SLAC–TN–91–10
July 1991
(TN)

AUTOMATIC NETWORK ANALYZER PROCEDURES FOR 5045 KLYSTRON CAVITIES[★]

J.G. Judkins

Stanford Linear Accelerator Center

Stanford University, Stanford, CA 94309

Introduction

This Note describes the results of using Automatic Network Analyzers in measuring SLAC 5045 klystron cavities. Two different analyzers were compared; the HP8753 and HP8510. Both analyzers have frequency synthesizer accuracy and stability to perform the measurement without the need for a frequency counter. The klystron has six cavities which can be put into three categories; input, gain and output. The input and output cavities require an external Q measurement (Qe) to determine coupling (β) and center frequency (f_o). The gain cavities require a resonant frequency measurement only.

Overview

Both analyzers were suitable for measuring input and gain cavities. The HP8510 has an advanced calibration technique that enables it to measure high reflections accurately. The HP8753 does not have this technique which makes it unsuitable for output cavity measurements. This will be discussed in more detail later.

The input and output cavities are greatly overcoupled ($\beta >> 1$) which results in an S11 measurement near unity around the periphery of the Smith chart. The analyzers Smith chart display lends itself to determine Qe easily for such high reflections. The gain cavities require input/output coupling probes to determine resonance. The probes are inserted side-by-side into the drift tube and the analyzer is set for transmission measurement (S21). The coupling between the probes is approximately -25dB. This is used as the baseline to determne the resonant frequency peaks. The resonant frequency is determined by loosely coupling the probe assembly to the appropriate cavity. Over-coupling at this point will detune the cavity. Therefore, the probes are inserted until the resonance peak is barely discernible on the LOG magnitude display of the analyzer. Most of the gain cavities have a frequency specification of $\pm 2MHz$. Moving the probes in and out; you can see the effect of overcoupling on frequency determination.

The output cavity requires a waveguide calibration. Two calibration techniques were tried and only one proved accurate. The Thru-Reflect-Line (TRL) method proved accurate and consistent with slotted line measurements. The TRL cal is available on the HP8510 and not the HP8753. The Cal method for the HP8753

[★] Work supported by the Department of Energy, contract DE–AC03–76SF00515.

uses a short, quarter-wave short, and a load. The load is the weak part of this method. Although it works well for moderately high reflections, it is not accurate for very high or small reflections in the order of $0.98 < S11 < 0.02$. The quality of the load determines the accuracy of the directivity component of the calibration. A waveguide load with a return loss of 50 dB would be necessary to accomplish the measurements within spec. This high quality load is attainable but fragile and difficult to maintain. The waveguide load used in the comparison tests has a return loss of 36 dB (1.02:1 VSWR). This was not sufficient to measure the output cavity reflection magnitude of 0.99 within spec.

The TRL calibration standards are lower cost, easy to maintain and more accurate. The short, quarter-wave short, load technique was tried on both the HP 8510 and HP 8753 with the same undesirable results.

Summary

In comparison to the slotted line, the network analyzer takes more time to calibrate but measures much faster. For consistent results the analyzer should be calibrated every four hours. Several cavities could be measured with one calibration faster than the slotted line. With the addition of a PC, documentation can be down-loaded automatically. The data stored on disc is readily available for statistical analysis. The measurement procedures and configurations can be guided by software. This speeds up the setup process, improves repeatability and consistency of test results.

In summary, the HP 8510 will provide all the measurements necessary for 5045, PEP and X-band klystrons. The HP 8753 is limited to 5045 input/gain cavities and PEP tube cavities. Although the PEP tube cavities were not part of this analysis, the methods in general can be applied. The PEP tube input and output cavities have Type-N adapters which makes them suitable for either network analyzer.

INPUT CAVITY MEASUREMENT

The input cavity has a Type-N coaxial input to the coupling loop. This connector will be treated as part of the cavity. A Type-N, S11-1 port cal will work on either the HP 8753 or HP 8510 network analyzers. The HP 8510 requires a sliding load to characterize the directivity; whereas the HP 8753 uses a fixed load. The HP 8753 has a high precision fixed load specified to 3 GHz which covers its entire frequency range. The fixed load for the HP 8510 is specified to 2 GHz. It may be worthwhile to acquire the higher precision Type-N load to negate the need for a sliding load below 3 GHz.

NOTE : The input cavity bandwidth is narrower than the output. It should not be necessary to use Frequency Subset to determine the detune short position. If a fine dot cannot be achieved then the Frequency Subset method described in the output cavity section needs to be performed.

5045 INPUT CAVITY TEST PROCEDURE FOR HP 8510

SETUP

Press PRESET

STIMULUS MENU:

- START FREQ: enter 2.84 GHz
- STOP FREQ: enter 2.88 GHz
- NUMBER OF POINTS: select 401

CAL MENU:

- If Cal Kit Type-N B.1 is not already in CAL 1 or CAL 2; then load it from DISC or TAPE.

CALIBRATION

CAL MENU:

Select TYPE-N B.1

Select S11 1 PORT

Perform short, open, load calibratioin as indicated using Type-N Cal Kit.

After calibrating, connect network analyzer Port 1 to the cavity under test and insert shorting bar.

FORMAT MENU:

Select INVERTED SMITH CHART

ELECTRICALDELAY

Under RESPONSE MENU select ELECTRICAL DELAY. With the shorting bar in place, adjust ELECTRICAL DELAY either by key entry or knob to get a fine dot at the detuned short position (approximately 1.3 nsec).

MEASURE :

Remove the cavity shorting bar and note fo at the point where the arc crosses the real axis of the Smith Chart. Invoke markers 1,2 and 3 to measure fo and Qe. The Qe bandwidth points are determined where the S11 reflection arc intersects the inverted Smith Chart susceptance arc of $j\beta = 1$. See Figure 1.

5045 GAIN CAVITY MEASUREMENTS FOR HP 8510

The gain cavities require a center frequency measurement only. Since there are no coupling mechanisms into these cavities, an input and output probe assembly is inserted into the drift tube. It is important to loosely couple to the cavity so as not to pull the frequency resulting in an erroneous measurement. The probe assembly is inserted just far enough to discern the resonant frequency peak from the baseline.

Network analyzer calibration is not required for this measurement. The free space coupling between the probes is approximately -25 dB. This is used as the baseline.

SETUP

Press PRESET

STIMULUS MENU:

START FREQ.; enter 2.8 GHz

STOP FREQ.; enter 3.0 GHz

NUMBER OF POINTS; select 801

PARAMETER MENU:

SELECT S21

FORMAT MENU:

Select LOG MAG display

MEASURE

Connect network analyzer Port 1 and Port 2 to the dual probe assembly. Insert the probe assembly into the drift tube until a small resonant peak is noticed on the LOG MAG display. The frequency of resonance can be read by placing a marker on top of the peak. Notice that inserting the probe further will cause the peak to shift frequency. Therefore, it is important to couple as loosely as possible and still be able to discern the resonant peak. It is possible that false resonances can occur in the drift tube. The probe depth is read off the scale on the probe carriage. This will insure that the cavity is excited and not a coaxial mode in the drift tube. See Figures 2, 3 and 4.

5045 OUTPUT CAVITY MEASUREMENTS FOR HP 8510

Output cavity measurements can be made with or without the dual window section attached. The cavity is greatly overocupled ($\beta >> 1$), which causes a very high reflection ($S11 \sim 0.99$). An S11 measurement is used to determine the characteristics of the cavity. The high reflection requires an accurate calibration to minimize errors in connections and characterization of adapters.

SETUP

Press PRESET

STIMULUS MENU:

START FREQ; enter 2.75 GHz

STOP FREQ; enter 2.95 GHz

NUMBER OF POINTS; select 801

SWEEP TIME $\geq$ 200 msec

Response Menu:

Press MORE, select WAVEGUIDE DELAY;

Enter 2.078 GHz for CUTOFF FREQ.

CAL MENU:

If Cal Kit WR-284 is not already in Cal 1 or Cal 2; then load it from disc or tape.

Press MORE; select SET Zo; enter 1 ohm.

The need for TRIM SWEEP routine is that RAMP SWEEP can be as much as 3 MHz off frequency accuracy. TRIM SWEEP corrects for this difference and allows RAMP SWEEP to approach STEP SWEEP accuracy.

ADJUSTTRIMSWEEP

Connect Ports 1 and 2 with or without coax to waveguide adapters.

PARAMETERMENU :

SELECT S21

FORMAT MENU:

select PHASE

SCALE 1 degree per devision

STIMULUS MENU:

select STEP sweep

DISPLAY MENU:

Wait for display to update with one full sweep (~ 40 seconds).

select DATA—MEMORY

select MATH(/). Display should be a flat line.

STIMULUS MENU:

select RAMP sweep.

CAL MENU: press MORE; select TRIM SWEEP and adjust knob for flattest trace.

CALIBRATION

Select WR-284 calibration

Select TRL 2-Port

Perform TRL calibration as indicated. There is no need to perform ISOLATION Cal. To omit, select ISOLATION; then select OMIT ISOLATION. After calibration select S11, INVERTED SMITH CHART.

ELECTRICALDELAY

The FREQUENCY SUBSET is used to reduce sweep width in order to determine electrical delay. It is necessary to use FREQUENCY SUBSET and TRIM SWEEP method to achieve the accuracy required to determine fo and Qe. The output cavity Specs for fo are 2853 MHz; +3MHz, -8MHz. If we allow the network analyzer to have 10% error in determining fo, then the window of error would be about 1 MHz or $\pm 0.5 MHz$. This tanslates into a tolerance of 1.2 psec for adjusting electrical delay. The reduced sweep width provides a finer dot to achieve the detuned short position accuracy. After determining electrical delay, the full sweep will be turned back on to perform the cavity measurements.

CAL MENU:

Press MORE; Select MODIFY CAL SET; then Select FREQUENCY SUBSET. Select CENTER FREQ; enter 2.853 GHz.

Select SPAN; enter 20 MHz.

Select CREATE & SAVE, and store in an unused CAL SET.

Attach the coax to WR-284 adapter to the cavity waveguide. Place the shorting rod in the cavity.

RESPONSEMENU :

Select ELECTRICAL DELAY. Adjust DELAY to achieve a fine dot at the detuned short position. This is approximately 6.2 nsec with the window structure attached.

After correcting for electrical delay, Select the original-full sweep-Cal set to perform the cavity measurements. The electrical delay will be automatically carried over to the wider bandwidth Cal.

Measure:

Remove the cavity short and note fo as the point where the arc crosses the real axis. The Qe bandwidth points are determined where the S11 arc intersects the susceptance arc of $j\beta = 1$. See Figure 5.

The TRIM SWEEP adjustment can be checked by switching between wide and narrow Cal sets and noting the fo for each. The fo should be within 1 MHz.

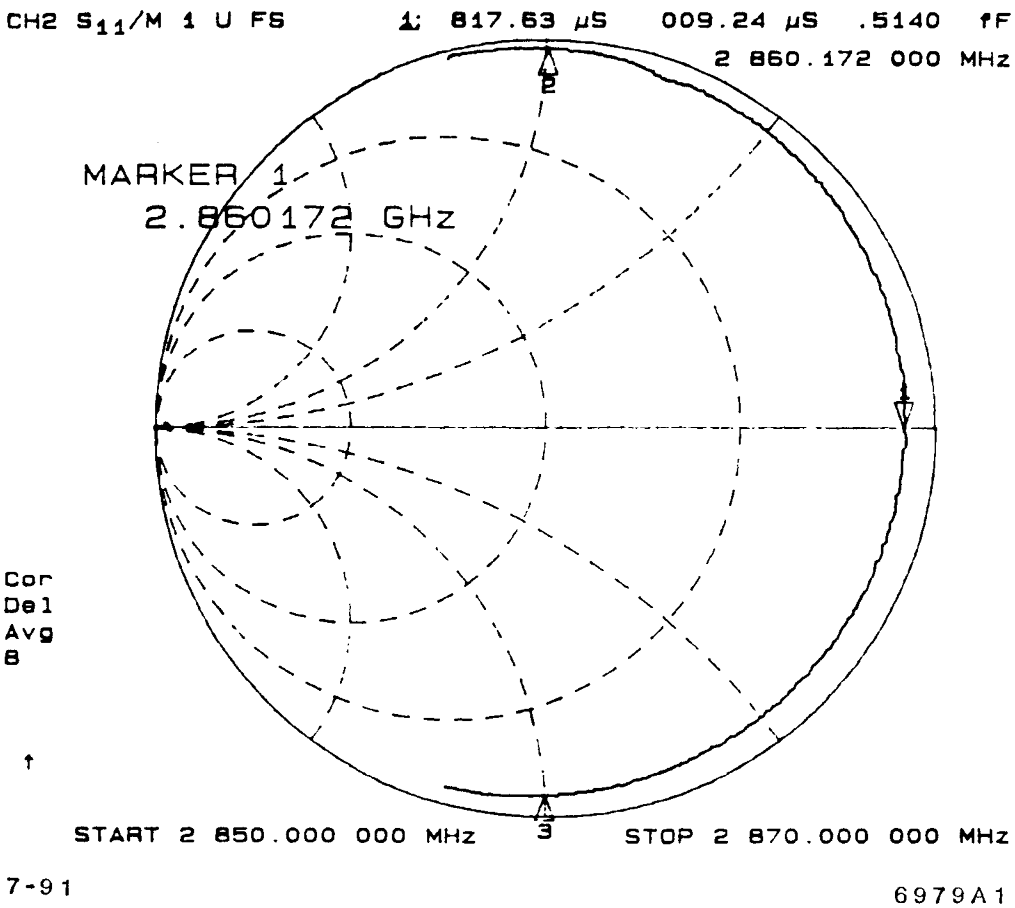
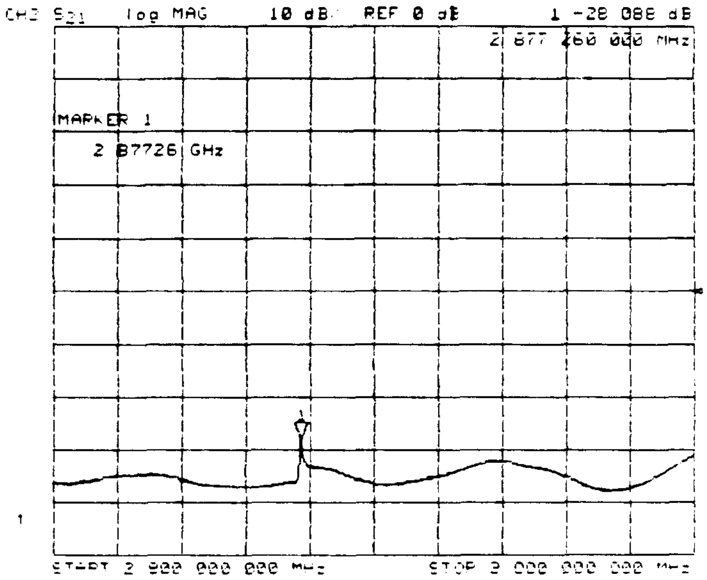

CH2 S11/M 1 U FS
1: 817.63 μS 009.24 μS .5140 fF
2 860.172 000 MHz
MARKER 1
2.860172 GHz
2
3
Cor
Del
Avg
8
START 2 850.000 000 MHz
STOP 2 870.000 000 MHz
7-91
6979A1

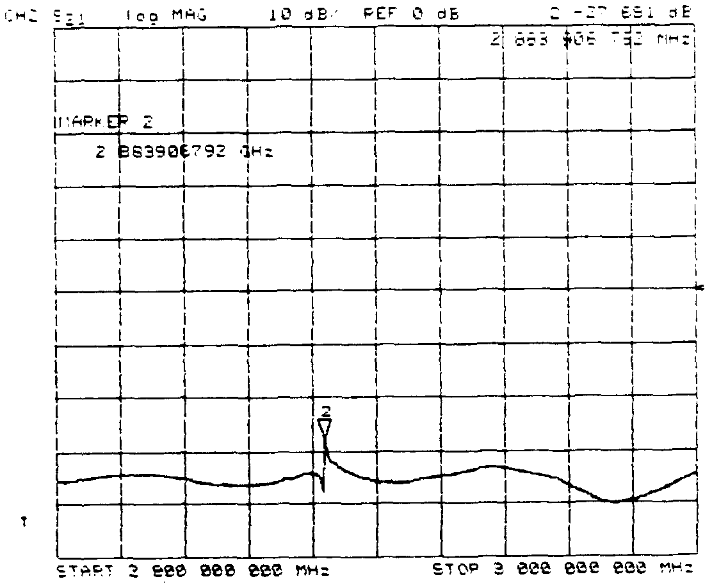
Fig. 1



7-91

6979A2

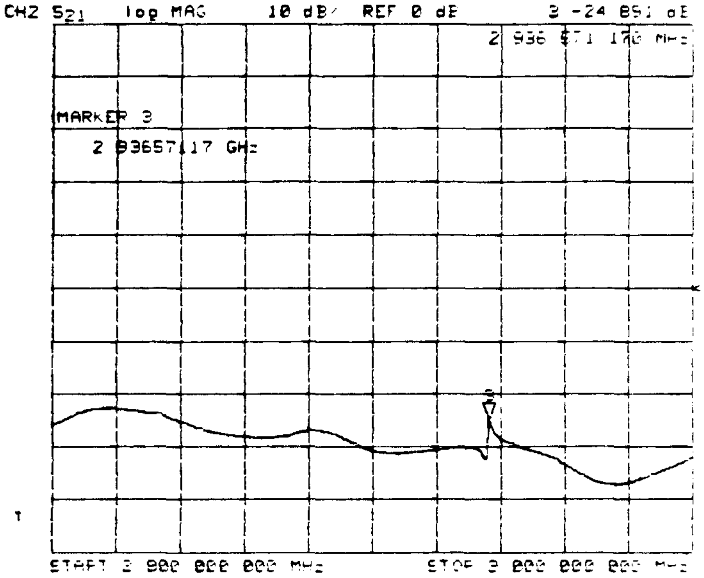
Fig. 2



7-91

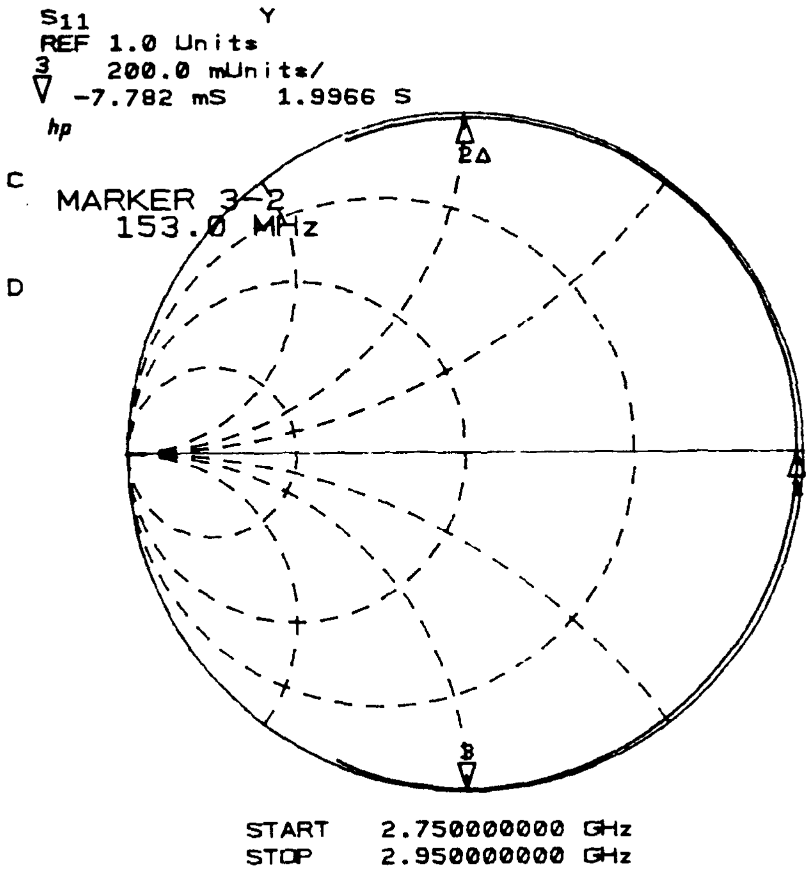
6979A3

Fig. 3



7-91 6979A4

Fig. 4



7-91 6979A5

Fig. 5