Jaques Audet, *VE2AZX*
7525 Madrid Street
Brossard, Quebec
Canada J4Y 1G3

UPGRADING BOONTON MODELS 92/42 RF VOLTMETERS

Replace the mechanical chopper and AC amps with chopper-stabilized, low-offset op amps

The Boonton model 92/42 transistorized RF voltmeters have been industry standards **since** the 1970s. Their wide frequency range, extending above 1 GHz (or 18 GHz depending on the probe used) combined with eight ranges (in the model 92) covering 1 mV to 3 volts full-scale, make them very useful equipment for general RF/microwave work. The model 92 was designed to replace the model 91 which used vacuum tubes. However, all models use a mechanical chopper to convert low-level DC (from the rectified RF) to a low-frequency AC signal (typically 90 Hz). Like all mechanical devices, this chopper is subject to wear and constitutes the weakest link in an otherwise excellent design.

This article describes a redesign of the Boonton model 92 and 42 front-end circuits that replace the mechanical chopper and AC amplifiers with chopper-stabilized, very low offset op amps. I'll also show how to recalibrate the modified instrument and provide results of linearity measurements done on my own instrument.

Original circuit

Refer to the block diagram shown in **Figure 1**. The RF probe generates a bipolar DC output that's converted to a square wave at the chopper frequency. The chopper is like a mechanical SPDT relay that alternately selects the probe "+" and "-" terminals to perform DC to AC conver-

RANGE (mV)	ATTENUATOR GAIN	FIXED GAIN AMP	SECOND AMP GAIN	TOTAL GAIN	NOMINAL INPUT V AT F.S.	MEASURED INPUT V AT F.S.
1	1	100	1000	100000	3.10E-05	3.80E-05
3	1	100	100	10000	3.10E-04	3.76E-04
10	1	100	10	1000	3.10E-03	3.68E-03
30	1	100	1	100	3.10E-02	3.19E-02
100	0.18716	100	1	18.72	0.166	0.1844
300	0.04231	100	1	4.231	0.733	0.748
1000	0.013325	100	1	1.333	2.326	2.610
3000	0.004231	100	1	0.4231	7.327	8.660

Table 1. Boonton RF voltmeter gain distribution before modifications. Rightmost column data is for the author's voltmeter.

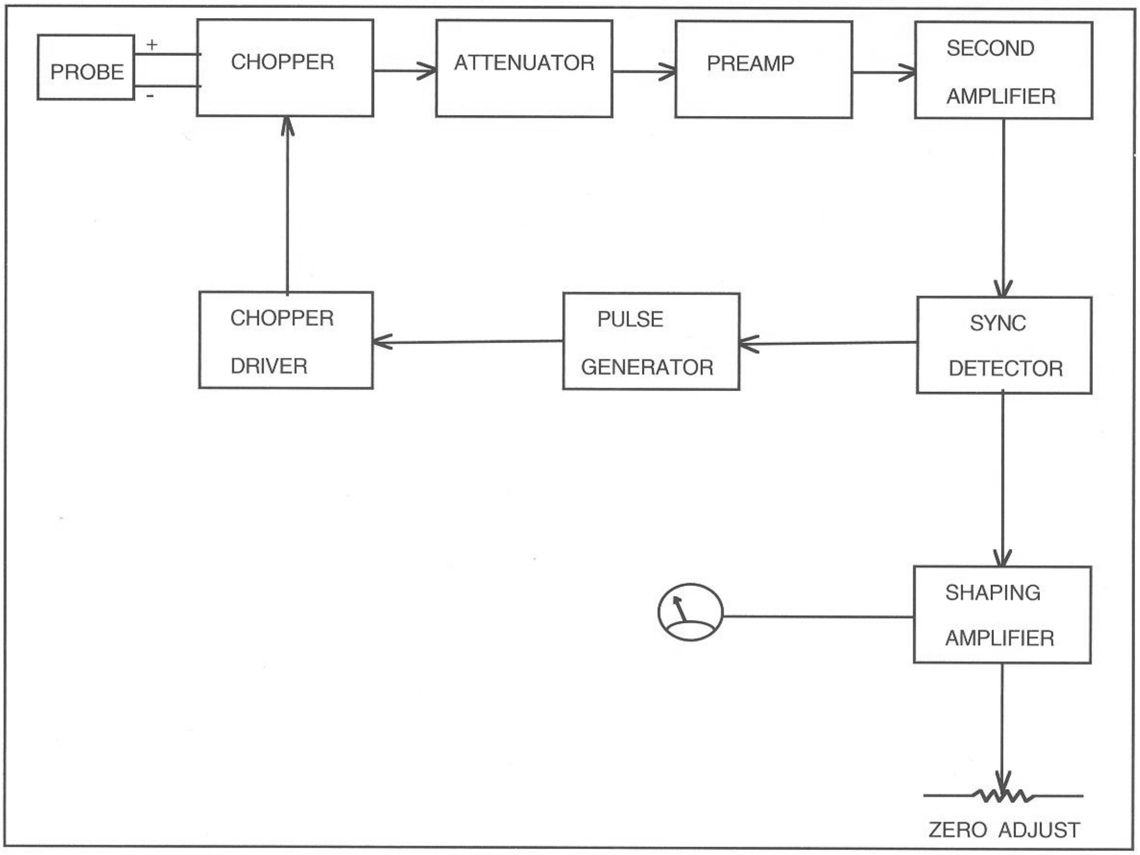

Figure 1. Model 92 series block diagram.

sion. This allows low-level AC signals to be amplified more easily than DC signals, because the amplifier offsets don't affect the AC signals. The attenuator scales the AC input level to a maximum of about 30 mV peak, which allows switching of AC signals with FET switches. Two AC-coupled amplifiers follow the attenuator. The first amplifier has a fixed gain of 100, while the second amplifier has gains of 1, 10, 100, or 1000 in order to bring the probe voltage to -3.1 volts full-scale at the sync detector output. **Table 1** shows the attenuation and gain values for the instrument's eight ranges. The sync detector converts the AC amplified signals back to DC and provides filtering against nonsynchronous signals—such as white noise that's present on the most sensitive ranges.

The amplifiers and attenuators are located on the motherboard; the chopper driver/sync detector resides on a plug-in pc board. A second pc board, called the shaping amplifier, provides the nonlinear compensation required, depending on the input level and the selected range, to give an output proportional to the AC signal voltage present at the probe input.

Proposed circuit

Figure 2 shows the revised block diagram of the new amplifier circuit. The previous chopper driver/sync detector circuits are replaced by two integrated circuit chopper-stabilized preamplifiers with gains of 1 or 100, depending on the selected range. The second amplifier has range-dependent gains that vary from 0.42 to 1000. As shown in **Table 2**, the gain of the second amplifier has been chosen to provide the same overall gain on every range as the unmodified voltmeter. This also means that the shaping amplifier may be reused because the new amplifiers provide the same -3.1 volts at full-scale output.

Figure 3 shows the circuit schematic of the new amplifier that plugs into the chopper driver/sync detector slot of the voltmeter (connector slot J101). This slot provides the ±15 volt supplies and the range control lines for switching the amplifier gains. The ICL7650 chopper-stabilized operational amplifiers IC1 and IC2 amplify the differential probe signals. Resistors R4, R5, and R6, and photo-MOS relay IC6 set the amplifier gain. The LO 4 line is derived from diode logic on the voltmeter motherboard. It turns on IC6 output MOSFETs at the 30-mV range and below. This sets the preamplifier gain at 100. The photo-MOS relay IC6 minimizes thermally induced offsets generated at the relay "contacts" (normal relay contacts can easily generate 10 μV offsets, while this device has 1 μV typical offset specification). IC6 also pro-

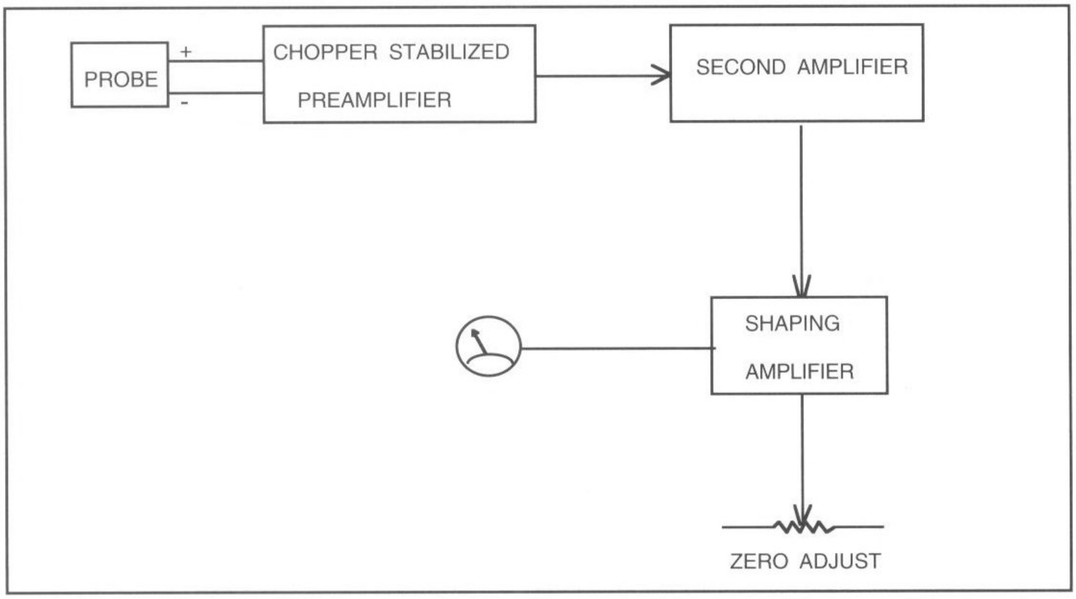

Figure 2. Revised block diagram incorporating new amplifier circuits.

vides very low leakage consistent with the high input impedance (5.6 megs) of the chopper-stabilized amplifiers. IC3 is a unity gain amplifier that provides balanced-to-unbalanced conversion. The second amplifier, IC4, has controlled gains of 0.42 to 1000, as set by the FET switches Q2 to Q7 with their associated drain resistors, or with analog switches IC5A and IC5D. On the 3-volt range, all FET switches are open and IC4 gets its input via resistors R11, R12, and R13. This "T" circuit synthesizes a 2.363-meg resistor by using resistor values of 100 k and below, thus eliminating the need for precise resistors above 1 meg. I also used the same technique for R17, R18, and R19 to synthesize a 1.734-meg resistor. Range selection is accomplished by grounding one of the FET gates either via the front panel push buttons or via the rear remote control connector.

The main concern when designing high-gain amplifiers is to minimize DC offsets. Here, it is mandatory to use chopper-stabilized op amps with input offsets in the microvolt range, as the probe DC output is around 31 µV at 1-mVAC input. With the preamplifier operating at a gain of 100, this translates to a 100-µV offset at the preamplifier output.

The voltage offsets at the second amplifier output may come from two main sources: first from its input offset voltage (typically 30 microvolts), and second from the FETs and analog switch leakage currents (0.1 nA gate-to-source leakage for every FET and 1 nA typically for every switch). Therefore, the revised offsets at the maximum total gain of 100,000 (1-mV range) will be:

Preamplifier offsets: 1 µV * 100 000 = 100 mV

Second amp offsets: 30 µV * 1000 = 30 mV

Second amp switch leakage currents: (0.1 nA * 6 FET's + 1 nA * 3 switches) * 1 Mohms = 3.6 mV.

RANGE mV	PREAMP GAIN	PREAMP OUTPUT VOLTS	GAIN SECOND AMP	TOTAL GAIN	FULL SCALE INPUT VOLTS
1	100	0.0031	1000	100000	3.10E-05
3	100	0.031	100	10000	3.10E-04
10	100	0.31	10	1000	3.10E-03
30	100	3.1	1	100	3.10E-02
100	1	0.166	18.716	18.72	0.17
300	1	0.631	4.909	4.909	0.63
1000	1	2.326	1.333	1.333	2.33
3000	1	7.327	0.4231	0.4231	7.33

Table 2. Boonton RF voltmeter gain distribution after modification.

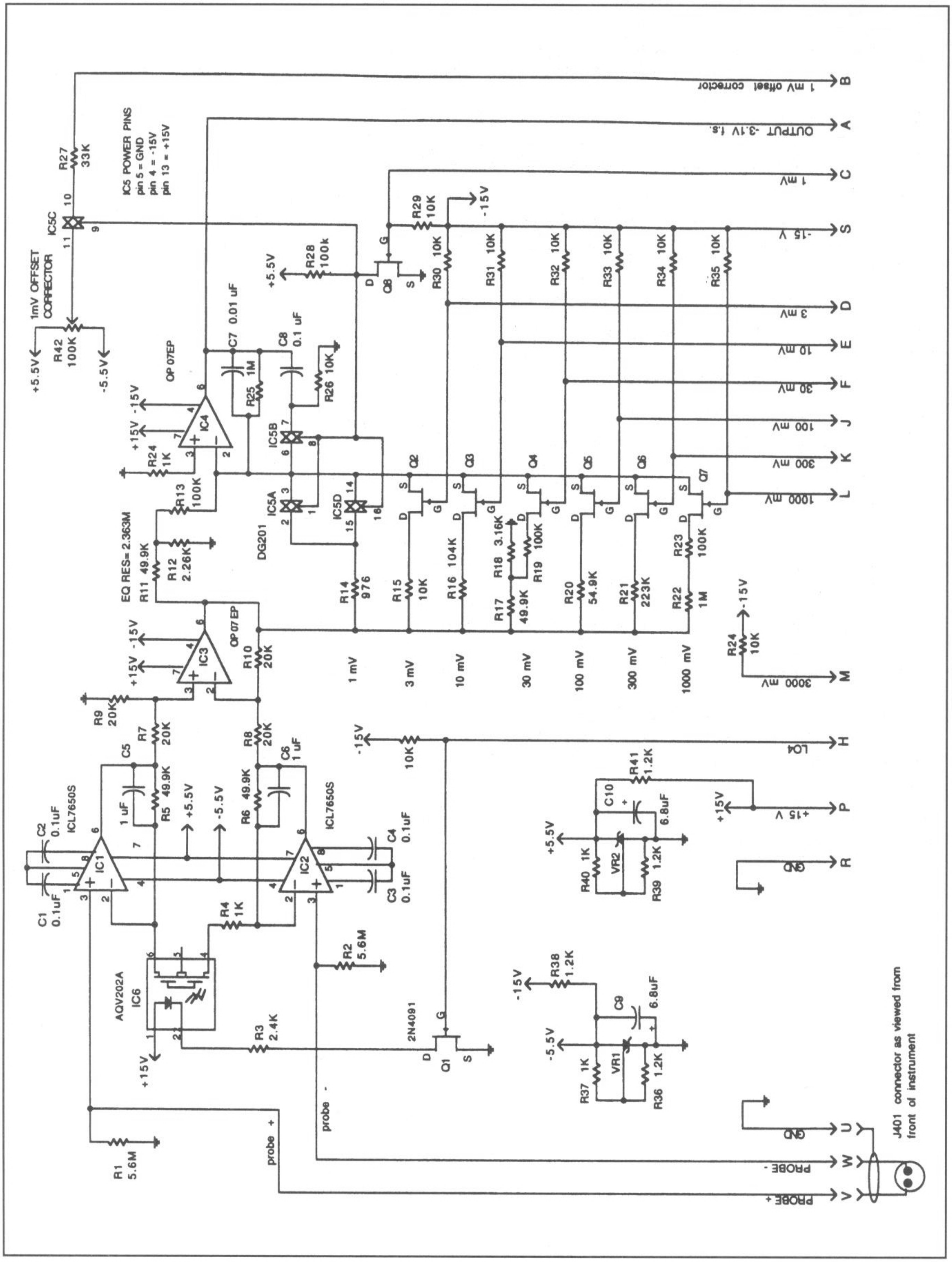

Figure 3. DC amplifier for modified Boonton 92 RF voltmeter.

Reference Designator	Parts Description
DIP plugboard	VECTOR #3662A-6 plugboard Includes ground plane on one side with clearance holes that clear the 0.1 in. X 0.1 in. hole pattern hole size = 0.042 in., 2 x 22 fingers, spaced 0.1 in. Cut to fit inside voltmeter.
IC1, 2	Op amps ICL7650SCPA1 (Harris)
IC3, 4	Op Amps OP-07 EP (Analog Devices)
IC5	Analog switch DG201CJ (Harris)
IC6	Photo MOS relay AQV202A (AROMAT)
Q1-Q8	N Channel FETs 2N4091 or 2N5459 or equivalent
VR1, 2	Shunt Regulators TL431CP (Texas Instruments)
C1-C4	Polycarbonate capacitors 0.1 uF 10%
C5, C6	Ceramic capacitors 1uF matched to 1%
C7	Ceramic capacitor 0.01uF 10%
C8	Ceramic capacitor 0.1uF 10%
C9, C10	Tantalum capacitor 6.8 uF
R1, 2	Resistors metal film 5.6 Mohms 5% (NOTE 1)
R3	Resistor 2.4K 10%
R4, 24, 37, 40	Resistors metal oxyde 1K 1%
R5, 6, 11, 17	Resistors metal oxyde 49.9K 1%, matched 0.1%
R7-10	Resistors metal oxyde 20K 1%, matched 0.1%
R12	Resistors metal oxyde 2.26K 1%
R13, 19,23	Resistors metal oxyde 100K 1%
R14	Resistors metal oxyde 976 ohms 1%
R15	Resistors metal oxyde 10K 1%
R16	Resistors metal oxyde 104K 1%
R18	Resistors metal oxyde 3.16K 1%
R20	Resistors metal oxyde 54.9K 1%
R21	Resistors metal oxyde 223K 1%
R22, 25	Resistors metal oxyde 1M 1%
R24, 26, 29-35, 43	Resistors 10K 10%
R27, 28	Resistors 100K 10%
R36, 38, 39, 41	Resistors metal oxyde 1.2K 1%
R42	Multiturn pot PCB mount 100K

NOTES:
R1, R2 resistors 5.6 Mohms: one already exists on motherboard as R104
Parts may be obtained from NEWARK Electronics tel 1-800-463-9275

Table 3. List of components.

Total offset voltage at the second amplifier output: 133.6 mV.

This corresponds to 4.3 percent (0.133 volt ÷ 3.1 volts) of full-scale, which is quite acceptable.

These simple calculations show that the combined offsets of the two amplifiers are dominated by the offsets of the preamplifier. The front panel zero adjustment cancels amplifier offsets at the shaping amplifier input on the three most sensitive ranges. Note that its offset canceling range increases by a factor of 10 on the 3-mV range and by a factor of 100 on the 1-mV range.

On the 1-mV range, two analog switches are used in parallel to increase the ratio of gain setting resistance R14 to the IC5A and IC5D switch resistance, as IC5 resistance will vary somewhat with temperature. On the 3-mV and 10-mV ranges, the voltmeter zero adjustment is the same for both ranges. IC5C brings in the offset corrector pot R42 on the 1-mV range. Pot R42 (connected in parallel with the front panel zero pot) fine tunes the offset on the 1-mV range, so the front panel zero doesn't need readjustment.

The DC probe signal is filtered by R5*C5 and R6*C6 (50-msec time constant) and R25*C7 (10-msec time constant). This sets a basic 60-msec time constant on all ranges. Note that the 0.1 μF capacitors connected across the probe + and - terminals also contribute additional filtering. On the 1-mV range, IC5B also turns on to add an additional 100-msec time

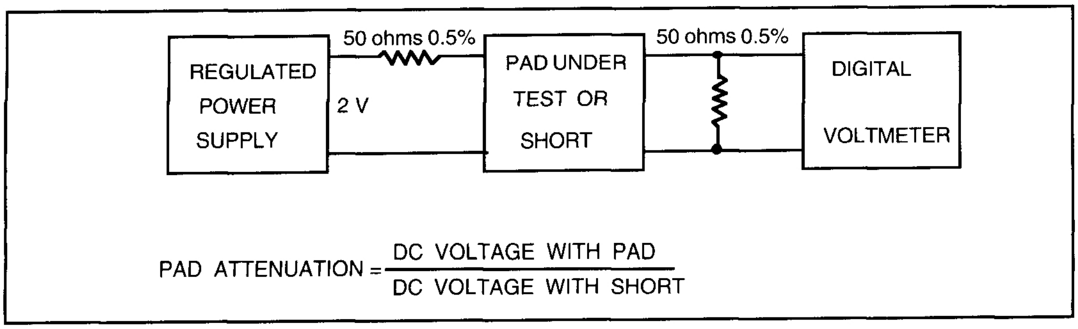

Figure 4. Pad attenuation measurement.

constant with R25*C8. Note also that R26 provides "hitless" switching because the left side of C8 is kept at ground potential (with a 1-msec time constant) when IC5B is off. When IC5B turns on, it connects the left side of C8 at IC4 virtual ground, preventing the meter from momentarily going off-scale. Resistor R26 has a negligible effect on IC4 open loop gain when IC5B closes.

The two shunt regulators, VR1 and VR2, provide ±5.5 volts to the chopper-stabilized amplifiers IC1 and IC2 because their supply can't exceed ±7 volts. This limits the amplifier outputs to ±5 volts and also sets IC1 and IC2 maximum gain at 100. See **Table 3** for the component list.

Construction

Refer to the detailed component description in **Table 3**. I built the circuit on an epoxy glass Vector plug-in board with a ground plane on the component side. It has gold-plated fingers that fit into the edge connector of the chopper driver/sync detector circuit (J101). The axial components are held in place with wire wrap pins—T42-1 "microclips"—also from Vector Co. I used wire wrap sockets for all ICs. I suggest you cut all pins, so they protrude about 1/8 inch on the wiring side. The DC probe output must be rewired to unused pins V and W of the plug board via a two-conductor shielded cable. Add a short jumper on the voltmeter motherboard between J101 pin B and the shaping amplifier connector J102 pin A. It's a good idea to clean the plug-in board with methanol to eliminate potentially conductive residues produced during the fabrication and to remove finger grease and salts. It's especially important to minimize stray leakage paths around the probe signals inputs. Note that the DVM motherboard is epoxy based and coated with a varnish to keep its insulation resistance up under high humidity conditions.

Testing and calibration

Verify that the ±15-volt and ±5.5-volt supplies appear at the proper pins before inserting the ICs. If necessary, adjust the -15 volts to read -15 ± 0.1 volts using pot R145 located on the motherboard.

Connect the RF probe with a 50-ohm termination, and verify the chopper amplifier offset voltage by connecting a DVM at IC3 output pin 6. Set the range to anywhere between 1 and 30 mV. The DVM should read within 0.0 ± 0.5 mV. With the range set to the 3-mV scale,

VOLTMETER F. S. RANGE mV	PAD NOMINAL ATTENUATION dB	PAD MEASURED ATTENUATION	SET GEN LEVEL mV
1	20+30	______	______
3.16	20+30	______	______
10	20+30	______	______
31.6	20	______	______
100	20	______	______
316	0	1.00	316
1000	0	1.00	1000
3160	0	1.00	3160

GENERATOR LEVEL FOR F. S. = F. S. RANGE / PADATTENUATION

Table 4. Boonton voltmeter calibration.

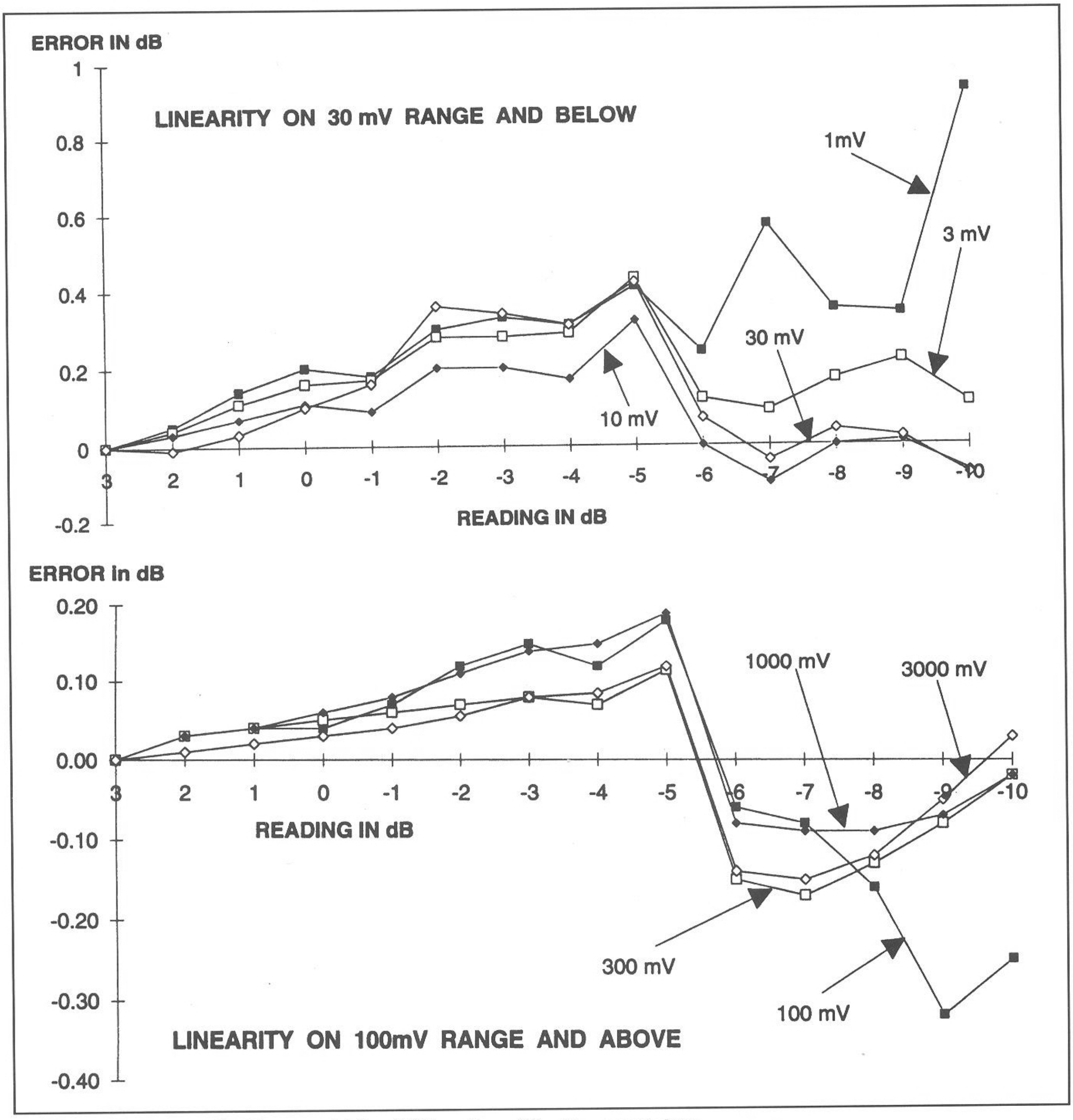

Figure 5. (A) Linearity on 30-mV range and below. (B) Linearity on 100-mV range and above.

adjust the front panel zero control for a zero reading on the Boonton voltmeter. Set the 1-mV range, and adjust R42 on the plug board (1-mV offset corrector) for a zero reading on the voltmeter. The remainder of the adjustments consist of calibrating the full-scale gain pots for every range.

I recommend performing the calibration with the 50-ohm probe termination in place, as this is most likely the way the voltmeter will be used most of the time (note that probe models 41-4x have a built-in 50- or 75-ohm termination). Using the 50-ohm shielded probe termination also minimizes the possibility of picking up stray signals with the high-impedance probe. Be careful if you use an audio signal generator for calibrating the RF voltmeter! I found that my Krohn-Hite 4200 audio generator acts like a VHF antenna and picks up close to 1 mV of broadband VHF signals because it doesn't have RF-type shielding. This occurred even with the oscillator turned off and with the power cord disconnected at the generator side. The stray pickup completely disappeared when I used an

PROBE TYPE	FREQUENCY RESPONSE	NOTES
91-4C	1 KHz - 250 MHz	Originally used on model 91 (vacuum tube)
91-12F	10 KHz - 1.2 GHz	Standard
952001A (silver barrel)	10 KHz - 1.2 GHz	Standard
Power Sensor 41-4E (50 ohms)	200 KHz - 18 GHz	Normally used on model 42xx microwattmeter
Power Sensor 41-4C (75 ohms)	200 KHz - 1 GHz	but works fine on model 92, (+13 dBm max.)

Table 5. RF voltmeter probes usable with Boonton Model 92 voltmeter as verified by the author.

RF signal generator with a shielded output attenuator. It's also a good idea to check the resistance of the probe termination with your ohmmeter; it should read 50 ±1 ohms.

I recommend using a minimum frequency of 100 KHz for calibrating the RF voltmeter for all probes except the 75-ohm power sensor model 41-4C, which should be calibrated at 1 MHz. Use an audio signal generator covering 100 Hz to 100 KHz (or 1 MHz) with less than 1 percent distortion. As shown in **Table 4**, the following calibration voltages are required: 316 mV, 1.000 volt, and 3.16 volts into a 50-ohm load. Measure these levels at 100 Hz using a DVM set on AC ranges. Using a scope, verify the generator flatness up to the calibration frequency of 100 KHz. Use the measured level at 100 Hz as the reference. Note that inexpensive DVMs (like the RadioShack variety) cannot be used at 100 kHz because they typically lose accuracy above 1 kHz and below 300 mV. Consult your DVM manual for frequency response specifications. If necessary, adjust the generator output level to maintain a constant peak-to-peak amplitude up to the calibration frequency.

Adjust the front panel zero and calibrate the lower ranges (1 mV to 100 mV) using previously calibrated 50-ohm, 20-dB and 30-dB coaxial pads or a 10-dB step attenuator. Use coaxial pads here to prevent stray pickup and to attenuate the low-level noise coming from the audio generator. Ensure that the pad reflection coefficient at both ends is below 1 percent: terminate one side of the pad into 50 ohms and verify the DC resistance on the other side. It should read 50 ±1 ohms. Repeat this test for the other side.

For greatest accuracy, first verify the exact attenuation of the pads at DC. See **Figure 4** for the test set-up. As shown in **Table 4**, compute the signal generator levels required for a full-scale voltmeter reading by dividing the full-scale voltage for the range being calibrated by the pad attenuation measured previously. Adjust the full-scale gain pots on every range for a full-scale reading. Note that the RF voltmeter calibration is only valid for the probe used during calibration. Exchanging one probe for another of the same or different model normally requires that a new calibration be performed. Errors up to 5 percent could result if the recalibration is omitted. As shown in **Table 5**, many types of probes may be used with the RF voltmeter. I found that the power sensor probe model 41-4E can be calibrated at 100 kHz, even though it is rated from 200 kHz up.

Linearity tests

Refer to **Figures 5A** and **5B** for voltmeter linearity test results as measured on my unit with probe model 91-12F. The test frequency used was 100 kHz. The reference point is at full-scale. I performed linearity tests from +3 dB (full-scale) down to -10 dB, in 1 dB steps, for all eight ranges of the voltmeter—using a calibrated step attenuator that covers 0 to 13 dB of attenuation. For these tests, I measured the RF voltmeter DC output with a Fluke model 8920A digital voltmeter that converts the DC readings to dB ratio. The estimated accuracy is ±0.02 dB.

Conclusion

The new circuit described above constitutes a reliable replacement for the old chopper circuit. It fits in place of the chopper pc board and is easy to calibrate. This circuit has been verified in my model 92A RF voltmeter. The same chopper/amplifier circuit works on the model 42 with one difference: the +20-dBm range is missing. After looking at the model 42 schematic, it appears that the above DC amplifier circuit could be used in place of the chopper driver/sync detector circuit. I have verified that the probes for both models can be interchanged as long as the power input to the 42-x probes doesn't exceed +13 dBm. The model 42 is called a microwattmeter because it only displays power (into a 50-ohm load), even though the two instruments are basically RF voltmeters. The above modifications also retain the programmability features of the voltmeter. A future article is planned that will describe how it can be easily interfaced to a PC computer.■

Bibliography

1. *Boonton Model 92 RF Voltmeter Service Manual.* Includes circuit diagrams.
2. *Boonton Model 45 RF/Microwave Power Meter Service Manual.* Includes circuit diagrams.
3. Keithly Instruments, Inc., *Low Level Measurements*, 1984 edition.