University of Missouri-Rolla
Electromagnetic Compatibility Laboratory

Title: # Filter-Pin Connector Evaluation

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This report describes prototype filter-pin connector measurements performed for Positronics Industries, Inc. This work was funded through the University of Missouri-Rolla Intelligent Systems Center (ISC). Positronic Industries is a member of ISC's Industrial Liason Program.

Introduction

This report describes the results of S-parameter testing completed on 21 prototype filter-pin connectors provided by Positronics Industries, Inc. The purpose of these tests was to evaluate the performance of existing connector designs and to experiment with the use of ferrite material in these connectors.

The test set-up used for these measurements is illustrated in Figure 1. Each connector was attached to a 50-cm length of 50-ohm coaxial cable. The shield of the coax was soldered to the body of the connector and the center conductor was soldered to a single pin. Each filter-pin connector was mated with an unfiltered connector and the opposite ends of the coax were connected to the S-parameter test set. The network analyzer was set to measure the magnitude of the forward transmission coefficient, S_{21}. The results were plotted from 300 kHz to 1 GHz.

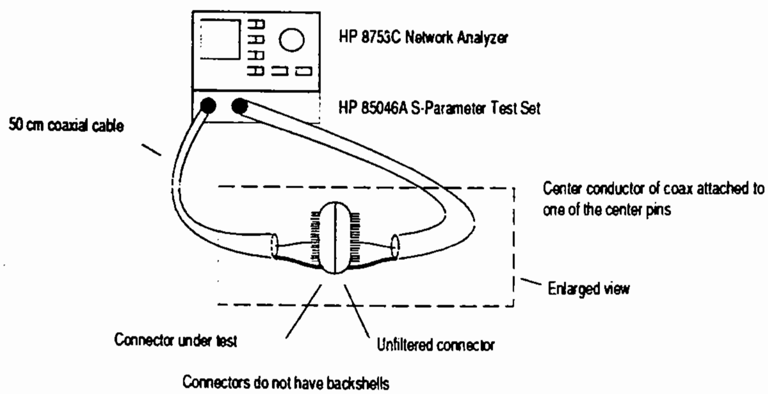


Figure 1: Test Set-Up

All of the filter-pin connectors tested were low-pass filters. At high frequencies where the power passing through the filter was significantly attenuated, the small amounts of power that coupled *around* the filter became significant. Therefore, at the high end of the frequency range, the attenuation is not as high as simple filter theory would predict. It is reasonable to expect that the high frequency attenuation would be significantly improved if metalized backshells with a 360^{o} connection to the cable shield were placed on each connector.

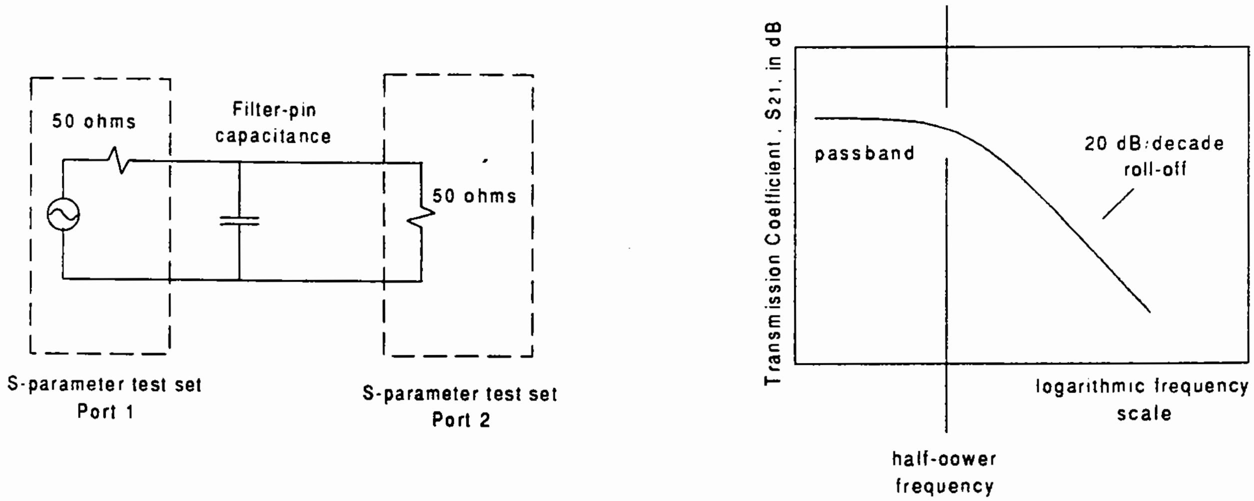


Figure 2: Capacitive Filter Model and Attenuation Curve

Capacitive Filters

The first nine connectors tested simply provided a capacitance between each pin and ground. A circuit model of this measurement and the predicted performance of this type of filter are illustrated in Figure 2.

The frequency at which the attenuation first reaches 3 dB (half-power) can be calculated using the equation,

$$f_{3dB} \text{ (in MHz)} = \frac{6370}{C} \quad (1)$$

where C is the filter-pin capacitance in picofarads.

Table 1 lists the first nine connectors, their nominal capacitance, their measured capacitance*, and their effective capacitance. Effective capacitance was calculated from the measured half-power frequency using Equation 1. Figures 6-14 (attached to back of report) show the transmission coefficient for each connector plotted as a function of frequency.

* Capacitance and inductance measurements were made with an HP 4261A LCR meter at 1 kHz. Measurements were made at the input to the coaxial cable. Connector was unterminated for capacitance measurements and shorted for inductance measurements. The cable alone had a capacitance of 54 pf and an inductance of 0.3 μH.

Note that with the exception of connectors #1 and #6, the connector attenuation could be estimated fairly accurately using the nominal capacitance up to a few hundred megahertz. Connector #1 apparently shorted itself whenever it was mated with another connector, so its attenuation could not be measured. The actual capacitance of connector #6 was significantly lower than the nominal value. This could be due to a defect in the ceramic or a poor connection with the pin.

Table 1: Capacitive Filter Connector Data

#	description	nominal capacitance	measured capacitance	effective capacitance	comments
1	FDX Size 25	500 pf	440 pf		short when mated
2	FDA Size 25	1000 pf	486 pf	1,023 pf	
3	FDB Size 25	2000 pf	2,080 pf	1,865 pf	3-pin test
4	FDC Size 25	3000 pf	2,930 pf	2,832 pf	
5	FDE Size 25	4000 pf	4,300 pf	4,130 pf	
6	FDF Size 25	5000 pf	1,170 pf	1,160 pf	apparently broken
7	FDD Size 25	30,000 pf	27,800 pf	26,220 pf	
?	FDX Size 15	500 pf	532 pf	493 pf	conn. not numbered
9	FDD Size 50	30,000 pf	31,500 pf	28,870 pf	
10	FDD Size 9	30.000 pf	28,300 pf	25,780 pf	

Inductive Filters

The next four connectors used a ferrite material to provide a lossy inductance in series with the signal path. A circuit model of this configuration is illustrated in Figure 3. Note that the predicted attenuation curve for this filter looks the same as that of the capacitive filter. The primary advantage of an inductive filter is that it generally works better in low-impedance circuits. This advantage is not apparent in these measurements which were all made in a 50-ohm system.

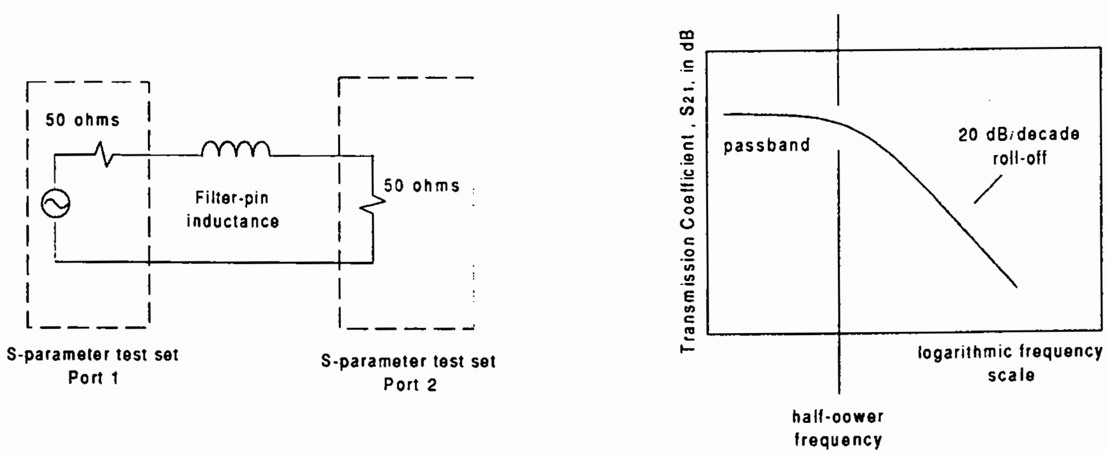


Figure 3: Inductive Filter Model and Attenuation Curve

Neglecting the resistive loss in the ferrite, the half-power frequency can be calculated using the equation,

$$f_{3dB} \text{ (in MHz)} = \frac{15.92}{L} \qquad (2)$$

where L is the effective inductance (in μH) of the loop formed by the filter pin and the connector shell. This inductance (normally negligible) is increased significantly by the presence of the ferrite material.

Table 2 lists the four connectors, their measured inductance, and their effective inductance calculated from the half-power frequency using Equation 2. Figures 15-18 show the measured transmission coefficient for each of these connectors plotted as a function of frequency.

Note that while the ferrite material does provide attenuation consistent with an inductive filter, the half-power frequencies to not correspond to the measured inductance of the ferrite. The measured inductance is roughly proportional to the thickness of the ferrite, however the thickest ferrite did not have the lowest half-power frequency.

There was not a large enough sample of ferrite connectors to determine why these inconsistent results were obtained. Possibly some ferrites were damaged or there was not a good tight fit between the pins and the holes in the ferrite material. This is a potential problem that should be thoroughly investigated before a ferrite loaded connector is marketed.

Table 2: Inductive Filter Connector Data

#	description	ferrite thickness	measured inductance	effective inductance	comments
11	Size 25	.135	2.1 μH	3.15 μH	
12	Size 25	.060	0.9 μH	0.05 μH	
13	Size 25	.273	3.6 μH	1.6 μH	
14	Size 25	.273	3.9 μH	2.28 μH	wouldn't mate correctly

T Filters and Pi Filters

T filters and Pi filters use a combination of inductance and capacitance to obtain a sharper roll-off in the frequency response above the half-power frequency. T filters are generally used in low-impedance circuits and Pi filters are used in high-impedance circuits. Circuit models for each of these filters are illustrated in Figure 4. Both filter configurations have a similar attenuation curve, which is illustrated in Figure 5. Note that, in general, there are two cutoff frequencies. Above the first cutoff, the response decreases at a 20 dB/decade rate. Above the second cutoff, the response decreases at a 40 dB/decade rate. These cutoff frequencies are a function of the inductance values, capacitance values, source impedance and load impedance. Often, the goal of a T or Pi filter design is to have the first and second cutoff occur at the same frequency, so that the response is essentially flat below cutoff and rolls off at 40 dB/decade above cutoff.

One T-filter and six Pi-filter connectors were evaluated. Table 3 lists each of these connectors and the measured open-circuit capacitance and short-circuit inductance. Figures 19-25 show the measured transmission coefficient as a function of frequency. Note that the scale in some figures has been changed to 10 dB/division in order to fit more of the curve on the plot.

Connector #16, the only T filter measured, used two .060 ferrites. Its response was very similar to connector #7 which was the same type of connector without the ferrites. Apparently, this ferrite is too thin to have any effect at all on the filtering in this frequency range.

All of the Pi filters measured used a thicker ferrite and all of them exhibited a 40 dB/decade roll-off. The first cutoff frequency for connector #20, which used a thick ferrite and two 30,000 pF capacitors, was well below the lowest measurement frequency. Connector #18, which used a thick ferrite, one 30,000 pF capacitor, and one 1000 pF capacitor, has a first cutoff at about 200 kHz. All

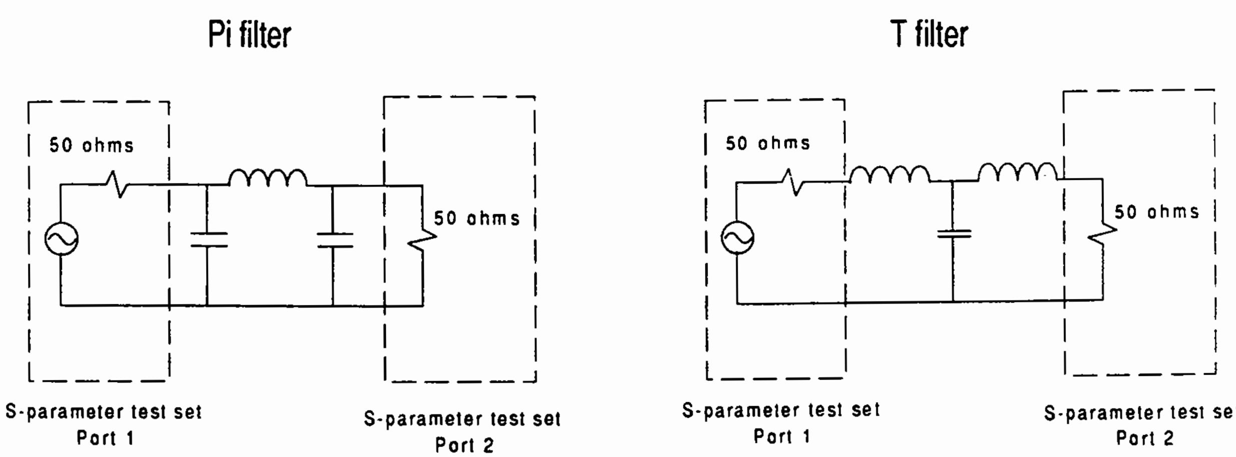


Figure 4: Lowpass Pi and T Filters

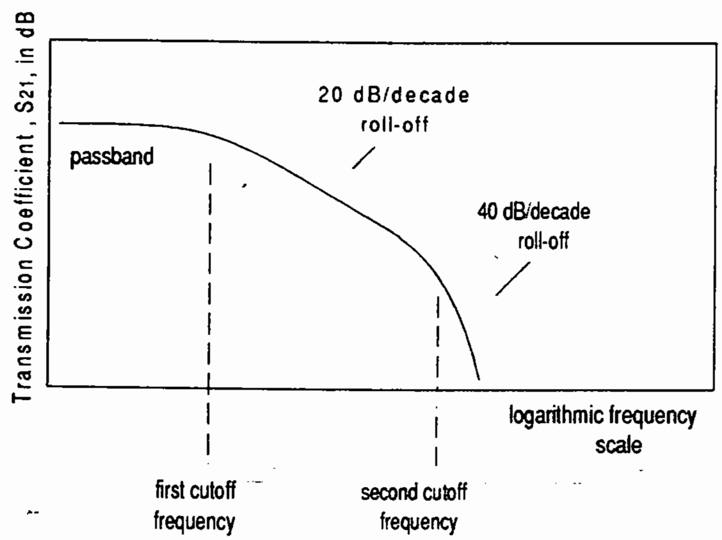


Figure 5: General Second-Order Filter Frequency Response

of the remaining Pi filters have first and second cutoff frequencies that fall within the 300 kHz - 1 GHz frequency range.

Table 3: T and Pi-Filter Data

#	description	element 1	element 2	element 3	open-circuit capacitance	Short-circuit inductance
16	25 pin	.060 ferrite	30,000 pf cap	.060 ferrite	28,500 pf	1.8 µH
18	25 pin	30,000 pf cap	.273 ferrite	1,000 pf cap	29,000 pf	4.0 µH
20	25 pin	30,000 pf cap	.273 ferrite	30,000 pf cap	56,000 pf	3.9 µH
21	25 pin	30,000 pf cap	.100 ferrite	30,000 pf cap	56,000 pf	1.8 µH
22	25 pin	1,000 pf cap	.135 ferrite	1,000 pf cap	2,170 pf	2.3 µH
23	25 pin	3,000 pf cap	.273 ferrite	3,000 pf cap	9,900 pf	4.2 µH
24	25 pin	5,000 pf cap	.273 ferrite	5,000 pf cap	5,640 pf	3.8 µH

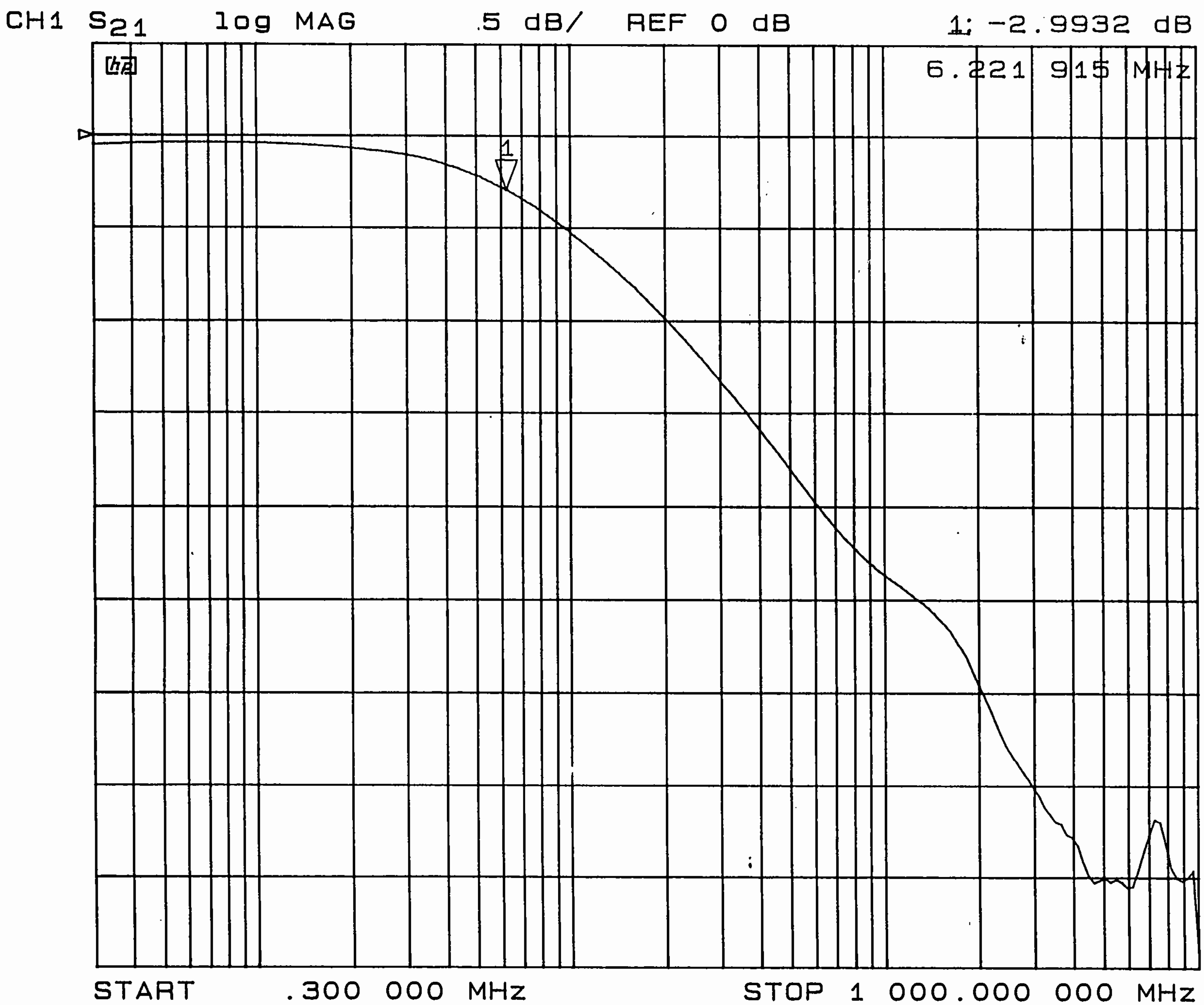
Conclusions

With the exception of two defective connectors, the capacitive filters performed as expected. The worse case error between a measured capacitance and a nominal capacitance was about 15%. The attenuation of these connectors above a few hundred megahertz was limited due to power coupling around the connector. Better high-frequency data could be obtained by using carefully constructed connectors with metal backshells.

The .100, .135, and .273 ferrites definitely provided a significant inductance, however the sample size was not great enough to establish a nominal inductance for each thickness. The few results obtained were not consistent, implying that ferrites may have been broken or inadequately connected to the pins.

The Pi-filter results were very encouraging. Clearly ferrites can be used to build a second-order filter into a single connector. Pi and T filters exhibit a sharper roll-off at high frequencies and they work with a wider range of circuit impedances than single-element filters.

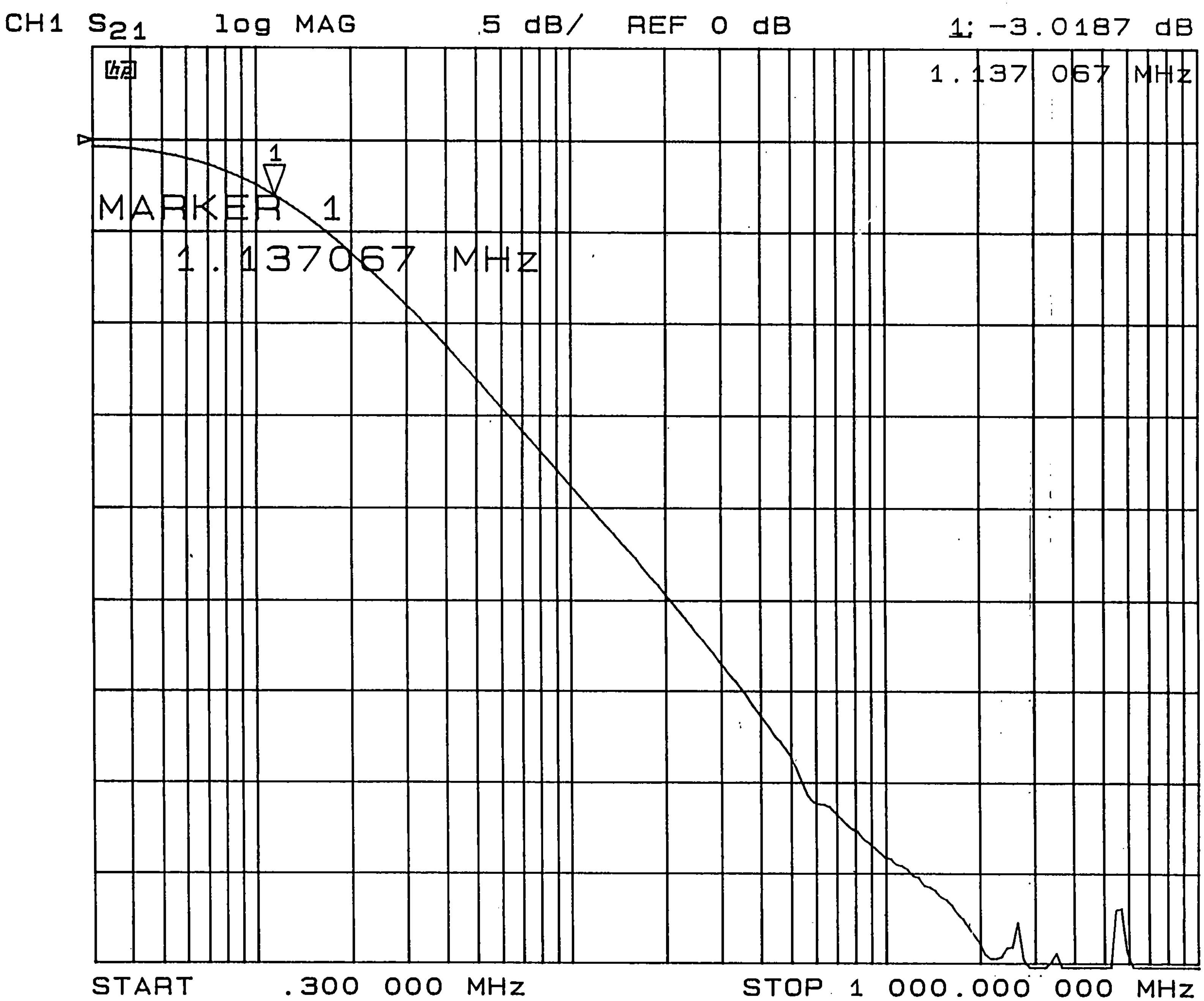
More work will be required in order to understand why the behavior of the ferrites was not more consistent. Once the ferrites are understood, Pi and T-filter connectors can be designed to have the exact attenuation characteristics necessary for any application.



Connector #2

25 pin
1000 pf

Figure 6

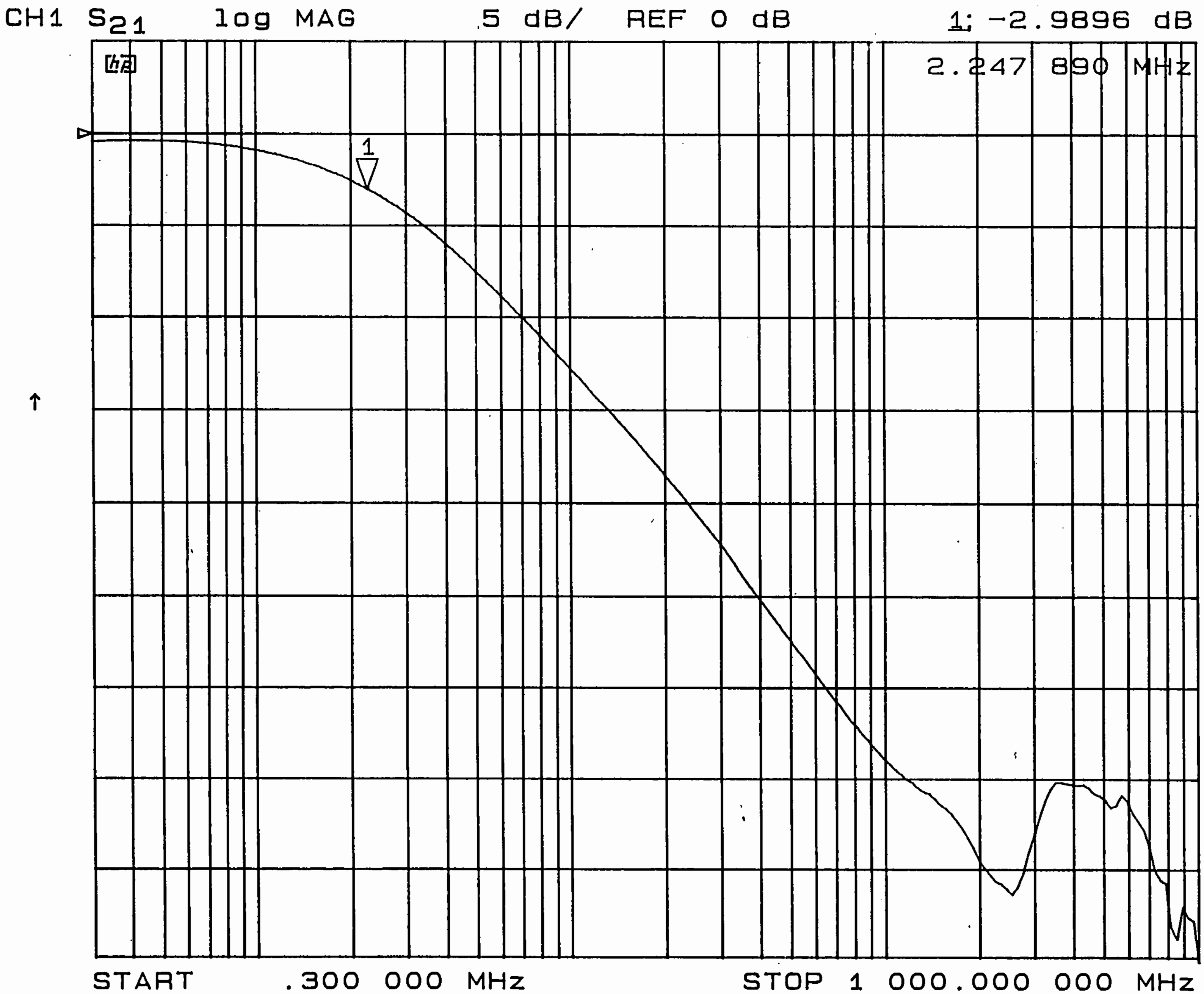


Connector #3

25 pin
2000 pf

3 pins tied together
for effective
nominal
capacitance
of 6000 pf

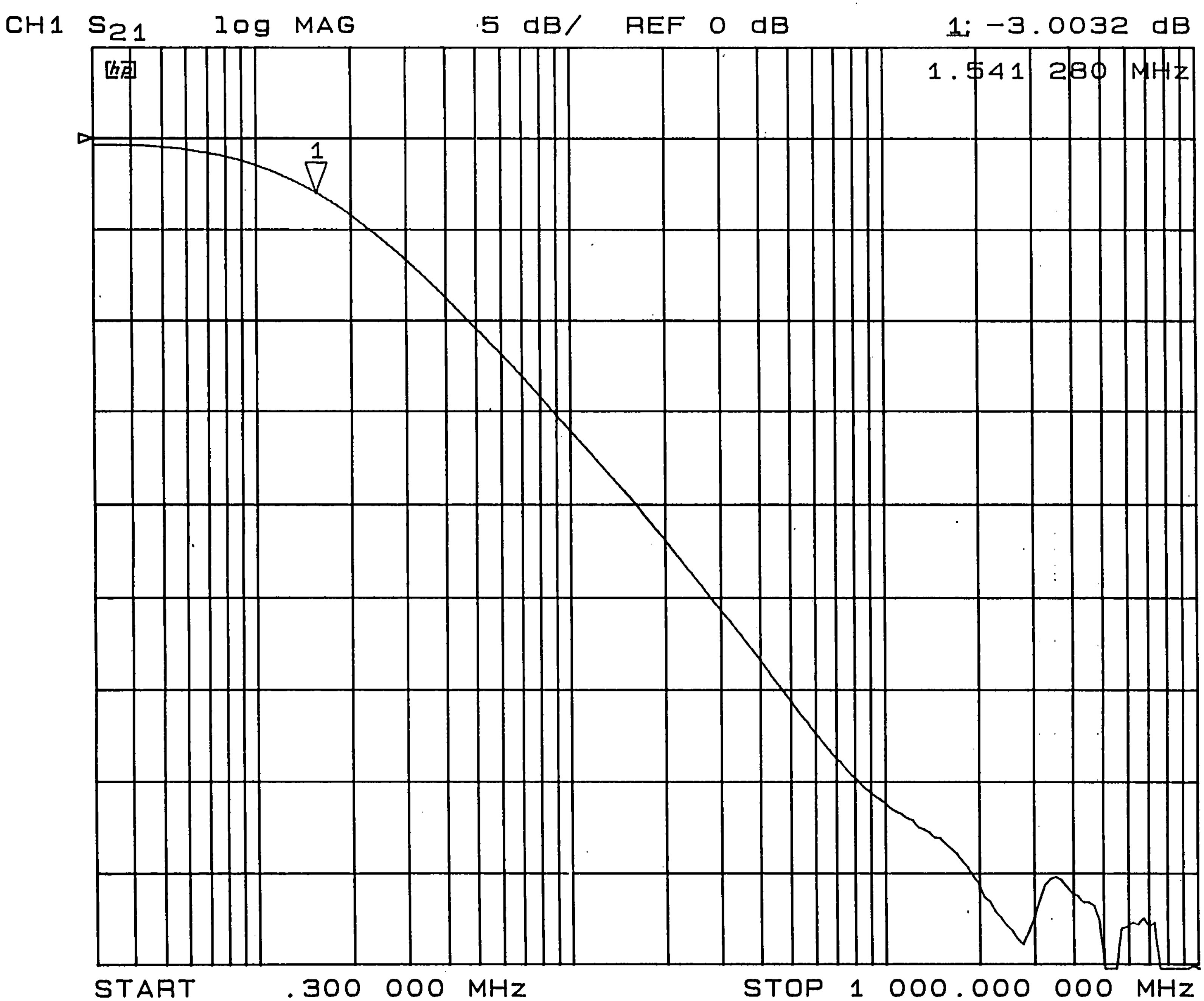
Figure 7



Connector #4

25 pin
3000 pf

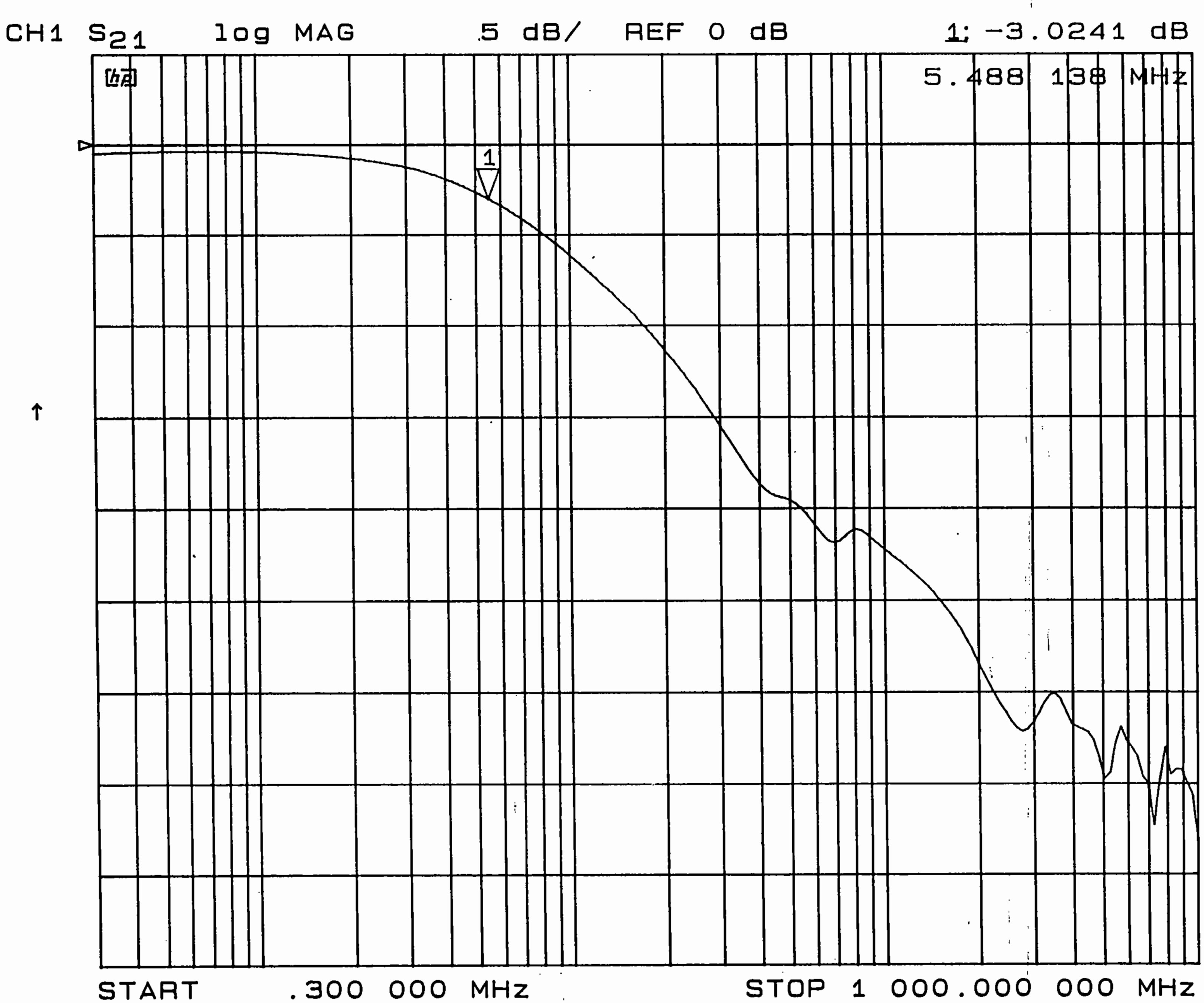
Figure 8



Connector #5

25 pin
4000 pf

Figure 9

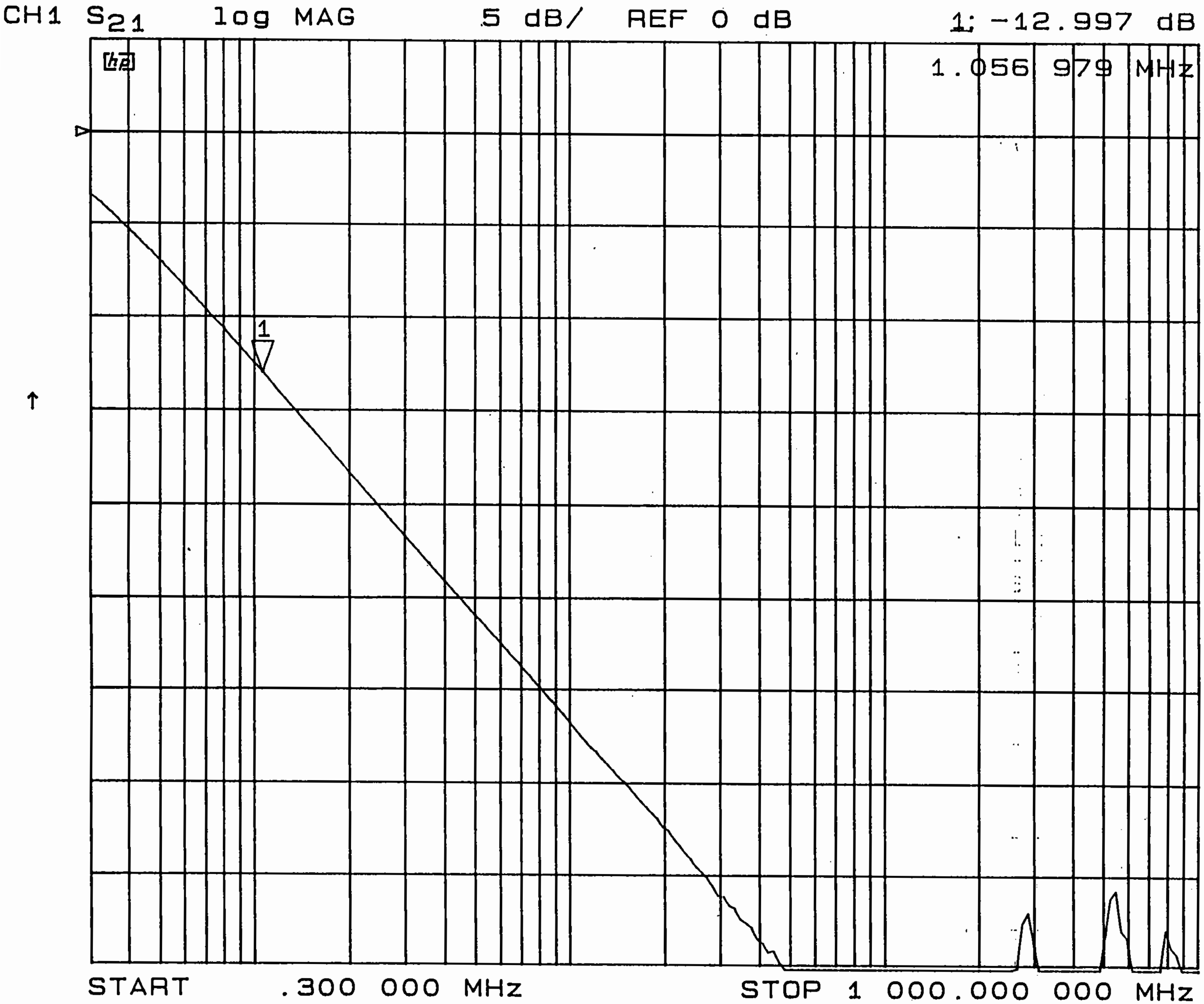


Connector #6

25 pin

5000 pf (n
1170 pf (actual)

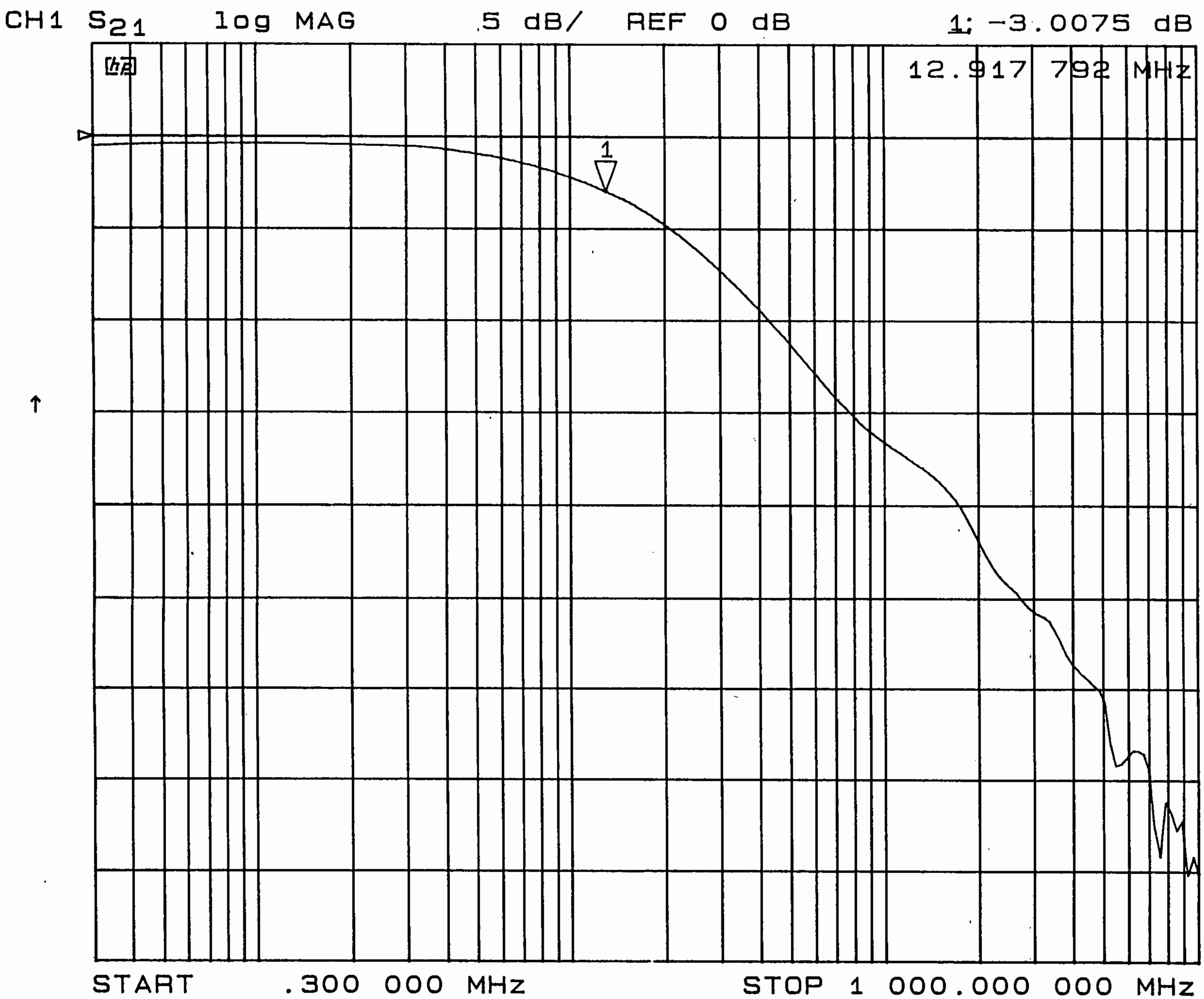
Figure 10



Connector #7

25 pin
30,000 pf

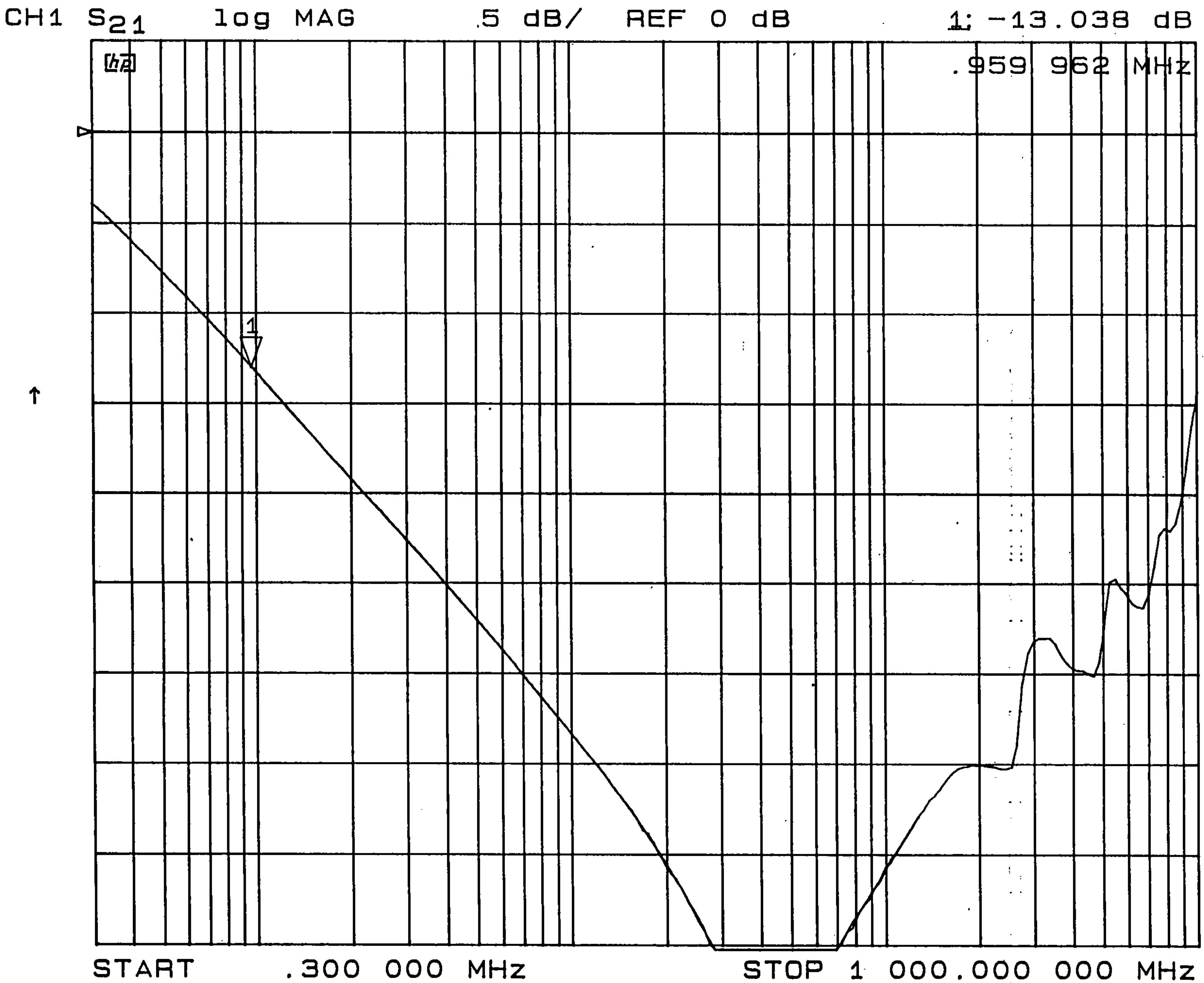
Figure 11



Connector not numbered

15 pin
500 pf

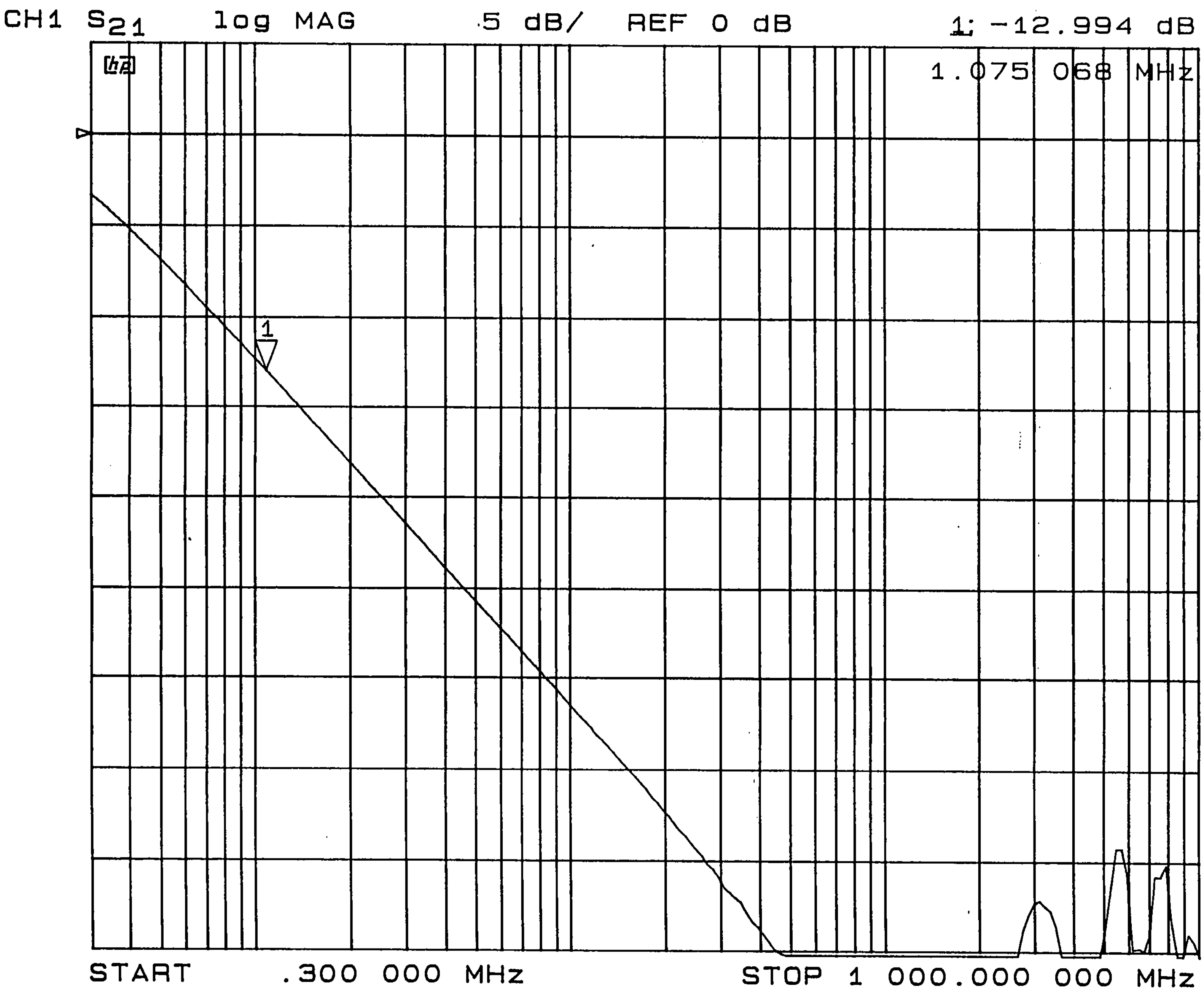
Figure 12



Connector #9

50 pin
30,000 pf

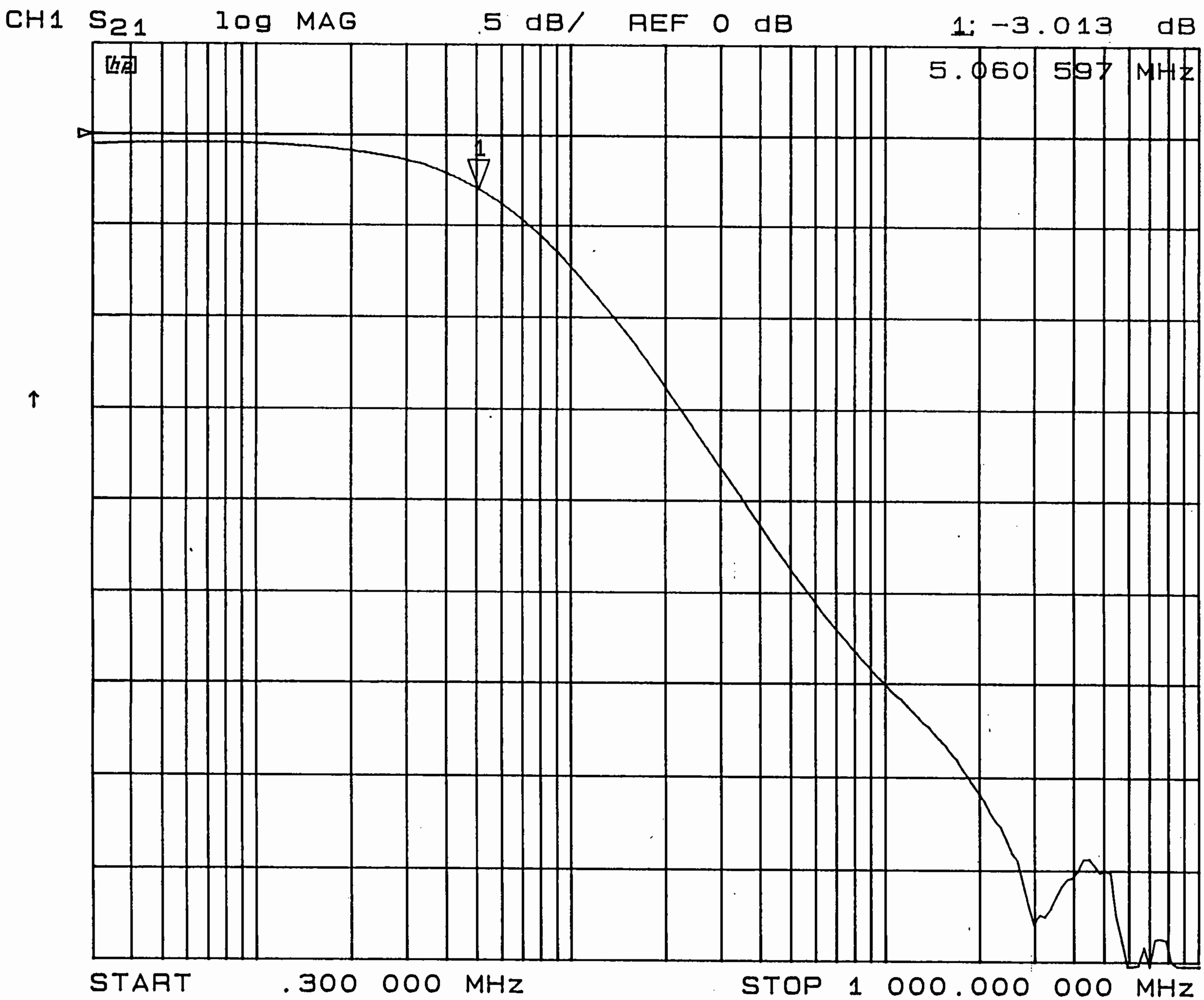
Figure 13



Connector #10

9 pin
30,000 pf

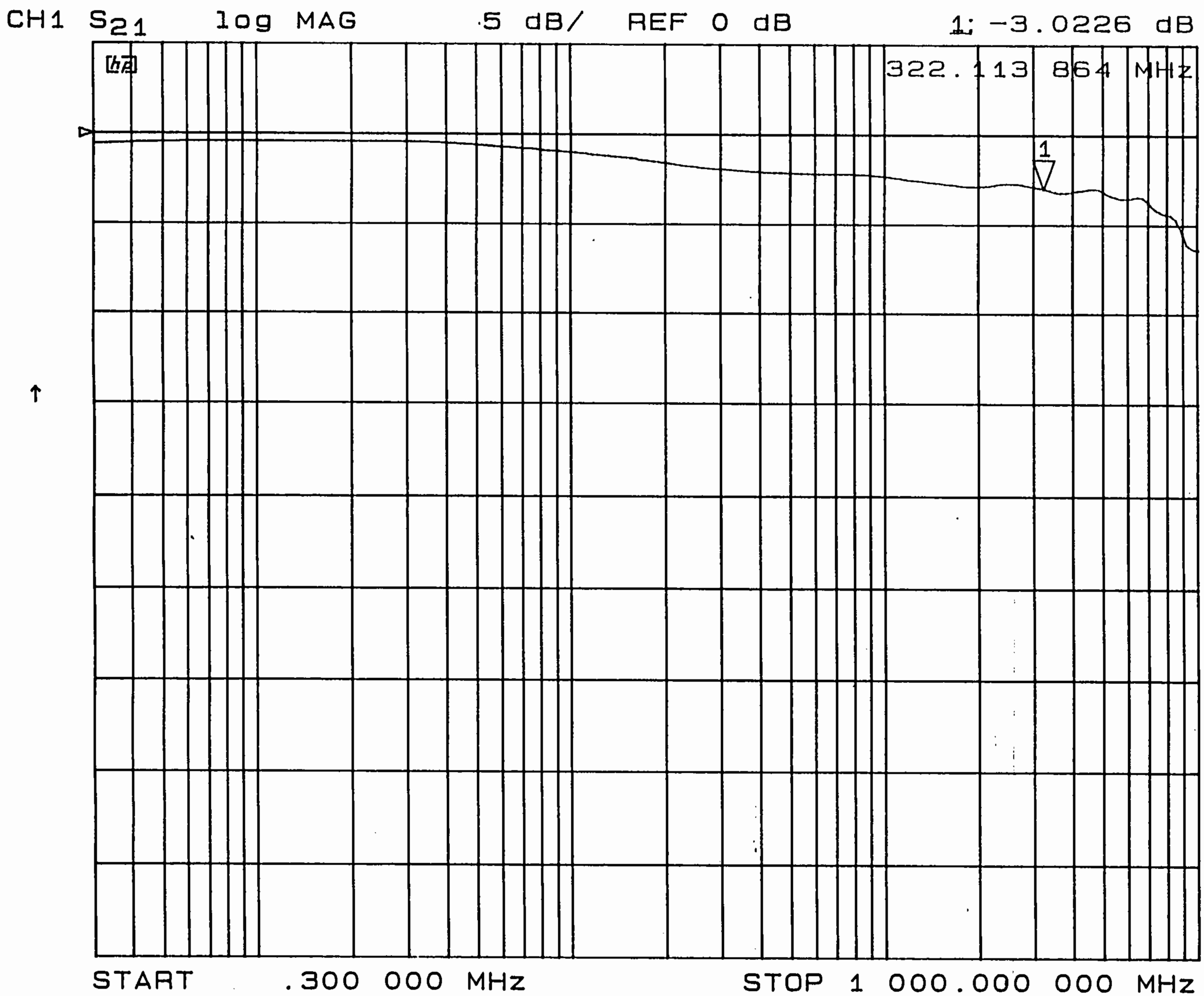
Figure 14



Connector #11

25 pin
.135 ferrite

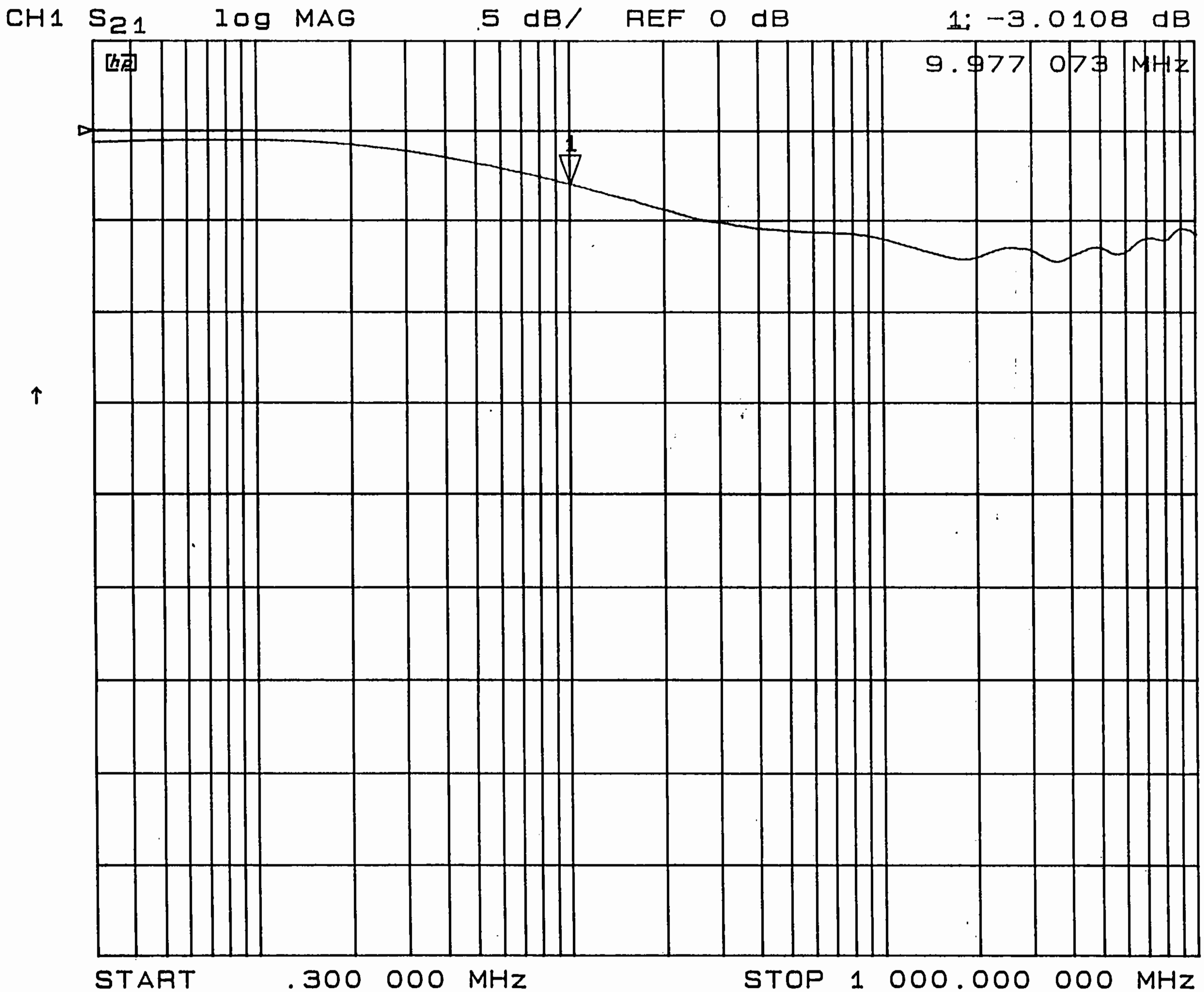
Figure 15



Connector #12

25 pin
.060 ferrite

Figure 16



Connector #13

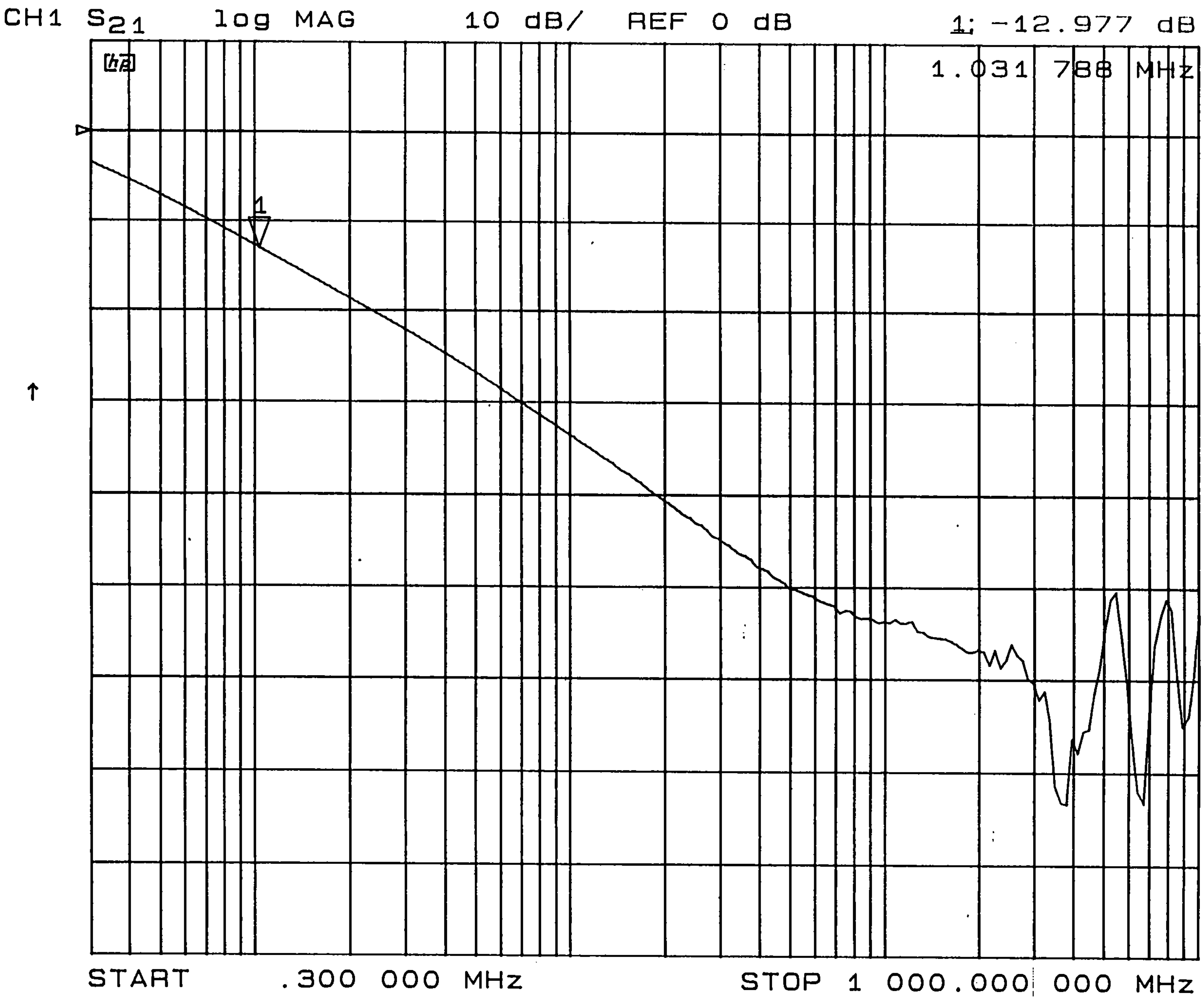
25 pin
.273 ferrite
male connector

Figure 17

Connector #14

25 pin
.273 ferrite
female
(partially blocked)

Figure 18

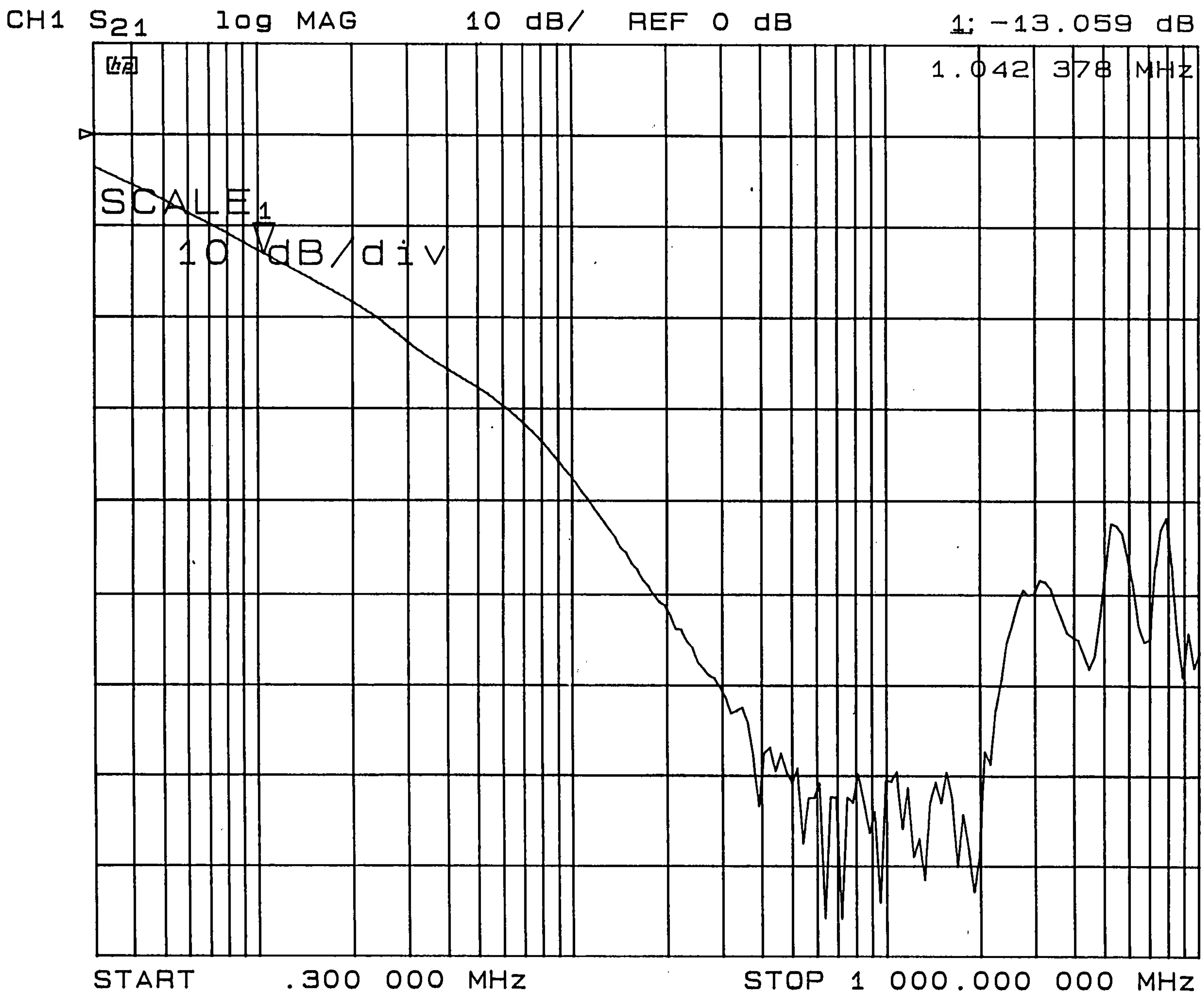


Connector #16

T Filter

.060 ferrite
30,000 pf cap
.060 ferrite

Figure 19

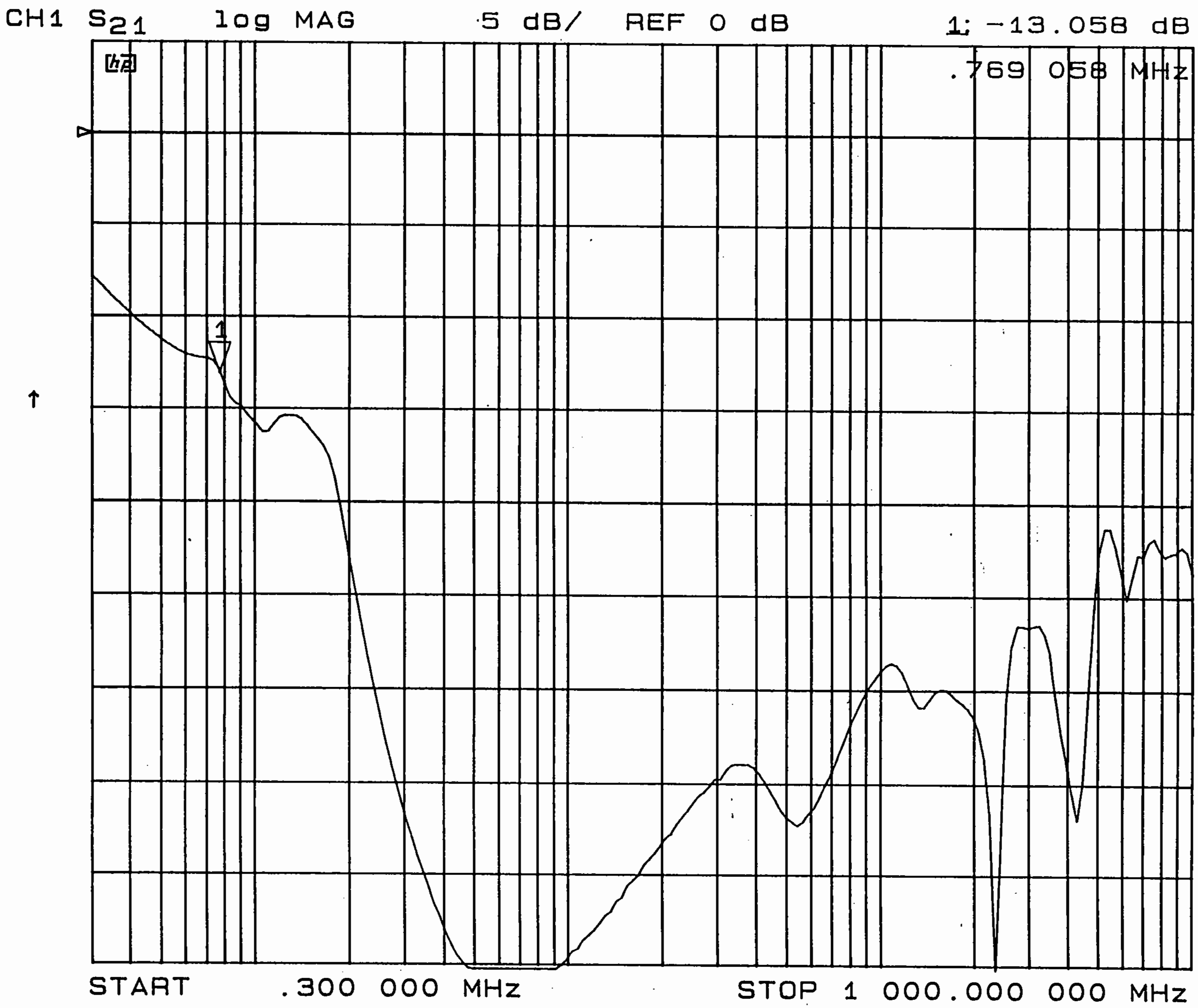


Connector #18

Pi Filter

30,000 pf cap
.273 ferrite
1,000 pf cap

Figure 20

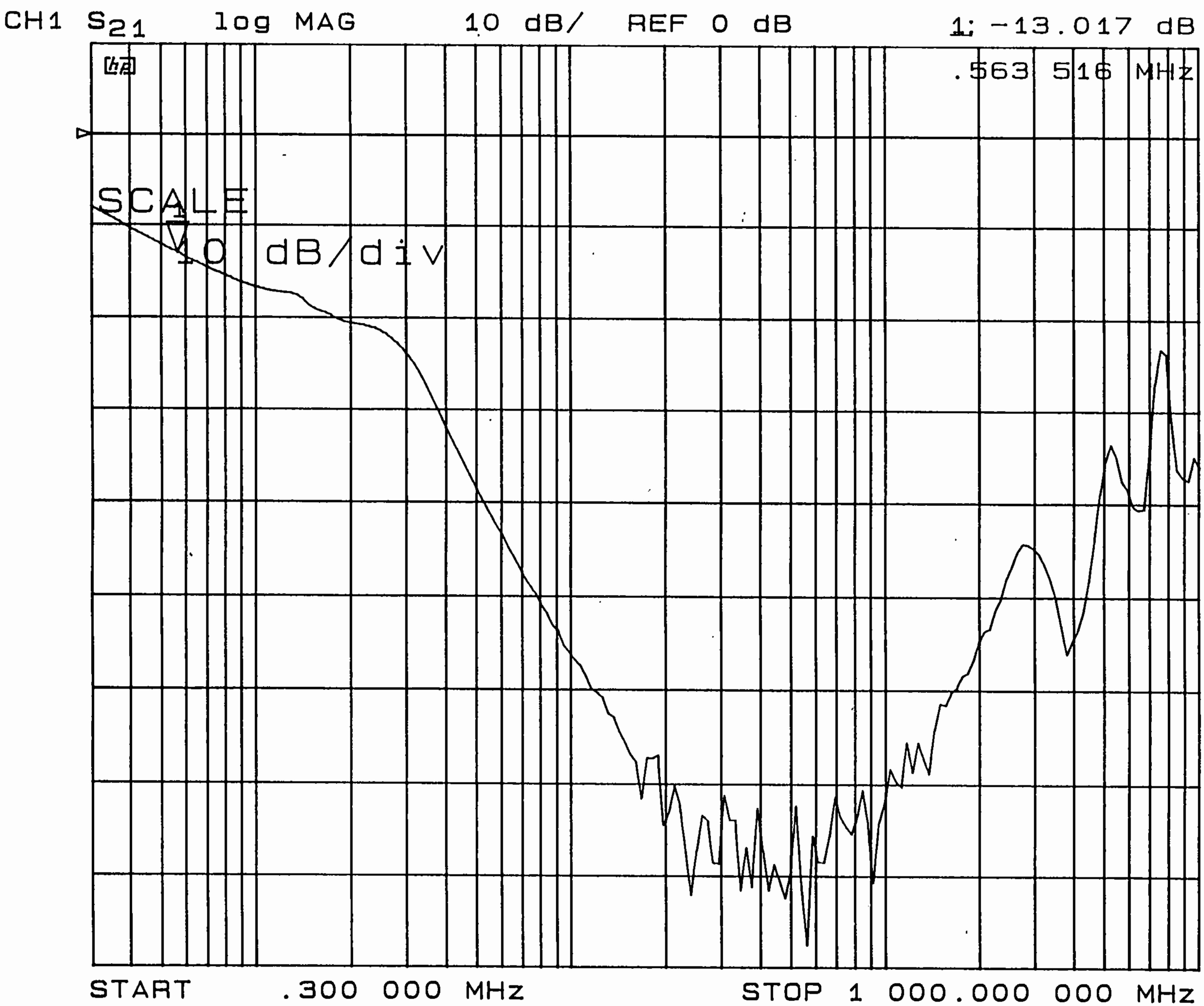


Connector #20

Pi Filter

30,000 pf cap
.273 ferrite
30,000 pf cap

Figure 21

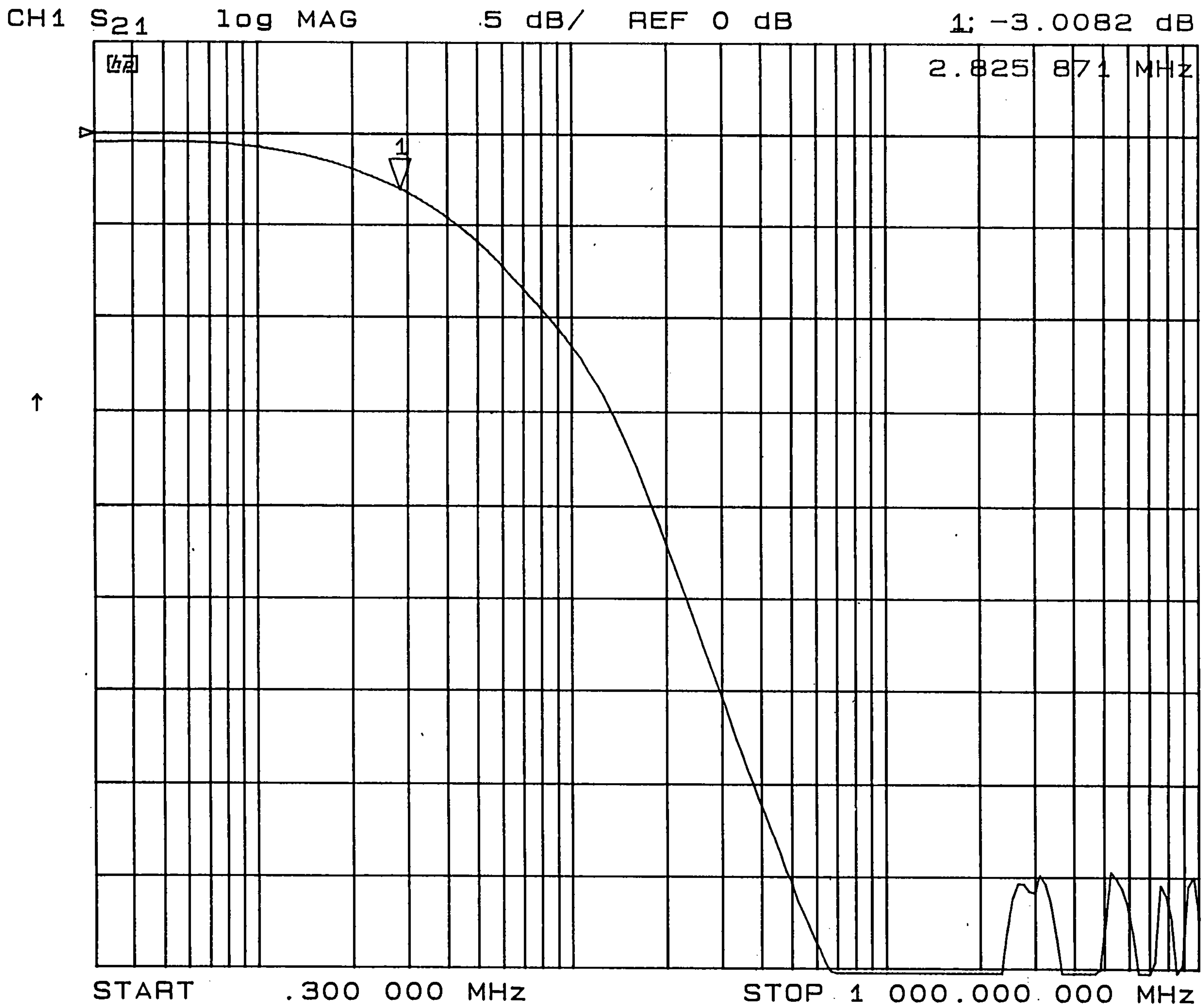


Connector #21

Pi Filter

30,000 pf cap
.100 ferrite
30,000 pf cap

Figure 22

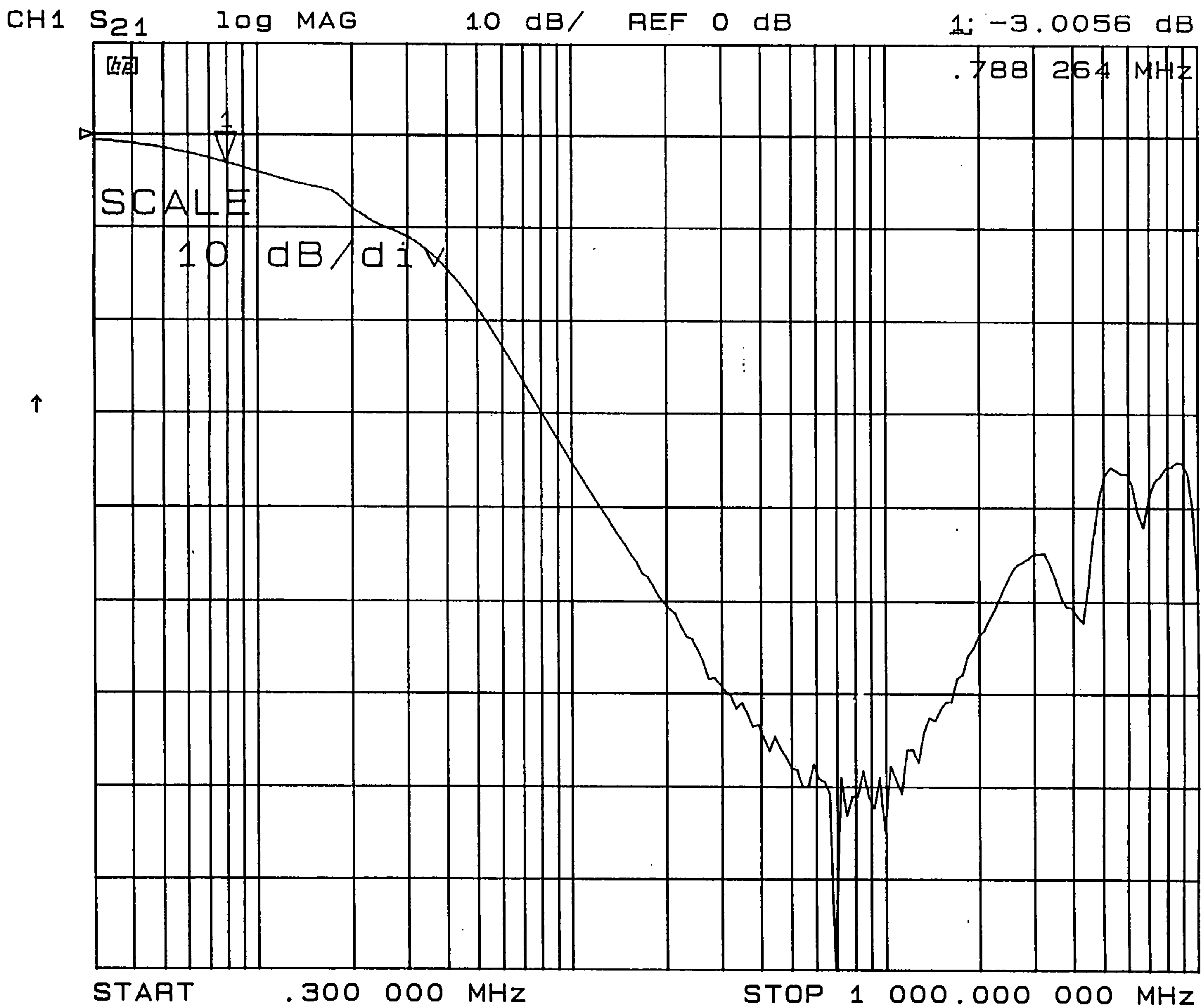


Connector #22

Pi Filter

1,000 pf cap
.135 ferrite
1,000 pf cap

Figure 23

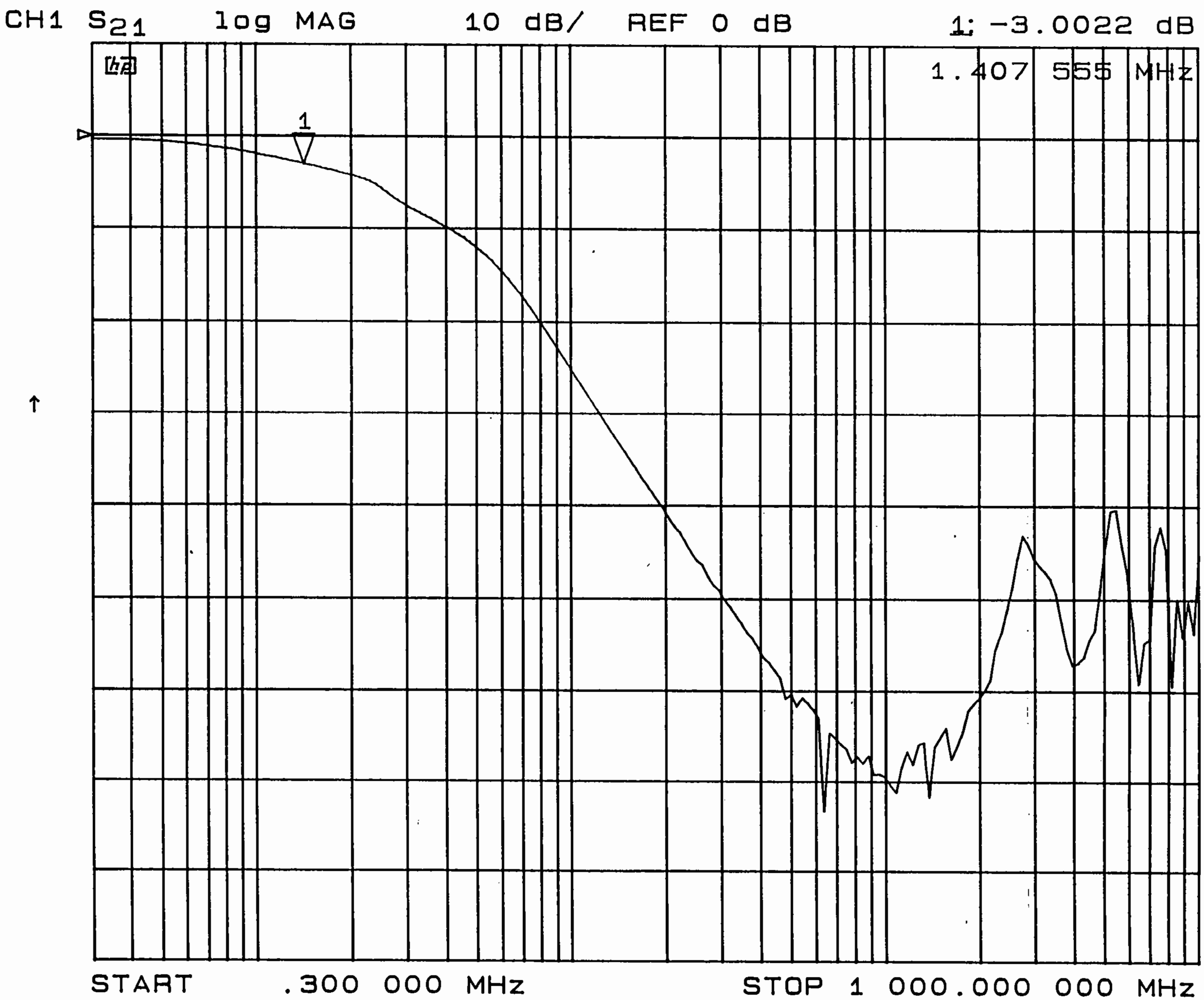


Connector #23

Pi Filter

3,000 pf cap
.273 ferrite
3,000 pf cap

Figure 24



Connector #24

Pi Filter

5,000 pf cap
.273 ferrite
5,000 pf cap

Figure 25