

Miniature SMA RF Step Attenuator

This design utilizes integrated RF attenuator surface mount device components that are very accurate over a wide frequency range.

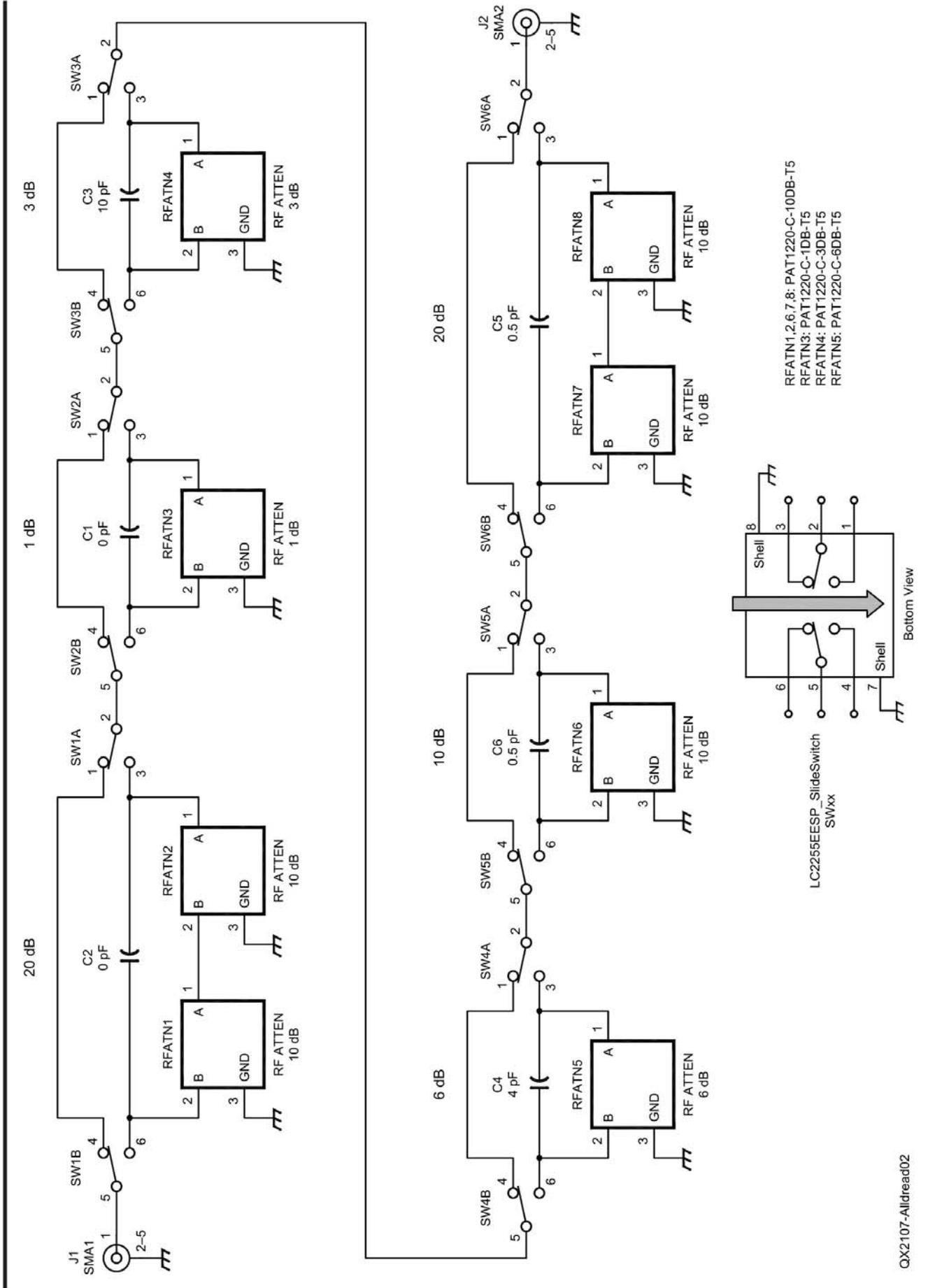
An RF step attenuator that provides a user friendly means for varying RF transmission path loss is a useful accessory for numerous amateur radio applications. Some examples are: to vary the output level of a signal source in calibrated steps, extend the measurement range of a signal analyzer, prevent the overload of a broadband receiver module, or as a comparison reference to establish the loss of a network. This step attenuator, which uses miniature SMA type coaxial connectors and wide band RF attenuator surface mount components, makes a convenient palm size companion for a number of small SDR receiver dongles. It also could prove to be a useful accessory for some of the portable, inexpensive RF measurement instruments that have recently become available such as the nanoVNA1 [1] and the tinySA [2].

Some traditional relatively large size step attenuator designs utilize toggle switches that required inter-stage shielding to prevent stray coupling. They typically were based on attenuator stages made up from multiple resistor combinations, some lacked wideband accuracy and because of the need for inter-stage shielding, they were relatively complex to build.

This article describes how to build an inexpensive, low power, relatively small size step attenuator similar to those shown in **Figure 1**. These attenuators have a 60 dB range and are small enough to fit in the palm of one's hand. They have demonstrated excellent accuracy to mid VHF frequencies and, with less accuracy, are still usable to 450 MHz.



Figure 1 — SMA RF step attenuators with accessories.



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Figure 2 — SMA step attenuator schematic. The parts are listed in Table 3.

This design utilizes integrated RF attenuator surface mount device (SMD) components that are rated for microwave use up to 10 GHz. They are available in 1 dB increments up to 10 dB, and cost about 50 cents each. Since only one chip is needed for most attenuation stages they provide a very inexpensive, tidy, highly accurate wideband solution for this application. The attenuator chips are roughly 0805 size, which most builders find are large enough to install using regular soldering tools while using commonly available magnification such as that provided by a magnification light or hood. The low cost latching push switches used here are enclosed within a metal body that eliminates the need for the provision of separate inter-stage RF shields. The components are mounted on a double-sided PCB strip that in turn is fastened to the enclosure lid via the input/output PCB edge SMA coaxial connectors. This PCB mounting method eliminates the need for any additional mounting hardware. Chassis work is easy, since the die-cast aluminum enclosure is fully prepared by simply drilling holes in the front panel lid according to the drilling template pattern provided here. This should be an easy single weekend project for the experienced builder.

Circuit Description

As shown in the **Figure 2** schematic, this attenuator has 6 stages that occupy the full

length of the small Hammond 1590A type, die cast aluminum enclosure. The design has some flexibility since the step sizes can easily be changed to suit one's needs by simply installing different loss attenuator chips. The chips are available with losses in 1 dB increments from 0 to 10 dB. The first attenuator that I built has a maximum attenuation of 50 dB and a pair of 10 dB steps. The second version, described here and shown in **Figure 2**, has two 20 dB steps and a maximum attenuation of 60 dB. The additional 10 dB range is provided by replacing the second 10 dB step with a 20 dB step, which I deemed preferable after measuring the enclosure stray coupling. I found it to be much higher than 60 dB, which confirmed that it was feasible to incorporate an additional 10 dB of range. This was determined by doing a frequency sweep with the 1 dB attenuator chip removed and with all attenuator stages switched in.

I provided step sizes of 20, 1, 3, 6, 10, 20 dB. A 2 dB step was not provided due to space limitations. The 2 dB increment was not considered as important as optionally using the last available stage to provide a higher maximum loss setting. The 1, 3 and 6 dB steps were considered significant for inclusion. The 1 dB step is important for calibration checks. The 3 and 6 dB steps are important for measuring the half-power and half-voltage points of a signal and have significance for checking response bandwidths and S-units.

The two SMA connector ports connect directly to the 20 dB stages, see **Figure 2**. These stages consist of two 10 dB attenuator chips in cascade. The SW1 – SW6 DPDT switches either bypass or insert the attenuator chip stages into the transmission path depending on the desired selection. The direct connection of the 20 dB attenuation stages to the SMA connectors at each end of the circuit maximizes the stray path isolation of the attenuator. This is important when using high attenuation settings. When both 20 dB stages are inserted into the signal path the most extreme high and low level signals within the attenuator enclosure travel only on very short PCB traces at each end of the PC board. This helps minimize the stray coupling between the input and output ports.

Mounting pads for compensation capacitors, that can be used to provide improved UHF response by compensating for stray high frequency losses, are provided for each stage. However not all stages are equipped with capacitors, note C1 and C2 are 0 pF in **Figure 2**. The values shown were selected empirically based on through-path swept frequency response and good port SWR across the spectrum of interest.

RF Performance Measurements

The swept frequency response loss from each individual stage and also the steps in cascade were measured with the wide dynamic range Signal Hound SA44B



Figure 3 — Signal Hound loss and nanoVNA SWR frequency sweep.

Table 1 – SMA step attenuator setting and measured attenuation for various frequencies.

Attenuator setting, dB	3 MHz	30 MHz	50 MHz	150 MHz	222 MHz	300 MHz	440 MHz
0	0.06	0.11	0.14	0.29	0.31	0.54	0.57
1	0.95	1.00	1.03	1.20	1.24	1.47	1.50
3	3.07	3.11	3.17	3.32	3.44	3.63	3.81
6	6.05	6.10	6.11	6.27	6.37	6.51	6.72
10	10.05	10.08	10.08	10.26	10.36	10.57	10.75
20	19.99	20.06	20.07	20.16	20.20	20.41	20.37
30	30.14	30.13	30.03	30.28	30.28	30.53	30.80
40	40.13	40.06	39.97	40.22	40.29	40.58	40.84
50	50.08	50.01	49.91	50.26	50.50	51.09	51.76
60	60.03	59.83	59.88	60.80	61.51	62.80	65.10

spectrum analyzer and companion tracking generator pair shown in **Figure 3**. The step attenuators shown here were the earlier versions. The frequency response resulting from one of the measurements with the attenuator set to 30 dB is shown in **Figure 4**. Direct views of some of the screen captured tracking generator measurement results can be downloaded from the ARRL **QEXfiles** web page [3]. The magnified vertical scale in **Figure 4** provides a detailed view of the response from 3 to 450 MHz where the high end rolls off about 0.8 dB.

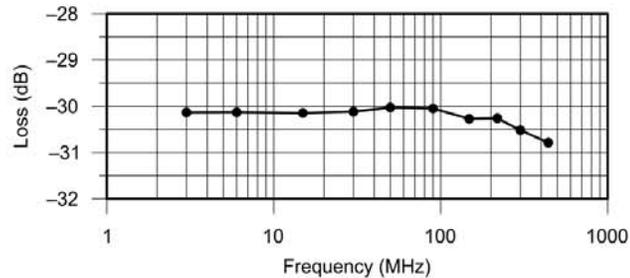
Table 1 shows the measured insertion losses obtained from similar frequency sweeps for 10 of the possible step attenuator settings. Results for steps from 0 to 60 dB at 7 frequencies from 3 to 440 MHz are listed. All steps up to 50 MHz were within 0.33 dB. Steps from 0 to 50 dB were within 0.50 dB up to 222 MHz. For 440 MHz the losses remain within 1 dB of the setting up to 40 dB. Note that for many cases the step change values are very close, which is an important consideration when making relative measurements. For example at 150 MHz the difference between the 30 and 40 dB steps is $(40.22 - 30.28) = 9.94$ dB, off by just 0.06 dB. For UHF signals the high insertion loss 50 and 60 dB steps are still of use for trouble shooting despite the diminished accuracy.

The quality of impedance match in terms of SWR for all the stages was measured using the nanoVNA (also seen in **Figure 3**). **Figure 5** shows SWR graphical results for the 6 dB setting obtained via the PC *nanoVNASaver* software application. **Table 2** lists SWR measurements at the marker frequencies obtained from similar tests for each of the steps. The quality of impedance match agreed very nicely with SWR results for all attenuation stages up to 150 MHz at better than 1.1:1 and better than 1.25:1 at 450 MHz.

For a practical test I made a comparison

Table 2 – Measured SWR for SMA step attenuator settings at various frequencies.

Attenuator setting, dB	3 MHz	30 MHz	50 MHz	150 MHz	450 MHz
0	1.01	1.02	1.02	1.06	1.17
1	1.01	1.01	1.01	1.02	1.25
3	1.00	1.01	1.01	1.02	1.10
6	1.00	1.00	1.01	1.03	1.20
10	1.01	1.01	1.01	1.02	1.25
20	1.01	1.02	1.03	1.07	1.21



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Figure 4 — 30 dB step frequency response from 3 to 450 MHz.

to my HP 8656B high quality signal generator. I set my HP8656B to 14.2 MHz in CW mode at a level of -100 dBm for starters. I connected it via the SMA step attenuator to an SDRplay RSP1 [4] type receiver controlled by spectrum analyzer software. I set the spectrum analyzer y-axis to 2 dB/div. I set the span to a narrow 1 kHz, an 8 Hz resolution bandwidth, and with 100 measurement averaging. With the step attenuator set to 0 dB I found the measured level to be -100.6 dBm. The HP8656B level was then increased to -70 dBm and the attenuator set to 30 dB using three different attenuator stage combinations. The measurement results were:

$$J1_20 + 10 \text{ dB} = -100.6 \text{ dBm}$$

$$J2_20 + 10 \text{ dB} = -100.5 \text{ dBm}$$

$$J2_20 + 6 + 3 + 1 \text{ dB} = -100.5 \text{ dBm.}$$

In all three cases in the middle of the HF band the step attenuator matched the HP8656B attenuator to within 0.1 dB. It was amazing to see how closely the SDR receiver spectrum analyzer measurement matched the absolute output level of the signal generator. Of interest for verifying the possibility of using the TinySA generator output as a signal source for receiver sensitivity testing, it was likewise set to -70 dBm at 14.2 MHz and used as the signal source in place of the HP8656B. The measured level was -101.1 dBm roughly a half a dB lower than the HP8656B output level, very close indeed!

The Switch Solution

My previous experiences with more than one commercial step attenuator have not always been that great because of erratic switch contact performance. In some cases toggle switches were used that did not have gold plated contacts that presumably had become tarnished or corroded [5]. The switches were essentially sealed and as such not designed to permit cleaning with contact cleaner. Nothing much could be done for repairing the problem except replacing the switches, which wasn't very practical to do.

The mechanical design of the plunger-activated slide switches chosen for this design is a nice fit for this application, since the switch metal body doubles as the inter-stage shield and the contact slider design presents a low impedance to the RF path. I would have preferred switches with gold plated contacts, however I could not find any with similar mechanical design features nor any that were affordable.

Initially I built two attenuators using very inexpensive switches that I purchased online from a source in China. I based the mechanical design and the PCB artwork layout for the use of these very economical switches. To make a long story short, I found the contact resistances to be unstable and higher than spec. Cleaning the contacts with a good contact cleaner got them to work okay for a while but after being left unused for a month or two the problems resurfaced.

In pursuit of a better switch alternative

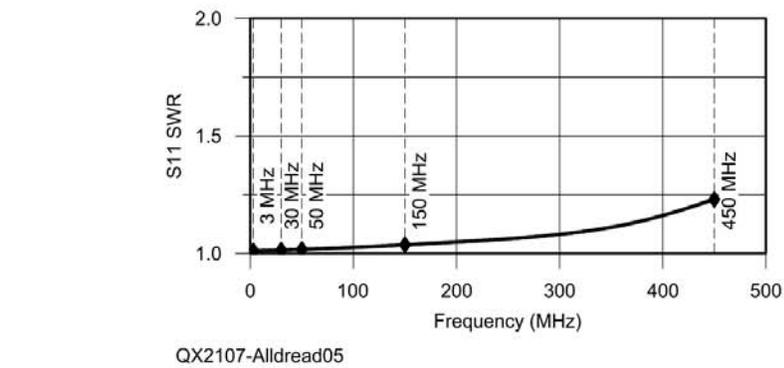


Figure 5 — 6 dB step SWR frequency sweep from 50 kHz to 450 MHz.

I tried a somewhat more expensive set of switches from a North American supplier. Fortunately they have a matching mechanical design and have an identical PCB footprint that matched my existing PCB board artwork. Based on the spec sheet illustrations these alternative switches looked almost identical to ones I initially used, thus I got the impression that they may have been made by the same manufacturer. I wasn't optimistic that they would be any better. But upon delivery and close examination I noticed these alternative switches were clearly a more rugged design. I built up two more attenuators using these slightly pricier switches. I was delighted to discover the contact resistances measured lower than spec and remained consistent. There was no need to mess with any contact

cleaning. The extra cost for a full set of the better switches amounts to about US\$6 total per attenuator, which is less than half the cost of a can of contact cleaner; clearly it is a better choice. At the time of this writing the alternative switches recommended here continue to work flawlessly.

Parts Acquisition Tips

The parts cost per attenuator can be reduced significantly if a small group gets together to build several attenuators, and purchase a small batch online of bare PC boards, enclosures and connectors from a supplier in Asia. In a quantity of 5 or 10, printed circuit boards can be delivered by courier to North America from a variety of PCB houses in China for \$5 or less per board. The enclosure

Table 3 – Parts list.

Reference	Description		Manufacturer Part #	Manufacturer	Digi-Key #
RFATN1,2,6,7,8	RF ATTENUATOR 10DB 50OHM 0805	5	PAT1220-C-10DB-T5	Susumu	PAT1210CT-ND
RFATN3	RF ATTENUATOR 1DB 50OHM 0805	1	PAT1220-C-1DB-T5	Susumu	PAT121CT-ND
RFATN4	RF ATTENUATOR 3DB 50OHM 0805	1	PAT1220-C-3DB-T5	Susumu	PAT123CT-ND
RFATN5	RF ATTENUATOR 6DB 50OHM 0805	1	PAT1220-C-6DB-T5	Susumu	PAT126CT-ND
C5,6	CAP CER 0.5PF 50V COG/NPO 0805	2		Yageo	311-1094-1-ND
C4	CAP CER 4PF 50V COG/ NPO 0805	1		Yageo	311-1093-1-ND
C3	CAP CER 10PF 50V COG/NPO 0805	1	CC0805JRNPO9BN100	Yageo	311-1099-1-ND
SW1,2,3,4,5,6	SWITCH PUSH DPDT 0.3A 30V	6	LC2255EESP	E-Switch	EG5891-ND
J1,2	CONN SMA JACK STR 50OHM EDGE MNT	2	732512120	Molex	WM5536-ND
RF tight Enclosure	BOX ALUM UNPAINTED 3.64"LX1.52"W	1	1590A	Hammond Manufacturing	HM150-ND
rubber feet	BUMPER HEMI .37" DIA X .21" BLK	1	BS22BL05X06RP	Bumper Specialties Inc.	2042-1050-ND
Bare PC Board	Order direct from Mfr or contact VA7TA	1	Gerber Step Atten zip file	JLPCB	N/A

and connectors can also be purchased online from Asian sources at a lower cost compared to North American pricing. However the purchasing of the enclosure and connectors from Chinese sources may not be worth the inconvenience for making just a single attenuator considering the typical tardy delivery times for low-cost shipping methods and minimal saving for a one-off build. The SMD chips and better quality switches need to be purchased from local suppliers — fortunately they are quite inexpensive.

Table 3 includes a reference parts list intended as a guideline for the identification and procurement of components.

Construction

Figure 6 shows the switch side of the completed PCB, which is mounted via the SMA connectors to the underside of the enclosure lid. The pads for the compensation capacitors can be seen behind the switch housings. **Figure 7** is a view of the attenuator chip side of the PCB. The

two pairs of cascaded 10 dB attenuators that make up the 20 dB stages can be seen at each end of the PCB. The manufacturing Gerber files for the PCB are contained within a zip archive that is available for download from the ARRL **QEXfiles** web page [3]. The author has a few extra boards left over from the batch which was obtained from a professional PCB manufacturer that are available to those that may wish to purchase just a single board via regular letter mail delivery.

To ensure proper switch plunger shaft alignment with the front panel holes, the two SMA PCB edge coaxial connectors should be left unsoldered to the PCB until after mounting to the enclosure lid. This allows for the shifting of the PCB ever-so-slightly for final switch plunger actuator shaft alignment to the front panel hole centers. Once proper alignment has been achieved the connectors can be soldered to fix the PCB board in place. I found with one connector I needed to bend one of the connector ground tabs out slightly to match up with the corresponding PCB pad.

Figure 8 is a close up view of the plunger shaft style slide switch. I attached 1/4" cylindrical caps for my very first attenuator (see **Figure 3**). A downside to using caps is that they require larger holes in the front panel, which could lead to signal leakage. I discovered that the plunger shafts are long enough to protrude beyond the front panel and the switches can be easily operated without caps. I decided to not use caps for later versions. I found it easier to tell the attenuation IN/OUT position of the switches without the plunger shaft caps. A black indicator band that is visible only when the shaft is out (i.e., when the attenuator stage is bypassed) can be drawn around the plunger shaft with a very fine marking pen.

A drilling template graphics file is also available for download from the ARRL **QEXfiles** web page [3]. **QEXfiles: Photo7** shows the drilling template that I used for the first attenuator version. It is shown centered and taped to the enclosure lid front panel face. The template has since been updated mainly to specify smaller holes for the switch plunger shafts without caps. It is important to use a template to achieve proper positioning of the holes. The template graphics file has 100 mm scale calibration lines for each dimension. After printing, it is important that the line lengths on the printed copy be carefully measured and confirmed to be within the 99.5 to 100.5 mm range. Once the template is cut out, properly positioned and securely taped to the panel face, a center punch was used to accurately mark the holes. Then a small diameter, 1/16" bit was used to drill pilot holes through each punch mark. Then progressively larger bits were used to enlarge the holes to the final size as specified on the template. For the recommended design without the push button knob caps 13/64" holes are used for the switch plunger shafts and 1/4" holes for the SMA connectors. To ensure the square switch shafts don't catch on the sharp edges of the 13/64" holes a larger 5/16" bit should



Figure 6 — Step attenuator PC board, switch body side up view.

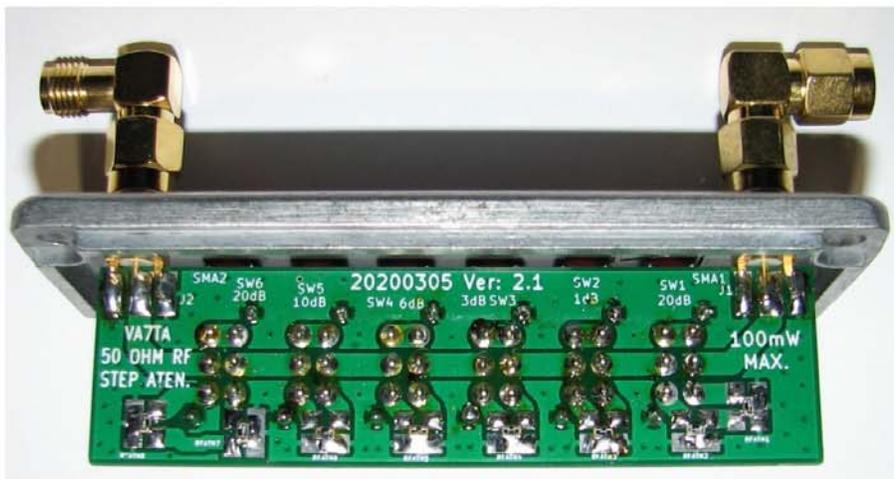


Figure 7 — Step attenuator PC board, attenuator SMD side up view.



Figure 8 — Plunger style slide switch.

be spun by hand from both the inside and outside of the front panel to bevel-shave the sharp edges off each switch shaft hole.

To confirm the switches are functional, the through resistance of all the switch contacts in cascade should be measured with a low measurement voltage digital ohm meter set to the lowest scale. This is done by setting the attenuator to 0 dB, which bypasses all of the attenuation stages. A pair of extra SMA female PCB connectors was used with short SMA jumper cables to connect to the attenuator. Alligator test leads completed a secure connection to the ohm meter. With the attenuator set to zero the center conductor through resistance should measure no more than a few tenths of an ohm. The attenuator described here measured 0.1 Ω . The actual meter reading was 0.7 Ω as the test lead resistance was found to be 0.6 Ω leaving 0.1 Ω within the attenuator. Exercising each switch from **BYPASS** to **INSERT** and back to **BYPASS** did not change the all-bypassed reading. In contrast, after not being used for a few months my first attenuator with the switches purchased from an Asia supplier measured 4.0 Ω , after exercising the switches the resistance dropped to 1.9 Ω , dramatic consistency difference between switches! To put this into perspective, an unwanted 5 Ω switch contact resistance within this 50 Ω transmission impedance environment would result in roughly a 10% voltage drop, which would be roughly equivalent to 1 dB additional unwanted insertion loss.

High humidity and moisture from condensation is the contact corrosion enemy. As shown in **QEXfiles: Photo 8**, to maintain a dry environment, a couple of small packets of silica gel desiccant were placed in the bottom of the housing prior to closing the enclosure. I plan to replace the gel packs about once a year, which I think should keep the switches nice and dry.

QEXfiles: Photo 9 shows the completed attenuator labeled with Brother Ptouch® self adhesive label tape. Rubber stick-on feet were attached to the bottom of the enclosure, which helps prevent the attenuator from sliding around and of course protects bench/desktop surfaces.

Applications

The RF step attenuator compared to other attenuator types offers spur-of-the-moment ease of use for the operator. In comparison fixed coaxial attenuator alternatives, which must be swapped out to change the path loss, are relatively awkward to use. In the case of the SMA type coaxial attenuator this swapping involves the process of loosening and re-torquing the connector retaining nuts. In applications where the attenuation value needs to be changed rapidly, fixed attenuators are not practical. In such applications the step attenuator shines.

This project could provide a good accessory for many RF signal sources with fixed level outputs. It could be used to provide an adjustable output level capability for a number of inexpensive RF generator module designs that can be purchased online. Most are based on either direct digital synthesizers that are best operated at full output level or PLL integrated circuits that have fixed output levels.

The step attenuator can be a useful accessory for extending the output level range of signal sources for making measurements. As mentioned above, the recent tinySA2 [2] handheld battery operated spectrum analyzer has a signal generator feature. Its output level can be varied from -6 to -76 dBm. However the -76 dBm output, which is close to S9 on an S-meter, is too high a level for receiver sensitivity testing. This attenuator could be used as a tinySA accessory to provide levels as low as -136 dBm (0.0355 μ V) to accommodate measuring typical receiver sensitivity.

Limitations

The maximum power rating of the attenuator chips is 100 mW, which is less than traditional step attenuators that use half watt resistors. However the power handling range could be extended to a full 2 W with the use of an external 20 dB SMA barrel attenuator accessory (**QEXfiles: Photo 10**). These SMA attenuators are available in several different loss values from an online supplier [6]. The right angle SMA adapters (**QEXfiles: Photo 10**) are a convenience that allow the use of shorter and/or less flexible test leads when the attenuator is used on a bench top.

Conclusion

This attenuator design provides very accurate insertion loss steps for RF signals up to mid VHF frequencies and remains usable with some accuracy limitations up to the 70 cm amateur band. It can be built using low cost readily available components and is easy to build with hobbyist level electronics construction tools. With minimal routine maintenance it should provide many years of reliable service.

Tom Alldread, VA7TA, was interested in electronics since grade school. In his teens he repaired radio and television sets. He obtained his amateur radio license in 1965, and upon graduating from technical college obtained his commercial radio operator certification. He graduated from the Capitol Radio Engineering Institute Engineering Technology program. Tom worked in the telecommunications industry as a microwave, multiplex and VHF radio equipment maintenance technician, an instructor, an engineering standards and design specialist, and in the Middle East as adviser for long distance network operations management. Now retired, Tom and his wife Sylvia, VA7SA, live on Vancouver Island. Tom, is a member of The Radio Amateurs of Canada, enjoys operating CW, designing equipment, and supporting emergency communications. He has been net manager for the SSB/CW 20 meter Trans-Canada Net (www.transcanadanet.com) for more than a decade. His interests include microcontroller development projects associated with amateur radio. Tom won second place in the Luminary 2006 DesignStellaris contest and first place in the 2011 Renesas RX contest. Other hobbies include computing, RVing, hobby farming and bicycling.

Notes:

[1] <https://groups.io/g/nanovna-users/>.

[2] <https://groups.io/g/tinyasa/>.

[3] www.arri.org/qexfiles.

[4] <https://www.sdrplay.com/spectrum-analyser>.

[5] <https://www.finishing.com/>.

[6] <https://www.aliexpress.com/>.

Additional resources listed here are on the www.arri.org/qexfiles page:

QEXfiles Photo 7 – Drilling template taped to enclosure front panel lid.

QEXfiles Photo8 – Desiccant pack humidity protection.

QEXfiles Photo9 – Assembled step attenuator completed with labels.

QEXfiles Photo10 – Recommended accessories: right angle adapters and 2 W 20 dB attenuator.