HOMELAB PROJECT

RF Step Attenuator

Adjustable attenuation gives precise signal levels

By **Alfred Rosenkränzer** (Germany)

When dealing with radio-frequency signals it often comes in handy to have an easy way to attenuate a signal level in discrete steps. For example, you might want to reduce the output of an RF generator to a lower level than the output control on the generator allows, and there are many other applications of attenuators in the adjustment and repair of receivers and other radio equipment. Unfortunately professional attenuators are rather pricey, but they do not contain any expensive electronics and so a DIY approach is an eminently practical alternative.

Sometimes it is necessary to attenuate an RF signal by a known amount. If the signal comes from an RF source whose level cannot easily be adjusted, then there is no real alternative to an external attenuator, which is normally simply inserted into the RF output connection. Such an arrangement is useful, for example, when testing the sensitivity or small-signal behavior of a receiver: just insert the attenuator in the antenna lead and increase the degree of attenuation

Features

- Switched RF attenuator with six stages, 0 dB to 31 dB attenuation in 1 dB steps

to the point where reception starts to fail or where whatever phenomenon is being investigated, perhaps noise or AFC artifacts, starts to raise its head. Many other applications of attenuators will be immediately obvious to any RF engineer. The familiar names in test equipment manufacture produce good-quality attenuators (see **Figure 1**) but unfortunately at a price that not all experimenters will be comfortable shelling out. But an attenuator basically consists only of an enclosure, connectors, switches and a few resistors. With a little care it is perfectly possible to build a good attenuator for the common frequency bands yourself for a much more reasonable price.

Attenuator circuit

There are two different but equivalent circuit configurations used to attenuate signals while maintaining impedance matching (in other words, the input and output impedances of the circuit are the same, but the signal level is not). These are called a T-type attenuator and a pi-type attenuator. Each configuration consists of three resistors (see **Figure 2**). For this project I selected the pi-type attenuator as it makes the printed circuit board layout more convenient. When working with RF a printed circuit board is preferable to hand wiring, as it ensures that all stages can be made geometrically identical and helps keep parasitic inductances and capacitances under control. **Figure 3** shows the resulting circuit of a

Figure 1. Example of a VHF attenuator by HP, long since out of production.

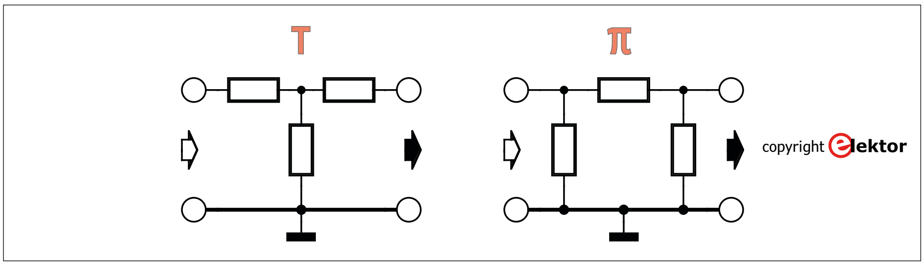

Figure 2. T-type and pi-type attenuator networks.

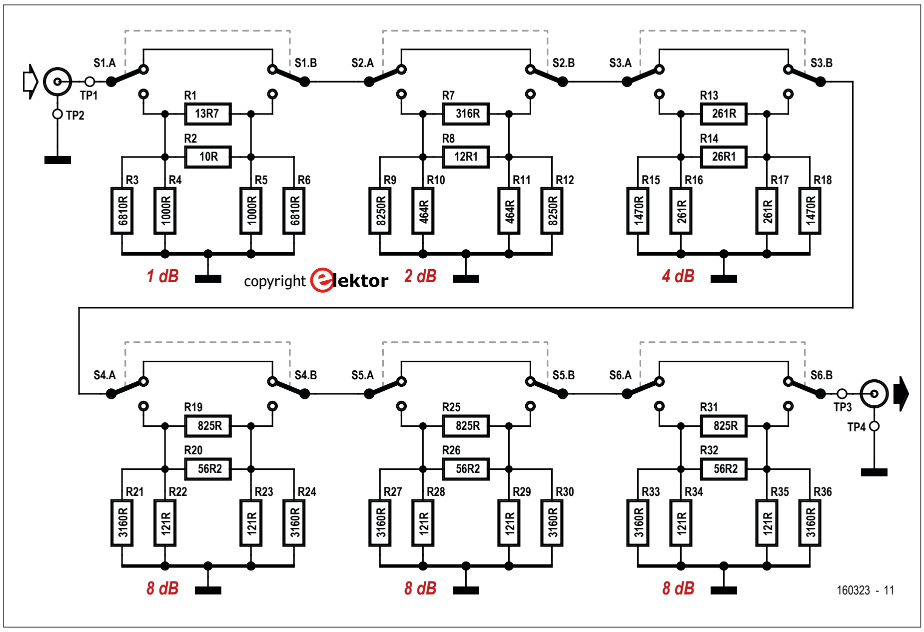

Figure 3. Complete circuit of the six-stage attenuator.

six-stage attenuator. It simply consists of six cascaded pi-type attenuator stages each of which can be optionally bypassed using a double-pole switch. A point to note is that each resistor in each pi network has been replaced by a parallel combination of two resistors. This allows the calculated ideal value of each resistor to be realized accurately despite only using standard E-series values. In total, then, the circuit comprises six switches and (up to) 6 × 3 × 2 = 36 resistors.

The desired attenuation of each stage is achieved by choosing appropriate values for the resistors. In theory any attenuation between 0 dB and ∞ dB can be realized; however in practice the maximum attenuation is limited to about 10 dB, as beyond that parasitic effects in the components, printed circuit board and switches (which are not specially designed for RF applications) come into play. The smallest degree of attenuation used in the circuit is 1 dB, although fractions of a decibel could of course be implemented.

If a switch is in its upper position, its stage is bypassed and the signal is not attenuated. In the lower position, the signal passes through the attenuator stage. The attenuation levels of the individual stages can be chosen independently, as the input and output impedances of all the stages are the same. In my prototype I built attenuators of 1 dB, 2 dB, 4 dB, 8 dB, 8 dB and 8 dB. Together these allow RF attenuation in steps of 1 dB (about a 10 % reduction in amplitude) from 0 dB to 31 dB, which makes sense for the typical uses to which I put the device. Other combinations are of course possible: for example six 10 dB stages would allow attenuation from 0 dB to 60 dB in steps of 10 dB, or stages of 0.5 dB, 1 dB, 2 dB, 4 dB, 8 dB and 8 dB would give attenuation from 0 dB to 23.5 dB in steps of 0.5 dB.

Calculations

In order to calculate the required resistances I used the AADE software, which can be downloaded at [1]. The main use of this program is in creating more complex designs such as filters, but it is perfectly capable of helping to design attenuators and saves a lot of tedious calculation.

In the menu Design -> Attenuator Pad first select the 'pi' topology and in the next menu select the source impedance. In principle any value might be used here, but these days the conventional values are 50 Ω for test equipment and 75 Ω for antennas and analog video signals. The printed circuit board is designed for an impedance of 50 Ω. If required, the trace widths and board thickness can be modified for use in a 75 Ω environment. Programs to help with this design can be found on the Internet: if you are thinking of making such modifications and understand the issues involved, you may find the tool linked to at [2] worth a look.

The desired attenuation value is entered in the next menu and then the program shows the circuit with the required resistor values. Unfortunately the values

COMPONENT LIST

Resistors

36 pcs SMD case 0603 or 0805; see text for values and tolerances

Miscellaneous

S1–S6 = DPDT changeover switch, PCB mount (e.g. Reichelt TL 46 PO)

Cast aluminum enclosure, Hammond type 1550Z102

RF connectors as required (e.g. panel mount BNC sockets)

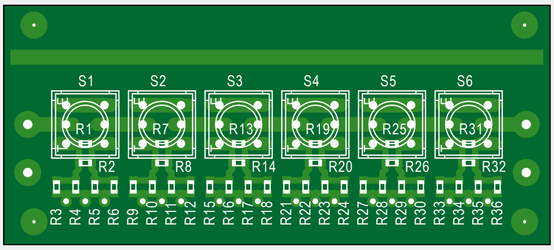

Figure 4. RF layout techniques are used on the attenuator circuit board.

PCB: see text

almost never coincide with E-series preferred values, and even if we allow ourselves to use E96 values it is not always possible to find a good solution. Instead it is possible to come up with pairs of resistors from the readily-available E24 series whose parallel combination hits the computed ideal value sufficiently closely, using either mental arithmetic, a pocket calculator, an Excel spreadsheet or a short program. An even easier approach is to use one of the online tools that are available: these do all the hard work and show possible combinations along with the percentage error in the result. A good choice is the tool found at [3]. For this application errors of up to 1 % are acceptable.

You might wonder why the circuit uses parallel resistor combinations rather than series combinations: the reason is that it simplifies the design of the circuit board and improves its RF performance.

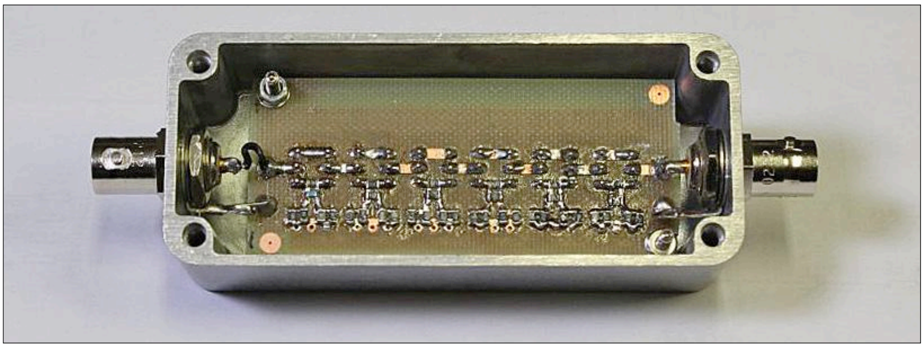

Figure 5. The circuit board fitted in the Hammond enclosure.

Figure 6. The completed prototype.

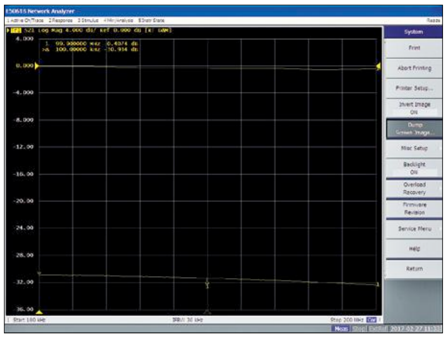

Figure 7. Screenshot showing the frequency response at minimum (0 dB) and maximum (31 dB) attenuation.

It's all down to the board

The board I laid out for this circuit is shown in **Figure 4**, and the design files (in Eagle format) are available for free download from the Elektor web page accompanying this article [4]. The switches are in the middle, and immediately below each are the six resistors corresponding to it. There are three vias connecting the network to the ground plane on the other side of the board. The trace widths, when used with an FR4 substrate 1.0 mm thick (this dimension is important!), are chosen to yield a characteristic impedance of 50 Ω. The resistors are intended to be 0603 SMD types, but their pads are sufficiently large that it is easy to fit 0805 components instead. The power handling capability of the attenuator depends directly on the power rating of the resistors used: the design is not intended for use in high-power applications, and it is best to keep power levels to below 100 mW. The layout also includes, above the main circuitry, a test structure and provision for two SMA connectors to allow measurement of the characteristic impedance of a trace. The connectors are optional and only required for this measurement.

The board is designed to fit neatly into a Hammond cast aluminum enclosure (see the component list). Input and output are on RF sockets: BNC connectors are conventionally used in test equipment applications. Populating the circuit board should not present any special difficulties, although soldering 0603 SMD resistors calls for good tweezers and a steady hand. After assembling the board it should be thoroughly tested by enabling each attenuation stage individually in turn (with the other five switches set bypass their stages) and then measuring the input and output impedances of the unit as a whole. When measuring the impedance at one port it is of course necessary to terminate the other port in 50 Ω (for example, using two 100 Ω resistors in parallel). If the measured impedance is within 1 % of 50 Ω, then you can be fairly sure that you have not accidentally got two resistors the wrong way around. The final test is to make sure that the attenuation introduced by each stage is correct. This can be done at DC: use a power supply (at no more than 5 V) and a 50 Ω series resistor to feed the input of the device and terminate the output with 50 Ω. Measuring the ratio between the voltage at the input terminals of the device and the voltage at the output terminals of the device will give the actual attenuation.

Figure 5 shows the board fitted in the Hammond enclosure and **Figure 6** the rather handsome (even if I say so myself) completed prototype. And it's not just a pretty face: considering the simplicity of the design its performance is more than acceptable. **Figure 7** shows the frequency response at attenuations of 0 dB and 31 dB: as can be seen, the attenuator performs well up to around 200 MHz.

(160323)

Internet Links

[1] http://w1hue.org/filter.html

[2] www.eeweb.com/toolbox/microstrip-impedance

[3] www.qsl.net/in3otd/parallr.html

[4] www.elektormagazine.com/160323

About the Author

Alfred Rosenkränzer has worked for over 30 years as a design engineer, initially in the field of professional television equipment. Since the end of the 1990s he has worked on high-speed digital and analog circuits for IC testing.