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Simple Lab-Built Test Accessories for RF, IF, Baseband and Audio

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Here are some practical tips for making simple test accessories to use at your engineering workbench: filters, detectors, attenuators and return loss bridges for audio and RF/IF

Every engineering lab bench needs a supply of handy test accessories—cables, adapters, attenuators, couplers, combiners, filters, detectors, limiters, etc. This article describes several accessories that can be built quickly (and cheaply), yet they provide sufficient performance from DC to 100 MHz. This frequency range includes most audio, baseband and intermediate frequency circuits, as well as many RF applications from VLF through VHF.

Connector-Mounted Accessories

Low cost tests pieces can be realized using BNC panel jacks and associated hardware, although improvements can be attained using UHF connectors and panel jacks, as well as the higher quality N and TNC connectors. SMA and similar microwave connectors can certainly be used, but most hand-built circuits will not require their microwave performance.

Low cost test pieces can be constructed readily, via machine screw and solder assembly, using four hole coaxial panel jacks without printed circuit boards or enclosures. This technique has been demonstrated for passive circuits using BNC connectors [1], and UHF connectors have been extensively used with low cost transmission line transformers [2].

Connector Performance

Some coaxial panel jack characteristics are shown in Table 1. With BNC hole spacing of 0.500 inch and #4-40 screws, the working cross section area of BNC and TNC connectors is 0.500 – 0.125 = 0.375 inch. The corresponding working cross section of N and UHF connectors is 0.718 – 0.138 = 0.580 inch. The additional area can permit construction of test pieces with larger components such as half inch diameter toroidal inductors.

Typical small quantity unit costs for commercial grade coaxial connectors from economical distributors are $1.25 for BNC panel jacks, $2.50 for TNC panel jacks, $2.50 for N panel jacks and $0.65 to $1.00 for UHF panel

Connector	Flange Size	Hole C/L	Hole Dia.	Peak Volts	Max. Freq.
BNC	.687 or .750	.500 or .531	.125	500	4 GHz
TNC	.687	.500	.125	500	11 GHz
N	1.000	.718	.125	1,500	11 GHz
UHF	1.000	.718	.125 or .138	500	300 MHz

Notes:
1. BNC, TNC, and N connectors have 50 ohm impedance. UHF impedance is not specified.
2. Flange is square with rounded corners. Dimensions are in inches.
3. 0.125 holes provide clearance for #4-40 screws; 0.138 holes are for #6-32.
4. Some BNC and TNC connectors are tapped for #3-48 instead of 0.125 diameter. These holes must be drilled if larger hardware is desired.

Table 1 · Mechanical and electrical characteristics of common coaxial connectors.

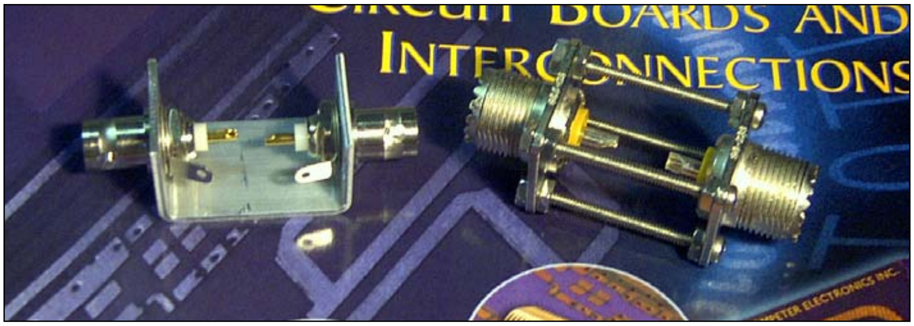

Figure 1 · Back-to-back mounting of low-cost coaxial connectors allows easy construction of test circuits.

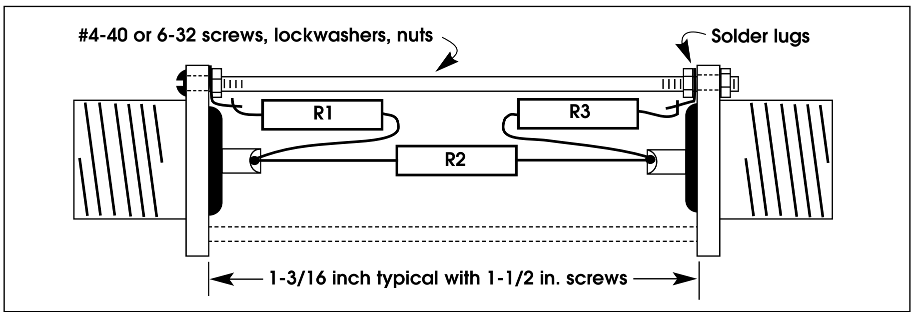

Figure 2 · Assembly diagram of a simple UHF connector-based pi-section attenuator (not to scale).

jacks, depending on quality and manufacturer. Quantity discounts have not been considered. Since UHF connectors have the lowest unit cost and are readily available, this article will emphasize low cost test pieces using UHF connectors. These costs will change with time, and higher prices will be paid for military grade connectors, different quality commercial connectors, and for retail purchase.

UHF Panel Jack Performance

Figure 1 is a photo that shows two UHF connectors in a mounting that allows various circuits to be constructed with components supported by their leads. Also in this photo is an assembly of two BNC jacks mounted to a U-shaped bracket, which allows similar circuit assembly using these connectors.

The upper frequency limit for UHF connectors is 300 MHz and the impedance is not specified. To evaluate these connectors, a preliminary 50 ohm test piece was constructed using two UHF panel jacks interconnected back-to-back with no special concern for impedance matching. Insertion losses were less than 0.1 dB up to 90 MHz.

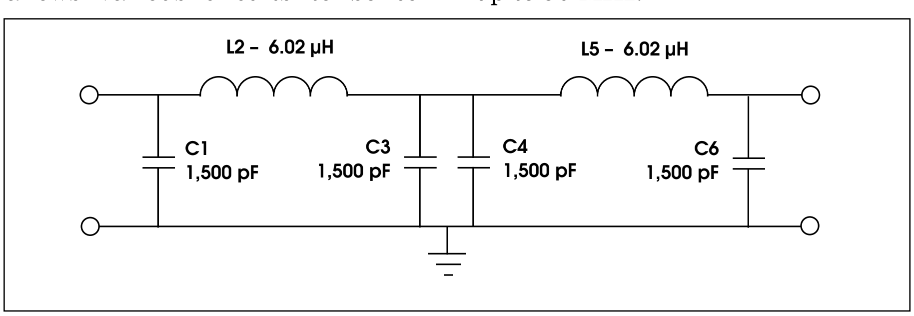

Figure 3 · Circuit diagram of a 2.2 MHz lowpass filter.

Practical Test Circuits

A pi-section fixed pad attenuator, using two UHF panel jacks and associated hardware, is illustrated in Figure 2. This simple circuit is displayed mainly for illustrative purposes—resistive pads are readily available and inexpensive, but custom attenuators with non-standard values can be made in this manner.

Another test piece with two UHF jacks separated by two inch long #6-32 screws was constructed and tested. This unit is a five pole low pass filter with nominal 0.02 dB passband ripples, three dB cutoff of 2.2 MHz, and 50 ohm impedance. The filter schematic is shown in Figure 3. All shunt capacitors are polypropylene units with two percent tolerance. The series inductors use 34 turns of #26 magnet wire on MicroMetals T50-2 toroids, which have a nominal 0.5 inch outside diameter. Measured test data is shown in Table 2.

Other Useful Circuits

As we have seen, low cost 50 ohm test pieces operating at typical frequencies from 100 kHz to 100 MHz can be readily constructed using UHF panel jacks and other connectors, soldered components, hand

Frequency (MHz)	Insertion Loss (dB)
0.3	<0.1
0.7	<0.1
1.0	0.1
1.3	0.2
1.6	0.3
1.8	0.4
2.0	1.1
2.2	3.5
2.4	7.2
2.9	18.0
3.5	27.0
4.0	34.3
10.0	>40
20.0	>40

Table 2 · Measured amplitude response for the 2.2 MHz lowpass filter mounted on UHF connectors.

tools, machine screws, ground lugs and other ordinary hardware.

In addition to the example attenuator and lowpass filter, some other simple circuits include:

RF detector—A Schottky diode detector can readily be constructed using this technique. The detector can be series or shunt, with or without a termination, as the user desires.

AM broadcast highpass filter—Communications facilities are often located near broadcast transmitters, and field measurements can be compromised by their strong signals. A highpass filter with a cutoff of about 2 MHz will reduce AM band (Medium Wave) interference.

FM or television band notch filters—The FM radio band can be reduced with a band reject filter, while interference from either FM or TV transmitters can be reduced with notch filters tuned to the frequency of the offending station.

These low cost test pieces are applicable to low frequency commercial, industrial and educational breadboards when "quick and dirty" implementation is sufficient to solve a measurement problem. They are most useful for passive circuits with non-standard specifications.

Of course, these lab-built test pieces are not meant to compete with standard manufactured products, which provide a much greater degree of precision and frequency coverage through microwave frequencies.

Low Cost Return Loss Bridges

Below 100 MHz, lumped-circuit passive return loss bridges can be implemented readily using commercially available transformers and die cast aluminum boxes.

Return loss is a more sensitive indicator of circuit performance than transmission behavior, such as insertion loss (used with passive circuits) or voltage transfer (used with active circuits). Return loss bridges are widely used from audio frequencies well into the microwave region. Below 100 MHz, reasonable quality return loss bridges can be realized using commercial transformers and uncomplicated construction methods.

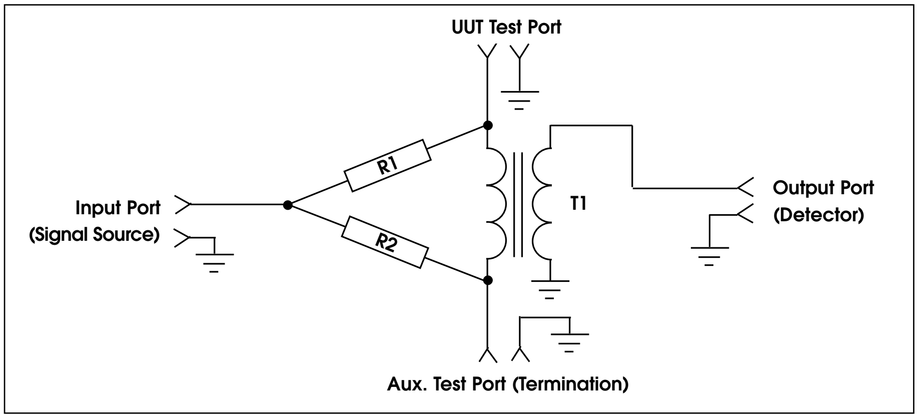

Figure 4 · Return loss bridge schematic.

Commercial grade coaxial connectors should conform to the impedance of the return loss bridge and the desired level of accuracy. At audio frequencies, fifty ohm BNC connectors can be used with seventy-five and six hundred ohm bridges.

Bridge Circuit

The schematic of a typical return loss bridge, based on the classic Wheatstone Bridge circuit, is shown in Figure 4. The four port bridge circuit uses resistors R1 and R2 to connect the unbalanced bridge input port to the two test ports. The four port bridge maintains circuit symmetry. (*Note:* Some commercially available bridges are three port units with an internal auxiliary termination.) The auxiliary test port is connected to an external matched termination. The other test port is connected to the input or output of the unit under test (UUT). The transformer connects the test ports to a detector at the output port, where the magnitude of the imbalance is proportional to the return loss. Internal bridge resistors R1 and R2 are typically equal to the bridge impedance Z_0.

Bridge Z_0	Components Used
49.9 ohms	BNC connectors T1: Mouser Electronics P/N 42TM030
75.0 ohms	Type F connectors T1: Mouser Electronics P/N 42TM030
604 ohms	BNC connectors T1: Mouser Electronics P/N 42TM016

Table 3 · Audio return loss bridge components.

At audio frequencies, three return loss bridge engineering models were constructed. Audio bridge components are listed in Table 3.

At lower RF and intermediate frequencies, two return loss engineering models were constructed. Components used in these RF/IF bridge models are listed in Table 4.

In both audio and IF units, the internal resistors R1 and R2 were nominal half-watt metal film units with one percent tolerances. Audio return loss bridges were constructed

Bridge Z_0	Components Used
49.9 ohms	BNC connectors T1: Mini-Circuits model T1-1
75.0 ohms	Type F connectors T1: Mini-Circuits model T1-1

Table 4 · RF/IF return loss bridge components.

Freq. (kHz)	50 ohm RL Bridge L (dB)	D (dB)	75 ohm RL Bridge L (dB)	D (dB)	600 ohm RL Bridge L (dB)	D (dB)
0.05	16	>40	17	>40	16.8	>40
0.1	14.6	>40	15.2	>40	15.2	>40
0.2	14	>40	14.4	>40	14.3	>40
0.5	13.7	>40	13.8	>40	13.7	>40
1	13.5	>40	13.5	>40	13.4	>40
5	13.5	>40	13.4	>40	13.3	>40
10	13.5	>40	13.4	>40	13.0	>40
15	13.6	>40	13.5	>40	12.9	39.8
20	14	>40	13.5	>40	12.9	37.5
30	14.5	>40	13.9	>40	12.8	33.9
50	16	>40	14.7	>40	–	–
100	20	>40	17	35.5	–	–

Table 5 · Audio return loss bridge insertion loss (L) and directivity (D) performance.

Freq. (MHz)	50 ohm RL Bridge L (dB)	D (dB)	75 ohm RL Bridge L (dB)	D (dB)
0.1	15.5	>40	–	–
0.5	13.1	>40	14.4	>40
1	13.2	>40	14	>40
3	13.2	>40	–	–
5	13.2	>40	13.2	>40
10	13.2	>40	13.3	>40
20	13.2	>40	13.0	>40
40	13.2	38	13.2	35
50	13.2	36	–	–
80	13.8	33	13.3	28
100	13.8	30	13.3	30
150	–	26	13.2	24.4
200	15.7	23	13.0	20.6

Table 6 · RF/IF return loss bridge performance.

in Hammond 1590LB (1.99 × 1.99 × 1.06 inch w/o lid) die cast aluminum enclosures. The RF/IF return loss bridges were constructed in Hammond 1590H (2.07 × 1.50 × 1.06 inch w/o lid) die cast aluminum enclosures. Transformers were turned upside down and affixed to the bottom interiors of the enclosures. Point-to-point wiring was used throughout with leaded components and no printed circuit boards.

For the audio bridges, the transformers had small quantity unit prices less than two dollars, while the transformers used in the RF/IF bridges had prices less than four dollars each. The enclosures were priced at less than seven dollars each.

Bridge Performance

Performance of the audio return loss bridge is tabulated in Table 5 where L is insertion loss from generator port to output port and D is directivity in dB.

The IF return loss bridge performance is tabulated in Table 6. Again, L is insertion loss from generator port to output port in dB and D is directivity in dB.

The transformer T1 is the crucial component in the return loss bridges. This conventional transformer acts as a wideband filter, providing the best return loss bridge performance in the central region of the "filter" passband, where loss is lowest and transformation accuracy is best.

Summary

At low frequencies, below 100 MHz, low cost test accessories can be constructed from readily-available components, using simple point-to-point assembly methods. Coaxial test pieces can be built directly on back-to-back connectors, with short lead lengths that provide acceptable performance for many test requirements.

Audio and IF return bridges can be constructed readily as engineering models. Through-lead components and point to point wiring, without printed circuit boards, yields useful performance.

Above 100 MHz, design considerations require much greater sophistication. Expensive test equipment can become necessary. Parasitic circuit elements can entail use of surface mount components with critical attention to layout and mechanical design. At these higher frequencies, usable coaxial components and return loss bridges are available from commercial vendors.

References

1. R. M. Kurzrok, "Coax Connectors Make Low-Cost Test Pieces," *EDN*, pp. 168, 170, June 22, 2000.

2. J. Sevick, *Transmission Line Transformers*, 2nd ed., American Radio Relay League, Newington, CT, 1990; current (4th) edition: Noble Publishing Corp., Norcross, GA, 2001.

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