - 2\Delta L \quad (2)$$

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{eff}}} \quad (3)$$

$$\Delta L = \frac{(\epsilon_{eff} + 0.3) \left(\frac{w}{h} + 0.264 \right)}{(\epsilon_{eff} - 0.258) \left(\frac{w}{h} + 0.8 \right)} \quad (4)$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + \frac{12h}{w}}} \right) \quad (5)$$

By using equations (1) to (5), the length, L and the width, W of the 7.5 GHz rectangular microstrip antenna is calculated to be $L = 12.5$ mm and $W = 15.8$ mm. Nevertheless, these equations are just the basic step to determine the initial dimension of the antenna for use at 7.5 GHz, and the performance results may slightly differ from the target research's demand. Thus, a huge number of recent studies and designs are referred in order to support the finding

of the optimum dimensions. Moreover, the antenna is designed using RT/duroid ® High Frequency 5880 substrate with a dielectric constant of $\epsilon_r = 2.2$, loss tangent of $\delta = 0.0009$ and thickness of $t = 1.574$ mm. The substrate is chosen due to its exceptional dielectric constant uniformity over a wide frequency range [12]. Fig. 1(a) and Table 1 depict the final dimensions of the proposed antenna.

The antenna is then manually fabricated. First, the CST file is converted into a Gerber File as the layout for the board, followed by printing out the layout with the exact dimensions. The board (substrate RT/duroid ® High Frequency 5880) is cut according to the exact dimension before the copper for the interior layers was printed on top of the board. Finally, the etching process is carried out to completely remove the unwanted copper. The performance of the fabricated antenna is measured to confirm the simulated results. The fabricated antenna can be seen in Fig. 1(b).

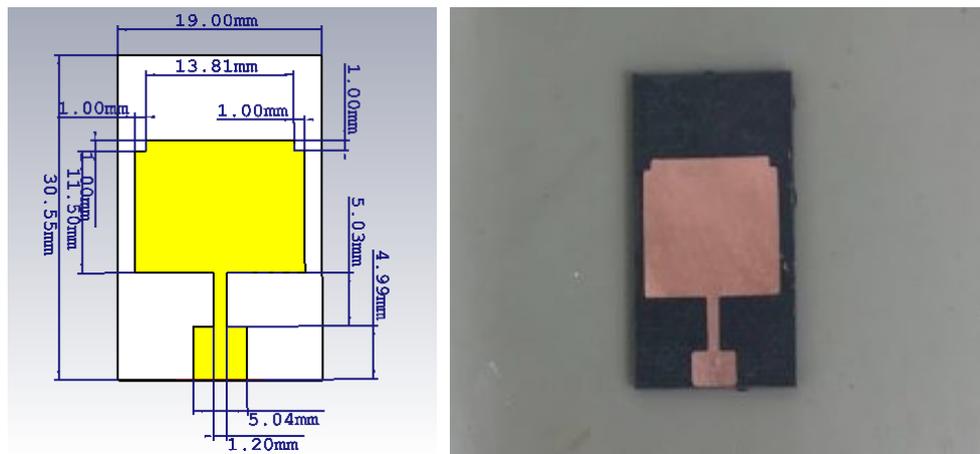


Fig. 1: (a) The front view of the microstrip patch antenna with dimensions, and (b) the front view of the fabricated antenna.

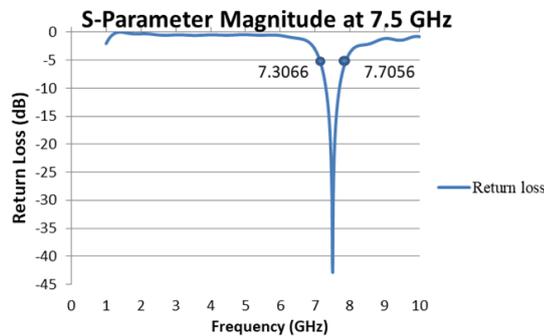
Table 1: The parameters and values of the microstrip patch antenna.

Parameters	Values
Patch width	13.81 mm
Patch length	12.54 mm
Transformer width	1.20 mm
Transformer length	5.03 mm
Feeding width	5.04 mm
Feeding length	4.99 mm
Patch thickness	0.035 mm
Dielectric and ground plane width	19.00 mm
Dielectric and ground plane length	30.55 mm
Dielectric thickness	1.575 mm
Ground plane thickness	0.35 mm

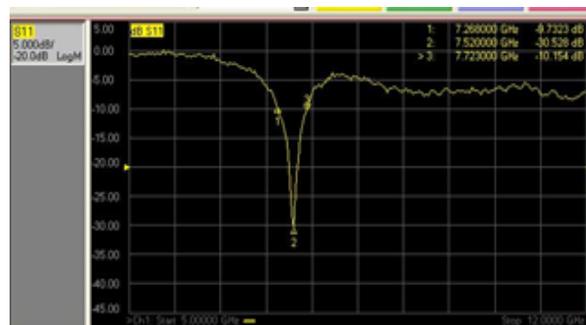
3. SIMULATED AND MEASURED RESULTS

The simulated and measured results of the antenna performances are presented and discussed in this section. Figure 2 shows the simulated and measured return loss of the proposed antenna. In Fig. 2(a), it can be observed that the microstrip patch antenna is resonating at the targeted frequency of 7.5 GHz with return loss, $S_{11} = -42.09$ dB, which proved that the designed antenna is well-matched to the 50 ohm reference impedance. Figure

2(b) shows the measurement result of the return loss of the antenna prototype using the Vector Network Analyzer, as shown in Fig. 3(a). The measurement result depicts a return loss of $S_{11} = -30.53$ dB which differs slightly from the simulated result, but still shows a very good transmission from the antenna.



(a)



(b)

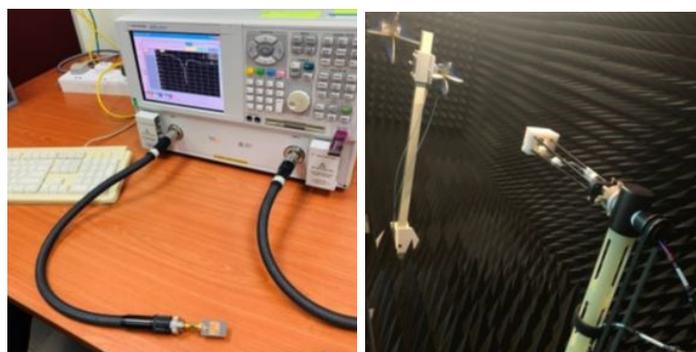
Fig. 2: The (a) simulated and (b) measured return loss S_{11} of the microstrip patch antenna.

From these results, the bandwidth of the antenna can also be observed. The simulated result in Fig. 2(a) depicts a bandwidth of $BW = 399$ MHz, while the measured result in Fig. 2(b) depicts a bandwidth of $BW = 455$ MHz. These bandwidth results are calculated based on equation (6);

$$\text{Bandwidth} = F_H - F_L \quad (6)$$

where: F_H = higher frequency at S_{11} at -10 dB

F_L = lower frequency at S_{11} at -10 dB



(a)

(b)

Fig. 3: The measurement of the microstrip patch antenna prototype with (a) Vector Network Analyzer and in (b) Anechoic chamber.

Figure 4 and 5 show the simulated and measured 3D far field radiation pattern of the microstrip patch antenna. Moreover, Fig. 6 and Fig. 7 show the simulated and measured polar far field radiation pattern (in E-plane and H-plane) of the microstrip patch antenna. The antenna's radiation pattern is measured in an anechoic chamber, as shown in Fig. 3(b).

It can be seen from Fig. 4 to Fig. 7 that the antenna exhibits a directive pattern in the 2D and 3D view. From the simulation, it is observed that the directivity and gain of the antenna at the intended frequency of 7.5 GHz are 7.63 dB and 7.18 dB, respectively. However, the directivity and gain for the measured antenna prototype are 5.51 dB and 3.88 dB, respectively. It is believed that the gain between the simulation results and measurement results varies due to the mismatch of impedance matching and also due the losses that occur during the measurement.

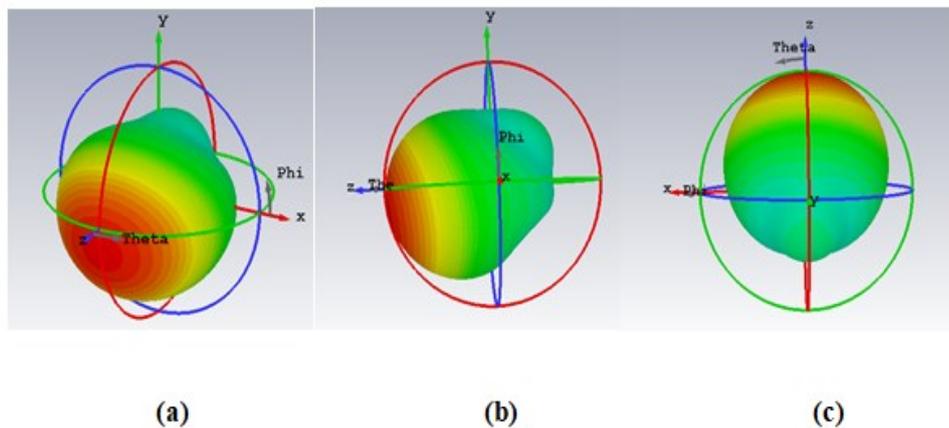


Fig. 4: The simulated 3D far field radiation pattern in (a) isometric, (b) y-axis and (c) x-axis view of the microstrip patch antenna at 7.5 GHz.

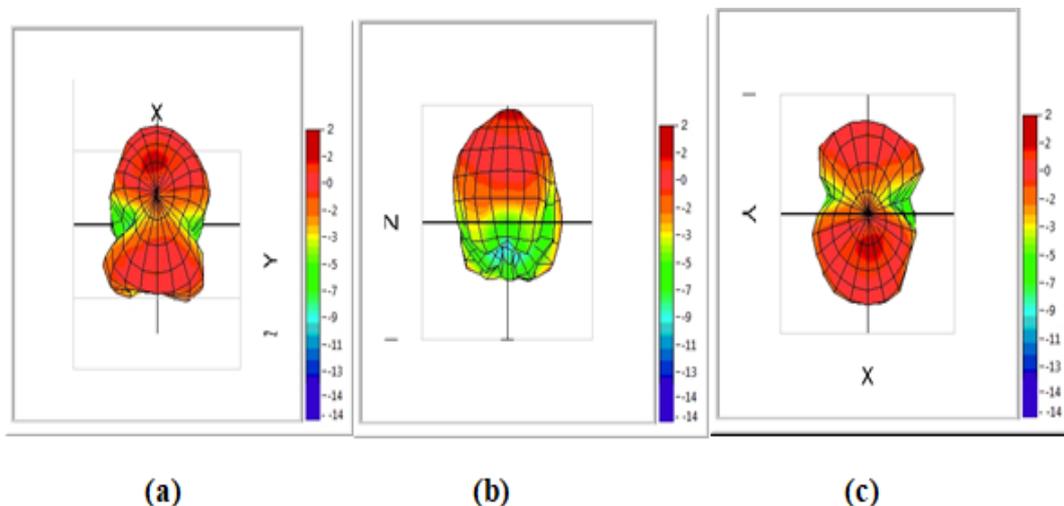
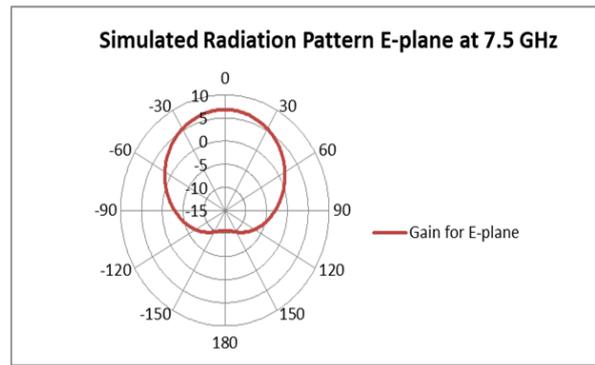
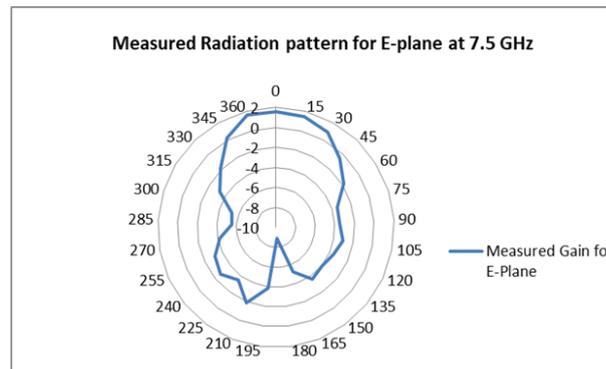


Fig. 5: The measured 3D farfield radiation pattern from (a) below, (b) front and (c) top view of the microstrip patch antenna at 7.5 GHz.

Finally, Table 2 summarizes the overall performances (simulated and measured) of the microstrip patch antenna in terms of return loss, bandwidth, directivity, gain, and main lobe direction.

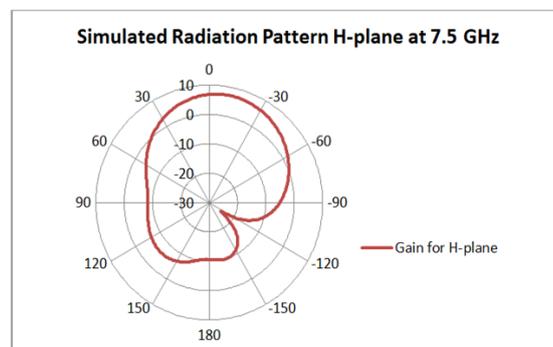


(a)

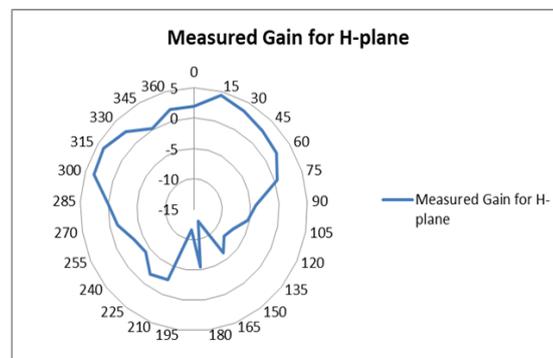


(b)

Fig. 6: The (a) simulated and (b) measured polar far field radiation pattern for E-plane of the microstrip patch antenna at 7.5 GHz.



(a)



(b)

Fig. 7: The (a) simulated and (b) measured polar far field radiation pattern for H-plane of the microstrip patch antenna at 7.5 GHz.

Table 2: The overall performance (simulated and measured) of the microstrip patch antenna at 7.5 GHz, in terms of return loss, bandwidth, directivity, gain and main lobe direction

Antenna performances	Simulation	Measurement
Return loss (dB)	-42.09	-30.53
Bandwidth (MHz)	399	455
Directivity (dB)	7.18	3.88
Gain (dB)	7.63	5.51
Main lobe direction (degree)	11.0	15.0

4. CONCLUSION

A microstrip patch antenna for X-band VSAT application at 7.5 GHz has been designed, simulated, and tested. The antenna has a compact and lightweight structure with an overall dimension of 19.00 mm × 30.55 mm. The antenna depicted a good simulated performance with a return loss of -42.09 dB, bandwidth of 399 MHz, directivity of 7.18 dB, and gain of 7.63 dB. The prototype of the antenna is then tested where the return loss S_{11} measurement is performed using a Vector Network Analyzer, while the radiation pattern measurement is carried out in an anechoic chamber. The antenna prototype exhibits a measured return loss S_{11} of -30.53 dB, bandwidth of 455 MHz, directivity of 3.88 dB, and gain of 5.51 dB. The proposed antenna can be a good replacement and a solution for the massive and bulkier parabolic reflector antenna for X-band VSAT application at 7.5 GHz and will also be suitable for use on a moving vehicle or station.

REFERENCES

- [1] Balanis CA. (2016) Antenna Theory - Analysis and Design. Hoboken, John Wiley & Sons, Inc.
- [2] Madiawati H, Suryana J. (2016) Design and implementation of mobile antenna VSAT with microstrip array based at Ku Band Frequency. In Proceedings of the 10th International Conference on Telecommunication Systems Services and Applications (TSSA), pp. 1-5.
- [3] Asci Y, Curuk E, Yegin K, Ozdemir C. (2016) Improved splash-plate feed parabolic reflector antenna for Ka-Band VSAT applications. In Proceedings of the 46th European Microwave Conference (EuMC), pp. 1283-1286.
- [4] Ruslan AA, Mohamad SY, Badron K, Ismail AF, Abdul Malek NF, Mohd Isa FN. (2020) Study of microstrip patch array antenna for side lobe suppression in the X-band region using uniform, binomial and tschebyscheff excitation methods. IIUM Engineering Journal, 21(1): 61-72.
- [5] Mohamed N, Mohamad SY, Abdul Malek NF, Mohd Isa FN. (2019) A compact and lightweight microstrip antenna array with Wilkinson power divider for X-band application at 9.5 GHz. In Proceedings of the IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE); pp. 1-5.
- [6] ESA-Satellite frequency bands. Available: https://www.esa.int/Applications/Telecommunications_Integrated_Applications/Satellite_frequency_bands.
- [7] Ishtaique-ul Huque MT, Hosain MK, Islam S, Chowdhury A. (2011) Design and performance analysis of microstrip array antennas with optimum parameters for X-band applications. International Journal of Advanced Computer Science and Applications, 2(4): 81-87.
- [8] Samsuzzaman M, Islam MT. (2014) Inverted S-shaped compact antenna for X-band applications. Scientific World Journal: 11.
- [9] Singh V, Mishra B, Singh R. (2015) A compact and wide band microstrip patch antenna for X-band applications. In Proceedings of the 2nd International Conference on Advances in Computing and Communication Engineering, pp. 296-300.

- [10] Ahmad Mustafa AM, Mohamad SY, Abdul Malek NF, Mohd Isa FN and Rafiqul IM. (2018) A wideband circularly-polarized spiral antenna for cubesat application. *Journal of Telecommunication, Electronic and Computer Engineering*, 10(1-8): 17-20.
- [11] Model 1098 Fly Away Integrated Terminal System (2017) Operations and Maintenance Manual, AVL Technologies, 900-085-001-D.
- [12] RT/duroid 5870 and 5880 Data Sheet – Rogers Corporation. Available: <https://rogerscorp.com/-/media/project/rogerscorp/documents/advanced-connectivity-solutions/english/data-sheets/rt-duroid-5870---5880-data-sheet.pdf>