Progress In Electromagnetics Research Letters, Vol. 75, 39–45, 2018

Compact Microstrip UWB Power Divider with Dual Notched Bands Using Dual-Mode Resonator

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Abstract—In this paper, a novel ultra-wideband (UWB) power divider with dual notched bands using square ring multiple-mode resonators (SRMMRs) is presented. The characteristics of the proposed SRMMRs are investigated by using even- and odd-mode analysis. Then, the initial UWB performance is achieved by introducing SRMMRs to the basic Wilkinson power divider. Finally, two desired notched bands inside the UWB passband are achieved by embedding a pair of coupled dual-mode stepped impedance resonators (DMSIRs) into the SRMMRs. The central frequencies of the notched bands can be easily controlled by the electrical length of the DMSIRs. To validate the design concept, a novel compact UWB power divider with dual notched bands centered at frequencies of 5.8 GHz and 8.0 GHz is designed and measured. The simulated and measured results indicate that it has a low insertion loss and good return loss performance at all the three ports, and a high isolation between the two output ports across the UWB bandwidth from 3.1 to 10.6 GHz with a small size of $0.46\lambda g \times 0.69\lambda g$, where λg is the guided wavelength at 6.85 GHz.

1. INTRODUCTION

Power dividers play an important role in communication systems, such as transceivers, phase arrays, and power amplifiers, due to their ease of design and good performance. The most popular power divider is the Wilkinson power divider, which obtains completely matched output ports with sufficiently high isolation between them. However, it has less than 20% fractional bandwidth. With the rapid growth of unlicensed use of ultra-wideband (UWB) for radar imaging system, short-range broadband communication, and indoor wireless communications systems, there has been tremendous interest in exploration of various UWB components allocated $3.1 \sim 10.6$ GHz band. To achieve this goal, a few typical methods to design UWB power dividers have been developed so far [1–10].

In [3], multi-section Wilkinson power dividers have to be cascaded, which increases the size and insertion loss to obtain wider bandwidth. However, the fractional bandwidth is not ideal. In [4], a waveguide power divider with high power capacity and very low insertion loss is designed. However, the waveguide structure is large and inflexible. In [5], parallel-coupled lines and stepped-impedance open-circuited stubs are directly cascaded to construct UWB power dividers, which will increase fabrication cost. In [6], a multilayer broadside-coupled structure is used to obtain UWB performance, but the multi-layer structure is hardly compatible with the existing microwave-integrated circuit. What is more, the existing wireless networks like 5.8 GHz WLAN signals and some 8.0 GHz satellite communication systems signals can interfere with UWB networks, thus compact power dividers with dual notched bands are emergently required to reject these interfering signals.

Received 9 January 2018, Accepted 24 March 2018, Scheduled 11 April 2018
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In this paper, a novel UWB power divider with dual notched bands based on square ring multiple-mode resonators (SRMMRs) is proposed and designed. The resonance properties of the proposed SRMMRs with two pairs of resonance modes are theoretically analyzed. Then, the UWB performance is obtained by introducing SRMMRs to the basic Wilkinson power divider. Finally, two desired notched bands inside the UWB passband are achieved by embedding a pair of coupled dual-mode stepped impedance resonators (DMSIRs) into the SRMMRs. The central frequencies of the notched bands can be easily controlled by the electrical length of the coupled DMSIRs. To validate the design concept, a new compact UWB power divider with two notched bands centered at frequencies of 5.8 GHz and 8.0 GHz is designed and measured. Both simulated and experimental results are provided with good agreement.

2. INITIAL UWB POWER DIVIDER

Figure 1 shows the layout of the proposed initial UWB power divider. The microstrip line $l_0 = \lambda g/4$ is used to achieve good impedance match at port 1. An isolation resistor R is placed at the end of l_7. Notice that meander transmission lines are also utilized in the design to further reduce the power divider size. The layout of the equivalent circuit of the SRMMR is shown in Fig. 2.

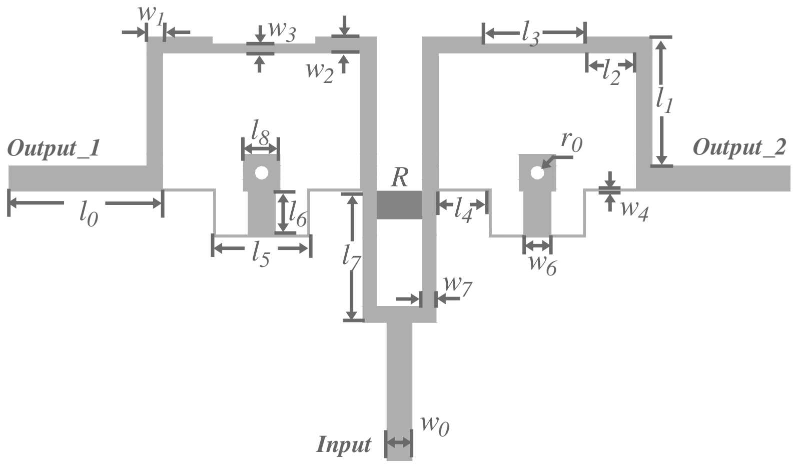

Figure 1. Layout of the proposed initial UWB power divider.

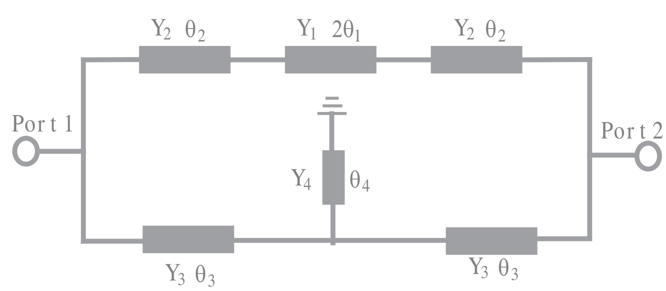

Figure 2. Schematic of the proposed SRMMRs.

To illustrate the design theory, the resonance characteristics of the initial UWB power divider with various dimensions are analyzed with HFSS 12.0. The proposed UWB power divider is fabricated using Rogers 4050B with a thickness of 0.508 mm, relative dielectric constant of 3.38 and loss tangent of 0.009. The dimensions are selected as follows: $l_0 = 6$ mm, $l_1 = 5.7$ mm, $l_2 = 2.9$ mm, $l_3 = 4.4$ mm, $l_4 = 2.1$ mm, $l_5 = 4.1$ mm, $l_6 = 2.0$ mm, $l_7 = 5.7$ mm, $l_8 = 1.5$ mm, $w_0 = 1.1$ mm, $w_1 = 0.7$ mm, $w_2 = 0.7$ mm,

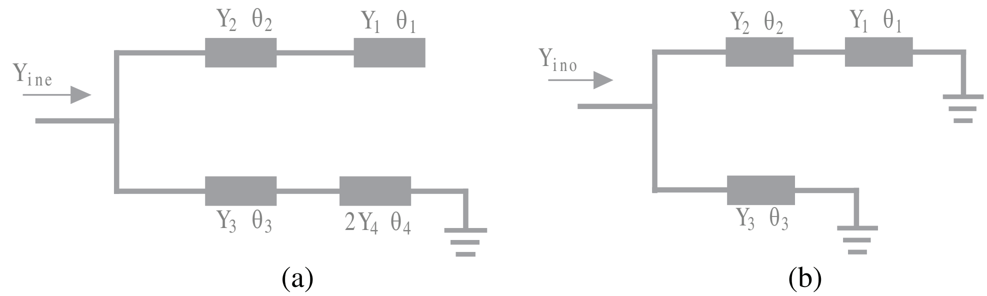

Figure 3. The Equivalent circuit model of the proposed SRMMRs. (a) Even mode circuit model. (b) Odd mode circuit model.

$w_3 = 0.5$ mm, $w_4 = 0.1$ mm, $w_6 = 1.2$ mm, $w_7 = 0.6$ mm, $r_0 = 0.3$ mm. The size of the whole circuit is 20 mm × 30 mm.

The even- and odd-mode analysis method can be employed to the proposed initial UWB power divider for the symmetry characteristics of the new structure. The simple schematic of the SRMMR is shown in Fig. 2, while the odd- and even-mode equivalent circuits are shown in Figs. 3(a) and (b).

From port 1 to port 2, two transmission paths with characteristic admittance Y_2 and Y_3 are introduced, a shorted stub with characteristic admittance Y_4 and electrical length θ_4 is connected in the center of the second transmission path. The characteristic impedance at port 1 is 50 Ω. When the even-/odd-mode signals are excited from ports 2 to 1, a virtual open/short stub-loaded resonator appears along the centre of the square ring resonator. In the even mode, the stepped impedance stub is divided in half along the plane of symmetry. In the odd mode, the plane of symmetry can be considered as a ground plane, with no current flows through the plane of symmetry. The even/odd-mode input admittance Y_{ine}/Y_{ino} of Fig. 3 can be illustrated as:

$$Y_{\text{ino}} = -jY_3 \cot\theta_3 - j\frac{Y_1 \cot\theta_3 - jY_2 \tan\theta_2}{Y_2 + Y_1 \cot\theta_1 \tan\theta_2} \quad (1)$$

$$Y_{ine} = jY_2 \frac{Y_1 \tan\theta_1 + Y_2 \tan\theta_2}{Y_2 \tan\theta_2 - Y_1 \tan\theta_1 \tan\theta_2} - jY_3 \frac{Y_4 \cot\theta_4 + 2Y_3 \tan\theta_3}{2Y_3 + Y_4 \cot\theta_4 \tan\theta_3} \quad (2)$$

As analyzed in [3], due to the symmetry of the square ring resonator, the resonance frequencies can be calculated when $Y_{ine}/Y_{ino} = 0$ from one end of the even- and odd-mode circuit. Hence, it cannot solve the expressions for the two pairs of resonance modes directly. Thus, another two odd mode resonator frequencies f_{odd1} ($\theta_1 = 120°$, $4f_0/3$) and f_{odd2} ($\theta_1 = 180°$, $2f_0$) can be realized. As we can see, the bandwidth of the UWB power divider decreases as Y_3 increases, and increases as f_0 as θ_4, Y_4 increase. In this way, the bandwidth for the passband of the UWB power divider with the SRMMRs can be conveniently controlled by varying the characteristic matrix Y_3, Y_4 and θ_4 when Y_1, Y_2 and θ_1, θ_2 are fixed. Therefore, by properly tuning the dimensions of the SRMMRs, a new compact microstrip UWB power divider can be achieved with a wanted bandwidth.

The measurement was carried out on the network analyser Agilent 85052D. The measured and simulated results are shown in Fig. 4. As we can see from Fig. 4, the fabricated UWB power divider has a passband from 2.1 GHz to 11.7 GHz. The return loss is under −10 dB, and the insertion loss is close to 3 dB, which ensures the good transmission performance in the passband.

3. UWB POWER DIVIDER WITH NOTCHED BANDS

To realize band-notched characteristics, we introduce a pair of coupled DMSIRs into the basic UWB divider. This structure is simple and flexible for blocking undesired narrow band radio signals that may appear in UWB band. Fig. 5 shows the layout of the DMSIR coupled to a section of main transmission line and its corresponding equivalent circuit. The DMSIRs can result in dual band-stop performance when being placed next to the microstrip line.

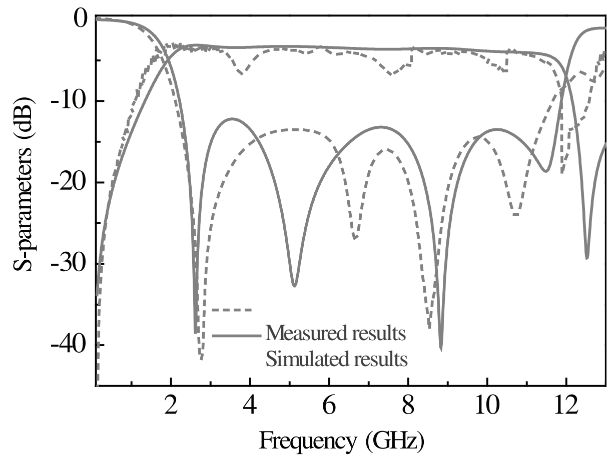

Figure 4. Simulated and measured performance of the initial UWB power divider.

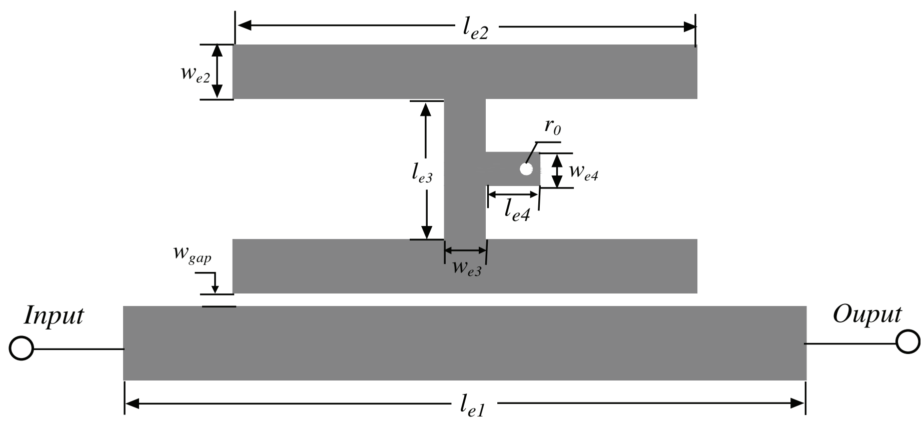

Figure 5. Geometry of the coupled DMSIRs.

The transfer characteristics of the proposed DMSIRs with various dimensions are studied by HFSS 12.0, as shown in Fig. 6. It can be seen that the dual notched bands decrease simultaneously as w_{e2} increases. However, only the upper notched band increases as l_{e4} decreases, and only the lower notched band increases as l_{e3} decreases. Therefore, by appropriately adjusting the resonator dimensions, dual notched bands can be achieved at desired frequencies.

When a pair of coupled DMSIRs is embedded into the SRMMRs of the proposed initial UWB power divider, a novel UWB power divider with dual notched bands is proposed and designed as shown in Fig. 7. Compared with the above initial UWB power divider, the physical dimensions of the UWB power divider with two notched bands do not change dramatically, which indicates two simple notched bands design procedure. Fig. 8 shows simulated S-parameters of the proposed UWB power divider with two notched bands. Fig. 9 plots the full-wave simulated and measured S-parameters of the proposed UWB power divider with dual notched bands. The notched bands have high selectivity (3 dB bandwidths are 7.9% and 6.4%, respectively), and the attenuation is more than 10 dB at the center frequency. The deviations of the measurements from the simulations are expected mainly due to the reflections from the connectors and the finite substrate. Fig. 10 shows a photograph of the fabricated UWB power divider with dual notched bands. The overall size of the designed UWB power divider is only $20 \times 30\,\mathrm{mm}^2$, which corresponds to a compact electrical size of $0.46\lambda g \times 0.69\lambda g$. Comparisons with other reported UWB dividers with notched bands are listed in Table 1, which demonstrates that the proposed UWB divider has good characteristics.

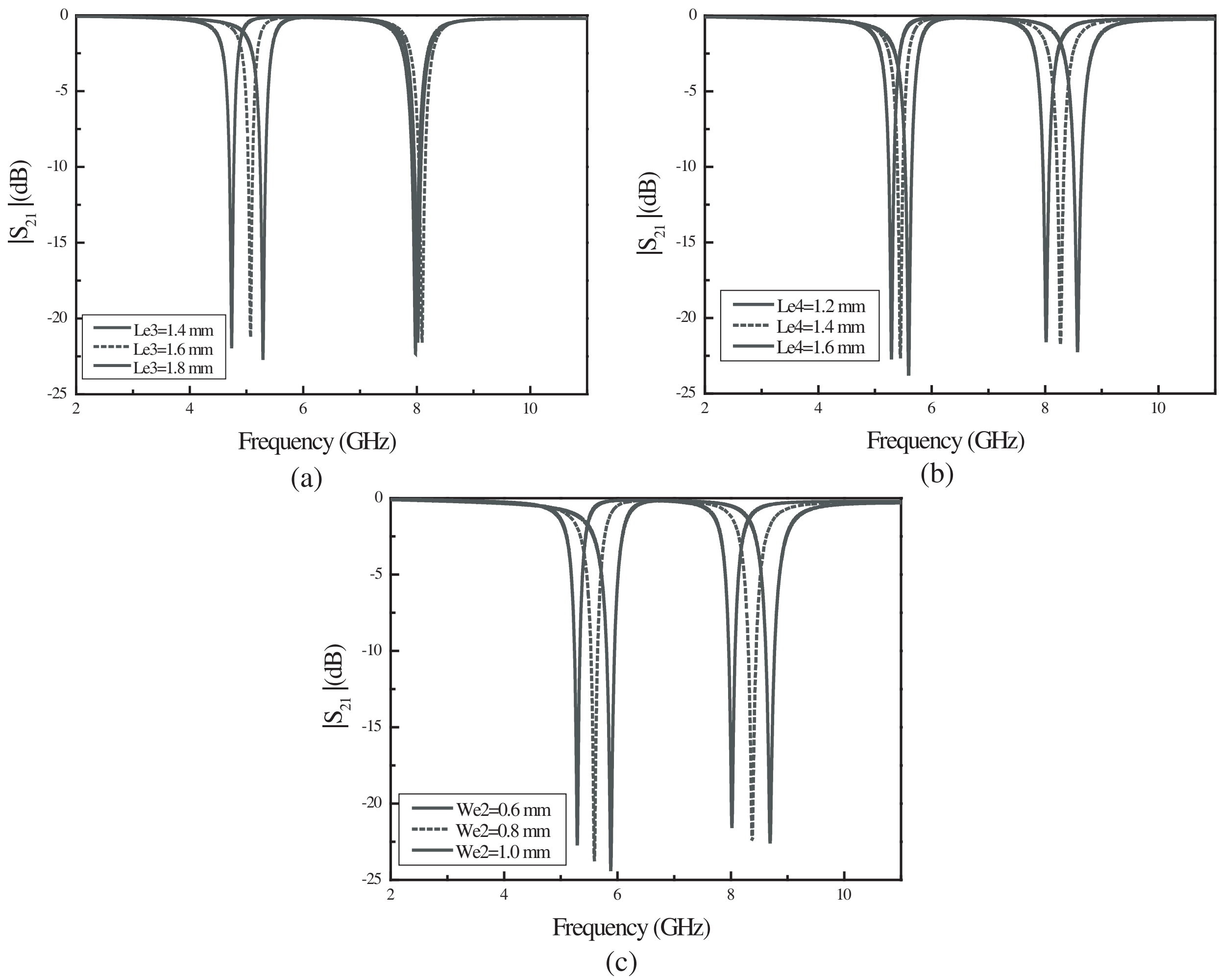

Figure 6. Simulated S-parameters of the coupled DMSIRs for various dimensions: (a) $Le3$, (b) $Le4$, (c) $We2$.

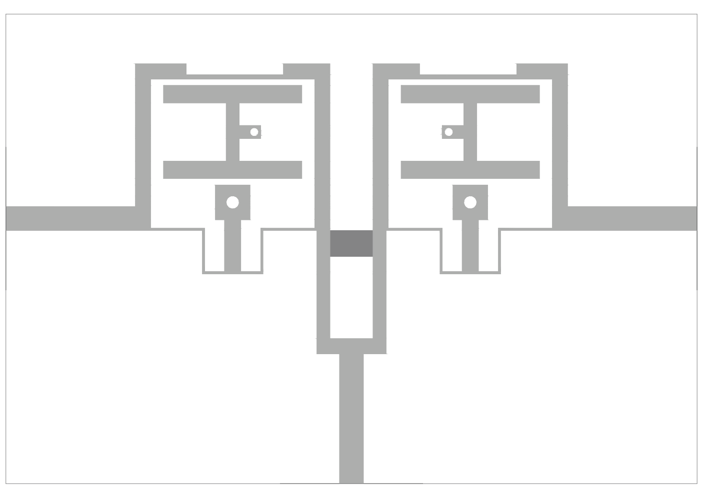

Figure 7. Layout of the proposed UWB power divider with dual notched bands.

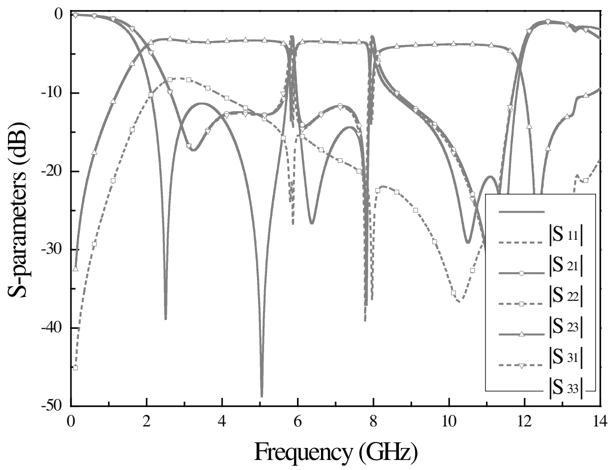

Figure 8. Simulated S-parameters of the designed UWB power divider with dual notched bands.

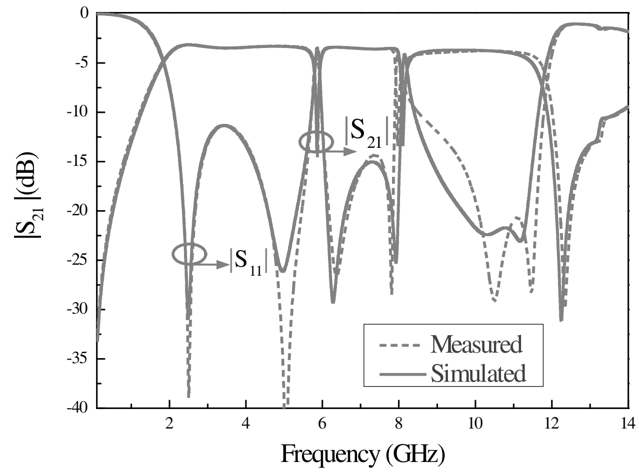

Figure 9. Simulated and measured S-parameters of the designed UWB power divider with dual notched bands.

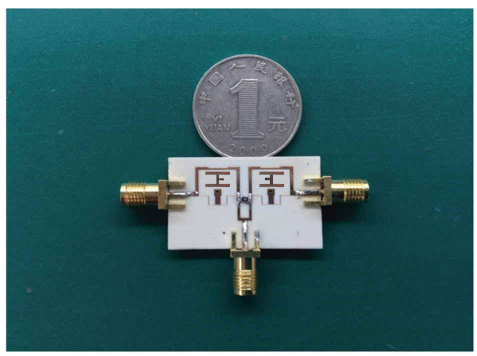

Figure 10. Photograph of the proposed UWB power divider with dual notched bands.

Table 1. Comparisons with other proposed UWB divider.

Ref.	Circuit dimension	Pass band (GHz)	Insertion loss (dB)	Notch frequency (GHz)/
[4]	3-D	3.5 ~ 10.8	0.5	N/A
[5]	2-D	3.5 ~ 10.1	0.4	N/A
[6]	3-D	3.1 ~ 11.5	2.0	N/A
This work	2-D	2.1 ~ 11.7	0.3	5.8/8.0

4. CONCLUSION

In this work, a high-performance UWB power divider, with dual highly rejected notched bands using SRMMRs, has been successfully implemented and investigated. The characteristics of the proposed SRMMRs are investigated by using even- and odd- mode analysis. Then, the initial UWB performance is achieved by introducing SRMMRs to the basic Wilkinson power divider. Finally, two desired notched bands inside the UWB passband are achieved by embedding a pair of coupled dual-mode stepped impedance resonators (DMSIRs) into the SRMMRs. The two notched-bands can be easily tuned to the desirable frequency location by controlling the parameters of the DMSIR. The introduced DMSIRs are simple and flexible for blocking undesired narrow band radio signals appearing in UWB band. Using the advantage of small real estate, outstanding performance can be realised for broadband power divider, which is now widely demanded in UWB applications. To summarize, the proposed power divider is very useful for modern UWB wireless communication systems owing to its marked properties of simple topology, compact size, and excellent performance.

ACKNOWLEDGMENT

This paper is supported by the special fund of Guangdong frontier and key technology innovation (No. 2016B010108005), special fund of Guangdong applied science and technology research and development (No. 2016B010125001), Guangdong science and technology plan (No. 2016B090918110), 2015 Guangdong provincial-level information industry development special fund (Internet of Things Supports Industrial 4.0-oriented Steel Structure Intelligent Manufacturing System Development and Demonstration).

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