Plating the Inside of Stainless Steel Waveguide To Reduce RF Losses While Retaining the Thermal Isolation of Stainless Steel

Gerry Petencin

Historical Background

For at least 20 years, NRAO has employed techniques for the interior plating of stainless steel waveguide in order to reduce microwave signal path losses. Stainless steel is a desirable waveguide material only from the standpoint of thermal resistance and isolation, particularly in cryogenic applications at (typically) 20K and lower. The microwave losses of stainless waveguide are several times greater than for similar copper waveguide.

Plating a thin layer of copper onto the interior of stainless waveguide will yield a composite structure with essentially the thermal properties of stainless but the electrical properties (lower signal losses) of copper. Unfortunately, the shielded interior of waveguide can not be reliably plated in a standard plating tank, as both the electrical current and plating chemistry flows are limited inside the waveguide.

The NRAO approach to interior plating was developed by A. Kerr and J. Lichtenberger, with eventual contributions from V. Summers, R. Bradley, G. Petencin, M. Salotka and others. The approach is fundamentally simple: Suspend a platinum anode wire down the center of the waveguide and pump plating bath through the guide. Over the years a set of fittings have been developed which allow us to reliably achieve the necessary configuration.

Problems Specific to Internal Plating

One specification for all commercial plating chemistries is “anode to cathode ratio”. Typically the anode (source of metallic ions or in our case just the positive electrode) will have several times the surface area of the negatively connected (cathode) piece which is to be plated. With internal plating the centrally suspended wire will obviously have less surface area than the surrounding waveguide. In practice this non specified anode to cathode ratio is accommodated by operating the plating chemistry at the lower end of its nominal current range, as specified by the manufacturer. Recent work at NRAO, using Enthone-Selrex UBAC R1 “acid copper” chemistry, has achieved excellent results at currents of about 12 Amperes per square foot of exposed waveguide surface area. With short sections of waveguide this will typically require currents in the tens of milliamps.

Other problems that have been solved with the present generation of fittings include proper tensioning of the platinum anode wire, so as to not flex and contact the surrounding waveguide. Fittings must be designed for proper sealing to the flanged waveguide, with O-ring seals to the anode wire. Pumping is done with a lab grade tubing (peristaltic) pump, using UBAC R1 chemistry.

Plating Fundamentals

The process of "electro-deposition of metals", electroplating, has been in use for over 100 years and is a well established industrial process. As such, process for the user is generally defined by commercial manufacturer's product specifications, NOT from first principals of physics and electrochemistry. Essentially all commercial plating chemistries are proprietary "secret formulas" and subject to the first rule of business: Products do the job right or don't get bought again. If one follows manufacturer's guidelines the results should be acceptable.

In practice, the plating process has three major steps:

1. Cleaning (Activation in plating jargon)
2. Plating
3. Rinsing

All steps are specified by the product manufacturer. "Plating" process will typically be specified in terms of bath chemistry maintenance, plating current in terms of Amperes per square foot, and the expected deposition rate of plating metal, often in terms of Ampere minutes of current flow required to deposit a given thickness over a given area. For example, our UBAC R1 process will deposit 1000 u" (.001") on a square foot of base metal with a current flow of 1062 Amp minutes. For easier computation on small areas this may be reduced to 1 Amp minute depositing 136 u" of copper on 1 square inch of base metal.

The key pre-process step is to specify the desired finish, in terms of thickness and material. Not all base metals and processes will be compatible, and galvanic corrosion processes may dictate that certain metallic combinations be avoided. In practical terms these issues have been long resolved at NRAO: A few skin depths of acid copper plating will yield excellent results on stainless steel.

Recent Waveguide Plating as a Useful Process Example

In early June, 2005, we were asked to copper plate the interior of six pieces of WR10 waveguide, assembled with round "butt" (not thru) flanges. This was a typical job request in terms of waveguide size and length, the length being 1.42" from face to face of the flanges.

The interior wall area for the 1.42" piece was calculated at .43 square inches. That area requires a plating current of 40 mA to achieve a current density of 12.5 Amperes per square foot. The UBAC R1 process mentions 10-80 ASF as an acceptable current density range and we operate at the low end to accommodate the non optimal anode/cathode ratio.

Skin depth in copper is approximately 8 u" at 100 GHz and "rule of thumb" suggests that five skin depths will achieve the same RF loss as that of a pure copper waveguide. Therefore we determined the plating thickness should be 40 u". Referring to the manufacturer's data sheet indicating that 1062 Amp minutes will deposit 1000 u" of copper on 144 square inches of area it was calculated that 3 minutes of UBAC R1 plating at 40 mA will yield the desired five skin depths of copper. (Please refer to the useful Microwaves101.com website for a discussion of skin depth and its calculation.)

Step 1. --- Cleaning

Recent lab tradition had been to only electroclean the waveguide interior with 30% H2SO4 and a normal (waveguide cathodic, negative terminal) current of about 100 ASF. The H2SO4 is pumped through the same fittings as used for the eventual plating. Such cleaning has proven adequate, but we may wish to use the lab's standard ultrasonic and acid dip cleaners to further assure excellent results. Current was set at 300 mA with circulation for about four minutes. These values are standard but non critical, longer times should be avoided as there will be some erosion of the brass flanges.

Step 2. --- Plating

Please refer to the attached photo for a view of the plating apparatus. The platinum anode wire is .010" in diameter and weighs about .15 gm. The wire will last for 5-6 plated pieces and is the major material cost for this operation, with wire at about $50 per gram.

Plating is initiated by moving the bath inlet (suction) tube from the H2SO4 cleaner to the beaker of UBAC R1 copper bath. The bath is blue in color and as it moves toward the work piece we reduce the current from 300 mA (cleaning) to the nominal plating current of 40 mA. Timing of the three minute plating period begins when the blue copper solution enters the piece. As three minutes approaches the inlet tube is moved to a beaker of rinse water and after about 10 seconds the power supply voltage will be seen to increase (constant current supply) as rinse water displaces plating bath from the waveguide. When that voltage rise is noted the power supply is turned off and plating ceases.

Step 3. --- Rinsing

As soon as the power is turned off the pump speed may be increased to increase the rinse water flow. After a few seconds the pump may be turned off and the lines removed from the fittings and tap water can be run through the assembly for a minute or so. At this point the waveguide may be removed and rinsed with warm tap water for 15-20 minutes before being blown dry with lab nitrogen.

Plating is a Visual Art

Good plating is pretty plating. Inspection of the rinsed and dried waveguide is done by holding one end up to the lab's sunlit window and observing the quality of the interior plating. The desired result is bright, shiny copper, with close to a mirror finish. Some copper will have plated out on the flanges and this can be removed with a Scotchbrite abrasive pad. The flanges will eventually be finished with BDT-200 "bright gold", typically to 100 u".

But the Proof is in the Network Analyzer Measurement (HP8510)

All six pieces of waveguide, when plated to the same thickness of copper, were essentially identical in RF loss. Results stated here were measured on piece "WG-2", as labeled on the removable flange caps. Stated values are at 100 GHz, for 1.42" of WR10, with flanges. Data plots for 70-117 GHz are attached.

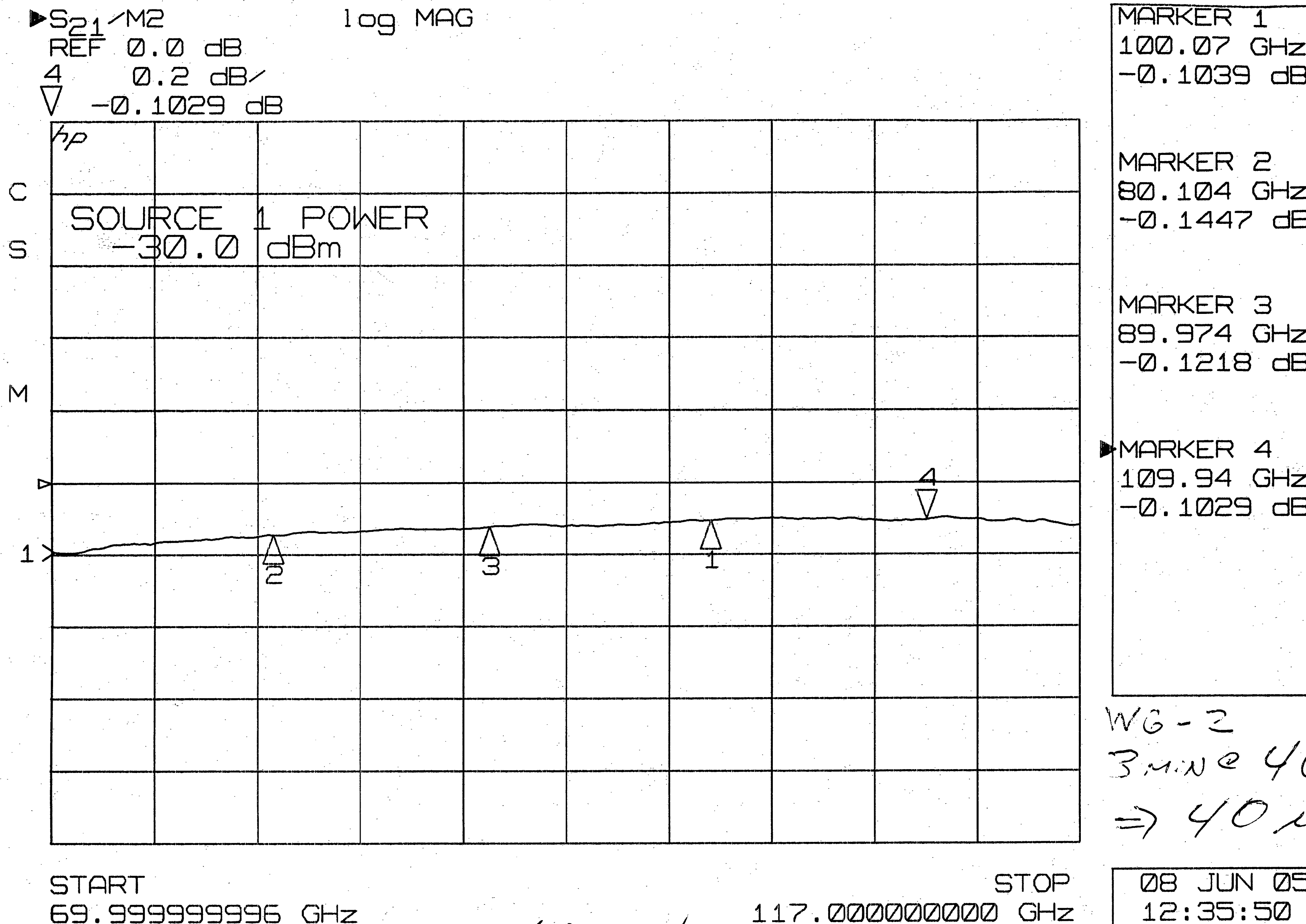
Loss of original waveguide, stainless steel:	0.523 dB
Loss of waveguide, 40 u" copper plated:	0.104 dB
Reduction of loss with copper plating:	0.419 dB

An Option for the Thermally Challenged

As an experiment, one piece of waveguide (WG-5) was plated to only one skin depth of copper, about 8 u". With that thickness of copper the loss at 100 GHz was reduced by .382 dB as compared to the original stainless. Plating to five skin depths (40 u") yields a loss reduction of .419 dB as compared to .382 dB for a single skin depth. If maximizing thermal resistance is of critical importance, very thin plating will result in a loss penalty of only a few hundredths of a dB. Plating to 10 skin depths did not yield a further reduction of losses, compared to the 40 u" pieces.

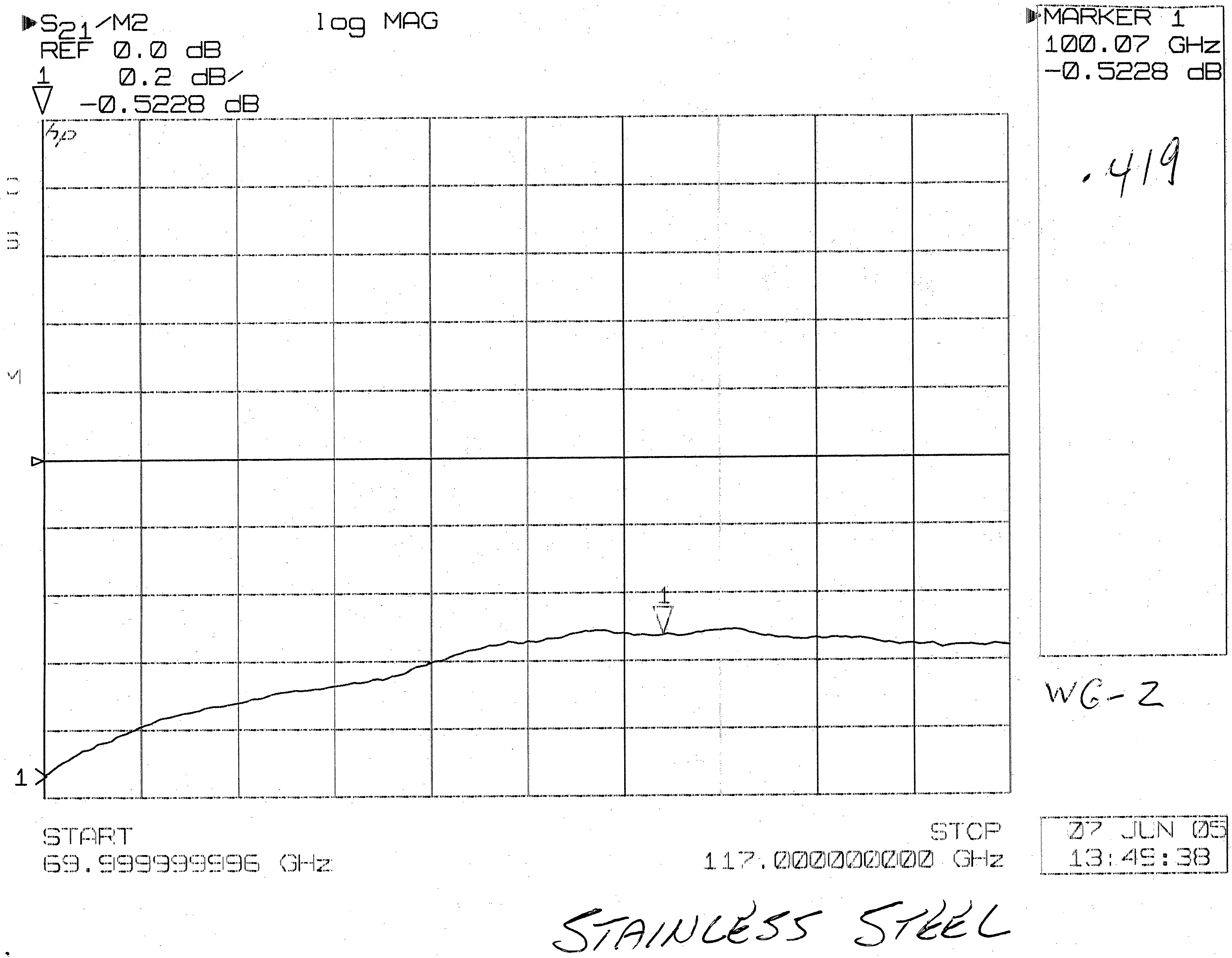
Conclusion

We can reliably copper plate the interior of stainless steel waveguide using standard industrial process and NRAO developed fittings. With copper plating a loss reduction factor of four or better can be expected. This process is considered reliable and robust, having been used for over 20 years at NRAO. Very thin (single skin depth) plating can be considered if thermal management is critical. The long term reliability and possible aging of such thin plating has not been evaluated. Five skin depths should be the nominal plating thickness for maximum loss reduction with an established history of long term reliability. Anecdotal accounts (A. Kerr) mention such copper plated waveguide as displaying no deterioration in performance over periods 10-20 years.

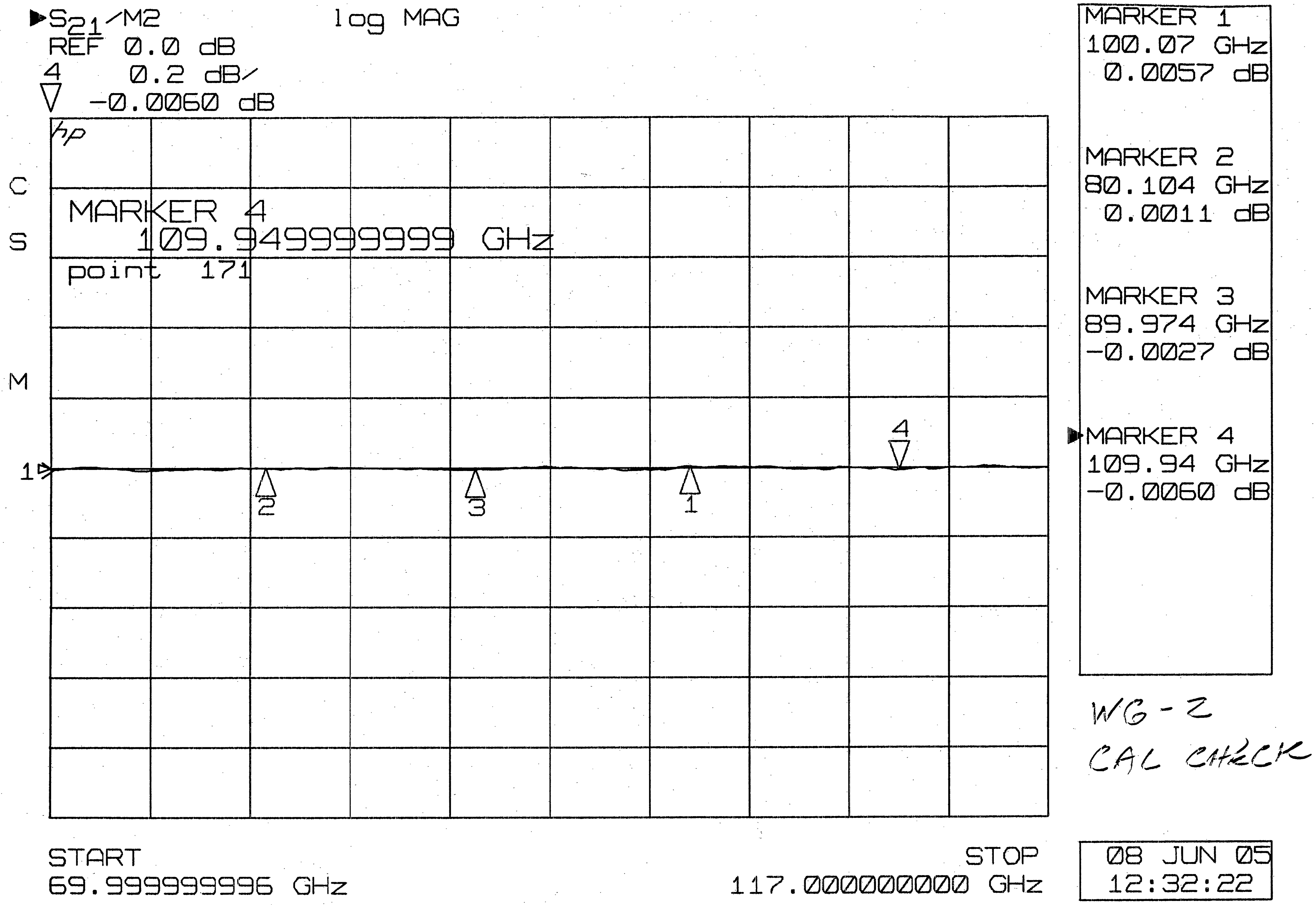


WG-2
3 min @ 40 mA
⇒ 40 u"

40 u" COPPER PLATED



S21/M2
log MAG
REF 0.0 dB
1 0.2 dB/
-0.5228 dB
hp
MARKER 1
100.07 GHz
-0.5228 dB
.419
WG-2
START
69.999999996 GHz
STOP
117.000000000 GHz
07 JUN 05
13:49:38
STAINLESS STEEL


S21/M2
log MAG
REF 0.0 dB
0.2 dB/
4
-0.0060 dB
hp
C
S
M
1
MARKER 4
109.949999999 GHz
point 171
2
3
1
4
MARKER 1
100.07 GHz
0.0057 dB
MARKER 2
80.104 GHz
0.0011 dB
MARKER 3
89.974 GHz
-0.0027 dB
MARKER 4
109.94 GHz
-0.0060 dB
WG-Z
CAL CHECK
START
69.999999996 GHz
STOP
117.000000000 GHz
08 JUN 05
12:32:22