Membrane Tip Probes for On-Wafer Measurements in the 220 to 325 GHz Band

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Abstract: We have developed a membrane-tip wafer probe for on-wafer measurements of passive structures, semiconductor devices and amplifiers in the 220 to 325 GHz WR-3 waveguide band. The probe provides the connection between an Oleson Microwave Labs Vector Network Analyzer (VNA) mm-wave extender head and on-wafer ground-signal-ground contacts. The probe has a section of WR-3 waveguide with a standard flange, a waveguide-to-coax transition with provisions for adjustment of both the E-field launch and back short. From the waveguide-to-coax transition, a short length of UT-013 coax connects to a thin-film membrane that includes a coax-to-microstrip transition and three wafer contacts manufactured photolithograpically using Cascade Microtech's thin-film process. The wafer contacts use the same mechanical structure and metallurgy as Cascade's Pyramid probe series, and are rated for millions of touchdowns with contact resistance of a few tens of milliohms even on aluminum pads.

Initial measurements on a pair of WR-3 probes and a standard calibration substrate with Cascade's 140 to 220 GHz VNA system suggest that loss is dominated by the length of waveguide between the coax-to-waveguide transition and the Oleson Microwave Lab mm-wave extender head. Measurements on the WR-5 band VNA are limited to the lower third of the WR-3 band. A second set of probes was built using significantly shorter waveguide sections. The original probes and short waveguide probes were then measured on the Jet Propulsion Labs WR-3 VNA system [1,2]. Loss through the longer probes was more than 5 dB from waveguide flange to probe tip, and loss through the short waveguide probes was near 2.5 dB for most of the WR-3 band, with increased loss above 300 GHz. Increased loss above 300 GHz is apparently due to poor contact with the back short during the measurements for the probe we tested.

Since the waveguide probes have electrically floating center contacts on the Ground-Signal-Ground membrane, we have also developed integrated bias Ts. To date, in-band performance of the bias Ts has only been measured on the WR-5 VNA, and the out-of-band performance measured using a DC to 110 GHz VNA.

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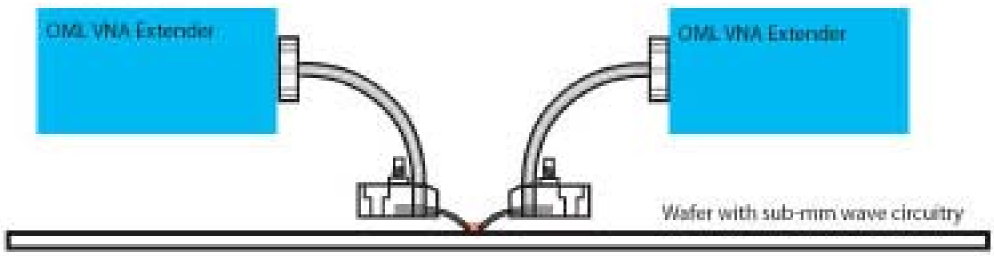
This work was supported in part by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

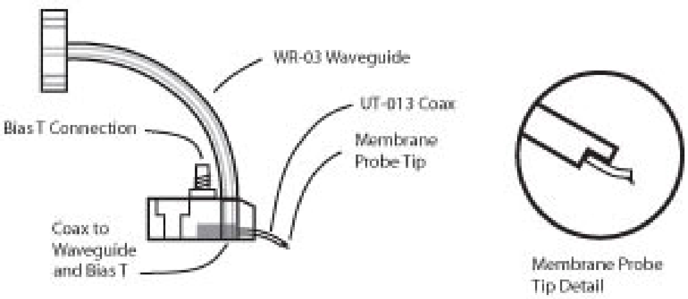
Introduction to on-wafer probing of sub-mm wave circuits

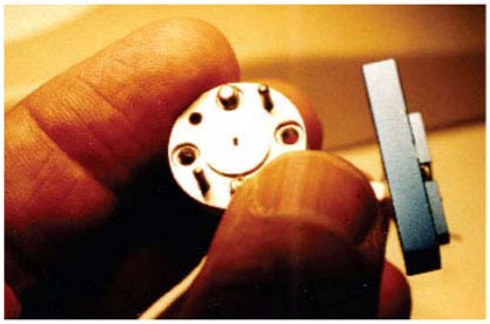
Figure 1 illustrates how a pair of wafer probes is used to test a circuit. Figure 2 is a close-up sketch showing the parts of a wafer probe, and figure 3 is a photograph of a WR5 probe showing scale.



On Wafer Measurement using OML VNA Extenders and Wafer Probes

Figure 1





Probe Detail Sketch

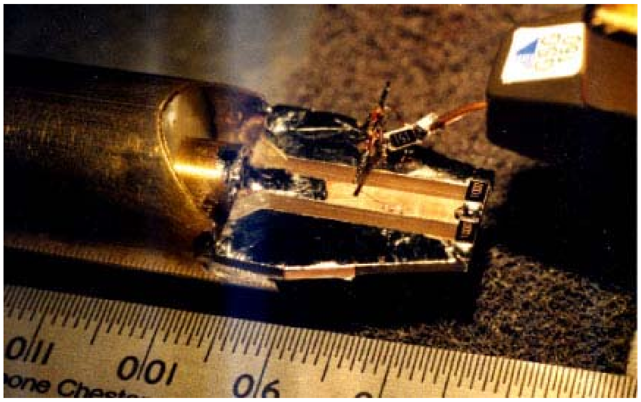
Figure 2

WR05 Probe Waveguide Flange

Figure 3

Membrane Tip measurements and fabrication

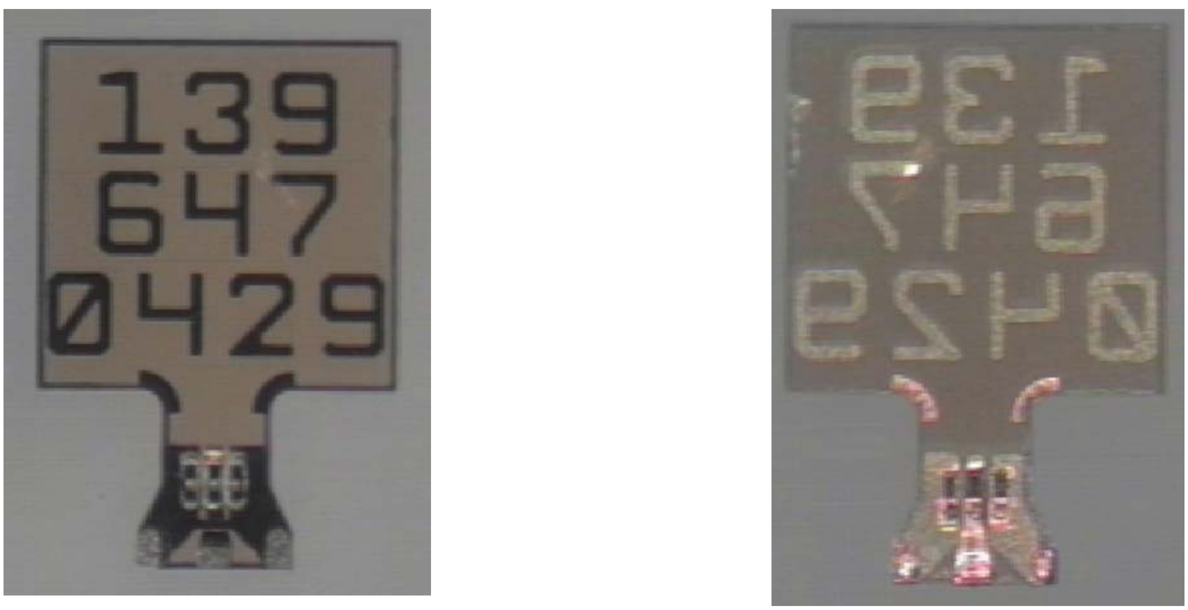
The membrane probe tip and coax-to-membrane attachment were analyzed with basic theory and studied using a Modulated Scatterer Near-Field measurement system on X50 Scale Model at 6 GHz [3,4]. The measurements revealed high E-fields near the ground attachments to the outer coax connector that were reduced by reshaping the membrane. Figure 4 is a photograph of the X50 scale model of the original membrane. Figure 5 is a photograph of the top and bottom side of the thin-film membrane contact structure with 50 micron contact pitch. Note that the final membrane is shorter than the model. The membrane is fabricated in Cascade's thin-film process. The large structure on top with identification numbers is a handle that is removed after the tip is attached.



X50 Scale Model of 325 GHz Wafer Probe Tip

Figure 4

The Ground-Signal-Ground contacts and the metallization for attachment to the UT013 coax center and outer conductor may be seen clearly on the bottom of the membrane structures.

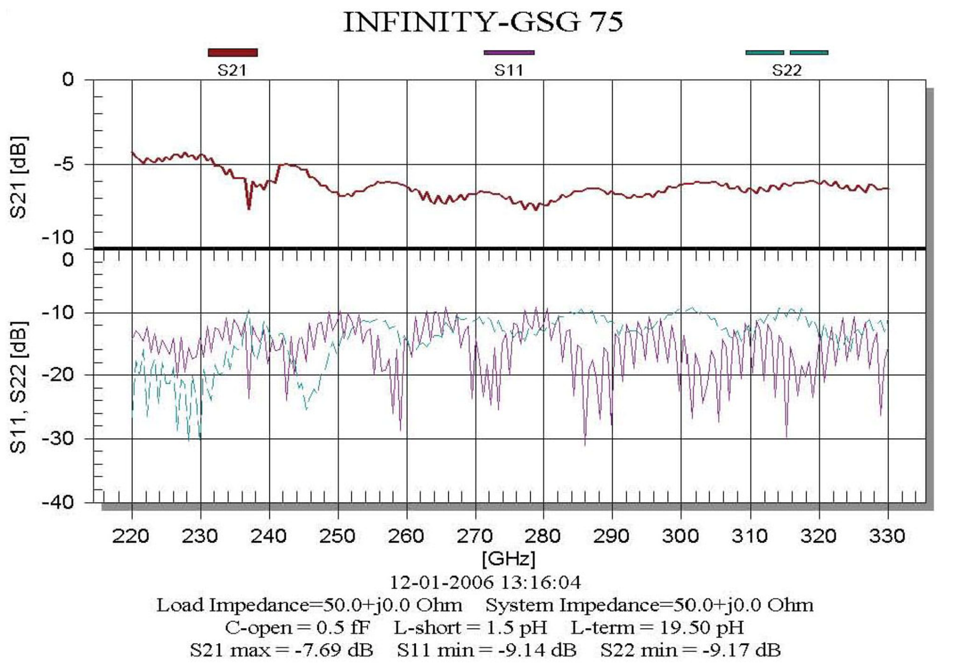


Top and Bottom Views of the Membrane Contact Structure

Figure 5

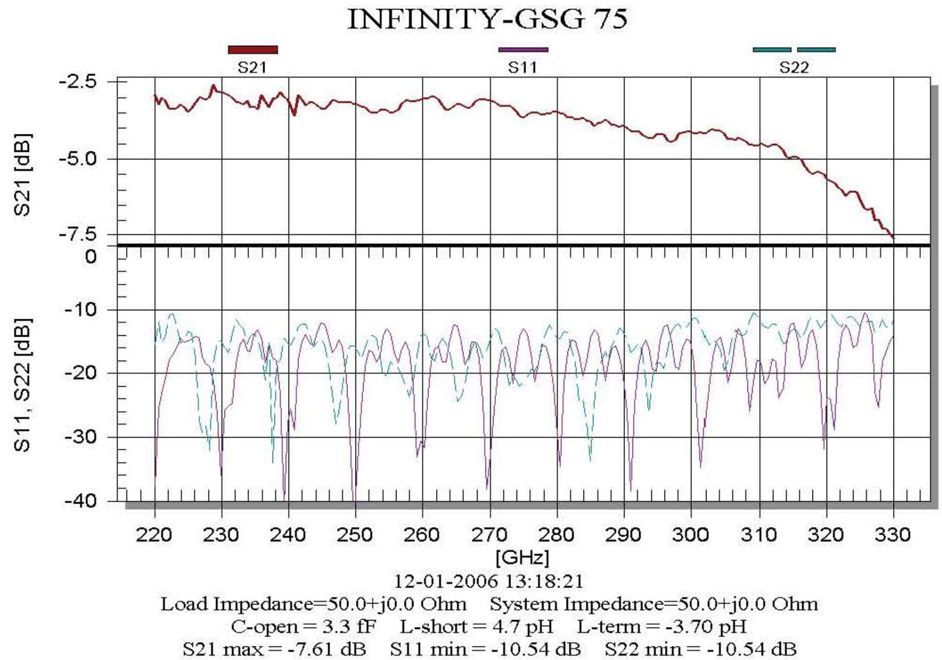
One-Port Measurements

Four 325 GHz wafer probes were assembled at Cascade Microtech and measured on the JPL 325 GHz Network Analyzer. A waveguide cal was performed with the flange that connects to the probe as the reference plane. The first measurements were One-Port measurements, in which S11 is measured with the probe on a short, open and load. The round-trip loss through the probe can then be calculated from the S11 measurements. Two of the probes included bias Ts, and two used short waveguide sections. At 1mm wavelength, waveguide has considerable loss—on the order of 1 dB loss in 3 cm. Figures 6 and 7 show that the loss of a probe with 3 cm long waveguide is significantly lower than the loss of the probe with 7 cm long waveguide. Unfortunately, the back short on the waveguide-to-coax transition of the probe in figure 6 was not making good contact on one corner, and this resulted in degraded performance at high frequency.



WR-03 Wafer Probe with 7 cm Long Waveguide

Figure 6

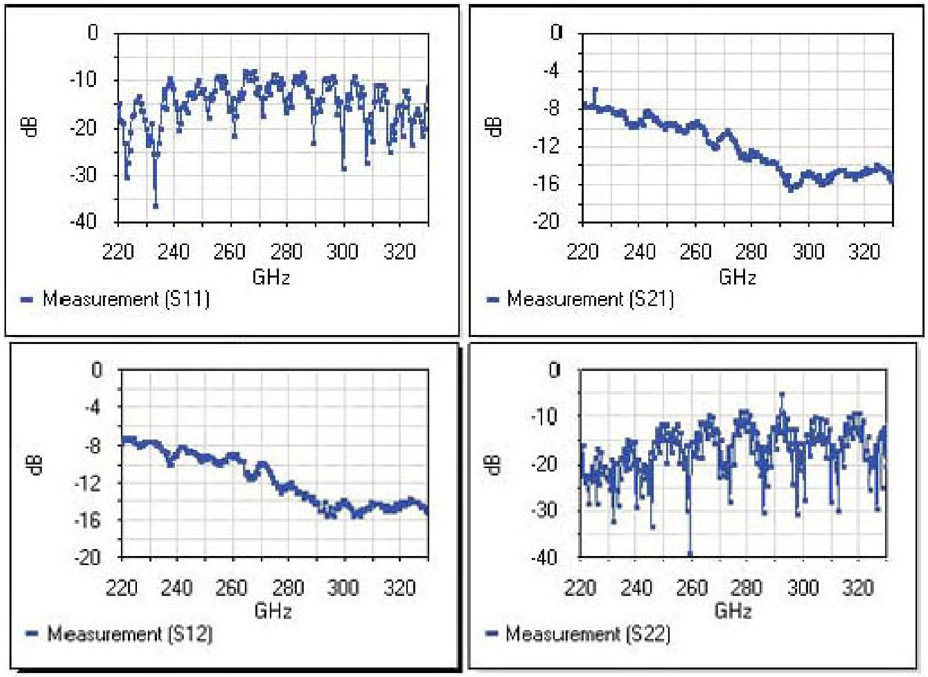


WR-03 Wafer Probe with 3 cm Long Waveguide

Figure 7

Two Port Measurements

After the One-Port measurements were complete, we performed a two-port calibration of the 325 GHz Network Analyzer system and attempted a two-port measurement using the two probes measured in figures 6 and 7 and an standard substrate. The calibration did not hold during these measurements, but the raw data was stored. A stable cal and useful measurements were later obtained by processing the raw data using WinCal. Figure 8 shows the set of four S parameters obtained. Note that the through data S12 and S21 appears to be the sum of the two probe losses shown in figures 6 and 7, plus the additional loss of the CPW transmission line on the standard substrate.



Two-Port Measurement Through the Probes in Figures 6 and 7

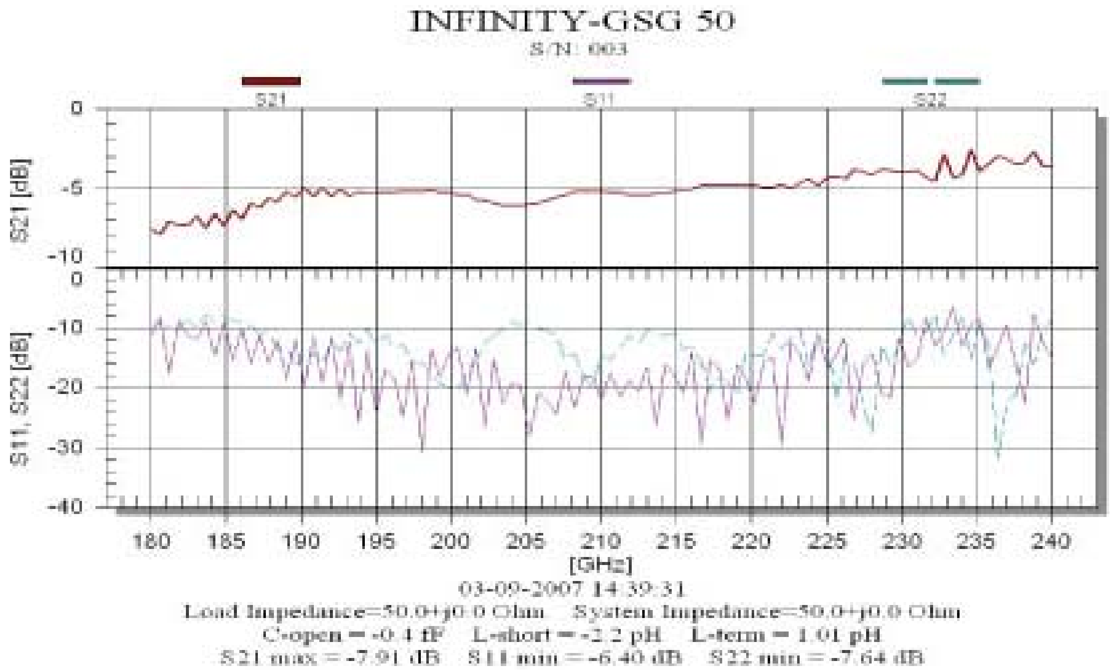
Figure 8

Improvements

The initial measurements were encouraging. The bias T, which is a scaled version of the latest version used on Cascade's WR05 probes, worked well, with no resonances up through at least 325 GHz. It was clear that the waveguide should be as short as possible to minimize loss. The back short was mechanically improved. Several different tip configurations were tried, and the easily interchanged photolithographic membrane tip made it easy to modify contact pitch.

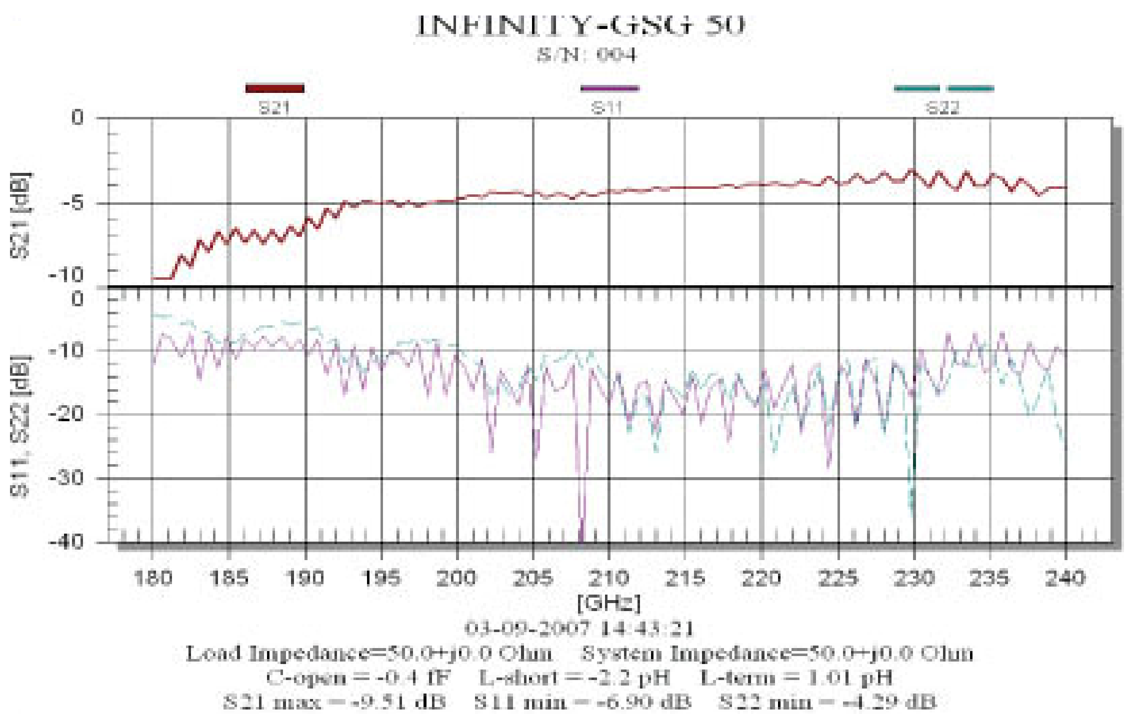
Measurement of WR-03 Probes on WR-05 VNA System

Cascade Microtech does not currently have a 325 GHz VNA system, but there is some overlap between the WR03 and WR05 bands, so the improved WR03 probes were measured on Cascade's WR05 system after a WR05 waveguide cal. This is very instructive, as the WR03 waveguide cutoff is easily observed in the reflection and transmission data, and the upper frequency limit of the WR05 system is also clear. Figures 9 and 10 are two different WR03 probes with bias Ts measured in Cascade's WR05 system, from 180 to 240 GHz. As expected, the loss is high at the low end of the frequency range, and the VNA measurements become unreliable above the nominal band edge at 220 GHz.



WR-03 Wafer Probe S/N003 on WR-05 System

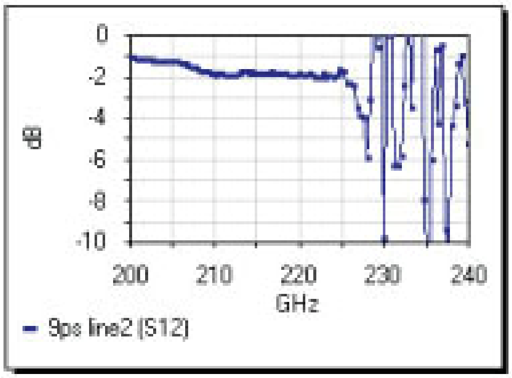
Figure 9



WR-03 Wafer Probe S/N004 on WR-05 System

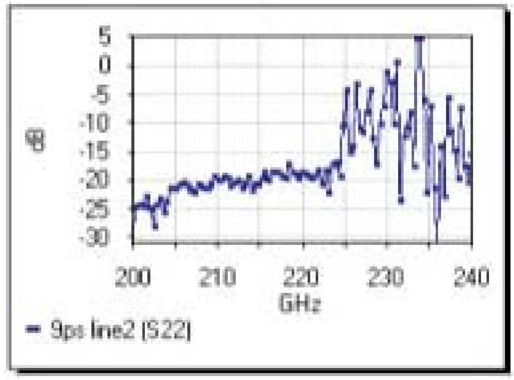
Figure 10

The system was then calibrated using WinCal with the reference plane at the WR03 probe tips using a calibration standard substrate, and figures 11 and 12 are measurements of a 9 picosecond length of CPW transmission line after the WR03 probe tip cal. Figures 11 and 12 clearly show that the cal through the WR03 probe tips is unstable above 225 GHz on the WR05 system, but is clean and stable from 200 through 225 GHz.



9 picosecond CPW Line Loss

Figure 11



9 picosecond CWP Line Reflection

Figure 12

Conclusions

Photolithographic Membrane Tip Wafer Probes have been designed, built and measured for the 220 – 325 GHz WR-03 waveguide band. Example probes have been demonstrated with and without an integrated bias T on both the JPL 325 GHz VNA system and in the upper frequency range the Cascade Microtech 220 GHz VNA system. A calibration with the reference plane at the probe tips has been achieved on both systems, and the probes will next be used to evaluate active circuits similar to those reported in references 5-7.

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