30dB Resistive RF Power Tap

Figure 1 - 30dB Resistive RF Power Tap

Last week, I built a 30dB inductive attenuating RF sampler, using a 1:32 transformer as the pickup device. This week, I am discussing another design that provides the same level of attenuation, but does it resistively instead of inductively. The result is the 30dB Resistive Power Tap (Figure 1), providing the 30dB of attenuation through a carefully-calculated voltage dividing resistor network.

As with the design I wrote about last week, this design can also be modified to provide different levels of attenuation. I will primarily discuss the 30dB variant, though I will provide information for building either a 40dB or a 50dB variant instead.

This design, as mentioned above, relies upon a resistive voltage divider network to provide the attenuation. This voltage divider network must be able to handle the power of the transmitter whose output signal will be imposed upon the attenuator. Interestingly enough, the higher the attenuation level, the less power is consumed in the attenuator, so resistors of lower power ratings can be used in those circumstances. Of course, this is because the greater attenuation is provided by resistors of higher ohmic values, thus resulting in less current flow through the resistors.

The schematic of the attenuator is provided in Figure 2. Note that the resistors R_1, R_2, and R_3 can be individual high-power resistors, or they can be made up out of series and parallel sets of resistors, as we will see later on. Whatever you decide, it is important that the resistors be non-inductive – in other words, *not* wire-wound resistors.

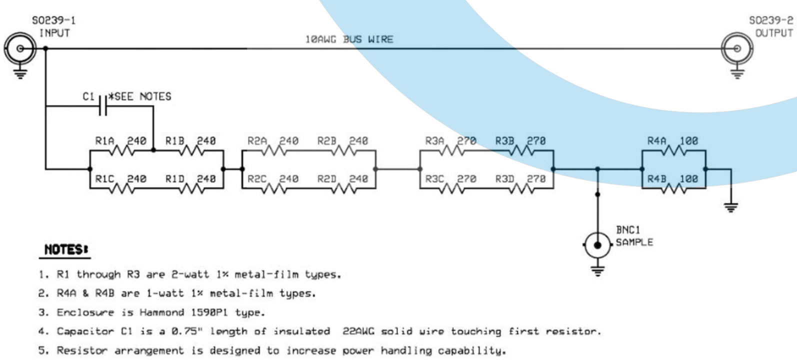

Figure 2 - Schematic diagram

The rather strange arrangement of resistors is meant to maximize the power capabilities of the power tap. As built, the power rating of the tap is twenty-four watts. The four resistors constituting R_1 work out to 240 ohms, as do those constituting R_2. The four resistors that comprise R_3 equate to 270 ohms. These values, taken in series, produce a nominal 750 ohms, the requisite resistance for a -30dB attenuation level. The two resistors at R_4 are meant to provide a 50-ohm shunt for the BNC connector, guaranteeing a 50-ohm load there. As the schematic notes indicate, the R_1, R_2, and R_3 component resistors are two-watt one-percent metal-film types, while the R_4 resistors are one-watt one-percent metal-film types.

As always in electronics, this project is once again governed by equations. There are several equations at work here. Table 1 shows the equations and their purpose in the calculations. In these equations, I will show the equations as they apply to the various attenuation levels that were mentioned at the beginning of this article. For the equations that follow, we are assuming a one-hundred-watt total transmitter output power. We could also insert a properly-tuned antenna in place of the dummy load, but then… we should not be testing much on the air, right?

Table 1 - Equations used

Attenuation Level	-30dB	$\frac{1}{1{,}000} = 0.001$
	-40dB	$\frac{1}{10{,}000} = 0.0001$
	-50dB	$\frac{1}{100{,}000} = 0.00001$
Instrument Power *(P_{INST})*	-30dB	$ATTENUATION \times POWER_{TOTAL} = 0.001\ x\ 100 = 0.1W$
	-40dB	$ATTENUATION \times POWER_{TOTAL} = 0.0001\ x\ 100 = 0.01W$
	-50dB	$ATTENUATION \times POWER_{TOTAL} = 0.00001\ x\ 100 = 0.001W$
Sample Factor (equal to Attenuation Level)	-30dB	$\frac{POWER_{INST}}{POWER_{TOTAL}} = \frac{0.1}{100} = 0.001$
	-40dB	$\frac{POWER_{INST}}{POWER_{TOTAL}} = \frac{0.01}{100} = 0.0001$
	-50dB	$\frac{POWER_{INST}}{POWER_{TOTAL}} = \frac{0.001}{100} = 0.00001$
Dummy Load Impedance *(Z_{DL})*	ALL	$Z_{DL} = 50\Omega$
Input Power *(P_{IN})*	ALL	$P_{IN} = 100W$
Input Voltage *(V_{IN})*	ALL	$V_{DL} = \sqrt{Z_{DL}\ x\ P_{IN}} = \sqrt{50\ x\ 100} = \sqrt{5{,}000} = 70.7V$
Instrument Impedance *(Z_{INST})*	ALL	$Z_{INST} = 50\Omega$
Instrument Voltage *(V_{INST})*	-30dB	$V_{INST} = \sqrt{Z_{INST}\ x\ P_{INST}} = \sqrt{50\ x\ 0.1} = \sqrt{5} = 2.24V$
	-40dB	$V_{INST} = \sqrt{Z_{INST}\ x\ P_{INST}} = \sqrt{50\ x\ 0.01} = \sqrt{0.5} = 0.707V$
	-50dB	$V_{INST} = \sqrt{Z_{INST}\ x\ P_{INST}} = \sqrt{50\ x\ 0.001} = \sqrt{0.05} = 0.224V$
Instrument Net Resistance *(R_{INST})*	ALL	$R_{INST} = R_4 \parallel Z_{INST} = 50\Omega \parallel 50\Omega = 25\Omega$
Total Resistance Needed *(R_{TOT})*	ALL	$\frac{V_{INST}}{V_{DL}} = \frac{R_{INST}}{(R_{TOT}+R_{INST})}$ $\ldots solve\ for\ R_{TOT}$
	-30dB	$\frac{2.24}{70.7} = \frac{25}{(R_{TOT}+25)} = \frac{1742.50}{2.24} = 777.902\Omega$
	-40dB	$\frac{0.707}{70.7} = \frac{25}{(R_{TOT}+25)} = \frac{1742.50}{0.707} = 2464.639\Omega$
	-50dB	$\frac{0.224}{70.7} = \frac{25}{(R_{TOT}+25)} = \frac{1742.50}{0.224} = 7779.018\Omega$

A further point of assumption at play in the Table 1 equations is that the full transmitter power, less the small amount consumed in the voltage divider chain, is being delivered to the dummy load. However, it is that small amount of consumed power that drives the entire list of equations, as we will see shortly.

The data in Table 2 provides the derived values for the resistive voltage divider network for each of the attenuation levels mentioned earlier, and the distribution of voltage, current, and power within the device. Note that the R_4 value is always 50 ohms, and that the power requirements for the resistors will vary with the attenuation level. The resistor values selected are based upon standards resistor values and provide approximate attenuation levels rather than exact levels.

Table 2 - Values input and derived

Input Values	**Target Attenuation**			**UOM**	**Comments**
	-30dB	**-40dB**	**-50dB**		
Instrument Impedance	50	50	50	Ohms	o'scope, s/a, etc.
Dummy Load Impedance	50	50	50	Ohms	standard dummy load
Dummy Load Voltage	68.4	70.7	70.7	Volts	calculated value
Calculated Resistance (R_{CALC})	777.902	2464.639	7779.018	Ohms	calculated value
R_1	240	820	2700	Ohms	standard value
R_2	240	820	2700	Ohms	standard value
R_3	270	820	2400	Ohms	standard value
Rounded Resistance (R_{ROUND})	750	2460	7800	Ohms	sum of above rows
R_4	50	50	50	Ohms	standard value
Derived Values	**Target Attenuation**			**UOM**	**Equation**
	-30dB	**-40dB**	**-50dB**		
Instrument Ω (R_{INST})	25	25	25	Ohms	$R_{INST} = R_4 \parallel Z_{INST}$
Series Ω (R_{SER})	775	2485	7825	Ohms	$R_{SER} = R_{ROUND} + R_{INST}$
Parallel Ω (R_{PAR})	46.97	49.01	49.68	Ohms	$R_{PAR} = R_{SER} \parallel Z_{DL}$
Total Current (I_{TOT})	1.505	1.44	1.42	Amps	$70.7 \div R_{PAR}$
Load Current (I_{DL})	1.414	1.414	1.414	Amps	$70.7 \div Z_{DL}$
Tap Current (I_{TAP})	0.091	0.028	0.009	Amps	$70.7 \div R_{SER}$
Tap Power (P_{TAP})	6.45	2.01	0.64	Watts	$70.7^2 \div R_{SER}$
Dummy Load Power (P_{DL})	93.55	97.99	99.36	Watts	$100 - P_{TAP}$
Dummy Load Voltage (V_{DL})	68.4	70.00	70.48	Volts	$\sqrt{P_{DL}\ x\ Z_{DL}}$
Tap Voltage	2.30	0.70	0.22	Volts	$70.7 - V_{DL}$
Series Ω Power $P_{(SER)}$	6.21	1.93	0.63	Watts	$I_{TAP}{}^2\ x\ R_{ROUND}$
Instrument Power (P_{INST})	0.12	0.04	0.005	Watts	$(P_{TAP} - P_{SER}) \div 2$
R_4 Power (P_{R4})	0.12	0.04	0.005	Watts	$(P_{TAP} - P_{SER}) \div 2$

I know – this seems like an awful lot of stuff and nonsense just to work out some resistor values. I went through all of the math here for one specific reason – to show the minimum power ratings necessary for the resistors used to build the voltage divider network. The key point of all of this is just that – if you are going to build one of these power taps for 30dB of attenuation, the resistors need to be able to handle a minimum of six and a half watts of power. Yes – you can build it for six watts, and with short duty cycles at a hundred watts of input power, it will survive just fine. But – you are then limited to those short duty cycles.

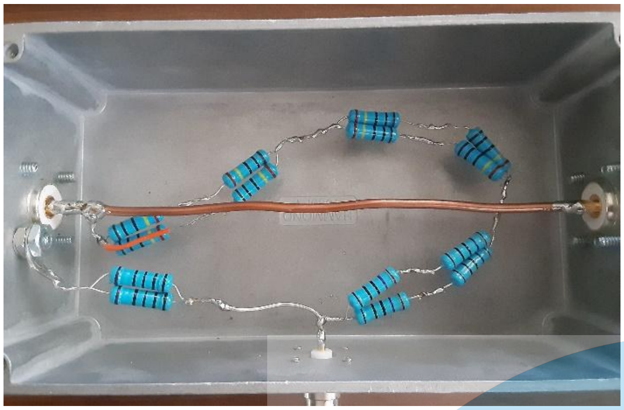
Figure 3 - Resistive voltage divider network

Let's look at some build alternatives for the 30dB version. The rounded resistance needed for the pre-tap portion of the voltage divider network is 750 ohms. As the data in the table above shows, this can easily be accomplished with just two 240Ω and one 270Ω resistors in series. If we use one-watt resistors, we will only support three watts of power across those three resistors. Part of the reason for using multiple resistors in the first place is to split the voltage drops and therefore the load among multiple devices. So… if we go to two-watt resistors, at three resistors in the string, we would provide only six watts of capability – not quite enough to handle the full load. What I chose to do was to seriously increase the load capacity by using an array of resistors.

In my build (Figure 3), I installed a total of eight 240Ω two-watt resistors, arranged in four two-resistor parallel pairs. Each parallel pair yields 120 ohms, and there are four of them taken in series, resulting in 480 ohms. I then installed a total of four 270Ω two-watt resistors, again in two two-resistor parallel pairs. Each parallel pair provides 135 ohms of resistance, so the two pairs connected in series make up the requisite 270 ohms to get me to the 750-ohm design goal. Because there are twelve two-watt resistors in the network, the power capacity is a whopping twenty-four watts. At a cost of only twelve cents per resistor, it certainly did not break the bank.

These twelve resistors are installed between the RF carry-through bus wire and the BNC tap for the measuring device. This power tap is easily suitable for just about any oscilloscope, and also for most spectrum analyzers, though it is slightly problematic when it comes to the popular and inexpensive TinySA spectrum analyzers. The TinySA has absolute maximum input power levels listed in its specification data as follows:

- a general limit of *+10dBm* with 0dB of internal attenuation selected;
- a short-term peak input power of *+20dBm* when 30dB of internal attenuation is selected;
- +0dBm when the internal attenuation is set to its automatic mode; and
- a suggestion that the input power be kept to a limit of *-25dBm* for best measurements.

That last line is an important number and something to really consider, as -25dBm equates to a mere 0.0000031623 (3.1623µW) of input power. The input power that would be present at the output of this power tap, with a one-hundred-watt input to the attenuator, would only be one-one-thousandth of that power, or 0.1 watts or 100 milliwatts. Even the 50dB version would only reduce that level to 0.001W or 1,000µW, or about three-hundred times the recommendation for best results on the TinySA. The equivalent power levels for the other TinySA limits are 0.01W for the +10dBm level, 0.1W for the +20dBm level, and of course, 0.001W for the +0dBm level.

Remember however that attenuators can be daisy-chained, and a lower-power capability attenuator can generally be safely installed downstream of the more power-capable device. Thus, if so desired, for example, a one-watt rated attenuator can be installed between this power tap and the TinySA to reduce the power below that level provided by this device. Attenuators add to each other, so if you added another 30dB of attenuation inline after the -30dB power tap, the resultant power sent to the oscilloscope or the spectrum analyzer would end up being one one-thousandth of one one-thousandth of the original input power. In the case of a one-hundred-watt input power to the first attenuator, this combination would give a final output power of 0.0001W, or one hundred micro-watts. I commonly do this, using one of my CMS SA-03 0-65dB step attenuators, usually set to the 40dB or 50dB level, which provides a power ratio of either 1/10,000th or 1/100,000th, respectively, of the input power at the output port.

Moving on to the build, I started out with a Hammond 1590-series diecast aluminum enclosure measuring 3.25" x 6.00" and 2.00" high. I installed a flanged SO-239 connector to the center of each end of the enclosure, drilling and tapping the enclosure for exterior mounting of the connector. The SO-239 locations were tapped for 6-32 machine screws. I also installed a flanged female 50Ω BNC connector to the center of one long side of the enclosure. The BNC location was tapped for 4-40 machine screws.

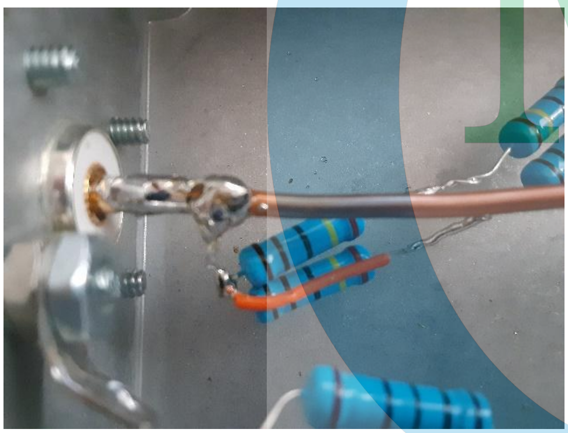

Figure 4 - 22AWG "gimmick" capacitor

A length of 10AWG solid copper wire was installed between the two SO-239 connectors as a bus wire. Then, I assembled the resistor network from the bus wire to the BNC connector. After that, I installed a pair of 100Ω one-watt resistors wired in parallel to provide fifty ohms of guaranteed load, placed in shunt across the BNC connector. Finally, I added the 22AWG "gimmick" capacitor, a 0.75" length of insulated solid 22AWG wire (Figure 4). This capacitor was installed extending from the bus wire out alongside the first resistor pair, with the wire insulation directly against the body of the first resistor. The capacitance is then between the wire core and the resistor core. The purpose of the capacitor is to reduce or eliminate as much as possible the high-frequency excursions that can exist in the signal.

The resistor chain is stretched almost the full length of the enclosure and then doubles back to a ground lug installed to one of the SO-239 retaining screws. While this arrangement may not be optimal, it works just fine, and provides the power capability that I wanted in this unit. The resistors are positioned below the bus wire, but above the floor of the enclosure far enough to prevent capacitive coupling to either the enclosure or the bus wire to the greatest extent possible.

This project could easily have been built using five-watt metal-film resistors, but I had the two-watt version in stock, as well as all of the other parts used in this build. Of course, building with five-watt resistors would reduce the resistor count to three pieces, but would also drop the power capacity to fifteen watts – which is still a very respectable level. The enclosure was the most expensive part used, coming in at a shade over five dollars when I bought it. The SO-239 connectors are about two and a half dollars each, and the BNC connector was another two dollars. The resistors, totaling fourteen of them at an average price of eleven cents each, made up another dollar and a half, and the wire and solder lug were mere pennies. All told, this build came in at a bit under fifteen dollars, including the machine screws.

In operation, with a 28.465MHz sine wave input at a peak-to-peak voltage of ten volts equating to a two-watt input at fifty ohms load, the resulting signal out to the oscilloscope was 316mV peak-to-peak. Taken against the same fifty-ohm load, this equates to a power level of 0.001997 watts. Of course, one-one thousandth of 2 is 0.002. With numbers like that, this power tap is pretty darn close to its target attenuation. How does that compare to the inductive RF sampler built and written about last week? Under the same test conditions, that device produced an output of 0.002577 watts, providing an input voltage of 359mV peak-to-peak to the oscilloscope.

Both devices do the job. The decision is yours as to which one, if any, to build. With the design that I used, a larger enclosure was strictly speaking necessary for the resistive type. However, because I used a sheet metal enclosure that I had on hand, the inductive unit was actually assembled in an enclosure with greater volume than was the resistive power tap. Either way, you will have a piece of equipment that should serve you well.