The Splattometer

—visual overmod warning

Ed. Note: "The Splattometer" was one of the honorable mention winners in our Home-Brew Contest. W1BG will be receiving a $50 bonus in addition to his normal article payment.

Penn Clower W1BC
459 Lowell Street
Andover MA 01810

The most common way to abuse a sideband signal at the transmitter is by overdriving the output amplifier. That generates splatter, spurious signals which can cause interference up to 50 kHz or more from the normal transmission frequencies.

The "Splattometer" connects easily into the transmission line, monitors the output signal, and flashes a warning lamp whenever it detects flattopping. An entirely new type of signal analyzer, it is a real help in getting the most power from a transmitter while minimizing splatter. The entire instrument, including the built-in ac power supply, can be built for $65 using all new Radio Shack components, or for much less if your junk box isn't completely empty.

Amplifiers used in sideband transmitters are linear amplifiers. That means the output signal, aside from being more powerful, should be an exact replica of the input signal. Amplifiers have limits, however, and overdriving one can cause it to exceed its linear range so that the peaks of the output waveform get clipped or flattened. These flattops cause the signal to splatter extra energy onto adjacent frequencies.

Splatter can be hard to control for several reasons. Operators naturally want to run their transmitters at full power, and that often leads to running the microphone gain too high. An swr-type power-output monitor will show more output power, but unfortunately much of that extra power is spread up and down the band.

Monitoring a transmitter for splatter until now also has posed a problem since it required the use of an oscilloscope. That solution can be complex and expensive. As a compromise, most hams leave the microphone gain control set at some customary point and hope the ALC is working well enough to avoid splatter. For some people that works and for some it doesn't. It usually doesn't work at club stations where operators may not be too familiar with the equipment, and it usually doesn't work during contests when the race is on and every Watt counts.

Photos by W1GSL

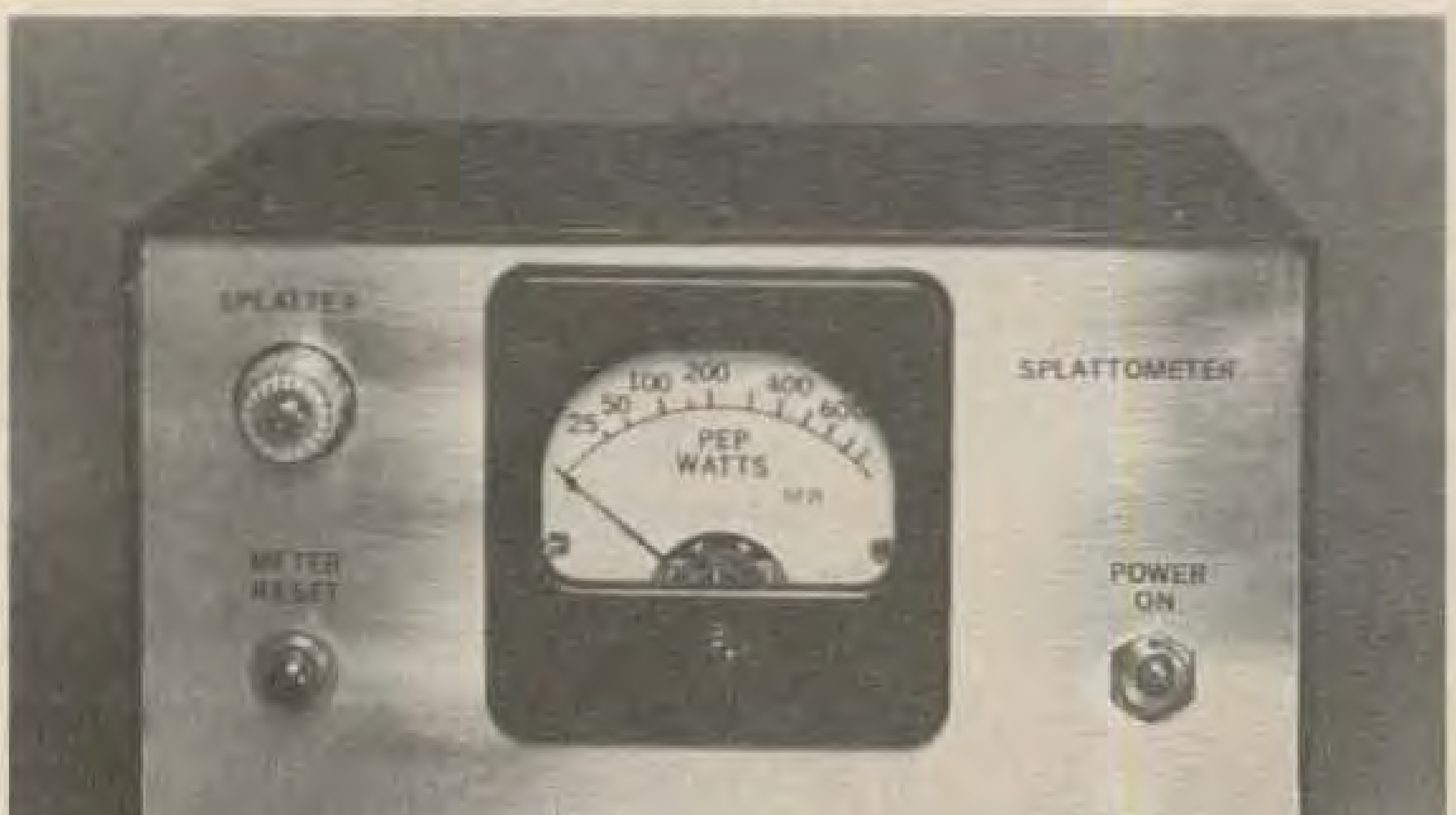

Photo A. The uncluttered 4" by 7½" front panel is dominated by the PEP wattmeter and splatter-alarm lamp. Only two operating controls are required, a power switch and reset push-button.

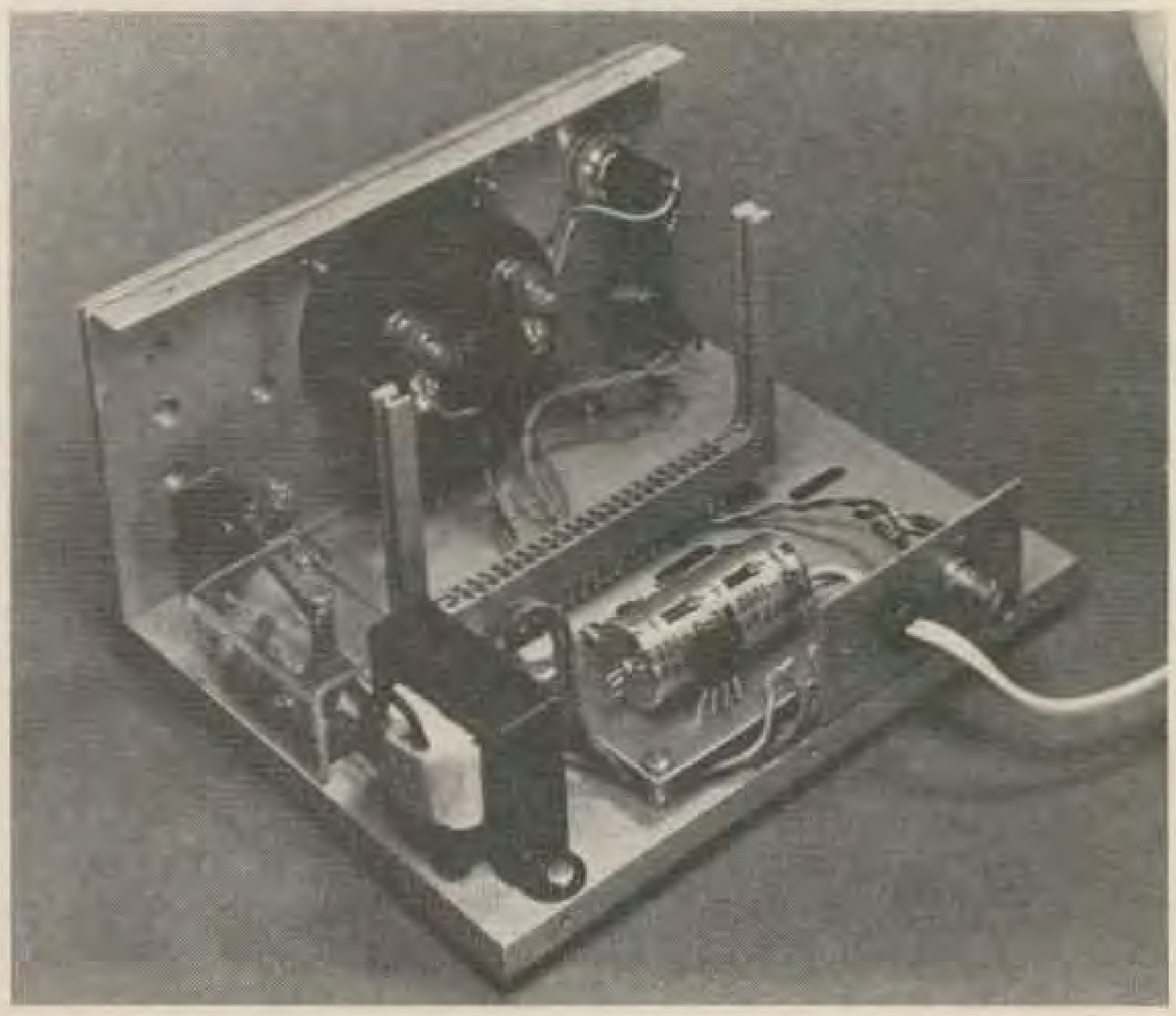

Photo B. Interior view of the recycled cabinet. The main circuit card plugs into the empty card socket while the power supply is mounted separately. Note that the rf voltage divider resistors are mounted directly on the input connector. A plastic shield keeps stray fingers off the ac line fuse.

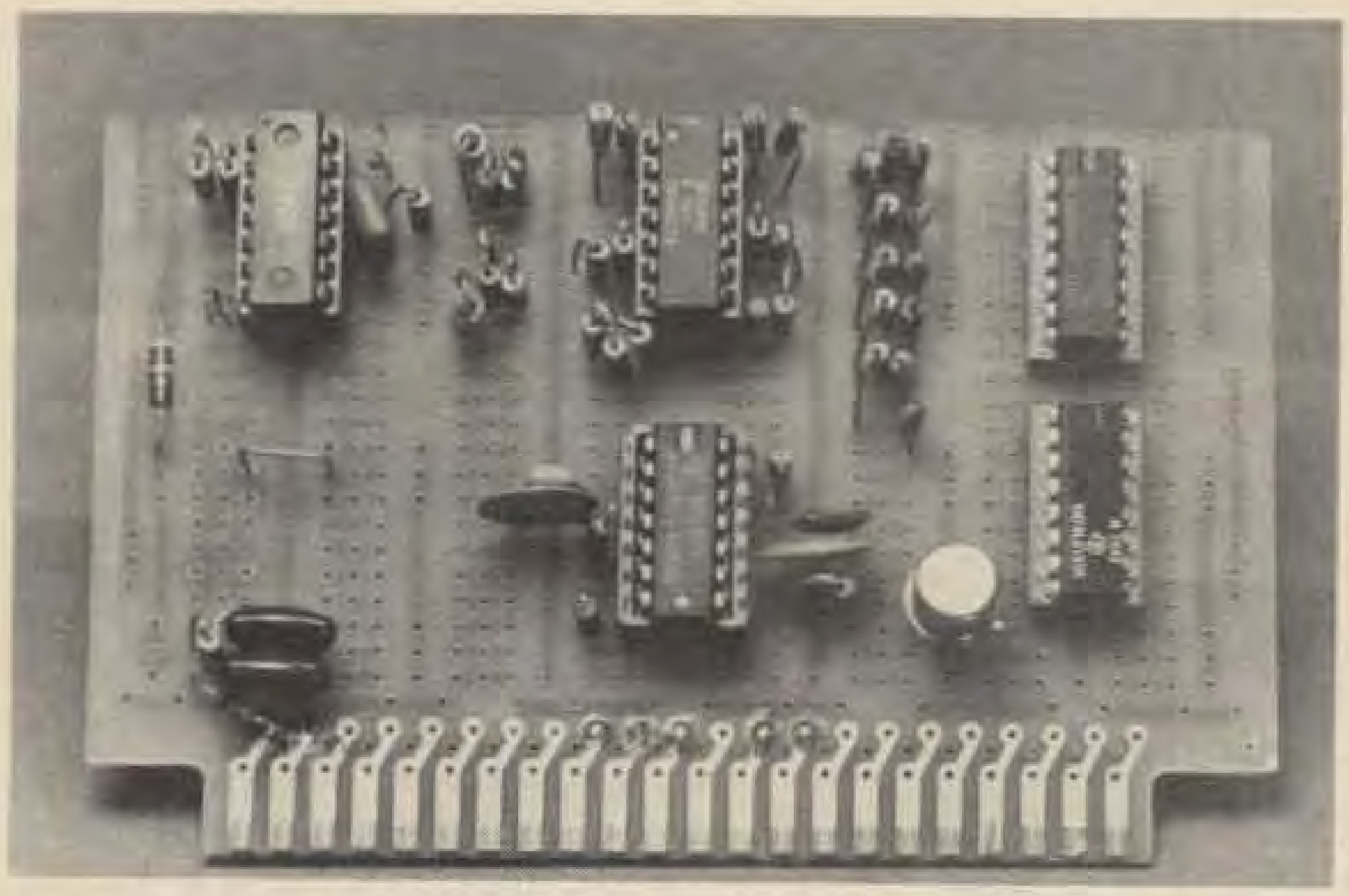

Photo C. Five ICs and the lamp driver transistor pack a lot of functions into a small space. The rf detector/filter components are grouped by themselves in the lower left-hand corner of the board. From left to right across the board are the quad op amp, quad comparator and dual timer, and finally the two up/down counters. One-quarter Watt resistors and miniature capacitors are mounted on end to save space.

Photo D. Although it fits nicely on top of the transceiver, the Splattometer can be placed anywhere within the operator's field of view. It doesn't need constant attention; when you splatter, it lets you know with a bright flash.

The "Splattometer" is a much better alternative. This simple flattop-monitor and -alarm circuit is usable over a wide range of transmitter power levels. The circuit basically consists of two sections. The first measures the peak voltage present in the transmitter signal. The second section measures how long the transmitter output has been at that maximum level. A clean SSB signal will just peak briefly to the transmitter's maximum output, but a splattering signal will be clipped and so stay at that level for a longer time. That time at maximum power is detected by the circuit and triggers the splatter indicator.

How It Works

A block diagram of the circuit is shown in Fig. 1. The antenna cable is looped through the unit and a small portion of the rf voltage is sampled with a restive divider. This signal is rectified and lightly filtered to create an accurate audio frequency reproduction of the rf envelope.

The peak-voltage measuring portion of the instrument is built around an up/down counter and simple six-bit digital-to-analog (D/A) converter. The converter output is a dc voltage nominally equal to the peak level of the detected rf waveform. If the detected level peaks higher than the existing D/A output, the counter gets clocked a step higher, thus raising the D/A output voltage. This feedback-controlled up-counting by itself would eventually set the converter output just above the rf peak voltage.

The counter, however, is also being clocked downward about two steps every second; as a result, the D/A converter output tracks within one or two steps (about .2 volts) of the detected peak envelope level. A threshold circuit freezes the counter state when the rf signal disappears between words, sentences, or transmissions. The dc measurement of the peak signal level also drives a simple voltmeter whose scale is calibrated to show the PEP Watts the transmitter is delivering to a 52-Ohm load. Notice that the relatively crude 6-bit D/A converter is perfectly acceptable since the feedback around the counter automatically adjusts the dc output to match the peak input. The actual counter state and converter linearity simply don't matter.

The flattop-detection portion of the Splattometer starts by low-pass-filtering the detected rf envelope with a one-millisecond time constant. This means that if the rf envelope suddenly jumps from zero to maximum, the filter outputs will take about three milliseconds to follow it. The splatter indicator is triggered whenever the output of this filter is greater than 80% of the measured peak signal level. The 80% and 1-ms time constant were chosen so that the instrument will detect any flattop lasting longer than 2 ms.

The output indicator is a panel lamp driven by an IC timer which generates a .1-second-long pulse whenever a flattop is detected.

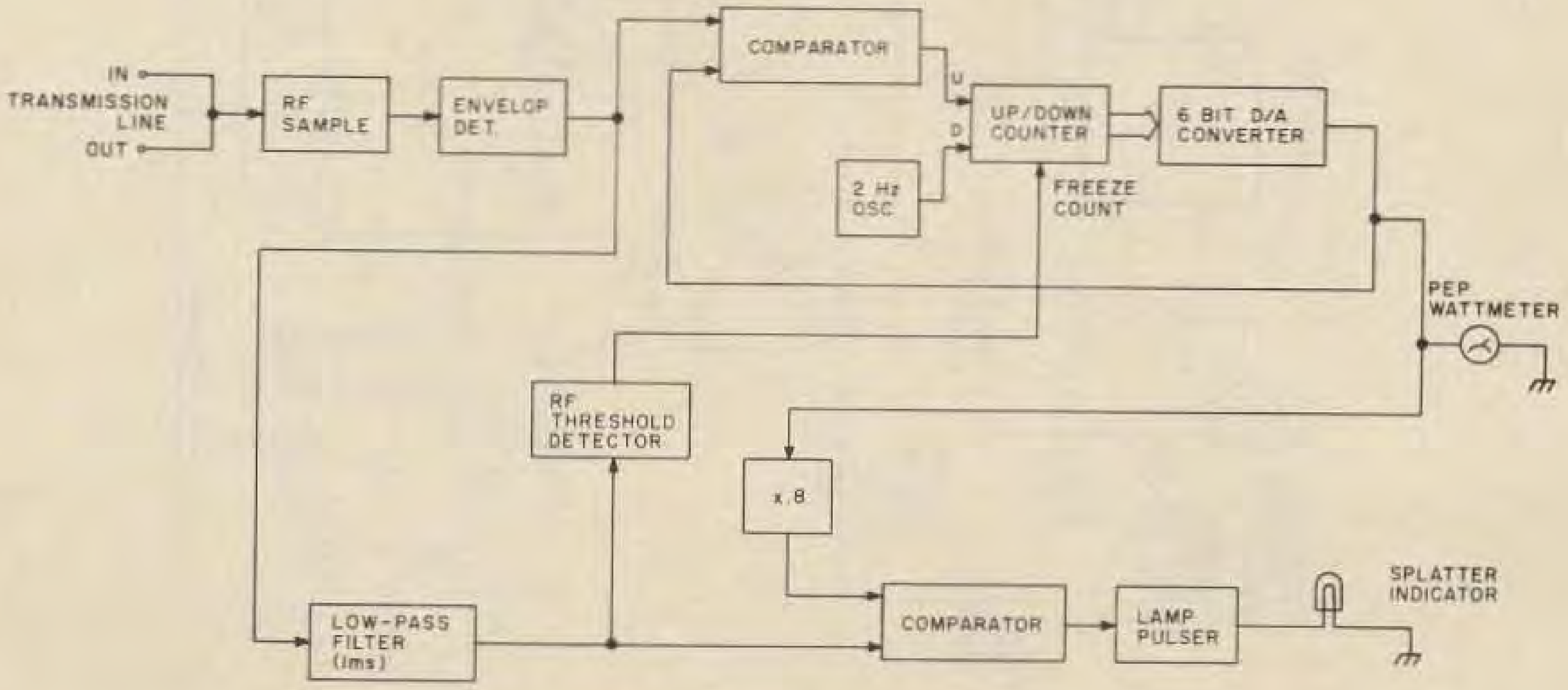

Fig. 1. Splattometer block diagram.

The .1-second pulses are just long enough to produce a bright eye-catching flash on each detection. This visual alarm works well.

One of the nicest features of the Splattometer is that you don't have to concentrate on watching it the way you would an oscilloscope. It just sits quietly off to the side until you start talking too loudly and then *Flash!*, it grabs your attention. A useful modification of the output indicator, particularly for sightless hams, would be to replace the lamp with a 4.8-kHz piezoelectric buzzer. The operator would certainly hear the buzzer, but its frequency would be too high to get past the transmitter's SSB generator.

The complete circuit diagram is shown in Fig. 2. The circuit proper uses just five ICs, and the power supply contains a sixth for 5-volt regulation. An LM324 quad op amp is used to buffer the several RC filtered signals and acts as the D/A output amplifier. A quad LM339 comparator gates the counter-up, counter-hold, and splatter-detection signals. The last comparator section is used in the 2-Hz countdown oscillator. One section of a 556 dual timer generates the output indicator pulses while the other prevents the counter state from underflowing from zero to all ones. That second timer section can also be triggered by the front panel push-button to reset the counter to zero. The reset button isn't used much except at power turn-on when the counter is likely to come up in an unrealistically high state.

The counter uses two 74LS193s. The standard 74193 chips will work just as well, but the extra 10¢ cost per chip seemed like a worthwhile expense in terms of reduced power consumption. The D/A converter is an R-2R ladder made entirely with 22k resistors. Five-percent resistors were used without problem, although the conversion linearity is poor. That doesn't matter, as mentioned earlier, and the 64 output levels are adequate for proper circuit operation.

The simple power supply has one unusual feature. The main circuit board requires 12 to 20 volts at 10 mA or so and 5 volts at 45 mA. Those needs are easily met with the 1000-uF filter capacitor and the 5-volt regulator. The indicator bulb draws about 150 mA, though, and if taken from

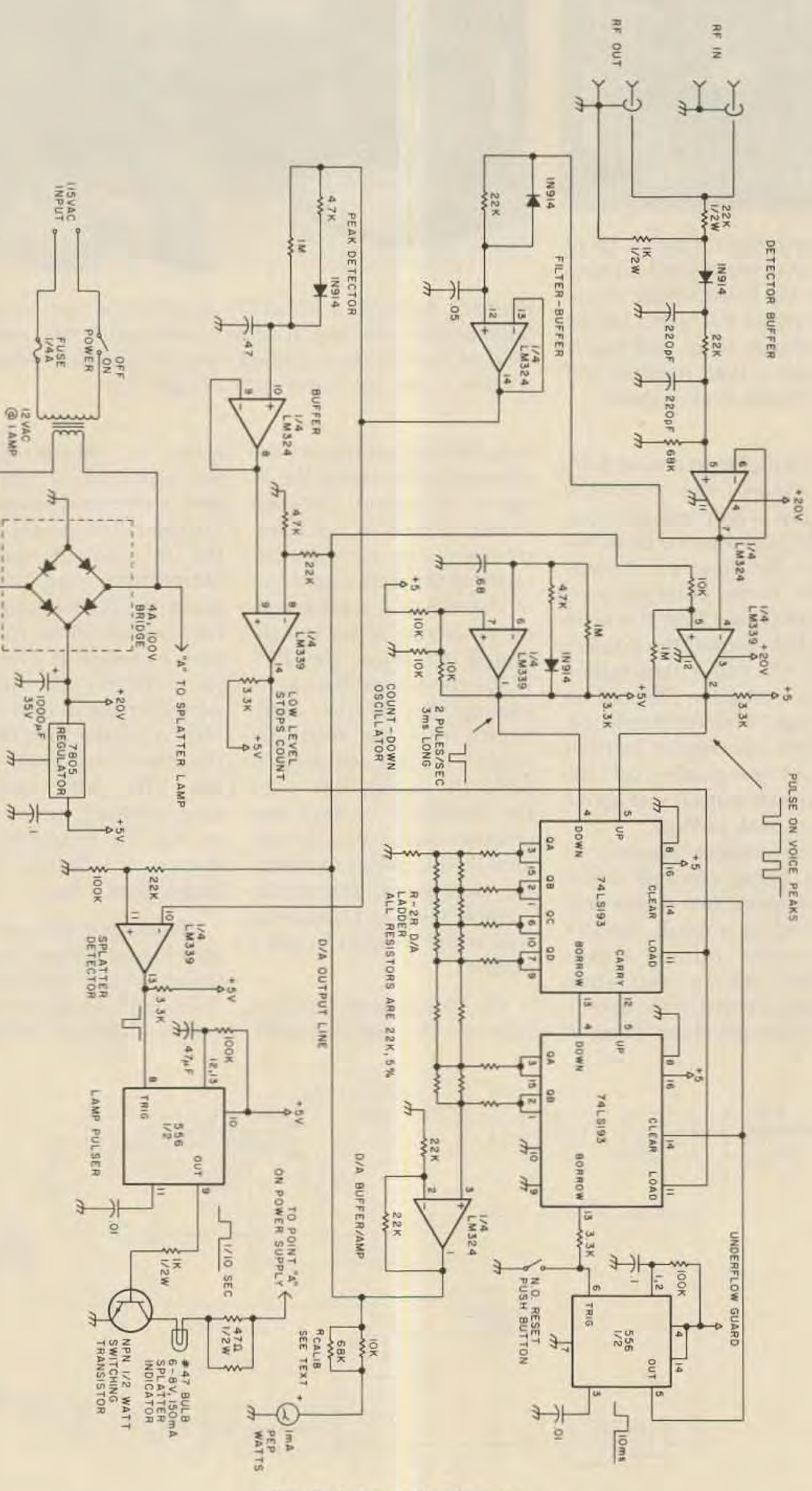

Fig. 2. Schematic diagram.

the 20-volt supply, this is enough to drop the filtered dc level several volts and significantly increase the ripple. As an alternative, the bulb is powered from the half-wave rectified voltage present between ground and either input side of the bridge. The rms level there is a better match for the bulb's design voltage, and the bulb current has little impact on the 20-volt supply since it is isolated from the filter circuit. The two 47-Ohm resistors in series with the bulb limit the current so that the lamp brightness is about the same as when powered from a true 6-volt source.

Construction

As can be seen in the photographs, my unit makes liberal use of flea-market components. The parts list specifies equivalent Radio Shack parts which can be used to build a similar-looking unit. Total cost using all Radio Shack parts is around $65, but there are many corners which can be cut to reduce that price.

My flea-market cabinet is a real deluxe job, so the parts list specifies a correspondingly nice $9 unit. A similar-size Bud Minibox or other enclosure would work as well and cost much less.

The Radio Shack meter also costs $9, but many surplus outlets having advertisements in *73* regularly offer similar meters at less than half that price.

My junk box contained a salvaged plug-in-type circuit board and socket; those two items purchased new total almost $7. Obviously the plug-in feature is nice, but it is also completely unrelated to the electrical operation of the circuit.

Radio Shack components are of reasonable quality and readily available, so they are a good yardstick to use in measuring the maximum cost of this project. Remember, however, that with a little resourcefulness, the cash outlay can be substantially reduced.

A SPLATTER DETECTOR FOR PROCESSED AUDIO?

Several people have independently suggested how to build a splatter detector which might work with both processed and natural audio. The suggested technique is certainly worth passing along as a guide to further experimentation. The idea is to identify the sharp clipped corners which cause splatter by doing some frequency analysis on the AM-detected SSB envelope. In this approach, the output of a lightly filtered AM detector would be separated into two channels—one each for frequencies above and below 3 kHz. Ideally, the signal filtered into the low-pass channel would be all "good" energy while the high-pass channel would contain only splatter signal. These two audio channels could then themselves be rectified, filtered, and compared in magnitude to provide some measure of the amount of splatter at any given time.

I see two main problems with this approach, one practical and one theoretical. First, the low-pass and high-pass filters may be difficult to design in an easily reproduced form. There will be a lot of signal in the low-pass channel, but not much in the high-pass section: perhaps 30 to 50 dB of rejection will be required over a small (less than an octave) frequency range. Each channel will probably need three or more cascaded active filters with closely matched cut-off frequencies, Q, and passband ripple. Second, the high-pass channel will also contain signals not caused by splatter—the 3rd and 5th order distortion products—and these signals may confuse the splatter-detection process. Their presence certainly adds an interesting element to the trade-off between time and frequency domain analysis. The detection approach outlined in Fig. 1 has a lot of positive features: it works fine with unprocessed audio, is auto-adaptive over a wide range of input levels, is easily reproduced, and is low in cost. The processed audio problem is ripe for experimentation and perhaps some readers would like to give it a try.

Using Radio Shack component values is also sometimes difficult. The R-2R ladder in my unit is actually constructed with 10k and 20k resistors. The schematic and parts list specify 22k resistors because they were in the Radio Shack catalog, but using only that size requires paralleling 5 extra resistors to create the 11k values. Electrically that's perfectly acceptable, but physically it's somewhat bulky. If you do buy the 22k resistors, the entire project uses 23 of them. Since only 17 go in the ladder network, be sure to use the opportunity to select out the closest matched group of 17 with an ohmmeter.

You'll see in Photo B that I used a single rf connector while the schematic shows a two-connector loop-through. I run the transmission line right by the back of the instrument and use a tee connector to connect to the input of the Splattometer. The two-connector loop-through is preferable as it avoids completely the temptation to connect the instrument to the line with a single length of cable, cable which would look like a reactive stub on the higher bands and so interfere with transmitter tuning.

Note also that the resistive divider is mounted directly on the back of the input connector. That minimizes stray coupling problems by keeping the large rf voltage away from the main circuit board.

For the same reason, the rf detector and filter components are grouped by themselves in one corner of the main board. I mounted the ac fuse inside the box since the back panel opening on my cabinet wasn't large enough for the ac line, rf input connector, and fuse, too. The parts list specifies a panel-mounted fuseholder since most people won't have my space problem.

The simple power supply is built as a separate unit. Certainly that handful of parts could be placed on the main board with the rest of the circuit. The advantage of the separate approach is that is is easier to disconnect and test the power supply by itself. It's also convenient to be able to insert current meters between the supply and main circuit during checkout.

The front panel can be laid out in any desired manner. Try to choose a lamp holder which will easily be visible over a wide angle. One advantage of the flashing indicator is that it can attract attention without being constantly watched. Don't ruin that feature by using a lamp assembly which has a narrow viewing angle. I didn't include a power-on indicator lamp on the assumption that it might lessen the visual impact of the splatter indicator.

The PEP wattmeter is actually a dc voltmeter reading 0 to 8.5 volts, so any dc current instrument with a full-scale range of 5 mA or less will work with a suitable selection of series resistor. The rf sampler and filter circuits of the Splattometer are designed so that a 3-volt dc output at the D/A converter corresponds to 100 Watts PEP delivered to a 52-Ohm load. Power is proportional to voltage squared and the D/A output can range from almost zero to 7.5 volts, so the meter will read from near zero to about 700 Watts PEP. Meter calibration is quick and easy using the calibration chart shown in Fig. 3.

I made a whole new face for my junk-box meter using India ink, press-on transfers, and a piece of good writing paper pasted to the *back* of the old metal meter face. The back of the metal plate

Rf Input Power Level (Watts)	D/A Output Voltage	Meter Reading (If full scale is 1.0)
25	1.5	.177
50	2.12	.25
100	3.00	.353
150	3.67	.432
200	4.24	.50
300	5.20	.612
400	6.00	.707
500	6.71	.79
600	7.35	.866
700	7.94	.935
800	8.49	1.00

Fig. 3. Meter calibration points.

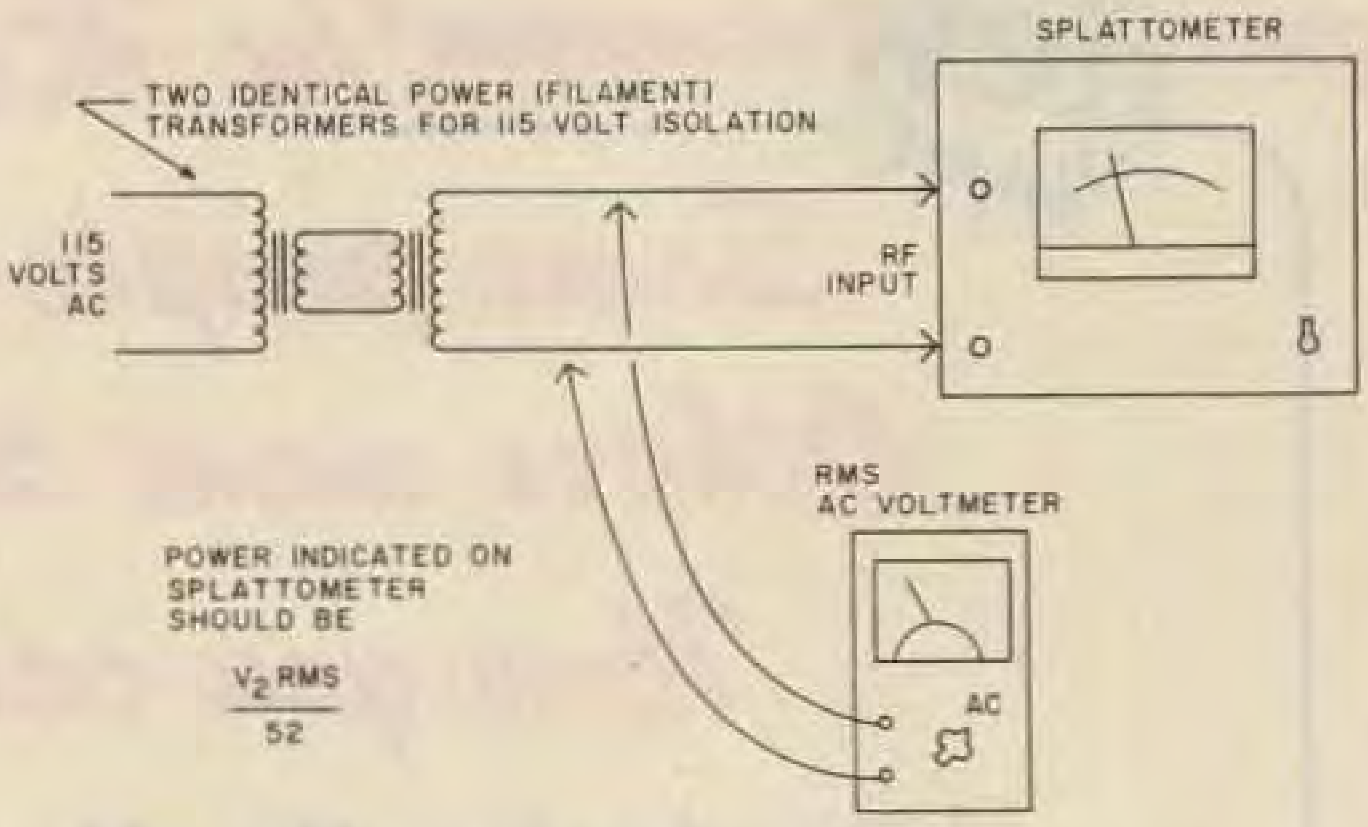

Fig. 4. Calibration using the 115-V, 60-Hz line.

is blank, of course; the original scale would show through paper glued to the front of the faceplate. To make the scale, draw an arc on the new meter face, replace the faceplate and connect the meter to a variable power supply through a resistor sized to make 8.5 volts read full scale. With a 1-mA meter, that resistor should be just under 8.5k. The schematic shows a 10k resistor in parallel with a higher value; 56k will do the job almost exactly. If you purchased the Radio Shack resistors, there will be a spare 68k, ¼-Watt resistor which will work fine.

With the chosen resistors in place, set the supply to 8.5 volts and mark that pointer position as 800 Watts. Now go down through the middle column of Fig. 3 marking the wattage levels at the corresponding voltage points. Finish up by removing the faceplate and adding the dry transfer numbers at the appropriate spots. If you don't want to go through the trouble of making a new meter face, the third column of Fig. 3 can be used to make a conversion chart for the existing scale on a 1-mA instrument.

For convenience, I built the main circuit on a plug-in prototype card. This board comes drilled with .1-inch spaced holes and has an array of printed circuit pads etched on one side. The IC sockets and passive components are mounted on the front of the board and the interconnections are made from the rear with short lengths of wire. Wire-wrap wire is nice to use for the wiring because of its small size. The finished board doesn't look as nice as a real printed circuit card, but it is quicker to make, works as well, and is easier to modify should a reason arise. If you wish, you can save some money by skipping the plug-in feature and hard-wiring the necessary external connections to a standard prototype board.

Checkout and Operation

There is nothing critical about this circuit that has to be "tweaked" in to allow proper operation. If the project doesn't work when first turned on, the reason is most likely a wiring error or sloppy soldering, so check your work carefully. It is always prudent to try the power supply first, making sure the proper operating voltages are there. With everything connected, the meter will probably read upscale when the power is switched on. This is because the counter stages turn on in some random condition. Pushing the reset button should drop the meter pointer almost to zero.

Connect a transmitter through the unit to a dummy load and tune up for normal SSB operation. To maintain calibration accuracy, the Splattometer should always be inserted in the line at a low swr position, that is, between the transmitter and antenna coupler if one is used. Push the reset button after tuning up, key the transmitter, and say a few words into the microphone. The splatter lamp will flash on the first few syllables and the meter will move rapidly upscale. The Splattometer has now calibrated itself to your transmitter's PEP output and is watching for flattopping. The meter will flicker only slightly as you continue to talk; between words and transmissions it will hold dead still. The typical efficiency of a linear amplifier is around 60%, so if the transmitter is rated at 200 Watts PEP input, the meter should indicate about 120 PEP Watts output.

Now turn up the microphone gain, talk more loudly, or cluck into the microphone. The splatter lamp will flash but the PEP output meter won't move upward any more than when you were talking normally. If you have an swr bridge or averaging power meter in the line, you'll notice that it *does* indicate more power when you flattop. A lot of amateurs make themselves unpopular because they don't realize some of that "extra" power is just splatter.

Incidentally, during CW operation the splatter lamp will flash on every key closure since the CW signal is detected as a severely distorted SSB signal!

One limitation of the Splattometer circuit is that it may not respond properly when speech processing is used. This failure results from assuming that splatter is always associated with an extended period of maximum transmitter output. The splatter isn't *generated* during the clipped interval, however; it's really a result of the sharp transition between the flattop level and the rising (or falling) envelope power at the beginning (or end) of the clipped peak. Key clicks on a poorly-shaped CW signal are caused in exactly the same manner. When normal unprocessed audio is used to generate the SSB signal, any peak clipping would be expected only in the output amplifier, so in that case splatter and limiting go together and the Splattometer will work beautifully.

With processed audio, the situation is different. Speech processors, whether designed to work at audio or rf, generally contain somewhere in their makeup a compression amplifier, clipper, and filter. The amplifier brings up the relative amplitude of the weaker voice sounds, the clipper limits the peak output level, and the filter removes the high-frequency distortion products caused by the clipping action. The SSB envelope produced with processed audio can have flattened peaks holding at the maximum output level for relatively long periods of time. Such peaks do not in this case indicate the existence of splatter because the clip-

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ping occurs in the speech processor (where it is also "cleaned up" with a filter) and not the transmitter's final amplifier. The Splattometer will detect these peaks and incorrectly indicate the signal is splattering.

This shortcoming is really not the handicap it first appears to be. Once the clipping level in the processor is correctly set, that circuit will prevent the transmitter output stage from being overdriven into saturation —no matter what happens at the microphone. Increased audio input to the processor or increased amounts of compression will raise the average output power (and the amount of distortion in the audio recovered at the distant receiver), but the *peak* input to the final amplifier will be safely limited by the processor's clipper and splatter will not occur. The Splattometer is needed most in the situation where it works best: an SSB transmitter running with unprocessed audio. In that case, clipping is most likely to occur in the transmitter's output stage. Such clipping will cause splatter and the Splattometer will correctly identify the condition.

PARTS LIST

Item		Number Needed	Radio Shack Part Number	Quantity per pack
Resistors				
47 Ohms,	½ W	2	271-009	2
1k	½ W	2	271-023	2
22k	½ W	1	271-038	2
3.3k	¼ W	5	271-1341	5
4.7k	¼ W	3	271-1330	5
22k	¼ W	23	271-1339	5
10k	¼ W	5	271-1335	5
100k	¼ W	3	271-1347	5
1 Meg	¼ W	3	271-1356	5
68k	¼ W	1	271-1345	5
Capacitors				
1000 uF,	35 V	1	272-1019	1
220 pF		2	272-124	2
.01 uF		2	272-131	2
.1 uF		2	272-135	2
.47 uF		2	272-1417	1
.68 uF		1	272-1418	1
.05 uF		1	272-134	2
Semiconductors				
1N914		4	276-1122	10
4 A, 100 V bridge		1	276-1171	1
7805 regulator		1	276-1770	1
NPN transistor		1	276-2030	1
LM324 quad amp		1	276-1711	1
LM339 comparator		1	276-1712	1
74LS193 counter		2	276-1936	1
556 dual timer		1	276-1728	1
Miscellaneous Electrical				
1-mA meter		1	270-1752	1
12-V transformer		1	273-1505	1
#47 lamp		1	272-1110	2
¼-Amp fuse		1	270-1270	3
Hardware				
Power switch		1	275-602	1
Reset switch		1	275-609	2
Fuse holder		1	270-364	1
Lamp socket		1	272-325	2
Rf connector		2	278-201	1
Cabinet		1	270-269	1
Plug-in board		1	276-153	1
Board socket		1	276-1551	1
Circuit board (for power supply)		1	276-158	1
16-pin sockets		2	276-1998	2
14-pin sockets		3	276-1999	2

The final wattmeter accuracy is dependent on several things but should be within 10 or 15 percent without further adjustment. If you're really finicky about such things, it can be set on the nose with an isolated 60-Hz source and a good ac voltmeter. Use a 1:1 isolation transformer or two filament transformers back-to-back as shown in Fig. 4 and feed the output into the Splattometer. Measure the equivalent input power as the square of the rms voltage divided by 52. If necessary, the series meter resistor can be adjusted so that the pointer exactly indicates the calculated power.

Wattmeter accuracy is also dependent on swr. Remember that the wattmeter is really a peak-reading rf voltmeter which can be calibrated in Watts only because the load is specified as 52 Ohms and $P = E^2/R$. The wattmeter scale will be inaccurate if another load impedance is used; for example, if the load is doubled to 104 Ohms, the indicated power will be twice the actual power. If the transmission line swr isn't 1:1, the problem is harder to solve since the wattmeter readings will vary with the electrical length of the line. The rf voltage on a line having 2:1 swr will vary over a 2 to 1 range depending on line length. The indicated power, if based only on the voltage measurement, would vary over a 4 to 1 range—from about half to twice the actual power! The Splattometer's PEP wattmeter can be calibrated and used as a worthwhile test instrument, but don't forget to consider errors caused by swr. The splatter-detection portion of the instrument will of course be unaffected by swr as long as the wattmeter reading settles out to something between 25 and 700 Watts.

The resistor values at the input rf voltage sampler can be changed to shift the Splattometer operating range if desired. Reducing the 1k resistor to 510 Ohms almost doubles the input voltage necessary to create a specific meter reading, so the instrument will then read from about 100 to 3000 Watts. For low-power operation, the 22k input resistor can be reduced to 9.1k and the resulting range will be approximately 4 to 120 Watts PEP.

During normal SSB operation, the splatter lamp should flash only occasionally, maybe once or twice per sentence. Any more than that is too much and calls for a reduction in microphone gain.

Nobody wants to overdrive his transmitter and cause splatter, but the desire to get maximum output power is a strong one. Until now, the preferred monitoring technique required an oscilloscope. That solution is bulky, expensive, and requires constant attention in a dim room. The Splattometer is a much better alternative: It's inexpensive, unobtrusive, and, unlike the complex oscilloscope display, tells you only what you want to know exactly when you need to know it. You'll certainly find it a worthwhile addition to your equipment if you operate much SSB. Even if you're primarily a CW operator, it might make an excellent Christmas present for that SSB operator down the block! ■