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Design of Substrate IntegratedWaveguide Power Divider and Parameter optimization using Neural Network

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Abstract: *Motivated by the key technology Substrate Integrated Waveguide (SIW) and an effective approach of Artificial Intelligence (AI), this paper aims at the design of an SIW based power divider for low return loss using Artificial Neural Network (ANN). A 15GHz SIW based power divider is presented, and parameters are optimized using error back-propagation in ANN. Results achieved shows how one can take help of ANN to make the design more efficient and faster by reducing the number of simulation, As we know that simulation time is a major issue in SIW components. In this paper, presented SIW based power divider is designed using T-junction configuration possess return loss of -31.72 dB and output power equality achieved is 3.39 dB and 3.40 dB at port 2 and 3 respectively at the designed frequency.*

Keywords: *artificial neural network (ANN),error back-propagation,power divider, substrate integrated waveguide (SIW)*

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I. Introduction

Whenever one talks about low loss, high-quality factor and high power microwave and millimetre-wave communication it was difficult to get a substitute of rectangular waveguide components before one of the key technology, substrate integrated waveguide first proposed [1] became dominant for the high-frequency application. The reason for replacement of rectangular waveguide was high cost, bulky size and difficulty to integrate with modern high frequency integrated circuits since the structure is nonplanar. In recent years, substrate integrated waveguide (SIW) technology become more popular due to its simple structure, low loss, appreciable quality factor, ease of fabrication and low production cost achieved by printed circuit board (PCB) process. A typical SIW structure is shown in Fig.1 is constructed by two parallel rows of via holes having diameter "d" is repeated by a period of "p", a substrate with height "h" and dielectric constant "ε_r" is sandwiched by the top and bottom plates of metal.

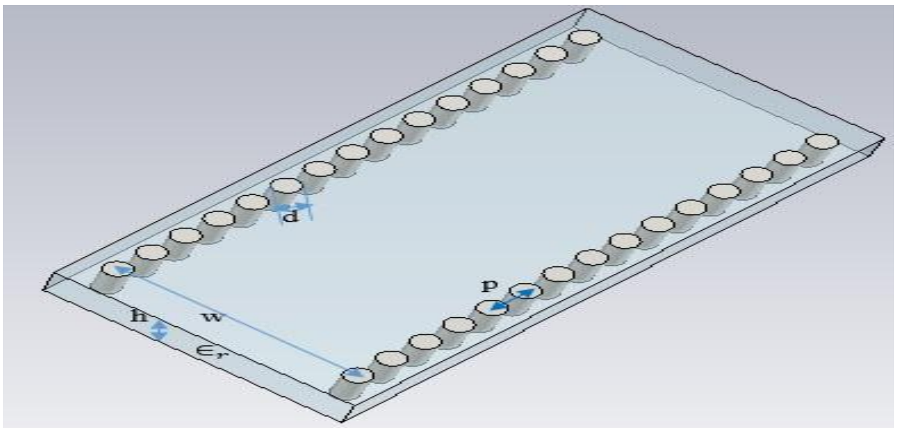


Fig. 1A typical SIW structure

The SIW is realized by metallic via arrays and have almost similar propagation characteristics [2-3] as a conventional rectangular waveguide and turned out a wonderful substitute for the same. Now speaking about the concept of power division comes from the term "one to many" as we have power divider, is the component which takes input from one port and divides it to output ports based on the properties of components.

Here in this paper, a 3-port SIW based power divider is presented with equal power division at both the output ports. Moreover, if we repeat same structure as many time we can realize even-numbered output ports depending upon our application requirement and each output port will have almost equal power in this paper, We have used Microwave CST Studio Suite (CST) to simulate our structure and collect data for training, and parameter optimization is done with the help of neural network modeled as a program in Matlab. The neural network is trained using the data collected through simulation in CST Studio Suite, once trained neural network helps us to predict parameters of our model and save lots of time. From the results, we have obtained it is convenient to say that neural network suites well for such application where we need to optimize the number of parameters and simulation require more amount of time to complete.

II. Design of the Power Divider

Whenever one is planning to make equal power divider, it is recommended to go for T-junction configuration since there exist ease and symmetry in structure. The designed T-configuration layout can be seen in Fig.2 below:

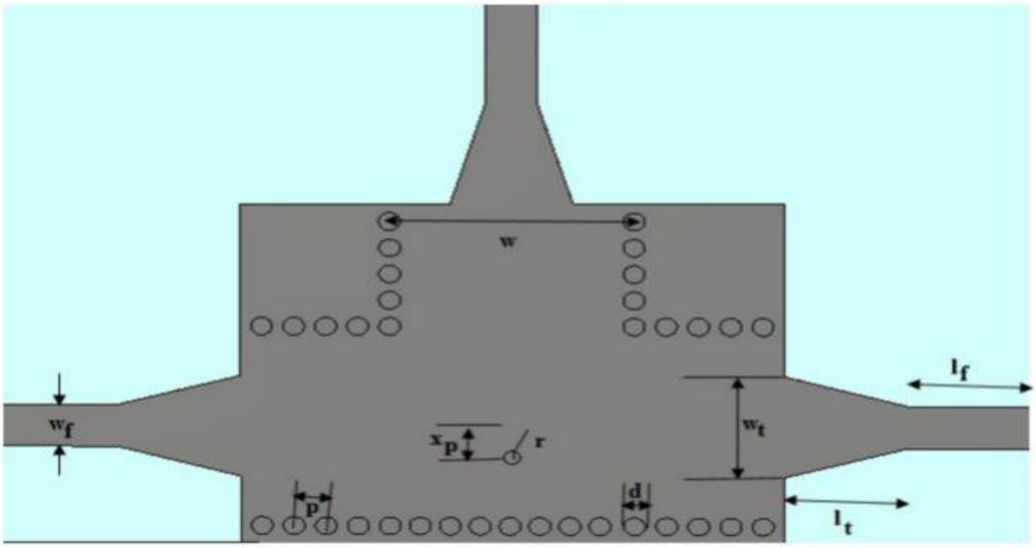


Fig.2 Layout of SIW power divider

A simple approach by analyzing the conversion of the conventional rectangular waveguide to its SIW equivalent [4] is followed in this paper to design the power divider. Considering TE_{mn} mode, cutoff frequency [4] is given by:

$$f_{cmn} = \sqrt{(m/a)^2 + (n/b)^2} \quad (1)$$

Where "b" is the thickness and "a" is the width of the waveguide.Since SIW supports TE_{m0}mode. To get SIW conversion, we first calculate width "**a**"forTE_{10} dominant mode using (2)

$$a = c/2f_{c10} \quad (2)$$

Later by considering a dielectric field waveguide with dielectric constant "$\boldsymbol{\varepsilon_r}$" and "$\mathbf{a_d}$" be its width we relate it to conventional waveguide width "**a"** as given in the equation (3) and further in the equation (4) [5] we relate dielectric field waveguide width "$\mathbf{a_d}$" to SIW width "**w**".

$$a_d = a/\sqrt{e_r} \quad (3)$$

$$w = a_d + p(0.766e^{\frac{0.4482\,d}{p}} - 1.176e^{\frac{1.214\,d}{p}}) \quad (4)$$

Microstrip to SIW transition can be seen in Fig. 2. Where width and length of the tapered section are "$\mathbf{w_t}$''and "$\mathbf{l_t}$" respectively. Width was calculated [6] by using (5)

$$\frac{w}{w_t} = 4.38e^{\frac{0.627 e_r}{e_0}} \quad (5)$$

An inductive post having radius "**r**" and its position is chosen "$\mathbf{x_p}$''distance from the center is placed in T-junction which helps to achieve better impedance matching and overcome the effect of junction discontinuity over a wide frequency range [7].

III. Artificial Neural Network

Nowadays engineers are using machine learning as an effective tool to predict the behaviourof a model, function approximation and can be implemented using ANN model as shown in Fig. 3. It is an interconnection by weights between three layers input,hidden and output respectively. In this paper neural network of size 1×10×1 is used that is 1 input, 10 hidden and 1 output neurons.

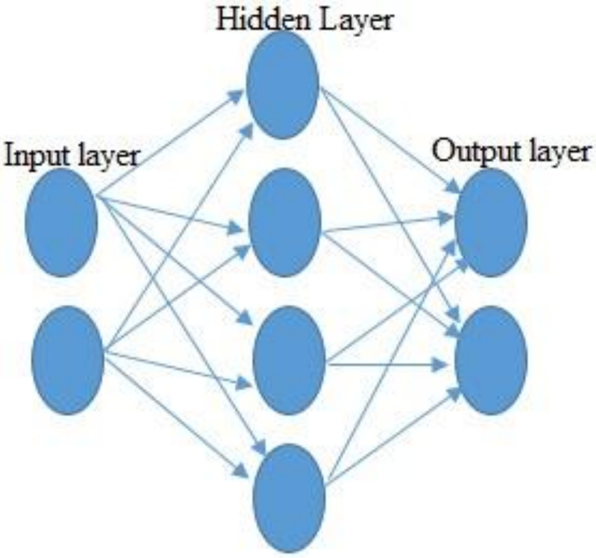


Fig. 3 Artificial Neural Network Model

3.1Error Back Propagation using Gradient Descent Algorithm

ANN is like a black box which takes input and generates output. Error backpropagation algorithm is used for training of neural network. Training means finding the optimum value of interconnection weights. Data which is a set of input and target, collected by simulation is used to train the neural network. Error backpropagation means we are back-propagating the error and accordingly we are updating weights of the neural network. We take a data set $(\boldsymbol{x_i}, \boldsymbol{y_i})$where "$\boldsymbol{x}$" is the input and "$\boldsymbol{y}$" is the corresponding target and "$\boldsymbol{i}$" is the number of training points available. We predict value of "$\boldsymbol{y}$" for given value of"$\boldsymbol{x}$" using weights"$\boldsymbol{w}$" as

$$y_i = f(x_i, w) \quad (6)$$

Gradient Descent algorithm [8] implemented in Matlab[9] is used in this paper to optimize parameters after updating weight vector "**w**", algorithm is expressed as

$$w_{t+1} = w_t - \gamma \frac{\partial J}{\partial w} \quad (7)$$

Where "$\boldsymbol{w}$" is the weight vector which is nothing but the collection of weights of the interconnection in neural network, "$\boldsymbol{\gamma}$" is learning rate which has an important role in convergence during training of ANN and "**J**" is the objective function to be minimized is basically sum square error of actual targets and are of those calculated using neural network model, is expressed in (8)

$$J = \sum_i (y_i - f(x_i, w)^2) \quad (8)$$

IV. Parameter Optimization and Results

We have optimized radius "$\boldsymbol{r}$" of the inductive post, its position "$\boldsymbol{x_p}$" from the center and taper width "$\boldsymbol{w_t}$" for better return loss performance in this section. Other parameters are shown in Table I.

Table I. Parameters of power divider

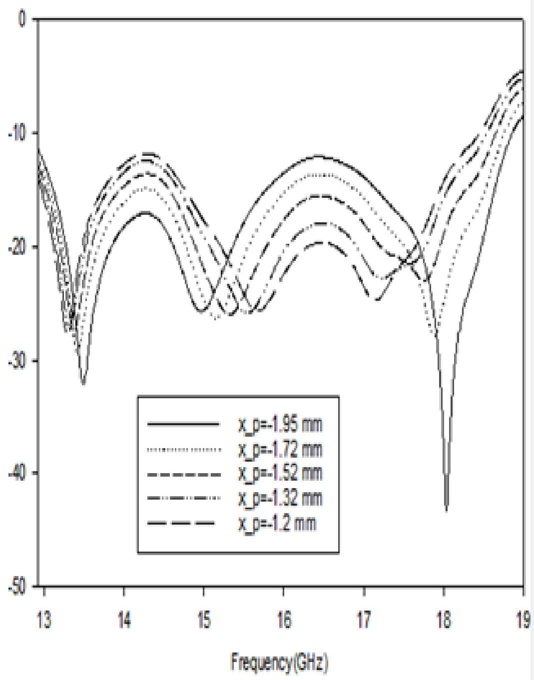
w	11.42 mm	w_f	2.40 mm
d	1 mm	l_f	5.77 mm
p	1.5 mm	l_t	5.77 mm

We start by assuming an initial value for radius $r = .5\ mm$, $w_t = 5.43\ mm$ (5) and first optimize the parameter position x_p of an inductive post by using the training data collected by Microwave CST Studio Suite is shown in Table II.

Table II. Training data for x_p

x_p(mm)	S_{11}(dB)	$x_p(mm)$	S_{11}(dB)	x_p(mm)	S_{11}(dB)	x_p(mm)	S_{11}(dB)	x_p(mm)	S_{11}(dB)
-0.98	-15.78	-1.32	-19.53	-1.57	-23.53	-1.7	-25.79	-1.86	-25.99
-1.1	-16.94	-1.41	-20.92	-1.6	-24.05	-1.74	-25.84	-1.9	-25.20
-1.27	-18.91	-1.47	-21.83	-1.65	-24.99	-1.82	-26.44	-2	-24.18

Using this training data ANN was trained in Matlab, the impact of changing x_p on return loss can be seen in Fig. 4 and sum square error during training is shown in Fig. 5 shown below:



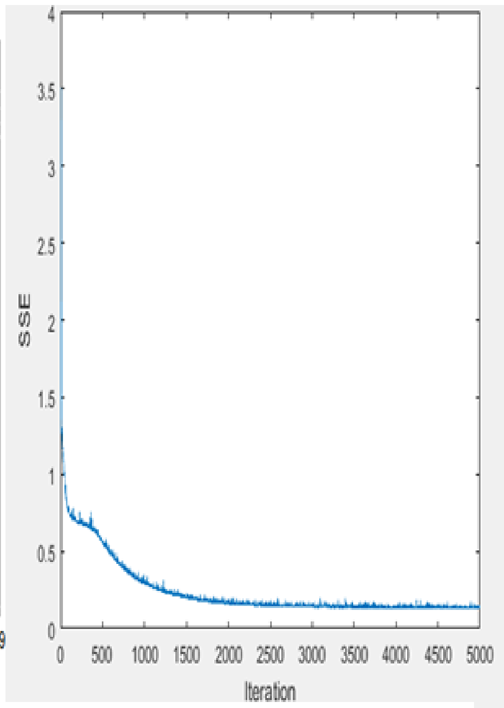


Fig. 4. Variation in S_{11} with x_p **Fig. 5**. Sum square error during training for x_p

After training to check weather predicted values by the neural network are close enough to actual values or not, testing data is given in Table III. From which we can see that neural network output and data simulated using CST fit well enough and better performance of return loss is achieved when x_p = -1.79 mm.

Table III. Testing Data for x_p

x_p(mm)	S_{11}(dB) (ANN)	S_{11}(dB)	x_p(mm)	S_{11}(dB) (ANN)	S_{11}(dB)
-0.9	-15.25	-15.04	-1.68	-25.37	-25.36
-1	-15.93	-15.96	-1.79	-26.37	-26.70
-1.2	-18.07	-18.06	-1.85	-25.74	-25.94
-1.54	-23.06	-22.95	-1.88	-25.60	-25.61
-1.61	-24.23	-24.17	-1.95	-24.74	-24.69

Now, optimize value of radius r taking x_p = -1.79 mm and w_t=5.43 mm. Training data for the radius is given in Table IV.

Table IV. Training data for r

r(mm)	S_{11}(dB)	r(mm)	S_{11}(dB)	r(mm)	S_{11}(dB)	r(mm)	S_{11}(dB)	r(mm)	S_{11}(dB)
0.03	-12.42	0.19	-17.96	0.3	-23.13	0.41	-27.84	.46	-27.25
0.11	-15.45	0.27	-21.60	0.38	-26.69	0.45	-27.87	.59	-22.04

Using this training data ANN was trained in Matlab, the impact of variation in r on return loss can be seen in Fig. 6 and sum square error during training for the radius is shown in Fig. 7 below:

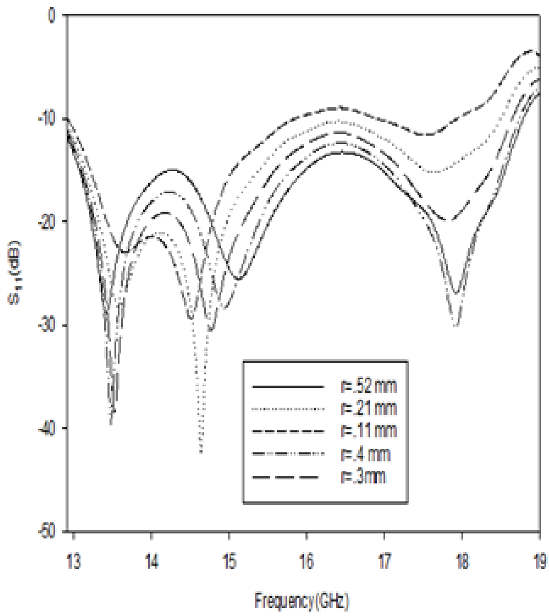


Fig. 6. Variation in S_{11} with r

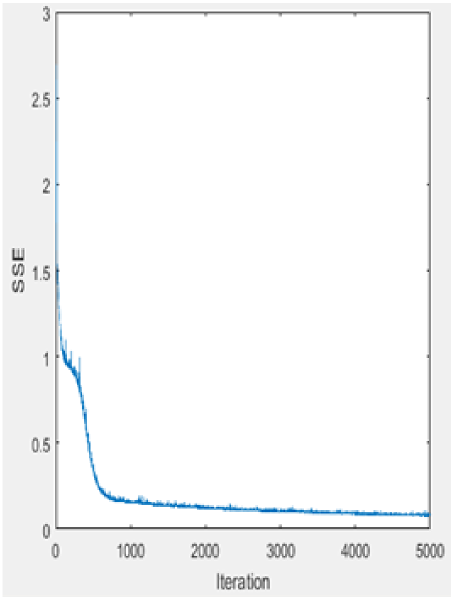


Fig. 7. Sum square error during training for r

Testing data for radius r is given in Table VI. from which we can see that neural network output and data simulated using CST fit well enough and better performance of return loss is achieved when r = .43 mm.

Table VI. Testing data for r

r(mm)	S_{11}(dB) (ANN)	S_{11}(dB)	r(mm)	S_{11}(dB) (ANN)	S_{11}(dB)
0.06	-13.55	-13.46	0.32	-24.07	-25.19
0.12	-15.65	-16.23	0.36	-26.02	-26.85
0.15	-16.70	-17.25	0.43	-27.94	-27.90
0.23	-19.75	-20.57	0.52	-24.86	-24.41
0.29	-22.57	-23.60	0.57	-22.86	-22.31

Now after optimizing r and x_p we are going to optimize tapered width w_t of transition from SIW to Microstrip line. Training data for w_t is given in Table VII. below:

Table VII. Training data for w_t

w_t(mm)	S_{11}(dB)	w_t(mm)	S_{11}(dB)	w_t(mm)	S_{11}(dB)	w_t(mm)	S_{11}(dB)	w_t(mm)	S_{11}(dB)
4.76	-19.33	5.23	24.90	5.55	-29.39	5.82	-31.10	6.23	-27.23
4.83	-20.02	5.32	-26.46	5.71	-30.89	5.91	-28.76	6.32	-25.68
4.98	-21.55	5.4	-27.28	5.75	-31.20	6.1	-26.84	6.4	-24.78

Using the training data above ANN was trained in Matlab, the impact of variation in w_t on return loss can be seen in Fig. 8 and sum square error during training for w_t is shown in Fig. 9 below:

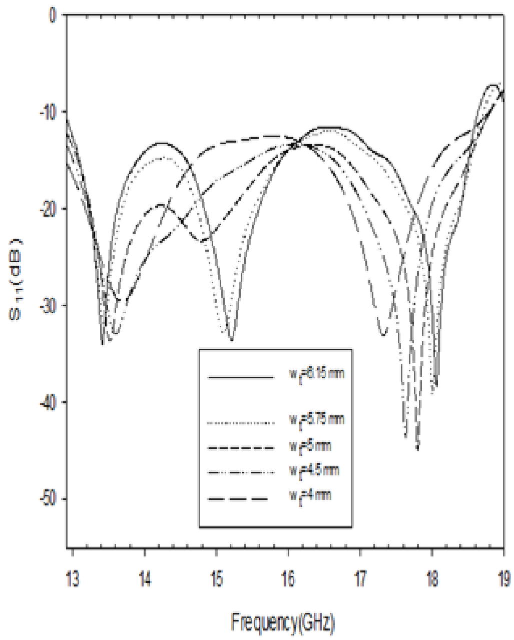


Fig. 8. Variation in S_{11} with w_t

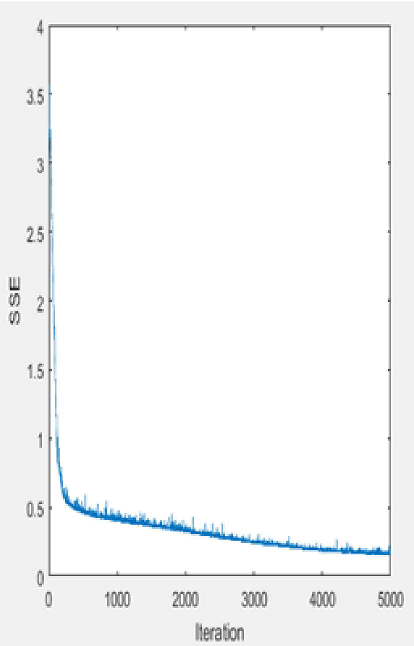


Fig. 9. Sum square error during training for w_t

Testing data for radius w_t is given in Table VIII. from which we can see that neural network output and data simulated using CST fit well enough and better performance of return loss is achieved when w_t = 5.79 mm.

Table III. Testing Data for x_p

w_t(mm)	S_{11}(dB) (ANN)	S_{11}(dB)	w_t(mm)	S_{11}(dB) (ANN)	S_{11}(dB)
4.9	-20.61	-20.68	5.79	-31.21	-31.72
5.1	-23.04	-22.89	5.95	-27.62	-28.32
5.28	-25.65	-26.14	5.97	-27.25	-27.87
5.38	-27.12	-27.45	6.15	-27.03	-27.67
5.43	-27.81	-27.78	6.28	-26.33	-26.52

Now we get the optimize values: radius “r"= 0.43 mm, position “x_p”= 1.79 mm below center and tapered width isw_t = 5.79 mm.By taking optimized values after doing simulation in CST Studio Suite, we got S parameters plot of designed power divider as shown in Fig. 10. We can see parameters “$\mathbf{S_{31}}$" and “$\mathbf{S_{21}}$” overlaps with each other since it is equal power divider.

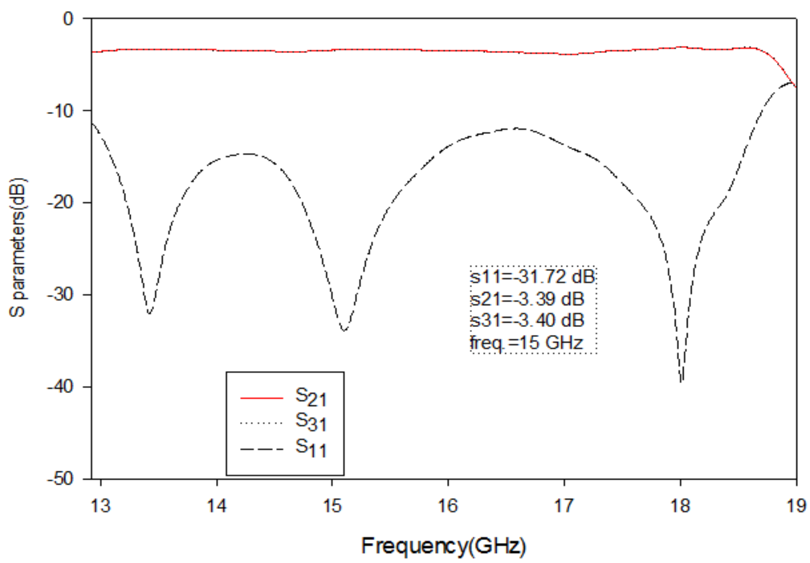


Fig. 10. S parameters of designed power divider

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III. Conclusion

Power divider based on Substrate Integrated Waveguide Technology is presented, and while optimizing three parameters,a neural network using gradient descent back-propagation algorithm was used was implemented that enhances the performance of return loss. From results, we can conclude neural network works well in the optimization of parameters to improve the performance ofpower divider. Using optimized values structure wassimulated, and results were shown. Optimized values are suitable enough for our application and, this power divider can work in the frequency range from 12.92 GHz to 18.70 GHz.

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