Novel 1.35 mm precision coaxial connector enables very high-performance E-Band cable assemblies

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INTRODUCTION

Research and Development (R&D) has always been slightly at odds with itself. The Research component wants to keep pushing the envelope of innovation and see what is possible in terms of speed, precision and paradigm shifts, while the Development component wants to take a snapshot of the Research at an optimal time and implement the new technology.

This is certainly true in the world of microwave cable assemblies and this narrative follows the pattern of an innovative company taking the lead in both creating standards (Research) and rolling out the initial applications (Development). Hewlett-Packard and Wiltron did this in the late-1980s with the 1.85 mm connector (V connector) and Hewlett-Packard did this again in 1989 with the 1.00 mm connector (W connector). Once the standards and initial products are established, the industry fills in the gaps with other products and applications.

Sometimes though, a more rapid acceptance of an existing technology is facilitated by the elegant/functional/effective packaging of that technology – e.g. the iPod. While the 1.00 mm connector encompassed both the E band (60 to 90 GHz) and the W band (75 to 110 GHz), due the physical constraints of transmitting 110 GHz – a wavelength of 2.73 mm – the design had certain built-in limitations. The applications at this point were not commercial so the major consideration for connector and cable design was the best transmission line that seamlessly attached to the connector. Most of the cable assemblies that emerged, as demand ramped up, were test lab applications with attention paid to keeping the cable protected since any small disturbance to cable integrity translates into degraded cable performance.

At the time, there was a sub-group of applications that were resident below 90 GHz and thus officially in E band. These applications, in the automotive and satellite/mobile communications industries, have traits of requiring larger volumes of assemblies while needing to be rugged and cost effective. SPINNER GmbH realized this in 2014 and decided these applications could sustain a business case for applications that needed some but not all of the W connector attributes. Learning from the V and W connectors in terms of design and limitations, SPINNER started developing a 1.35 mm connector (E connector) that would have a more rugged construction derived from the V connector and would perform broadband to at least 90 GHz. Knowing that international acceptance was key to the success of this new connector, SPINNER teamed with Physikalisch-Technische Bundesanstalt (PTB, the national metrological institute of Germany), Rohde & Schwarz and Rosenberger to fully define and develop the 1.35 mm interface. The resulting design was then proposed to the P287 subcommittee – a current IEEE activity to revise the IEEE Std 287-2007 for Precision Coaxial Connectors – where it was decided to include the 1.35 mm connector in the next edition of the standard. In parallel the interface design was also submitted to IEC – where the standardization process is expected to start during the next IEC meeting in Nuremberg, Germany in September 2018.

Requirement	1.85 mm connector (V connector)	1.35 mm connector (E connector)	1.00 mm connector (W connector)
Pin and socket design with an air dielectric interface	🟩	🟩	🟩
Two different connector quality levels (like the IEEE “metrology grade” and “instrument grade”)	🟩	🟩	🟩
Upper operating frequency of at least 90 GHz	🟥 65 (70) GHz	🟩 90 (92) GHz	🟩 110 (120) GHz
Robust design: not over-miniaturized, big centering cylinder & large contact surface	🟩	🟩	🟥
Fine-threaded coupling nut prevents loosening	🟩 M7x0.75	🟩 M5.5x0.5	🟥 M4x0.7
Socket connector is equipped with a locking groove to allow for a push-on pin connector	🟥	🟩	🟥
“Thru male” capability in conjunction with a standard semi-rigid cable	🟩 0.086-inch	🟩 0.047-inch	🟥
Applicable locking torque of 1.6 Nm without plastic deformation of outer conductor	🟩	🟩	🟥
Coupling nut with a flat size of 8 mm	🟩	🟩 option: 7 or 6.35 mm	🟥 6 mm
Accepts the same wrench as the 3.5 mm, 2.92 mm, and 2.4 mm connectors (equal in size and torque)	🟩	🟩	🟥

Table 1: Development requirement and connector conformity (green = conform, red = not conform).

SPECIFICATION OF THE 1.35 MM CONNECTOR INTERFACE

For the 1.35 mm connector interface, a number of development requirements have been defined and eventually realized. These requirements are listed in Table 1 along with a comparison of the new 1.35 mm connector requirements and capabilities to the other two existing connectors (the 1.85 mm and the 1.00 mm connectors) in the adjacent frequency bands.

Tables 2 and 3 show an extract from the 1.35 mm connector’s electrical and mechanical interface specifications. The complete specifications and all drawings are to be published in the next edition of the IEEE Standard 287.

MECHANICAL DESIGN OF THE 1.35 MM CONNECTOR INTERFACE

A 3D view of the 1.35 mm interface design is depicted in Figure 1. Figure 2 shows more details by means of an enlarged longitudinal section.
A few special features of the interface design are:

1: The overall design avoids any unnecessary over-miniaturization to make it strong and robust even for an application of a frequently used front panel connector of a test instrument.
   a: The pin connector features a relatively large centering cylinder (dia 3.5 mm x 2.6 mm). When pin and socket connectors are mated, the outer conductor is guided very precisely before the center conductors make contact (see Figure 3). The large size of the centering cylinder together with the fine thread (M5.5x0.5) of the coupling nut ensures the robustness of the 1.35 mm interface.
   b: The interface has a large contact surface to avoid plastic deformation of the contact area even when operated with a maximum locking torque of 1.6 Nm (14.6 in-lb). This is the precondition for the operational coupling torque of 0.9 Nm (8.0 in-lb) – the same as the lower-frequency precision connectors (3.5 mm, 2.92 mm, 2.40 mm, 1.85 mm).
2: The diameter of the contact pin is chosen equal to the nominal center conductor diameter of the standard 0.047-inch semirigid cable (MIL-DTL-17/151). This feature enables the design of high-quality, low-budget “thru male” pin connectors.
3: The 1.35 mm socket connector is equipped with a locking groove as standard, which allows mating with an optional push-on type pin connector.

CHALLENGES IN IMPLEMENTING THE 1.35 MM DESIGN

While there are always challenges when approaching a new design, there were a couple of mitigating factors that allowed SPINNER to easily transform the mechanical and electrical requirements of a theoretical design into a working model. SPINNER has been in the RF connector business for over 70 years

Description	instrument grade	metrology grade
Characteristic impedance	(50±0.25) Ω	(50±0.15) Ω
Guaranteed upper operating frequency	90 GHz	
H_{11}-cutoff frequency of unsupported air line	98.5 GHz	
Return loss	–20 dB	–24 dB
Repeatability of return loss	–43 dB	–48 dB
Insertion loss	0.05 dB	
Repeatability of insertion loss	0.03 dB @ 90 GHz	
Repeatability of transmission phase	1° @ 90 GHz	
Electrical length tolerance	±75 µm	
Shielding effectiveness	–90 dB	

Table 2: Selection of electrical specifications for the 1.35 mm connector interface.

Description	Specification
Outer conductor inside diameter	1.35 mm (0.053 in)
Inner conductor outside diameter	0.586 mm (0.023 in)
Connect/disconnect life	3000 cycles
Coupling torque	0.9 N m (8.0 in-lb)
Maximum safety torque	1.65 N m (14.6 in-lb)
Coupling thread	M5.5x0.5
Coupling nut wrench size	8 mm (7 or 6.35 mm for special applications)

Table 3: Selection of mechanical specifications for the 1.35 mm connector interface.

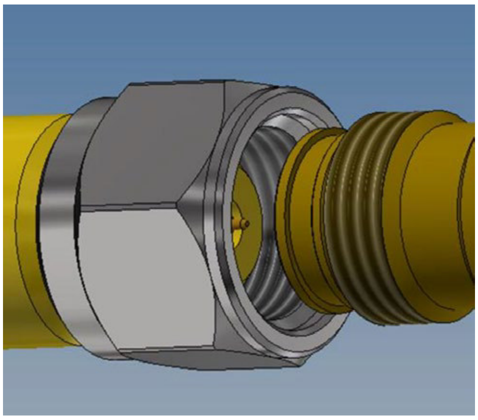


Figure 1: 3D view of 1.35 mm pin and socket connectors.

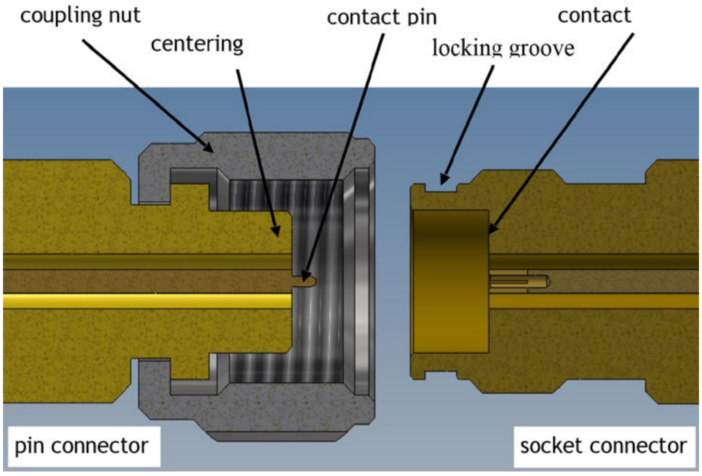


Figure 2: Longitudinal sections of 1.35 mm pin and socket connectors.

and thus has a vast body of experience in design and manufacturing. SPINNER was also an early adopter of connector design software (e.g. CST & HFSS) and had gone through the many iterations necessary (on past projects) to accurately model the connector parameters and dielectric materials.

CHALLENGES AND CHOICES CREATING THE 1.35 MM CABLE ASSEMBLY

There are many products needed to roll out a new connector family: calibration standards (airlines and kits), adapters, connectors (cable and PCB) and cable assemblies. With the key applications in mind, SPINNER knew that a rugged cable to create a cable assembly would be integral to the successful launch of the product. Having already done the development for a rugged W band cable, Teledyne Storm Microwave was chosen to partner with SPINNER on their 1.35 mm cable assembly.

Teledyne Storm Microwave did not need to modify the cable design used for the 1.00 mm connectors since this cable had a flat broadband response to 110 GHz. How the cable is prepared for termination with the connectors determines the ease of manufacture and the yield of the cable assemblies. Since the targeted markets of automotive and satellite communications are large and growing it was important to create manufacturing processes that provided a high yield and performance to achieve financial success.

Given the commercially focused reasons behind this connector development, the manufacture and preparation of the cable to the connector also needed to evolve. Even lowering the upper frequency by 20 GHz for the 1.35 mm connector allowed for a physical design with slightly larger parts. This meant the preparation of the cable could accept a greater latitude than if it was being prepared for 110 GHz without suffering any performance degradation. This did not alleviate the need for precise temperature control in the soldering process due to the higher heat needed when using lead-free solder. Heat is detrimental to dielectric materials, both in the cable and connector – and absolute temperature control is necessary to maintain dimensional control of the cable and connector dielectric material. Even the smallest dimensional change could slightly alter the impedance in the critical cable and/or connector areas.

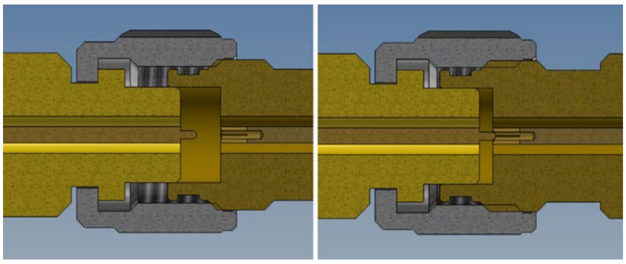


Figure 3: Mating of the 1.35 mm connector interface – left: engagement of the outer conductor's centering cylinder; right: engagement of the inner conductor's pin.

In the early days of prototyping connectors and cable assemblies there were very few component parts available. For example, only the 1.35 to 1.00 mm

adapters were available for testing the cable assembly in the United States. Figure 4 shows the early VSWR performance of a cable assembly and Figure 5 shows the contribution in the time domain of the added adapter to test the 1.35 mm cable assembly with a 1.00 mm calibration.

HOW TO POSITION THE 1.35 MM WITHIN A 1.00 MM ENVIRONMENT

Until recently, in the world of increasingly higher frequencies, VNA manufacturers have been leading the charge in advanced connector design – Hewlett-Packard and Wiltron championed the 1.85 mm connector and Hewlett-Packard championed the 1.00 mm connector. As the applications for these higher frequency cable assemblies became more numerous, it was clear available VNAs were sufficient while there was a need to improve connector functionality.

In 2014, SPINNER saw that the majority of applications in the E band needed a more robust connector design. The following information factored into the decision to create the 1.35 mm connector.

1: The 1.85 mm connector does not cover the entire V band (50 to 75 GHz), as initially its guaranteed upper frequency was 65 GHz (Table 1). Currently, that frequency limit is being raised to 70 GHz using an improved bead design.

2: Initially one only had to consider numerous automotive applications operating from 76 to 81 GHz. Since then satcom, 5G and WLAN applications have emerged in the 76 to 90 GHz frequency band.

3: The majority of applications is in industrial environments (e.g. automotive) or field environments (e.g. mobile communications). Common to those applications is a need for robust handling with field installation.

At the same time there was a conscious intent not to minimize the usefulness of the 1.00 mm connector but rather to emphasize the special attributes of the 1.35 mm connector. SPINNER had a number of design and marketing objectives:

1: Forge an alliance with national metrological institutes, connector competitors and VNA manufacturers to introduce a new IEEE 287 standard interface. There was never a notion this was going to be a proprietary interface.

2: While promoting the design advantages of the 1.35 mm connector, do not marginalize the usefulness of the 1.00 mm connector.

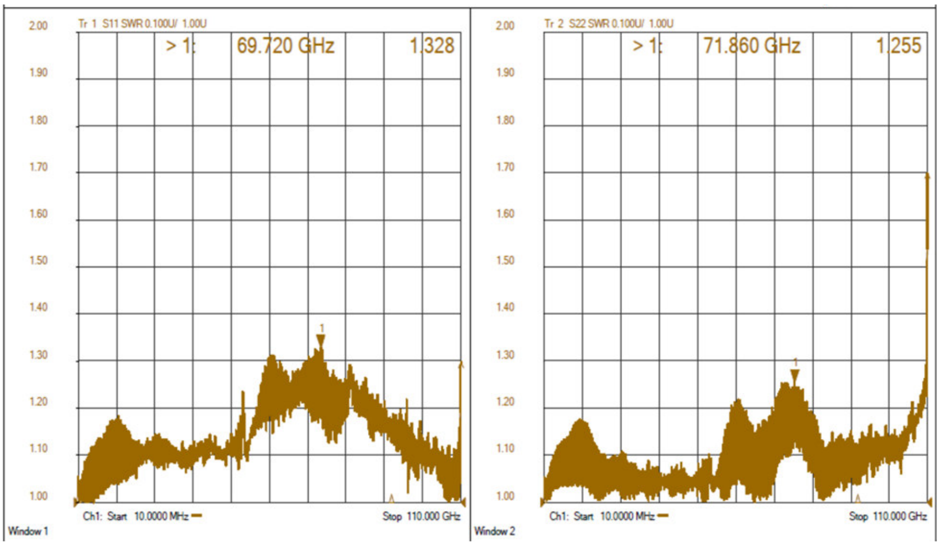


Figure 4: Early VSWR performance – testing with 1.35 to 1.00 mm adapters (in advance of receiving a 1.35 mm calibration kit) – note the frequency range is to 110 GHz.

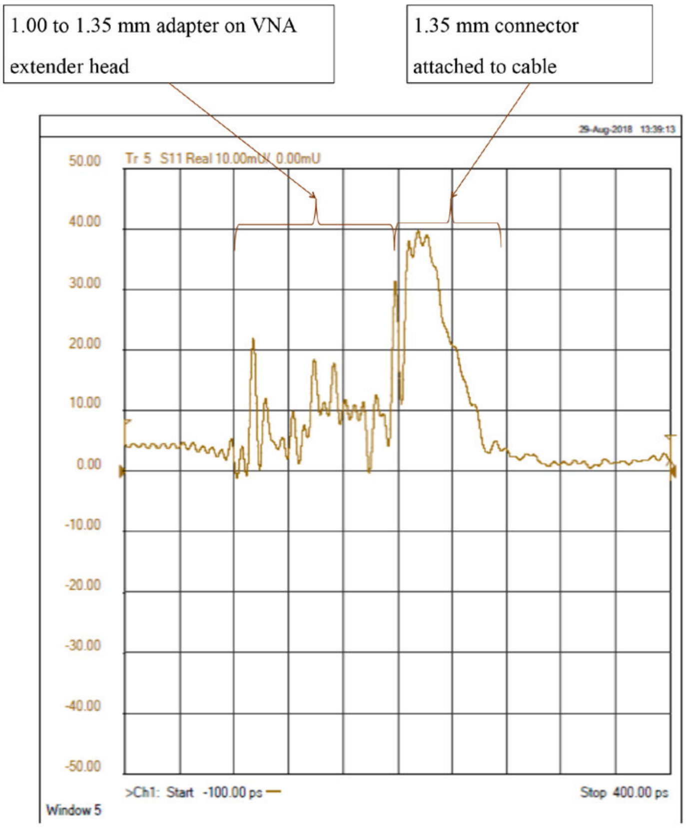


Figure 5: Time domain chart of the connector region when using 1.00 mm calibration with 1.00 to 1.35 mm adapter. NOTE: Early prototype shows areas for impedance matching improvement.

3: Knowing the potential applications (e.g. mobile, automotive) are price sensitive, make a design that could accommodate the implementation of a “basic” connector. This was done by specifying the 1.35 mm interface, which in turns allows the use of “thru male” capability of the standard 0.047-inch semirigid cable (MIL-DTL-17/151).

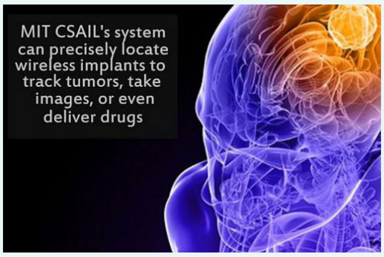
The positioning of the 1.35 mm connector is that it plays well in the rarified realm of 90 GHz while using a finer thread pitch to the 2.40/1.85 mm connectors and the coupling nut torque (8 in-lb) of a SMA. With this finer thread pitch and the 8 in-lb torque, there can be no unintentional loosening of the coupling nuts, which is possible with the 1.00 mm connectors. The specifications are flexible enough to allow “thru male” design strategy or the standard center contact.

LAUNCHING THE 1.35 MM FAMILY OF PRODUCTS

The end of research defines the scope of the product, the end of development defines the capabilities of the product and then comes the commercialization phase. As mentioned above, there are a minimum of components parts (e.g. calibration kits, connectors, cable assemblies) that are required for the product to make some connection with technical decision makers.

To cross the threshold from "that's a good idea" to "I am going to implement the product in my application" is a high bar. While the "good idea" is an intellectual exercise in appreciating the elegance of the design and the inherent usefulness of the product, the "I will use this in my application" is an act of trust in the design, test and manufacture of the family of components that constitute this product. The 1.35 mm connector product line is a result of years of experience in connector and cable assembly design and manufacture and is highly targeted towards solving problems that became evident after the rapid implementation of the 1.00 mm connector.

Low-power wireless in-body "GPS" keeps track of implants



Researchers at MIT (Cambridge, MA) have developed an "in-body GPS" system that can pinpoint the location of ingestible implants inside the body using low-power wireless signals.

Called ReMix, the system promises a way to allow medical practitioners a way to "see" inside the human body in a less expensive, invasive, and time-consuming manner than traditional methods. According to the researchers, their method opens future possibilities where doctors could implant sensors to track tumors or dispense drugs.

In animal tests, the researchers showed that they can track the implants with centimeter-level accuracy. In the test, the researchers implanted a small marker in animal tissues and then used a wireless device that reflects radio signals off the "patient" to track its movement.

They used a low-power Wi-Fi wireless technology similar to radar and sonar imaging that they had previously demonstrated to detect heart rate, breathing, and movement. A special algorithm uses the reflected signal to pinpoint the exact location of the marker.

The implanted marker itself does not need to transmit any wireless signal – it simply reflects the signal transmitted by the wireless device outside the body. Therefore, it doesn't need a battery or other external source of energy.

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SEPTEMBER 2018

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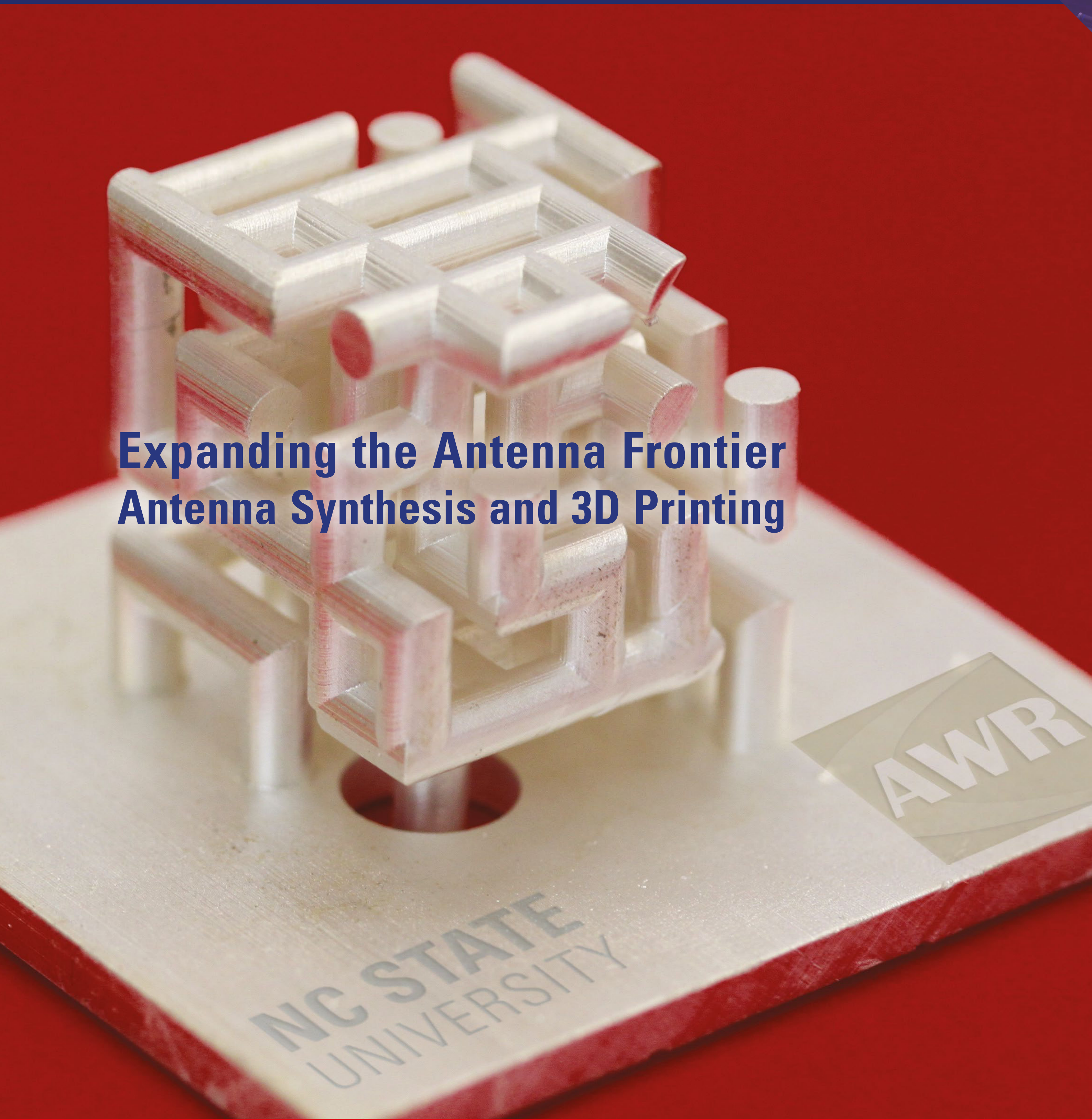

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