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In this issue of "Tech Notes," we feature just one article on the attenuators by Chris Fagas, WB2VVV. These nifty little gadgets have many applications in RF, HF, VHF, and UHF projects. Mounted in small boxes, they'll even serve as inexpensive VHF "Fox Hunting" adjustable attenuators. I'm sure you'll find many additional uses for these handy devices!
—Pete, K1ZJH

Adjustable 50-ohm Attenuators Make Level Matching Easy Between RF Stages

These nifty little attenuators have many applications.

Chris Fagas, WB2VVV

This approach to 50-ohm attenuators is usable almost anytime such a device, which can be tweaked to its final attenuation value in the operating circuit, is needed between stages.

Although this little-known technique has been used by many in the past, very little time and effort has been spent to date in understanding the performance characteristics that can be attained through it.

By carefully choosing component values, the response of this simple pi-network resistive attenuator (**Figure 1**) can be optimized to provide:

1. An appropriate range of attenuation;
2. A smooth response over the desired range.

Measurements

All of the examples discussed here will yield input and output VSWR with respect to 50 ohms of under 2:1 (return loss over 9.5 dB), even over their maximum adjustment range.

This low theoretical input/output VSWR has been calculated in the following tables and graphs (**Figures 2** through **4**) without taking component inductive/capacitive reactance into account. This is simply a matter of individual circuit execution, with an understanding that these reactances will become more bothersome at higher frequencies. In my experiences under 30 MHz, little regard for neat execution is necessary to achieve excellent performance. However, at higher frequencies more careful attention should be directed towards component choices and cleaner execution.

I used the Wiltron S331 Vector Network Analyzer to create the circuit plots from 25 to 330 MHz in the minimum, median, and maximum attenuation settings. These show the VSWR and Smith Chart of these settings over this frequency range. The Scalar Network Analyzer plots of the circuit from 300 kHz to 1300 MHz in the minimum, median, and maximum attenuation settings were created using the Hewlett Packard HP8711B. These plots show two channels for these settings over this frequency range. Channel number 1 is transmission loss, or loss through the circuit. Channel number 2 is return loss, or the delta between energy put into the circuit and energy

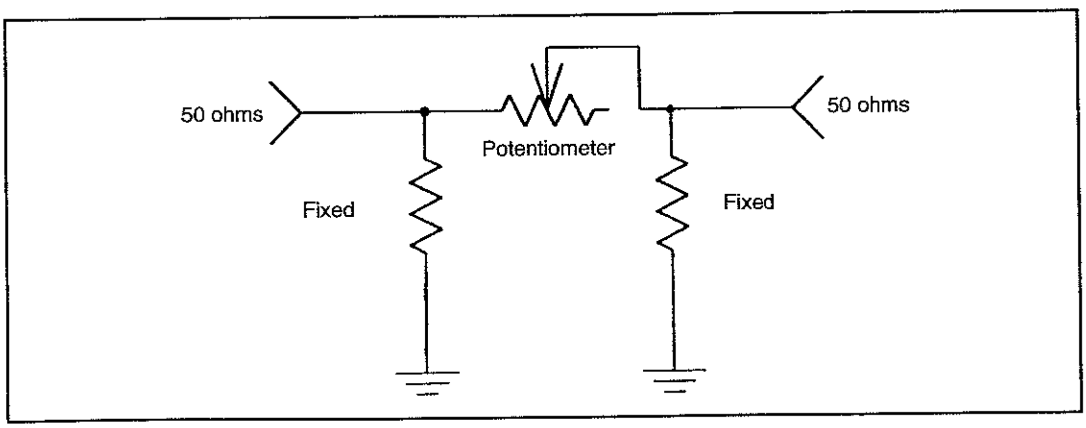


Figure 1. Pi-network resistive attenuator.

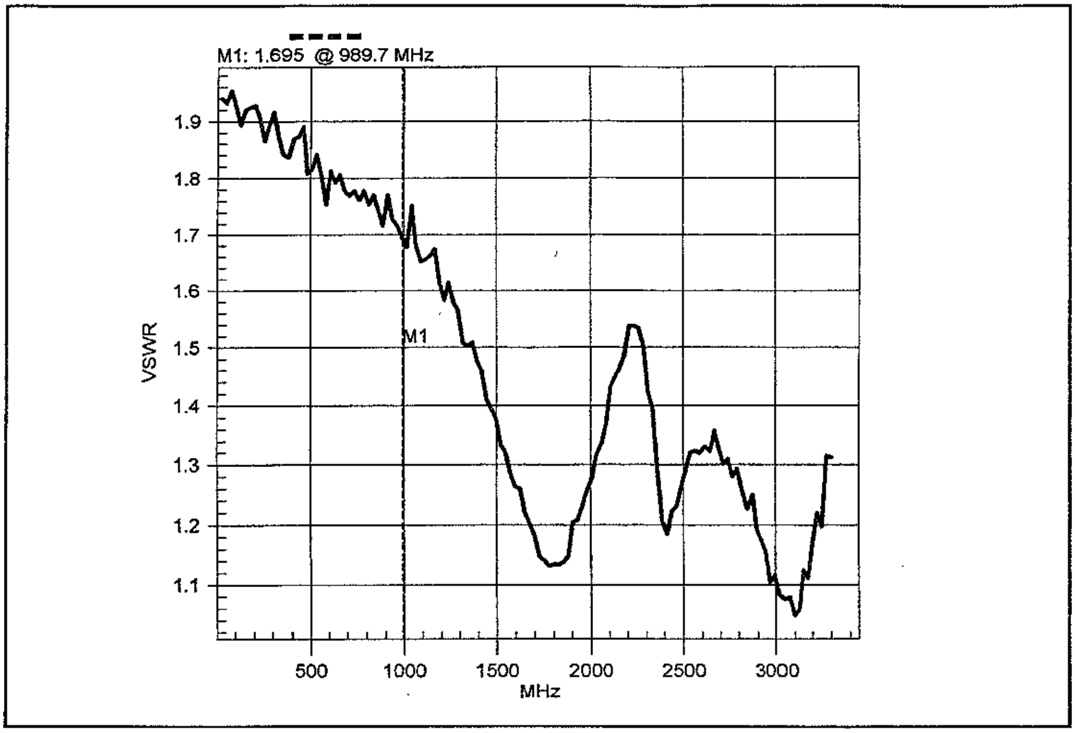


Figure 2. (A) VSWR (Reflection) of minimum attenuator setting (approximately -3 dB).

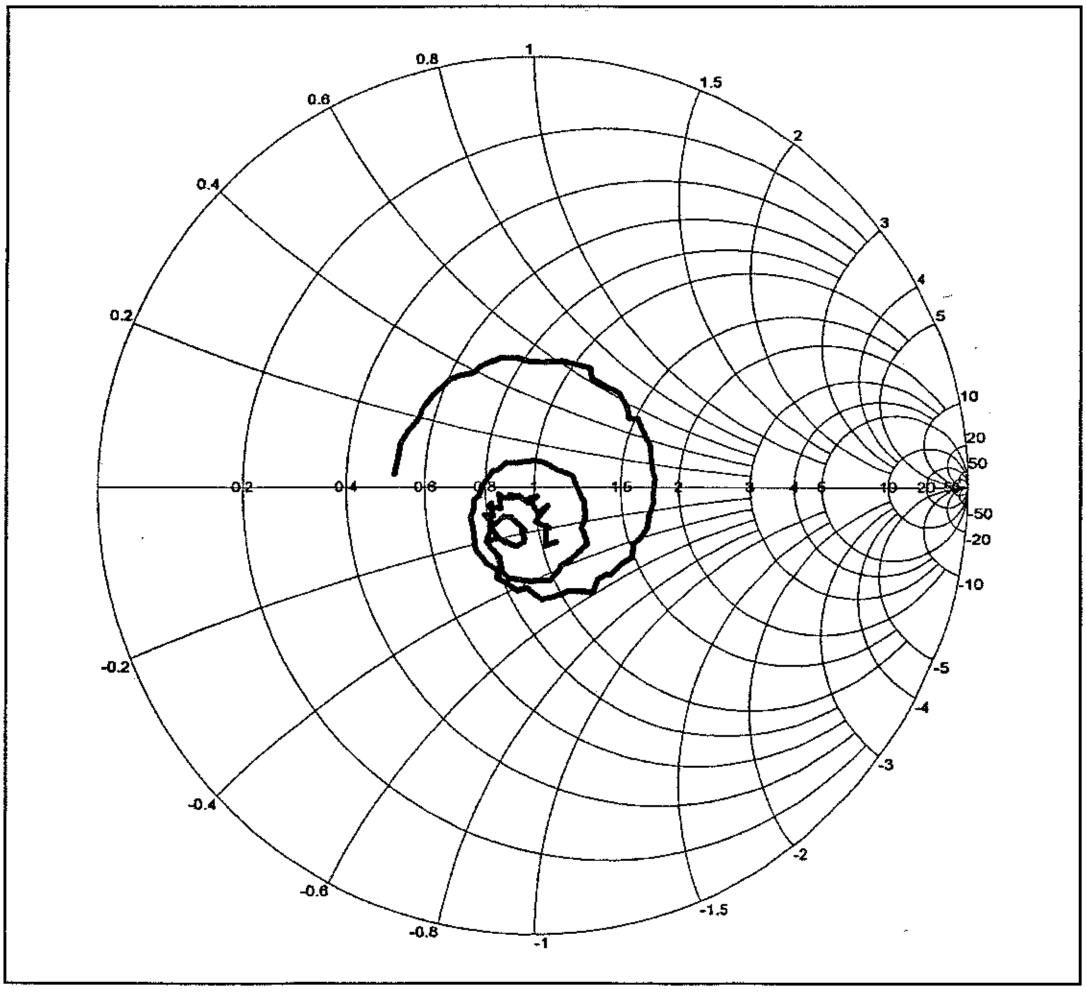


Figure 2. (B) Smith Chart plot.

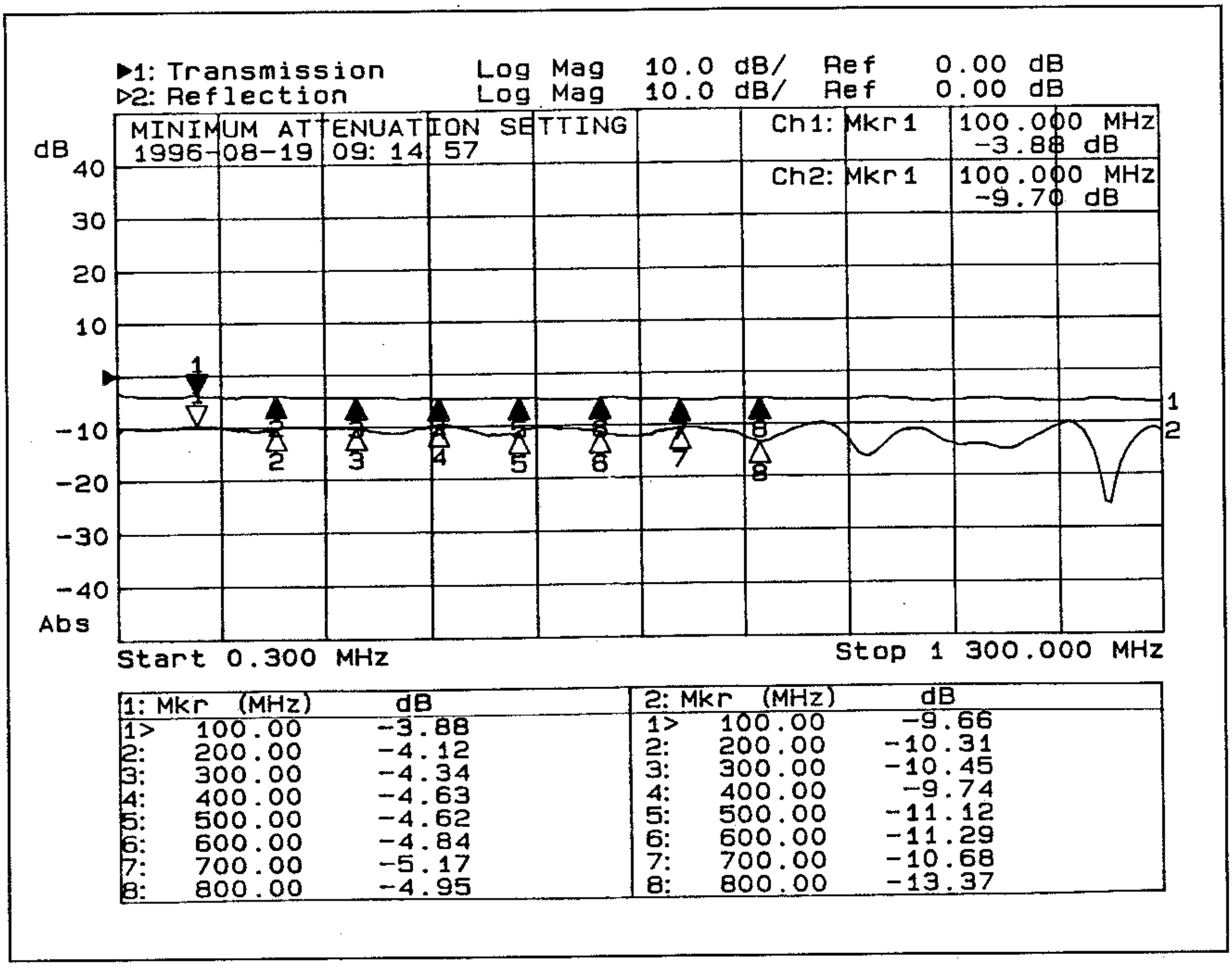


Figure 2. (C) Network analyzer plot of the circuit.

reflected by the circuit (for reference, 6 dB of return loss equals a VSWR of 3:1, 9.6 dB of return loss equals a VSWR of 2:1, and 14 dB of return loss equals a VSWR of 1.5:1).

Figures 5 through **8** show that 100-ohm fixed resistors yield the greatest adjustment range in this circuit. Standard carbon composition or metal-oxide fixed resistor legs to ground will generally yield excellent results. At higher frequencies, you'll need to keep all leads very short and neat for acceptable performance. At even higher frequencies, surface-mount chip resistors might be necessary to attain acceptable performance. Wirewound resistors must be avoided because of excessive inductance.

The choice of potentiometer is quite similar; again, wirewound varieties must be avoided. Unfortunately, this means that most of the high-quality, panel-mount, multi-turn potentiometers aren't usable because they're of the wirewound variety. However, many composition potentiometers are available in both the panel-mounted and on-the-board "trimmer"

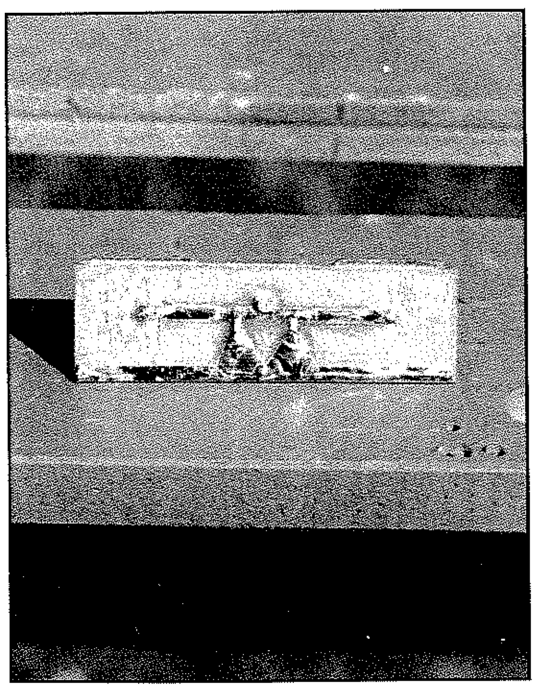


Photo A. Actual microstrip circuit usable to 1000 MHz.

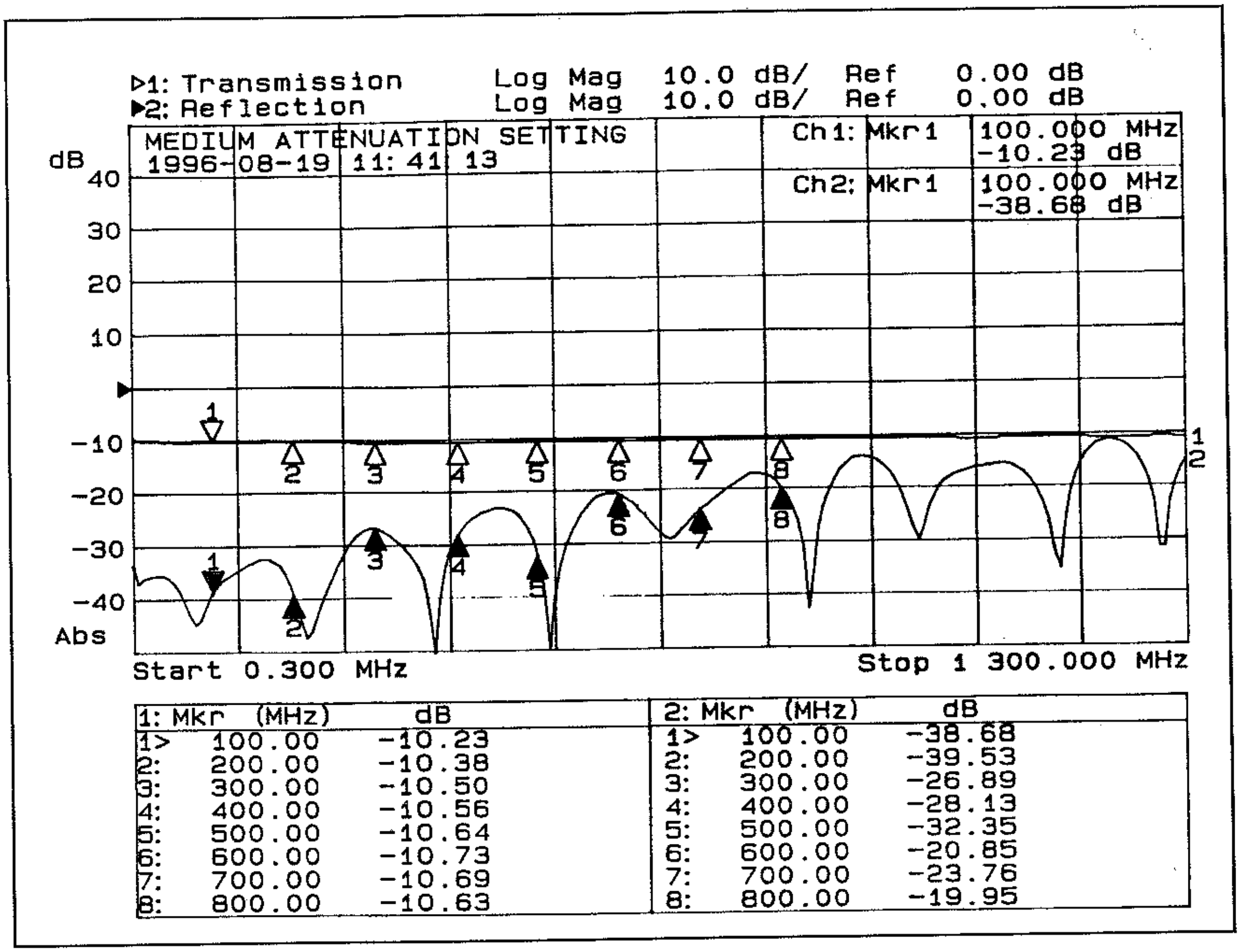


Figure 3. (C) Network analyzer plot.

style. Also, surface-mount "trimmer" potentiometers will push the upper frequency limit of the circuit even higher.

A Test Fixture

As an example, I made a test fixture with a surface-mount 5-k potentiometer installed on a 50-ohm microstrip, which I cut onto a small piece of glass epoxy FR4 double-sided board stock (**Photo A**). I used fixed value 100-ohm surface-mount chip resistors from the microstrip to a low impedance ground. I then tested this circuit on a network analyzer and was pleased to note excellent performance up to 1000 MHz.

For a lower frequency application at 28 MHz, I used a standard composition 1-k panel-mounted potentiometer on the side of a diecast box, with fixed value 100-ohm composition resistors to a grounding tab on the bottom of the box. The leads of the fixed resistors were left full size. The dressing of the mini-coax leads from the input and output BNC connectors on the opposite side of the box to the potentiometer weren't particularly neat or direct. However, the performance of this circuit was excellent to 100 MHz.

Circuit Applications

Applications in which I have successfully used this circuit, with various styles of execution, are as follows:

A. Panel mounted within a diecast box to allow smooth 28-MHz IF transmitter drive control for a transverter-based UHF system. A high-power amplifier is used with the moonbounce/terrestrial system, and a means of controlling drive is necessary during amplifier tuning. In addition, full transmit power isn't necessary for terrestrial communications, and this circuit allowed the 432-MHz RF output power to be easily adjusted from 10 watts to 1.5 kW (approximately 22 dB).

B. Board mounted and following an 850-MHz low noise amplifier, or LNA (preamplifier), which was to be used ahead of a spectrum analyzer. This allowed an accurate setting of

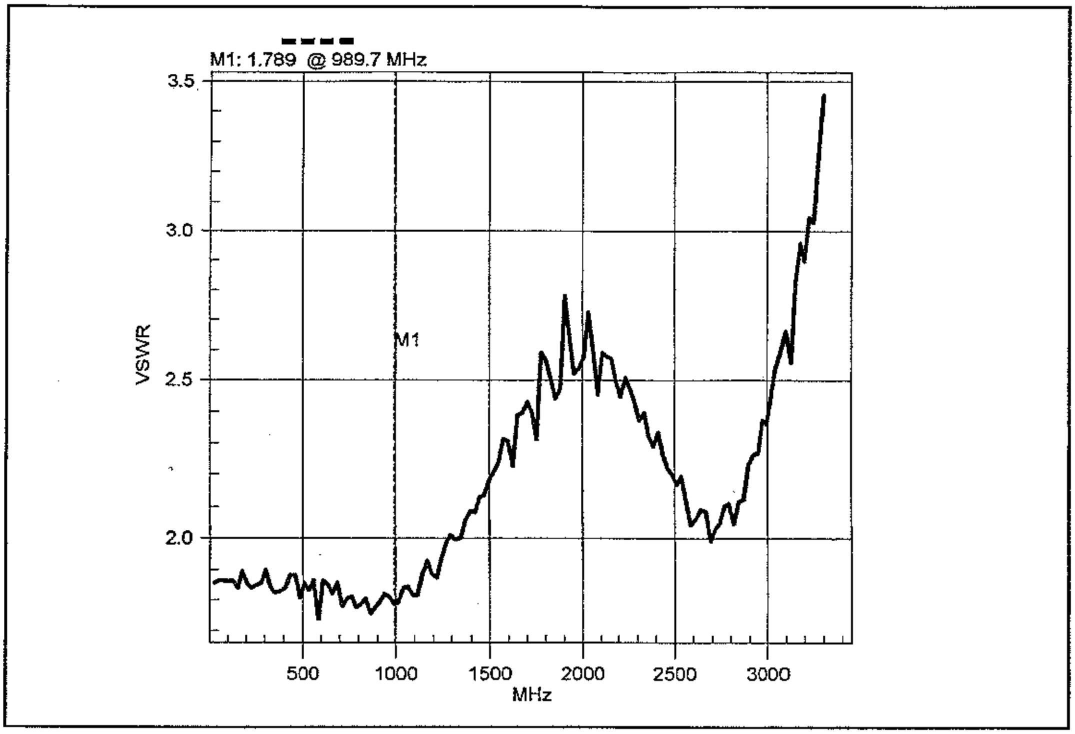


Figure 3. (A) VSWR (Reflection) of median attenuator setting (approximately -30 dB).

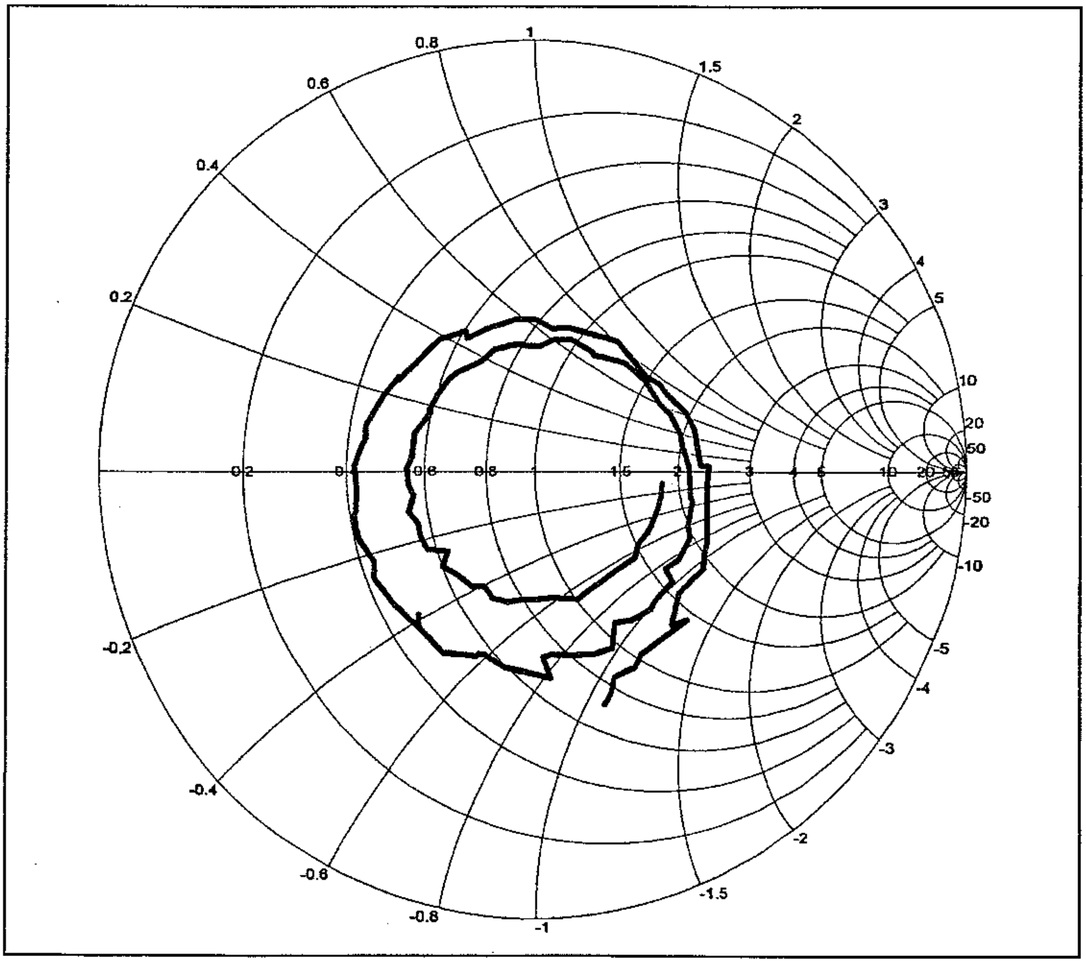


Figure 3. (B) Smith Chart plot.

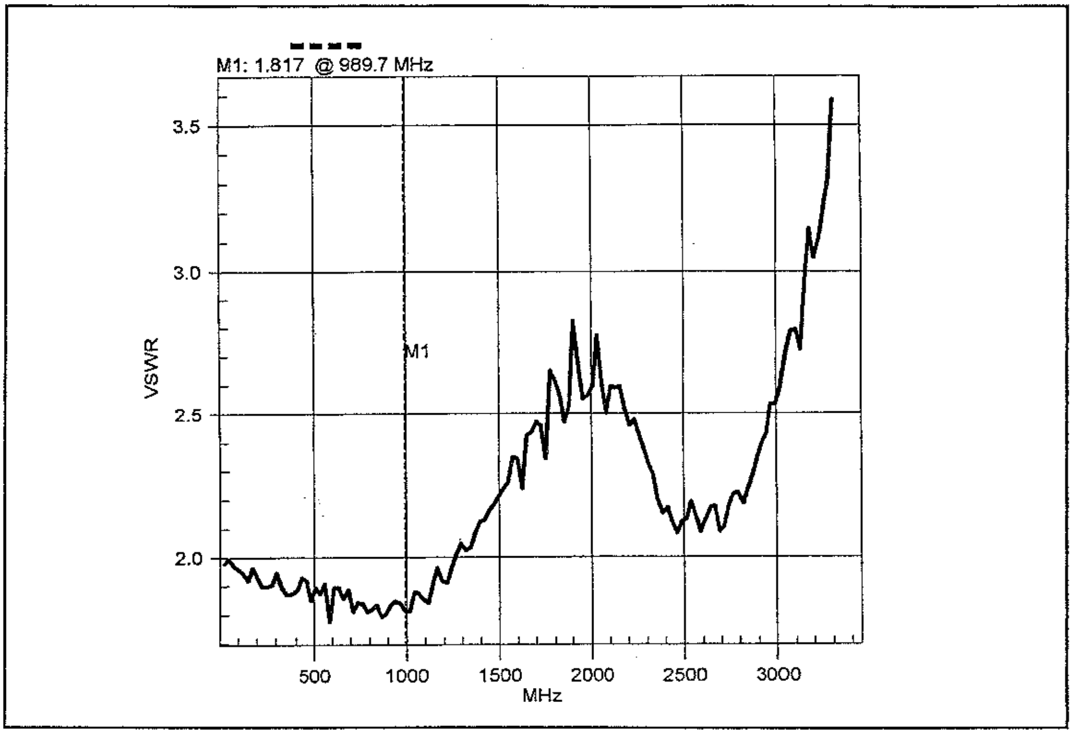


Figure 4. (A) VSWR (Reflection) of maximum attenuator setting (approximately -36 dB)

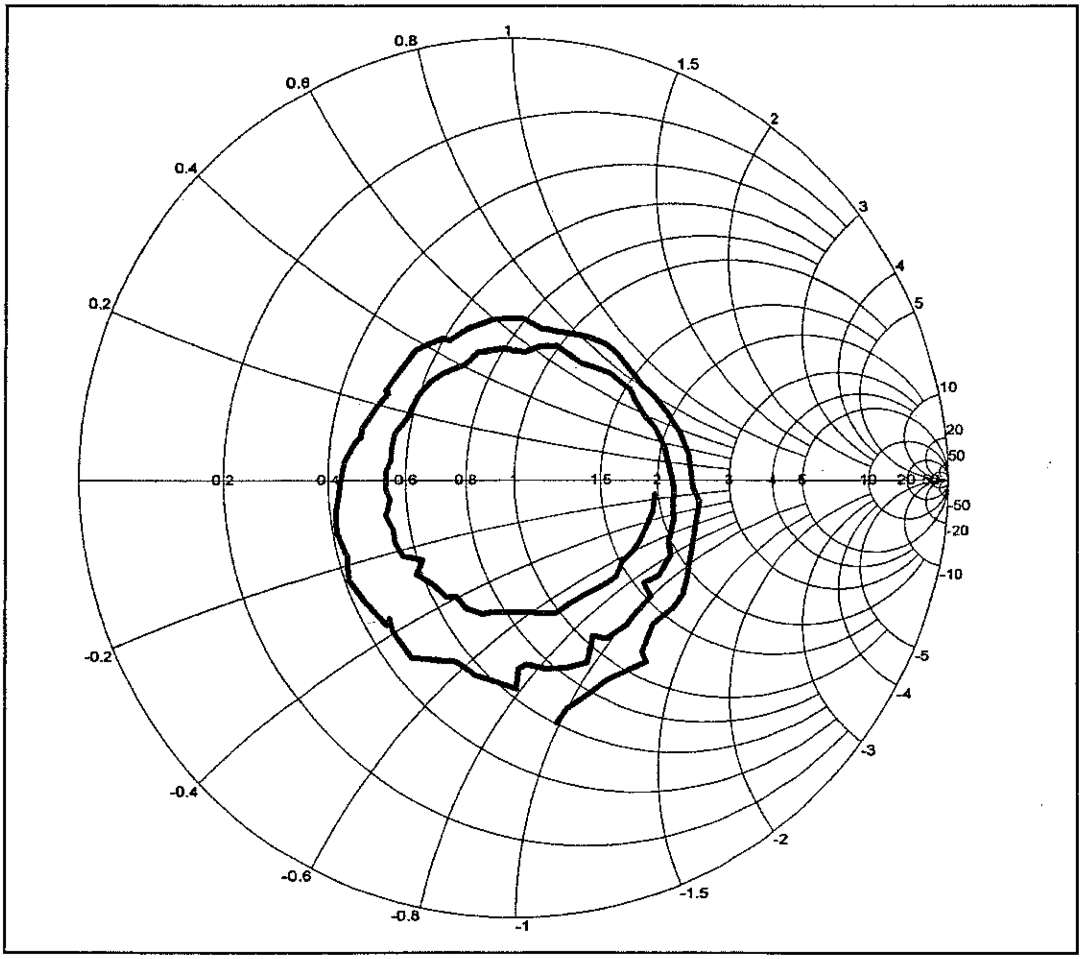
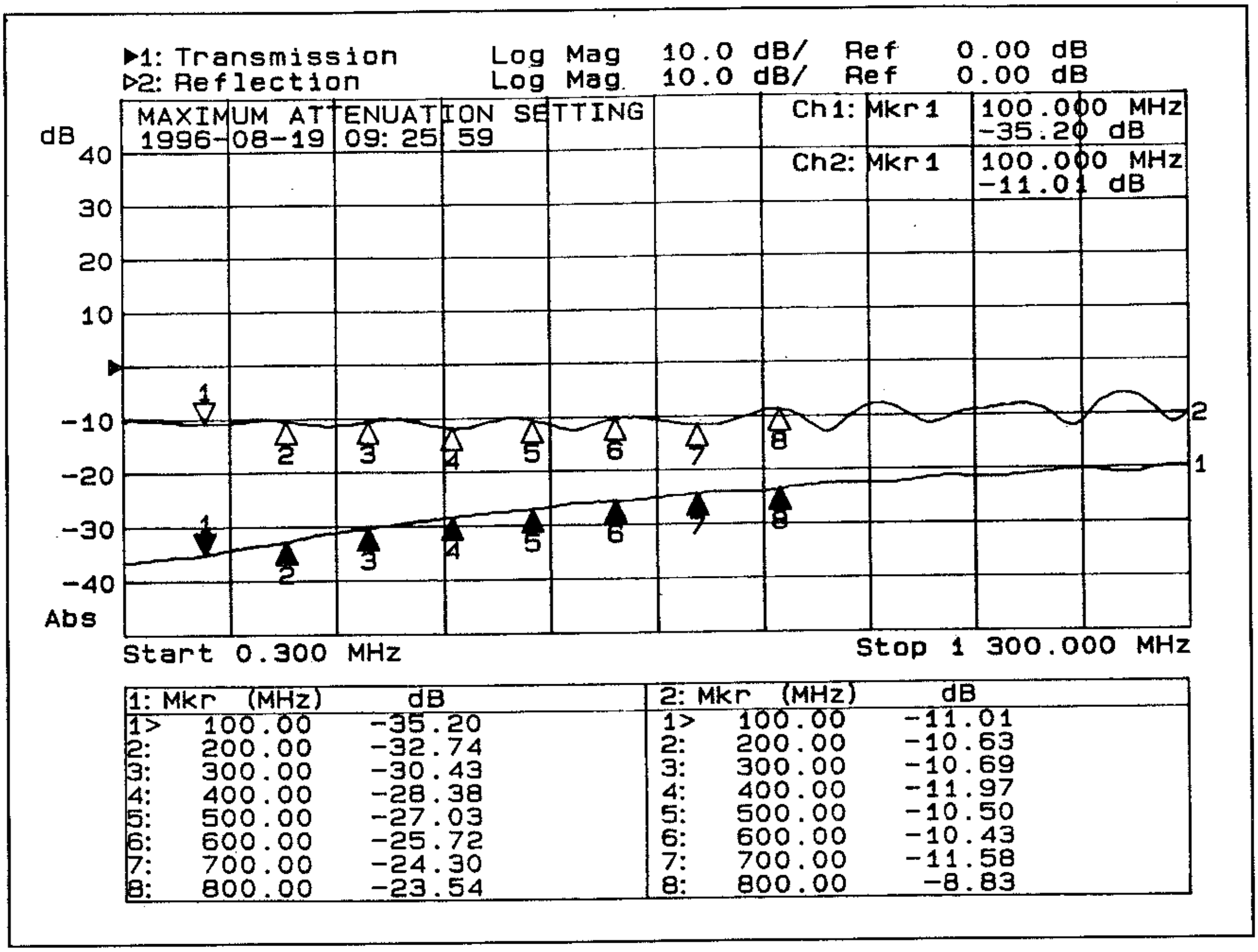


Figure 4. (B) Smith Chart plot.



1: Mkr	(MHz)	dB
1>	100.00	-35.20
2:	200.00	-32.74
3:	300.00	-30.43
4:	400.00	-28.38
5:	500.00	-27.03
6:	600.00	-25.72
7:	700.00	-24.30
8:	800.00	-23.54

2: Mkr	(MHz)	dB
1>	100.00	-11.01
2:	200.00	-10.63
3:	300.00	-10.69
4:	400.00	-11.97
5:	500.00	-10.50
6:	600.00	-10.43
7:	700.00	-11.58
8:	800.00	-8.83

Figure 4. (C) Network analyzer plot.

the system gain for noise floor measurements and calculations.

C. Board mounted between stages in HF, VHF, and UHF receivers to allow redistribution of gain for improvement in strong signal handling capability. This allows for the shifting of gain within the receiver for best strong signal handling while connected to the appropriate test equipment.

D. Board mounted and following a masthead preamplifier in order to avoid overloading a VHF receiver with excessive gain. This allowed the preamplifier's gain to be tweaked on the tower, once it was installed and tested, to take into account the feedline loss of the entire system.

E. Panel mounted and following a second-stage VHF preamplifier to allow adjustment in weak-signal receive system gain, this provided for changing antenna noise temperatures based on antenna position and time of day.

F. Panel mounted in small boxes as inexpensive VHF "Fox Hunting" adjustable attenuators.

Components for a practical attenuator

As a starting point, 100-ohm fixed resistors to ground with a 1, 2, or 5-k potentiometer will yield a very practical adjustable attenuator.

In **Figure 5**, you'll see that extraordinary adjustment range is possible via these potentiometer values. In addition, these potentiometer values tweak quite smoothly over their entire range. Potentiometer values over 5 k adjust extremely quickly and, as a result, are much coarser, albeit they allow for even greater range. This too is illustrated in **Figure 5**. It should be very clear that a tradeoff exists between adjustment range and smoothness. You must decide what it is that you need in your circuit.

When you're selecting potentiometers, you might also have a choice between linear and log varieties. Each has its own advantage based on the tradeoff you make between the adjustment range and the smoothness.

Good luck using these very practical adjustable attenuators. They've served me well!

Pi-Network Resistive Attenuator			
100 ohm Fixed Resistors to Ground			
Pot Value ohms	Attenuation dB	VSWR x:1	Reflection Coefficient
0	3.01	2	0.333
5	3.78	1.8	0.287
10	4.46	1.65	0.246
25	6.19	1.36	0.152
50	8.37	1.1	0.048
75	10.07	1.04	0.02
100	11.46	1.14	0.067
150	13.69	1.29	0.128
200	15.44	1.4	0.167
250	16.89	1.48	0.193
350	19.21	1.59	0.227
450	21.03	1.66	0.247
550	22.54	1.71	0.261
650	23.82	1.74	0.271
750	24.93	1.77	0.279
1000	27.22	1.82	0.292
1500	30.52	1.88	0.305
2500	34.77	1.92	0.316
5000	40.65	1.96	0.325
10000	46.61	1.98	0.329
100000	66.54	2	0.333

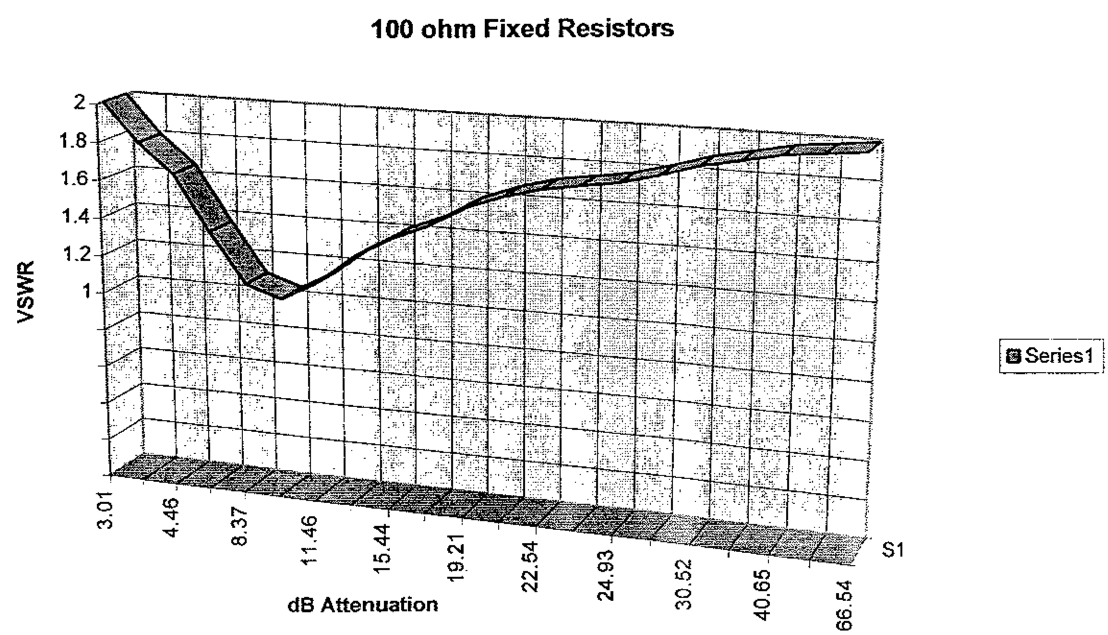


Figure 5. Pi-network resistive attenuator, 100-ohm fixed resistors to ground.

Pi-Network Resistive Attenuator			
150 ohm Fixed Resistors to Ground			
Pot Value ohms	**Attenuation dB**	**VSWR x:1**	**Reflection Coefficient**
0	2.22	1.67	0.25
5	2.88	1.51	0.203
10	3.47	1.39	0.162
25	4.98	1.13	0.063
50	6.92	1.11	0.05
75	8.45	1.29	0.125
100	9.72	1.43	0.179
150	11.76	1.67	0.25
200	13.39	1.84	0.295
250	14.74	1.97	0.327

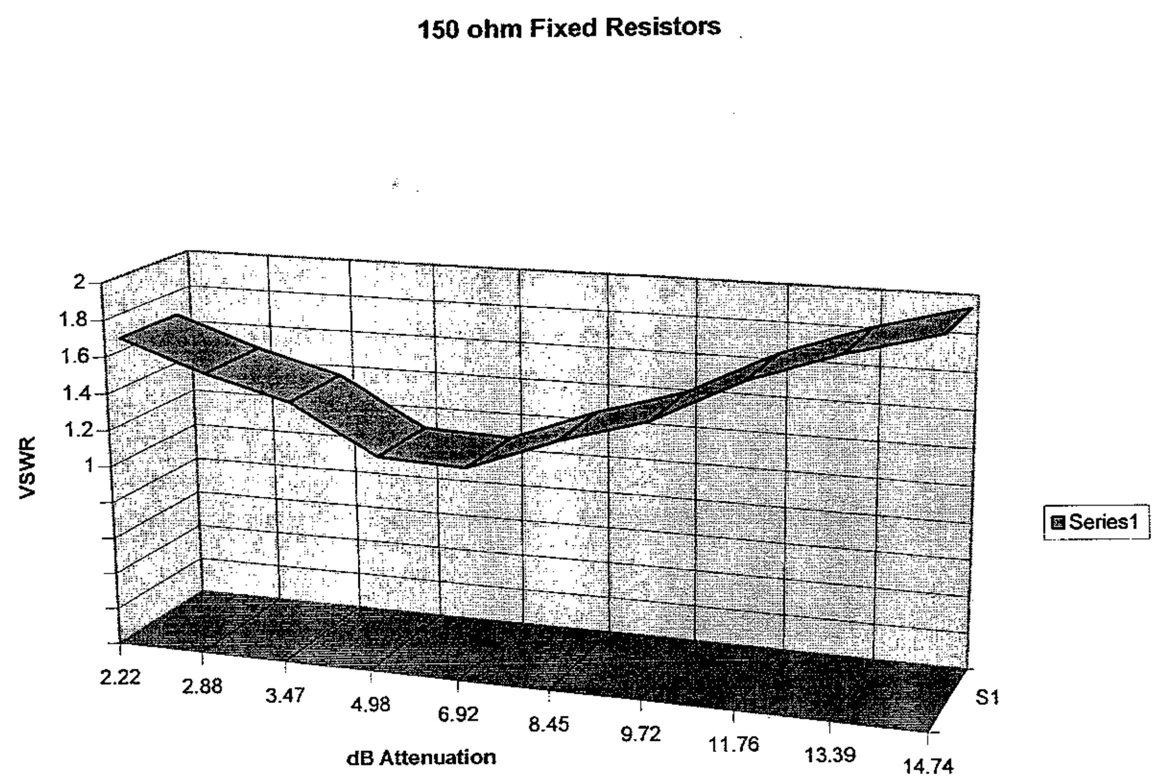


Figure 6. Pi-network resistive attenuator, 150-ohm fixed resistors to ground.

Pi-Network Resistive Attenuator			
220 ohm Fixed Resistors to Ground			
Pot Value ohms	**Attenuation dB**	**VSWR x:1**	**Reflection Coefficient**
0	1.63	1.45	0.185
5	2.21	1.32	0.138
10	2.74	1.21	0.096
25	4.1	1.01	0.006
50	5.87	1.28	0.125
75	7.26	1.52	0.205
100	8.42	1.72	0.264

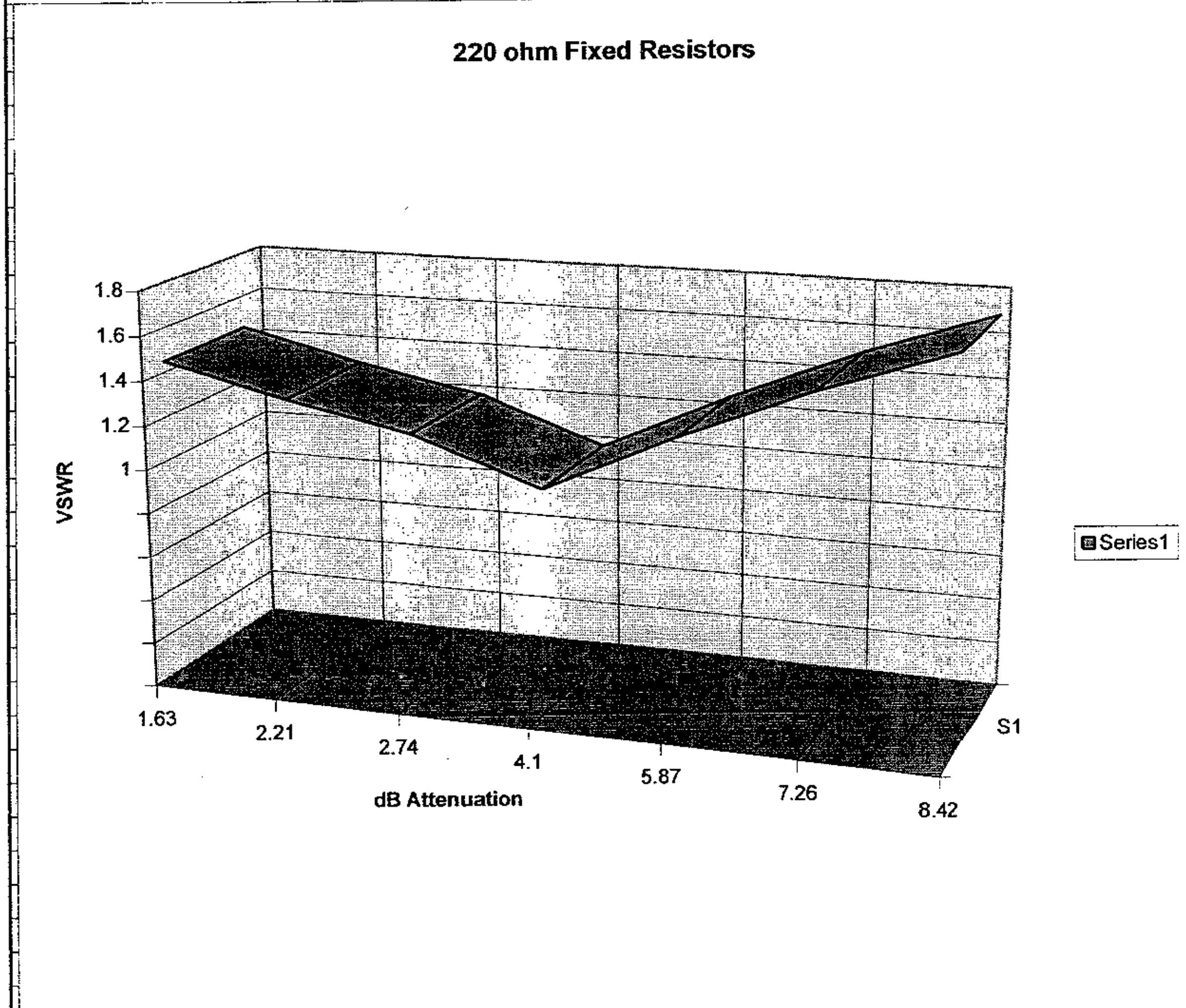


Figure 7. Pi-network resistive attenuator, 220-ohm fixed resistors to ground.

Pi-Network Resistive Attenuator			
1000 ohm Fixed Resistors to Ground			
Pot Value ohms	Attenuation dB	VSWR x:1	Reflection Coefficient
0	0.41	1.1	0.048
5	0.87	1	0
10	1.28	1.09	0.043
25	2.35	1.35	0.15
50	3.73	1.78	0.28

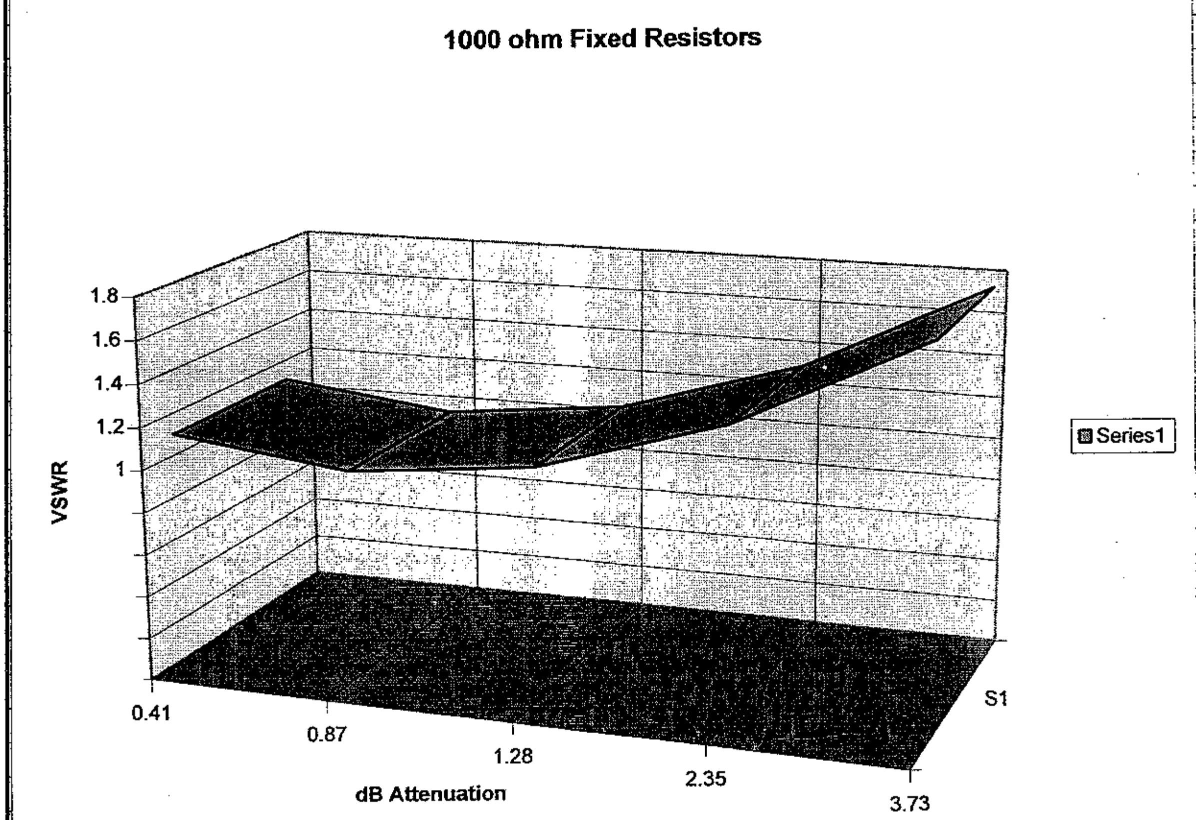


Figure 8. Pi-network resistive attenuator, 1000-ohm fixed resistors.