Looking Inside a Power Splitter

by Gerald Roylance

What's inside a TV power splitter?

Ever wonder what's inside a TV power splitter? Several events made me curious about how they worked and their performance, so I opened some up and made some measurements. Power splitters have an input port S and two output ports, A and B. Ideally, the signal power going into port S splits equally between the coupled ports.

Some important criteria for power splitters are:

- Port Impedance Matching
- Port Isolation
- DC Power Distribution

TV power splitters for 75-ohm cable should look like 75 ohms at each port. Mismatched ports cause reflections and power losses, and that hurts the signal-to-noise performance. Except for weak signal environments, the losses won't mean much (a two-way splitter has an intrinsic 3dB loss already), but the reflections can cause ghosts.

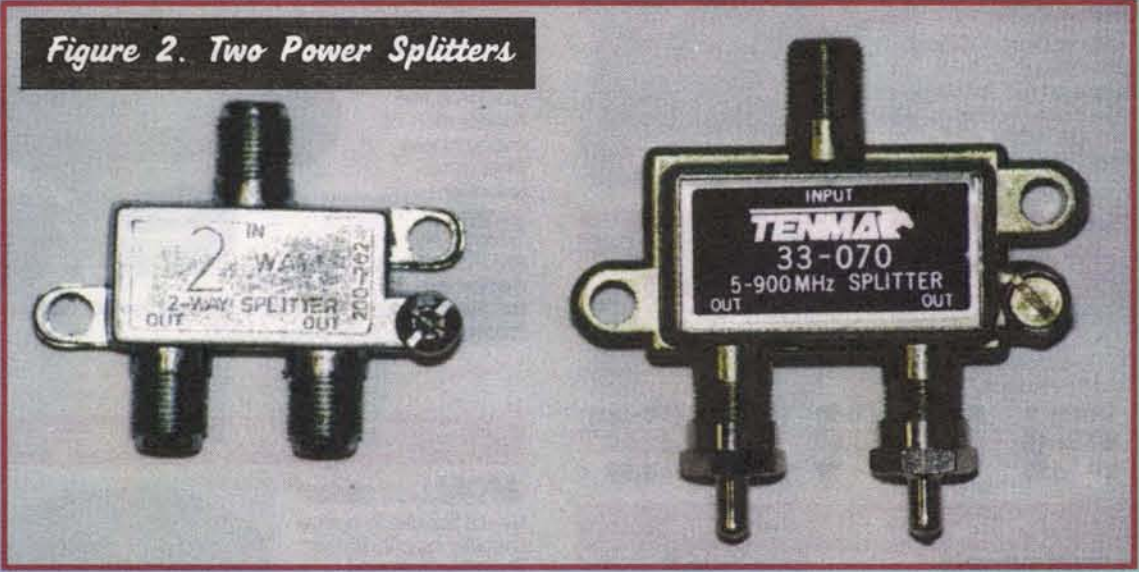


Figure 2. Two Power Splitters

The second criteria — port isolation — helps to keep signals clean even when there are reflections. A signal going into port A of a power splitter should not appear on port B. Port isolation prevents reflections and noise on port A from causing ghosts and interference on port B and vice versa.

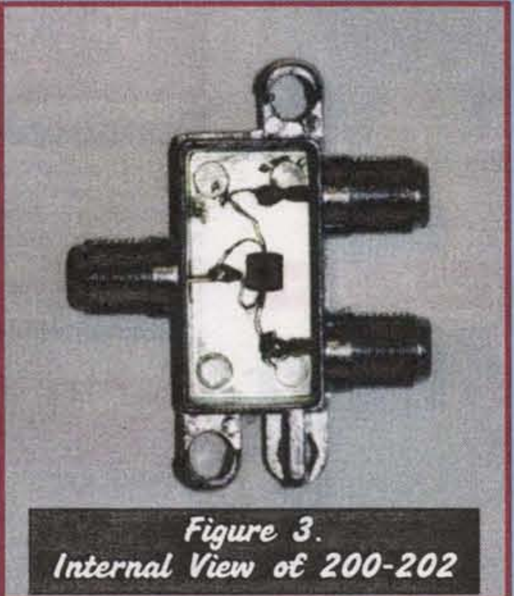


Figure 3. Internal View of 200-202

DC power distribution is important when a power splitter sits between an inline amplifier and its power source. In low signal strength areas, placing an amplifier at the antenna will eliminate feed line losses and improve reception. To simplify installation, these amplifiers often get their power over the coaxial cable from a power insertion module located inside the house. A power splitter that shorts DC to ground prevents power from getting to the amplifier; a splitter that blocks DC cannot be used between the amplifier and the power source. Three of the four splitters I looked at would pass DC.

Power Splitters

In his book *Introduction to Radio Frequency Design*, American Radio Relay League, 1994, Wes Hayward describes the basic power splitter as seen in Figure 1. The circuit — also called a zero degree hybrid — consists of a center-tapped ideal transformer and a balancing resistor. The circuit operation is clever, but its basic operation follows from a few observations.

Ignore the resistor for the moment and focus on how the transformer splits the power to the outputs. The transformer forces the two output currents to be the same ($i_A = i_B$). If the output currents are the same and they both flow into the same output impedance (Z_0), then the output voltages (V_A and V_B) will be the same. Thus, the transformer enforces the basic divider operation by forcing the input current to divide equally between the two output ports.

The transformer is also a voltage divider, so the center-tap voltage is at the midpoint of the two output voltages, $(V_A+V_B)/2$. If the output port impedances are similar, then the output voltages are equal. Consequently, the center-tap voltage also equals the output voltages, and there would be zero volts across the transformer.

The operation of the balancing resistor is subtle. If the output ports are matched, then the output voltages are equal and no current flows through the balancing resistor — it's as if the balancing resistor weren't there. If the output voltages are different, then a current will flow through the resistor. The value of the balancing resistor is chosen so that all of the unbalanced current flows through the resistor and none enters the transformer.

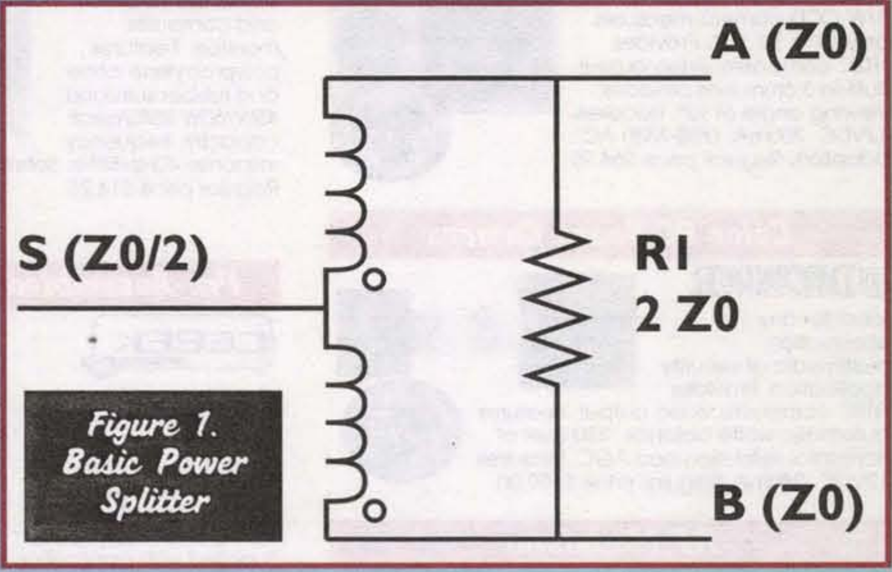


Figure 1. Basic Power Splitter

The basic power splitter has unequal port impedances: $Z_S = 0.5\ Z_A$ because the two output ports are essentially connected in parallel (when the loads are balanced, all the port voltages are the same). To make the impedances match, the splitter needs an impedance matching network. For broadband performance, that network is a 2:1 matching transformer.

The Power Splitters

Four different power splitters were tested. The first two are shown in Figure 2, and their internal parts are shown later. In addition to these two splitters, two other splitters were electrically tested.

Power Splitter Number One

The first power splitter of the group has model number 200-202 molded on its case. Black Point Products distributes the splitter as a BV-017, Two-Way Splitter, but other companies distribute the same part.

Figure 3 reveals the inside of the 200-202 power splitter — only the center-tapped transformer of the basic splitter design. This splitter design omits the matching transformer and the balancing resistor. Consequently, the match at the input port and the isolation should be poor. The design easily passes DC current among all ports because the transformer appears as a wire at DC.

Since the design does not have an impedance transformer, the input impedance will be 75 ohms divided by 2, or 37.5 ohms. The mismatch causes reflections at the input port, and the reflection coefficient is $\rho = (75 - 37.5)/(75 + 37.5) = 1/3$. One ninth (i.e., ρ^2) of the input signal power will be reflected and lost. The input mismatch causes a loss of 0.5 dB.

The missing balancing resistor will not affect the power split if the output ports are matched, but it will affect the isolation.

Power Splitter Number Two

The second power splitter is a Tenma model 33-070, 5-900 MHz splitter. The insides are shown in Figure 5, and its schematic is shown in Figure 6. This splitter has a matching transformer, but does not have a balancing resistor. The matching 4:3 autotransformer has a 16:9 impedance ratio, so the transformer converts the 37.5 ohms of the power splitter section to 67 ohms at the input port. The resulting ρ is 0.06 and the mismatch loss is 0.01 dB.

The matching transformer returns to ground through a 1nF blocking capacitor that prevents a DC short. Consequently, this splitter will pass DC power to all ports. The 2pF shunt capacitor tunes out the lead inductance to make the splitter have a broader bandwidth.

Other Power Splitters

Two other power splitters were electrically tested. Power splitter number three is a Gemini Industries, Inc., model number CV60. This model looks similar to the Tenma splitter. The fourth splitter is a Tru-Spec DSV-2, 5-450MHz, and is a splitter that my cable TV company installed.

Electrical Testing

Clearly, all power splitters are not created equal. Some are missing elements such as matching transformers and balancing resistors. Do these omissions affect performance a lot, or are there some subtler design tricks hidden in their design? Running some electrical tests will verify their performance.

To that end, a return loss bridge (RLB) was made for reflection testing, and some isolation measurements were made.

Return Loss Bridge

Reflection measurements can be made with a return loss bridge (Figure 7). The basic bridge looks like five resistors — four resistors for the bridge and one resistor (Rmeter) across the bridge that represents the

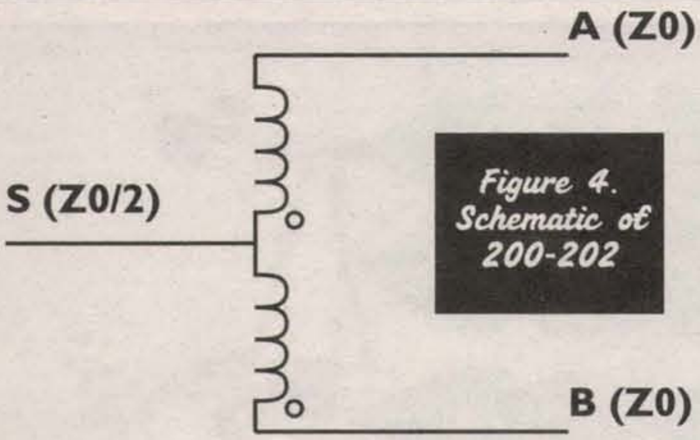


Figure 4. Schematic of 200-202

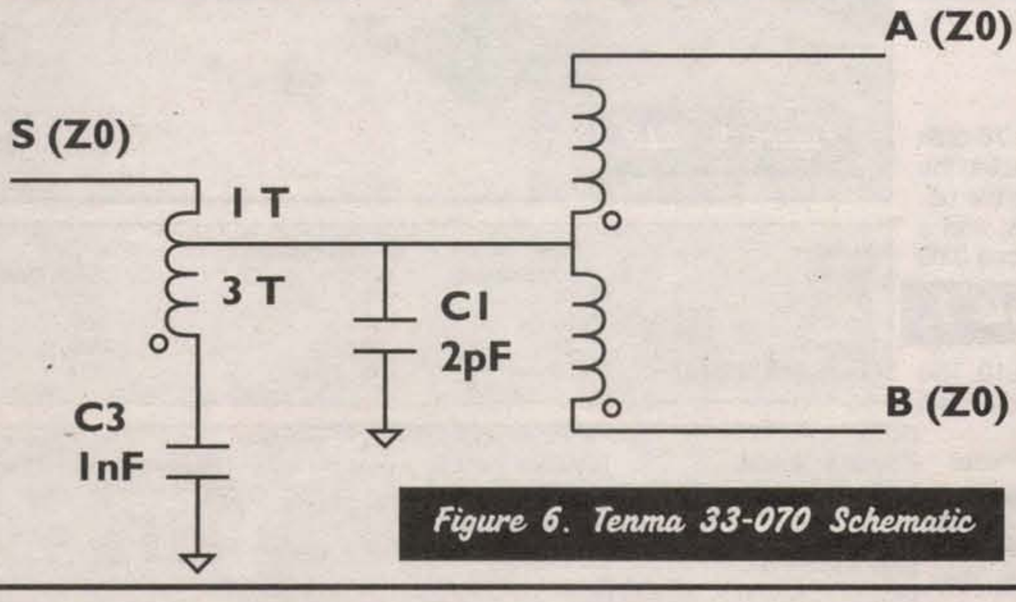
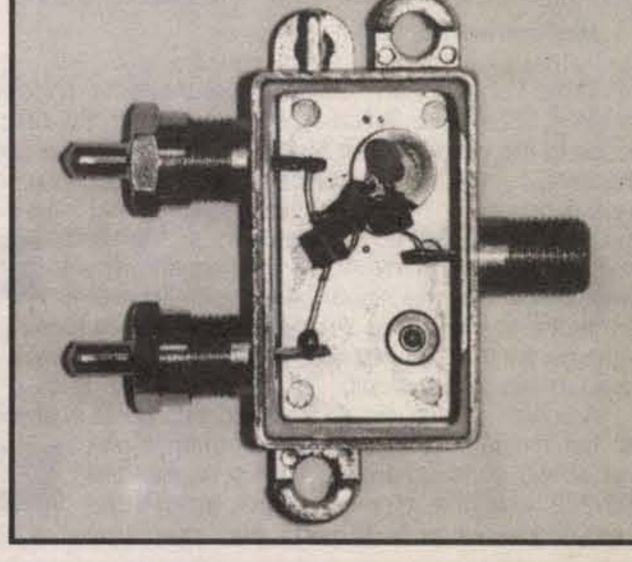


Figure 6. Tenma 33-070 Schematic

Figure 5. Tenma 33-070 Inside View



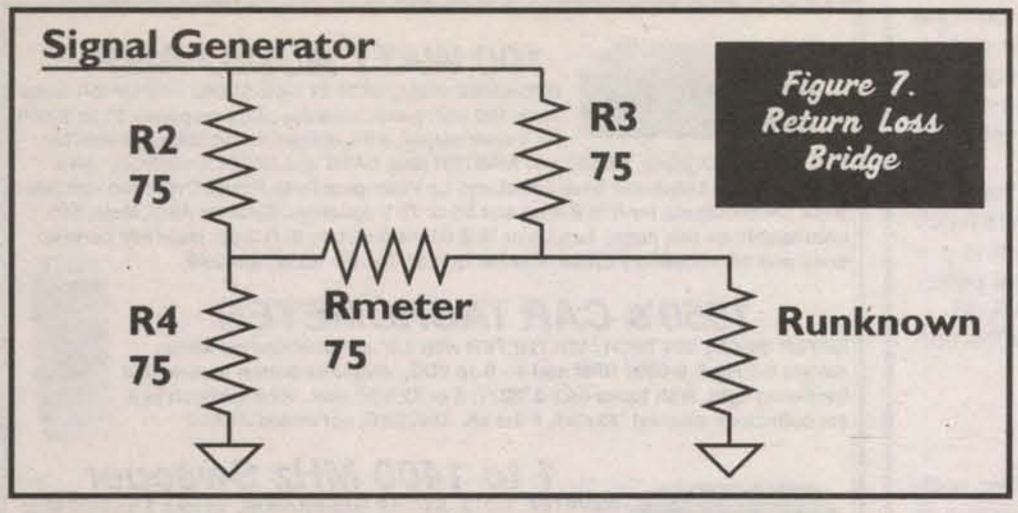


Figure 7. Return Loss Bridge

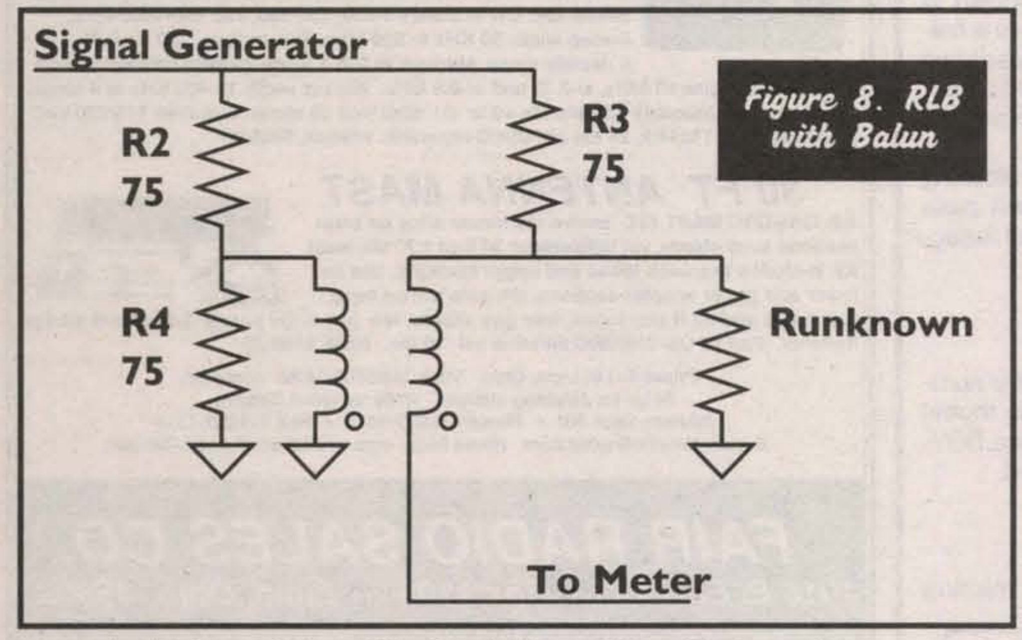


Figure 8. RLB with Balun

measuring instrument. One of the four bridge resistors (Runknown) is the transmission line that we are trying to measure. If the bridge is balanced, then the voltage across the bridge (between V2 and V1) will be zero and the measuring instrument will read zero. Hayward (c.f. page 151) describes how V2 - V1 is proportional to the reflection coefficient $\rho = (1 - y)/(1 + y) = (z - 1)/(z + 1)$.

Unfortunately, the voltage between VA and VB is floating, so it is difficult to measure with a grounded instrument. A balun transformer (see Figure 8) converts the balanced bridge voltage to an unbalanced signal that drives a terminated detector (I used my oscilloscope). The actual bridge is shown in Figure 9.

When making measurements, all ports and lines must be properly terminated. Most of my test equipment is 50 ohm, so I used some 75-ohm to 50-ohm min-loss attenuators in some crucial places, so my 50-ohm generator, cables, and scope would not compromise the measurement. The min-loss attenuator has a series 43.3-ohm resistor on the 75-ohm side and a shunt 86.6-ohm resistor on the 50-ohm side.

Reflection Testing

Table 1 shows the reflection measurements made with a 75-ohm bridge at 138.6 MHz. A two-foot length of foam RG-59 connected the bridge to the device under test. An open circuit was used as the reference ($\rho = 1.0$). A 75-ohm terminator produced $\rho = 0.18$, and a short produced $\rho = 0.89$. The terminator should have produced 0.00 and the short 1.00, so the numbers in the table have some uncertainty. A $\rho = 0.18$ means about three percent of the signal power is reflected. A terminator at the bridge (no RG-59 cable) produced $\rho = 0.10$. The numbers for the 200-202 and the Tenma are what we would expect from looking at the circuit.

A power splitter should be used with ports A and B terminated, but the table includes measurements with one or two ports unterminated. Notice that the 200-202 and the Gemini reflect almost the entire signal when both ports are unterminated. Curiously, the Tenma splitter reflection coefficient is not close to one when A and B are open — apparently the splitter consumes about 1/3 of the incident signal power.

Transmission/Isolation Testing

The isolation between ports A and B is tested by injecting a signal into port A while looking at port B. Port S is terminated in 75 ohms. The 200-202 splitter should have poor isolation because its S port is mismatched (remember it is 37.5 ohms). Here is how the S port mismatch hurts isolation. The test signal from port A travels to the S port, where some of it is reflected by the 37.5- to 75-ohm mismatch. The reflected portion travels back through the power splitter, where it divides equally between the A and B ports. Good input match is required for good isolation.

Although the Tenma splitter should have poor isolation because it does not have a balancing resistor, its isolation figure is reasonable. The transmission numbers agree with the reflection coefficients above: Those units with high reflection coefficients show more transmission loss (see Table 2).

Summary

Sadly, some power splitters have mismatched ports. TV splitters do not cost much, so some manufacturers have omitted the matching transformer and/or balancing resistor.

Although the Tenma and the Gemini splitters look almost identical on the outside, the Gemini's poor reflection coefficient suggests the inside is closer to the 200-202. Curiosity got the better of me just now, and my can opener reveals the Gemini is the same design as the 200-202. Maybe the Tru-Spec has all the right components, but it is not mine, so the can opener goes back to the kitchen.

All but the Tru-Spec splitter pass DC power among the three ports. The three Tru-Spec ports are DC shorts to ground, so the design is probably similar to the Tenma splitter without the 1nF DC blocking capacitor. Get out your ohmmeter before you apply power through a splitter. **NV**

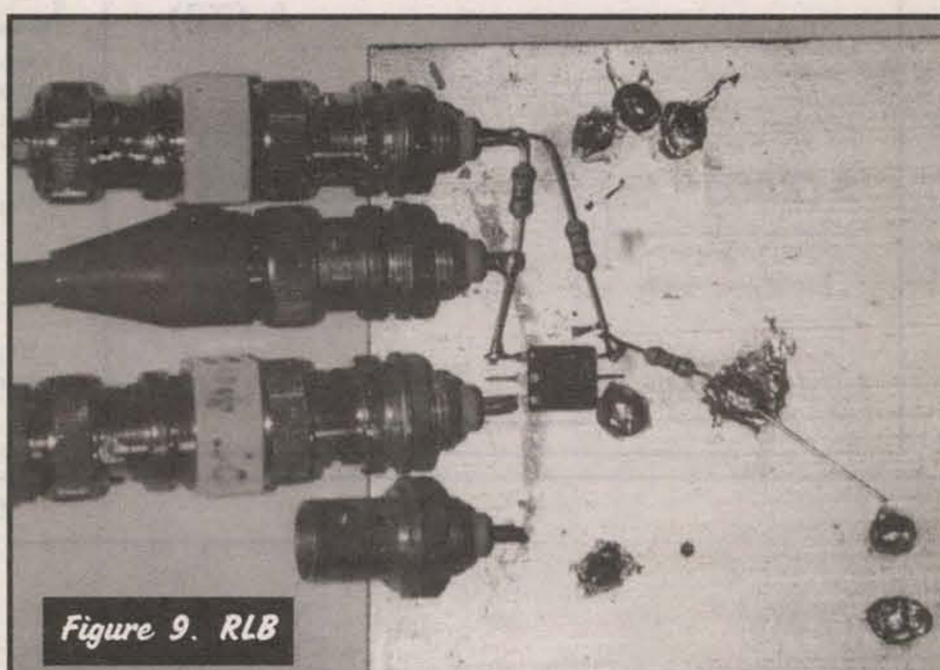


Figure 9. RLB

Table 1

Splitter Model	A&B Terminated	A Terminated, B Open	A&B Open
200-202	.34	.25	.95
Tenma	.13	.36	.80
Gemini	.32	.48	.98
Tru-Spec DSV-2	.15	.55	.90

Table 2

Splitter Model	Isolation port A -> port B	Transmission — Term
200-202	.17 = 15dB	.68 = -3.4dB
Tenma	.05 = 26dB	.69 = -3.2dB
Gemini	.08 = 22dB	.65 = -3.7dB
Tru-Spec DSV-2	.03 = 30dB	.70 = -3.1dB