BUILD THIS 1.6-GHZ COUNTER PRESCALER

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Build this low-cost, high-performance, 1.6-GHz amplifier/prescaler. You may want to keep that old frequency counter a while longer.

ENGINEERS, TECHNICIANS, AND EXperimenters who work with state-of-the-art electronics have an almost continuous need to update their test equipment in this rapidly changing field. Higher-frequency, less expensive circuits have brought forth a new generation of inexpensive frequency counters with improved sensitivity that can measure into the microwave region.

With the increased usage of higher frequencies, many quality-built counters are being discarded mainly due to inadequate range. Many of these instruments may only work up to 50–100 MHz, but have valuable features, including ultra-stable time bases that might yield much greater accuracy than could be found in newer, less expensive models.

Enter our solution, a two-stage amplifier and divide-by-10 or -100 prescaler, with 10-segment LED signal strength indicator. It's inexpensive, compact, and can fit into a much larger instrument, like the Hewlett-Packard (HP) Corp. 5245L counter shown in Fig. 1. It has a typical sensitivity of 5 millivolts RMS from 50 MHz–1.6 GHz, and used with such a high-quality, low-range counter, is a practical way to update your gear.

Many high-quality, major brand, low-range counters are available as surplus for $50–200. They're worth at least that much, if only for the time base, while a newer comparable counter may cost several times as much. The prescaler isn't just for old counters; it's for any counter you'd like to extend the range or sensitivity of, or provide with an LED bargraph indicator.

Several divider schemes were considered for the prescaler, trading off bandwidth against cost; the original goal was 50 MHz–1.5 GHz performance with excellent sensitivity. The prescaler divides (prescales) by 10 from 30–500 MHz, and by 100 from 300 MHz–1.6 GHz, for optimal resolution from a basic counter.

If you want to use a direct 50-MHz counter with 1-Hz resolution and a one-second gate to measure up to 450 MHz, you'd have to prescale by 10 for a 7-digit resolution in one second, compared with 6-digit resolution if you prescaled by 100. To maximize display resolution requires that the prescaler be able to divide by 10 to reach 500 MHz. Binary dividers are cheaper and more common than decimal versions, and prescaling by 256, 512 or 1024 is easier than by 100 or 1000, but decimal division lets you move a decimal point mentally, and easily understand the reading.

Circuit description

Figure 2 shows the block diagram of the prescaler, and Fig. 3 shows its schematic. IC5 has both ÷2 and ÷5 outputs, the one in use being selected using S2. With S2 set to ÷100, IC3 is a ÷4, and IC4 and IC5 are ÷5's, for a ÷100. With S2 set to ÷10, the input is routed around IC3 to IC4 by PIN diode D4 (acting as a bandswitch). IC4 is a ÷5 counter, and IC5 is a ÷2 counter, creating a ÷10 counter overall. IC1 and IC2 are broadband Monolithic Microwave IC (MMIC) amplifiers used on both ranges. The output of IC1 drives LED bargraph DSP1, the RF signal strength indicator. It's very useful as a relative field strength meter, for peaking the output of a circuit, or just as a convenient indication of signal presence.

In the prescaler, D4 is used for bandswitching. When reverse-biased, it's capacitance is almost constant from 0.65–0.75 pF. When forward-biased, it's capacitance rises rapidly to 6 pF or more. Its cathode is kept at about +2.5 volts DC by voltage divider R7-R8; the drop across L4 is negligible. S2-a and S2-b switch the anode of D4 between +5 volts DC and ground, so there's ±2.5 volts DC across D4, relative to the cathode.

With S2 set to ÷10, D4 is forward-biased, so its capacitance increases as noted above, and the total impedance looking into the anode of D4 goes down, routing the output of IC2 through D4 and C9 to IC4. When S2 is set to ÷10, IC3 is off, since pin 1 (V_{CC}) is connected to +5 volts DC through R5. The R5-IC3 voltage divider reduces the potential at pin 1 to about 1.25 volts DC, turning IC3 off. However, you might wonder: Why not just turn off IC3 altogether?

The reason is that C10 still looks into pin 7 (OUT 2), and would see too low an impedance if IC3 were totally off, and too much of IC2's output would be diverted away from IC4. The value of R5 was found by trial-and-error, to maximize the impedance looking into pin 7 (OUT 2), while keeping IC3 off. Conversely, when S2 is on ÷100, IC3 is now on, since it's now connected to +5 volts DC through R5 and R6, and their parallel value is under 1.5 ohms. The cathode of D4 is still at +2.5 volts DC, but the anode is effectively grounded, so D4 is reverse-biased.

The capacitance of D4 is now about 10% of its forward-biased value, increasing capacitive reactance by about a factor of 10. The impedance looking into the anode of D4 thus increases, and almost no output from IC2 reaches IC4 directly. The output of IC2 enters IC3, is divided, and passed to IC4.

To avoid splitting the output of IC3 between IC4 and the path along C9, trial-and-error again resulted in a high-impedance path looking into the top of C9. In other words, the high impedance of a reverse-biased D4 works both ways. It keeps the output of IC2 from being diverted to IC4, while keeping the output of IC3 from being diverted backward. The loss of output of IC3 through C9-L4-R8 is minimal.

The input enters through J1 and is AC-coupled through IC1 and IC2, Avantek MSA0104 MMIC amplifiers. They have double grounds and indirect biasing, through R1-L1-C26 for IC1, and R2-L2-C15 for IC2. Carbon-composition resistors R1 and R2 temperature-compensate collector current in IC1 and IC2. L1 and L2 prevent R1 and R2 from affecting the load impedance, which would reduce amplifier gain. IC3 is an NEC UPB582 ÷4 MMIC prescaler, with R3, C8, C9, and D4 as its bypass for the ÷10. D4 is a Motorola MPN3401 PIN diode, while R7 and R8 produce a +2.5-volt DC bias at the cathode (the output) of D4 via L4. D4 is biased on or off by the 0 or 5 volts DC switched through L3 at its anode.

Device IC4 is a Motorola MC12009 emitter-coupled logic (ECL) ÷5 prescaler, with a built-in ECL-to-TTL output level converter. R9 keeps the circuit stable with no signal input. IC5 is a TI 74S196 presettable binary/de-

FIG. 1—THE PANEL-MOUNTED VERSION of the prescaler, in an HP 5245L frequency counter. The HP5245L is often available as surplus for about $200, and the prescaler is a good way to update it.

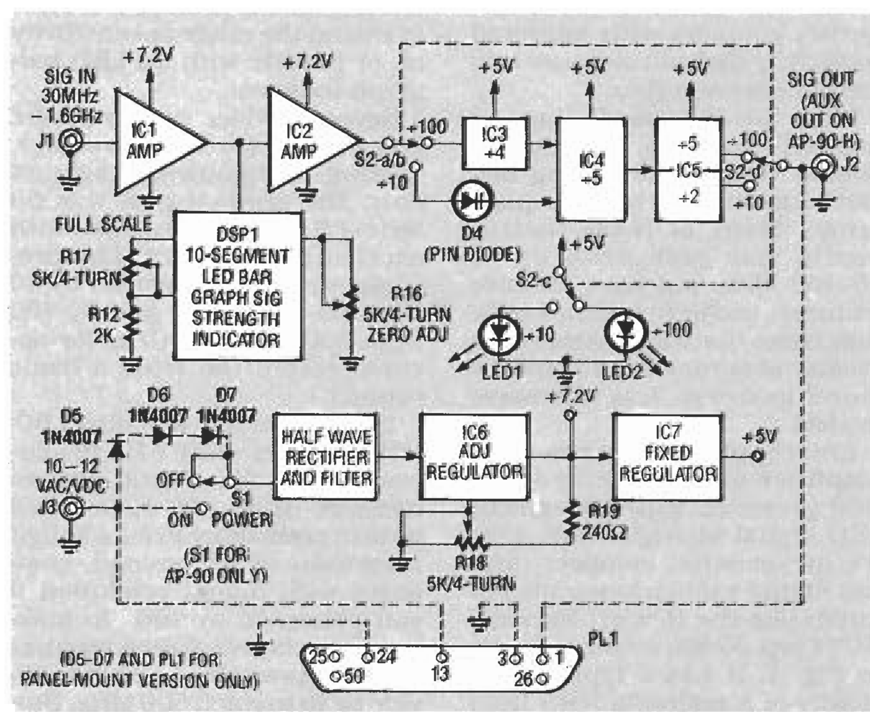


FIG. 2—THE BLOCK DIAGRAM OF THE prescaler. IC1 and IC2 are MMIC amplifiers, IC3 is a ÷4 counter, IC4 is a ÷5 counter, and IC5 has ÷2 and ÷5 outputs selected by S2. With S2 on ÷100, the input passes through IC3 and IC4, and IC5 is a ÷5 counter. With S2 on ÷10, the input goes around IC3, through PIN diode D4 to IC4, and IC5 is a ÷2 counter. IC1 drives DSP1, the RF signal indicator. PL1 is for the panel-mounted version only.

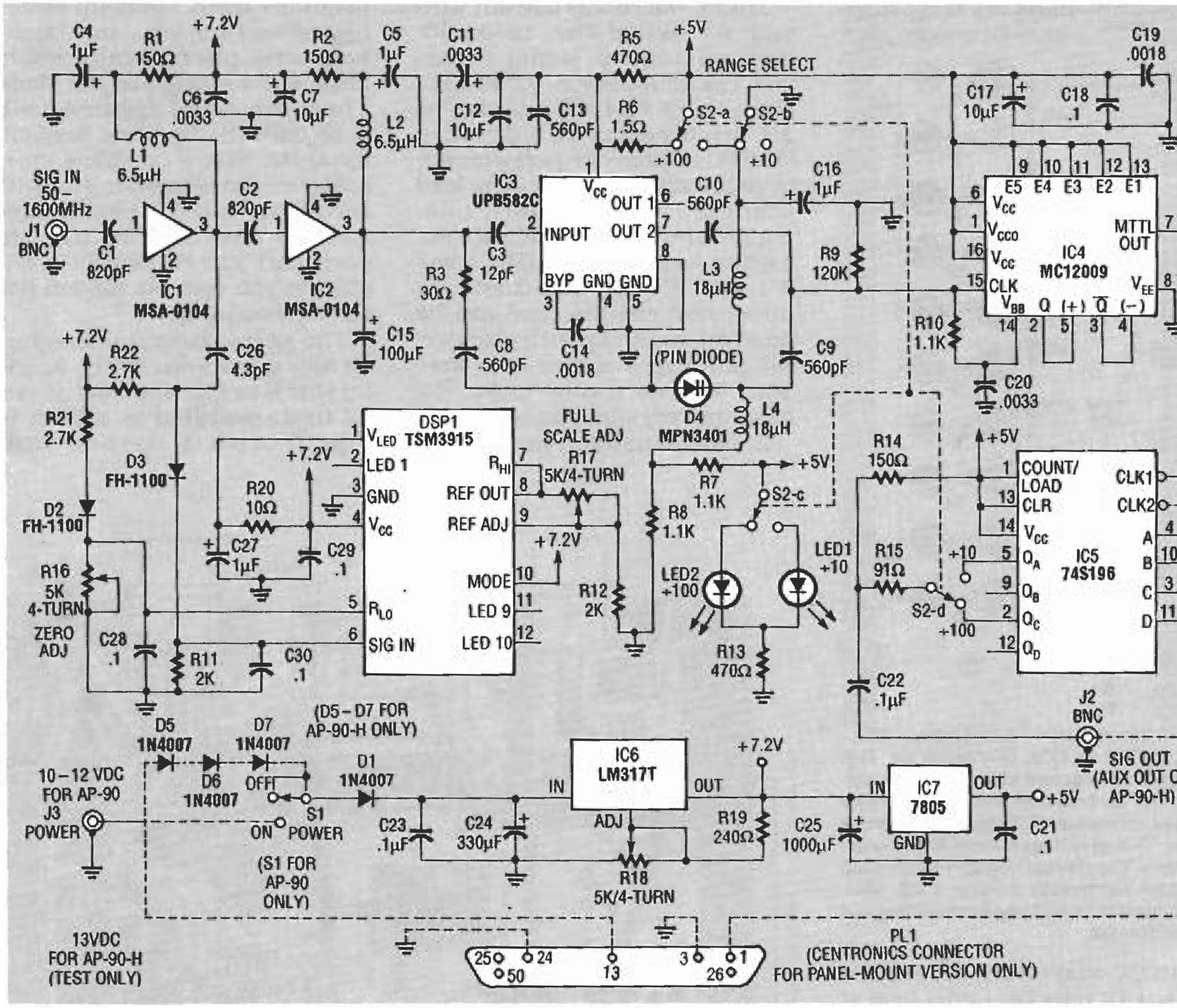


FIG. 3—THE SCHEMATIC DIAGRAM OF THE PRESCALER. DSP1 is a TSM3915 10-segment LED bar-graph display; R16 and R17 adjust zero and full-scale. D4 performs band-switching; it's reverse-biased capacitance is 0.65–0.75 pF, and over 6 pF forward-biased. With S2 on ÷10, D4 is forward-biased, so its impedance goes down, and it passes the signal to IC4. IC3 is off, but pin 1 (V_{CC}) is at 1.25 volts DC to raise the impedance on pin 7 (OUT 2). With S2 on ÷100, D4 blocks the signal, and it's now passed to IC3.

cade counter. It has separate ÷2 and ÷5 sections; the prescaler drives both, and you select the desired output using S2. R14 and R15 shape and pull up the output; the output will be 1–2 volts peak-to-peak into a load of 50 ohms or more.

Display DSP1 is the Three-Five Systems, Inc. TSM3915 (formerly the National Semiconductor NSM3915) 10-segment LED bar-graph display; Fig. 4 shows the block diagram. It has an on-board monolithic IC with an adjustable internal voltage reference, high-impedance input buffer, accurate 10-step voltage divider, and 10 comparators. R11 and R22 bias D3 as an RF level detector coupled by C26 from IC1. D2 is directly connected to the high impedance input buffer at pin 6. Within DSP1, the signal is applied to 10 comparators, each biased differently by the precision voltage divider, and driving one LED.

A low-voltage reference signal from R21-D2-R16 is applied to pin 5, to offset the input bias voltage making R16 the zero adjustment. R17 sets full-scale sensitivity by varying the internal reference voltage across the comparators. The current from REF OUT (pin 8) determines the display current and brightness. About 10 times this current is drawn through a lit segment, and is fairly constant despite voltage and temperature changes.

The display is logarithmic, with segment thresholds at 3-dB intervals. If you remove V_{CC} from MODE (pin 10) and join MODE (pin 10) and LED 9 (pin 11), the display changes from a bar graph to a dot graph, with only the top LED of a reading lit. That saves current, but the bar graph is easier to read.

The power supply provides regulated +7.2 volts DC from IC6 for IC1, IC2, and DSP1, and +5 volts DC from IC7 for all else. IC6 is an LM317T adjustable regulator set by R18 and R19. The input is polarity protected by D1. Capacitor C23 bypasses high-frequencies avoid instability, and C24 filters 60-Hz ripples. Power jack J3 needs a center-positive, 2.1–2.5-millimeter coaxial plug.

The maximum current through DSP1 with all segments lit is about 400 milliamps. An

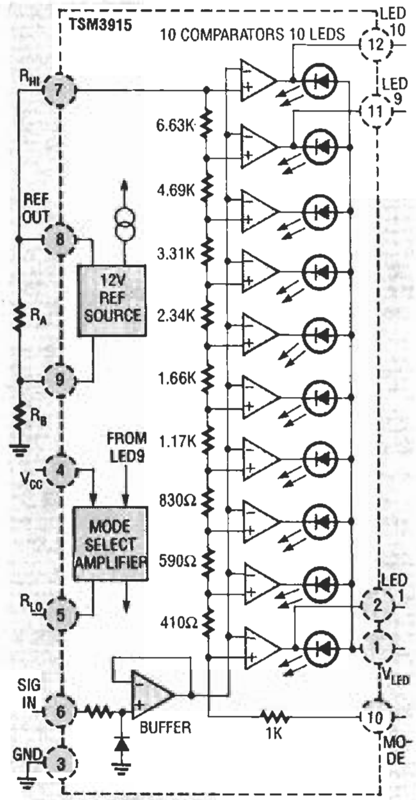


FIG. 4—THE BLOCK DIAGRAM OF THE TSM3915 10-segment LED bar-graph display. The on-board IC has an adjustable voltage reference, high-impedance input buffer, 10-step voltage divider, and 10 comparators. The display is logarithmic; each segment represents another 3 dB. Maximum current with all segments lit is about 400 milliamps.

AC-to-DC adaptor should provide +10–+12 volts DC under load at J3, but be careful, since excess voltage will burn out IC6. Such adaptors aren't regulated, so their voltage may vary greatly with load. The prescaler works fine with an adaptor rated at +9 volts DC and 500 milliamps, that actually delivers +10.5–+11.5 volts DC. Diodes D5–D7 provide an additional 1.8–2.1 volt DC drop, to avoid overheating IC6.

Construction

Build the PC board for the prescaler exactly as shown. Don't drill any additional holes, or modify the microstrip foils. If you do, you'll ruin the ground plane needed to achieve the 1.6-GHz bandwidth and excellent sensitivity. The cabinet-mounted and panel-mounted versions were designed for a 3.8×3.35-inch, double-sided, plated-through PC board, with solder masks and component screens on each side.

The PC board was laid out with tape 4× actual size, using 50-ohm microstrip signal paths, size calculated for a 0.062-inch glass-epoxy FR4 PC board. The 29 surface-mount devices (SMD's) improve RF performance by reducing size, component lead inductance, impedance mismatch, and poor grounding common in larger parts. MMIC's like IC1 and IC2 are mandatory for microwave circuits, and can be handled manually with practice; the prototypes shown here were built with no special tools. The parts are very small, so be careful.

At bare minimum, you'll need a magnifier lamp, small-tip soldering iron, tweezers, miniature long-nose pliers, and a sharp knife with a small, pointed blade. There are small vacuum tools with different tip sizes available for about $10; a complete kit of solder creme dispenser gun with cartridges (called caplettes), and vacuum tools, is $75 (see the parts list). The PC board is available, or you can use the foil patterns provided here.

The parts-placement diagram for side A is shown in Fig. 5, and for side B in Fig. 6. Install J1 and J2 first, modified as shown in Fig. 7, with a 1/16-inch wide

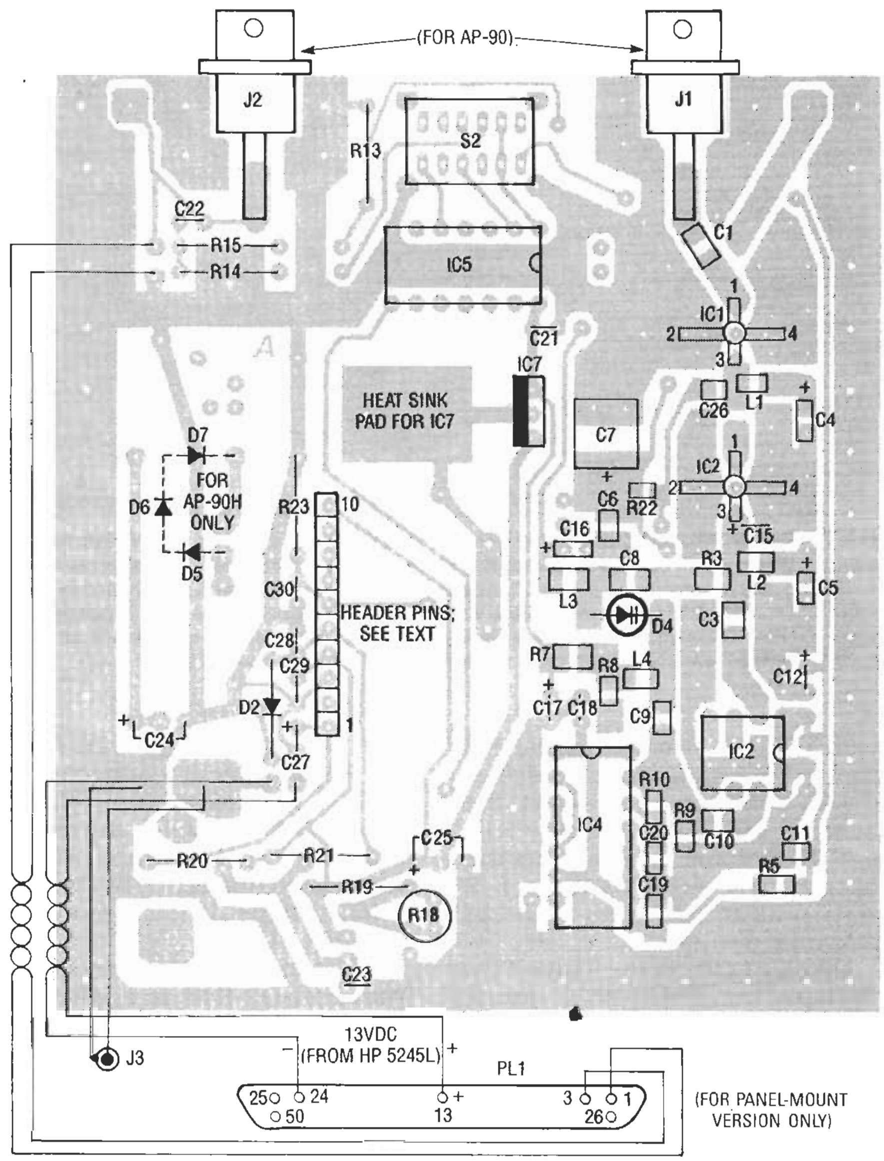


FIG. 5—PARTS PLACEMENT DIAGRAM FOR side A of the PC board. C15 has a hole for the negative lead; the positive lead is soldered to the foil where R3 meets L2. On IC1 and IC2, the dots are the outputs (pin 3); the input (pin 1) is opposite, and pins 2 and 4 are the grounds. D4 is black, rectangular, and has a brown ridge on the cathode end.

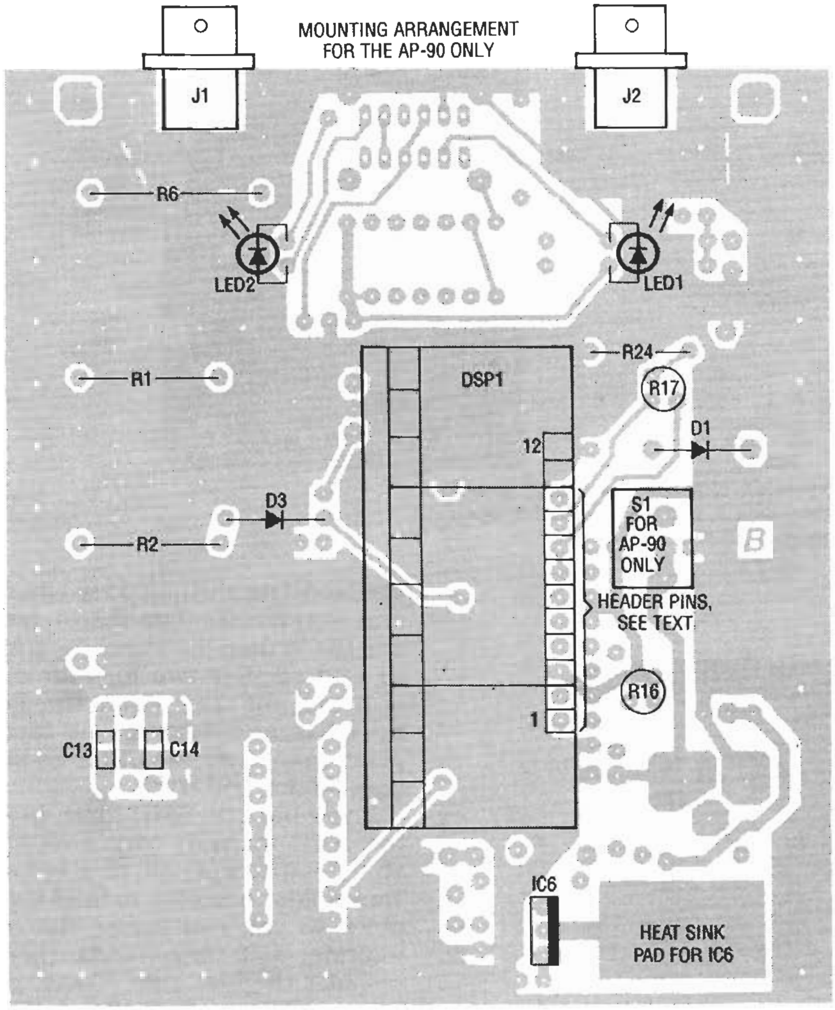


FIG. 6—PARTS PLACEMENT DIAGRAM FOR side B of the PC board. In the cabinet-mounted version, the header pins protrude from side A to holes 1–10 of DSP1 on side B; the separator is on side A. In the panel-mounted version, the header pins are inserted into side B; their other ends go to holes 1–10 on DSP1, with the separator on side B.

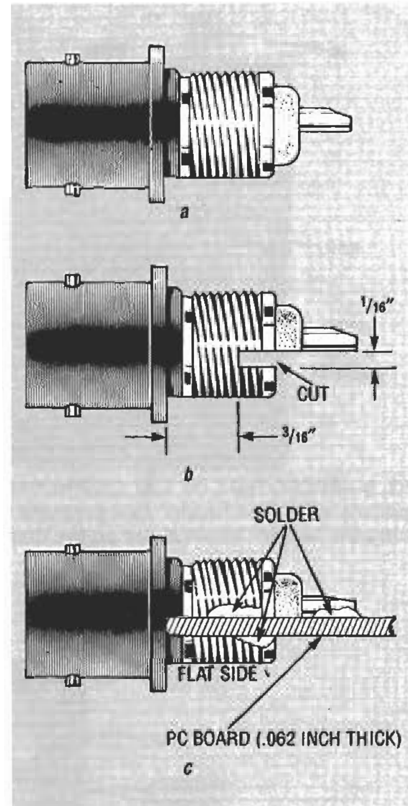


FIG. 7—BNC SOCKET MODIFICATION for the cabinet-mounted version. In (*a*) a side view is shown of a female BNC panel-mount socket. In (*b*), a slot is cut in the threads with a hacksaw or file. In (*c*), the slot fits snugly over its PC board notch. Solder it on both sides of the PC board; the center pin goes on side A.

groove. Use a medium iron for them, and the small iron elsewhere. The kit in the parts list has IC socket pins for IC3 and IC4, to shorten the leads and get them closer to the ground plane for better frequency response. For IC5, use a regular 14-pin DIP socket, since it operates over a lower frequency range.

Install the SMD's next; note the polarity of amplifiers IC1 and IC2, tantalums C4, C5, C7, and C16, and LED1 and LED2, and install all parts from smallest to largest. IC1 and IC2 should both have dots indicating their outputs (pin 3); the input (pin 1) is opposite this, and pins 2 and 4 are the grounds. With the dot on pin 3 pointing toward the bottom as in Fig. 5, pin 1 points upward, pin 2 points left, and pin 4 points right.

For the SMD tantalums, C4, C5, and C16 are the same size, while C7 is much larger. In the prototypes and the kit in the parts list, C4, C5, and C16 are orange in the center and silver on each end. They have a small tip on the positive end, and a green dot on the top side, C7 is yellow, with a brown band on the top of the positive end. Capacitor C15, at the middle right, will partially block IC2 and L2, so install them first. There's a hole for the negative lead of C15, but the positive lead is tack soldered to the foil where R3 meets L2. Insert the negative lead into its proper hole, and bend the positive lead outward at right angles. Diode D4 is black, rectangular, and has a brown ridge on the cathode end; the brown ridge faces to the right.

Install LED1 and LED2 last in the prescaler. For the case-mounted version, insert the LED's into their PC board holes without soldering. Hold them in place with your fingers and pull the leads through the holes, until they both almost touch the surface of side B. Fold the leads over slightly, so they can't fall out. Insert the PC board into the case, with side A facing out. Bend the LED leads back to vertical so they slide freely, maneuver the LED's so they protrude through their holes in front, then solder and trim. If you remove the PC board from the case, the LED's should slide out freely. When you put the PC board back in the case, the LED's should slide back into their holes.

For the panel-mounted version, don't install the LED's until you attach J1 and J2 to the faceplate, and are ready to attach the PC board. Pull the LED's through their holes in the PC board, and bend the leads to hold them in place. Insert the center pins and ground lugs of J1 and J2 into the holes next to the notches, and bolt the bottom of the PC board to

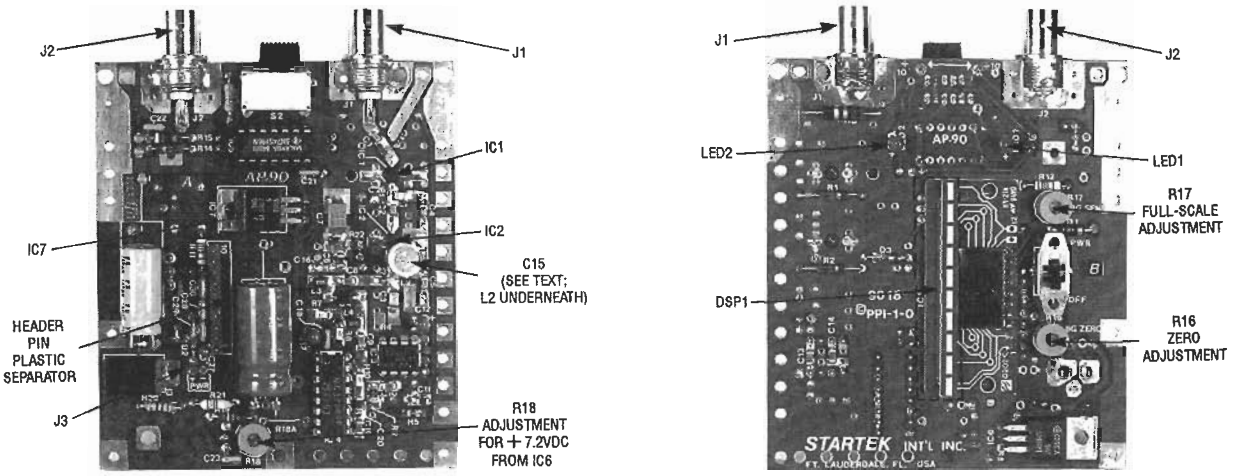


FIG. 8—PROTOTYPE OF THE CABINET-MOUNTED version; side A appears in (*a*), side B appears in (*b*). The header pins protrude through from side A, and are soldered to DSP1 using the bottom 10 pin holes on the display PC board.

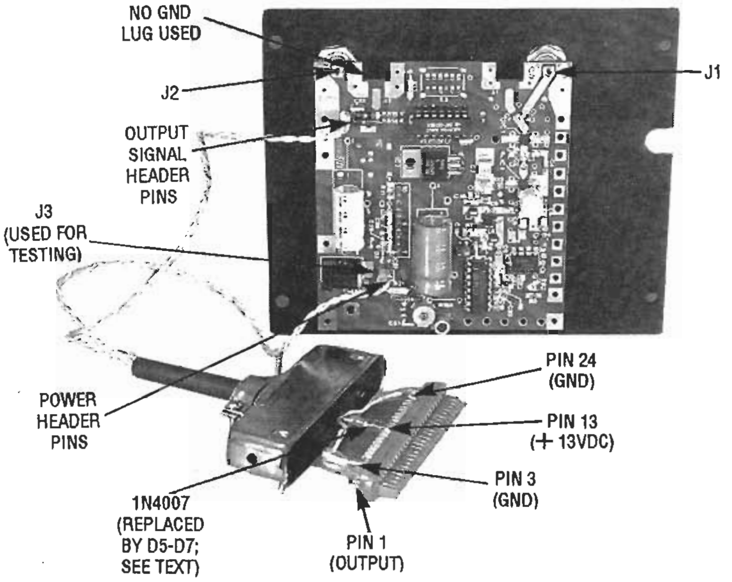


FIG. 9—PROTOTYPE OF THE PANEL-MOUNTED version, showing side A. The header pins are inserted into side B; the separator is on the same side. PL1 connects two twisted pairs; the output to the HP 5245L is from the header pins at upper left, and the +13 volts DC from the HP 5245L to those at lower right. The 1N4007 on pin 13 of PL1 has been replaced by D5–D7 at S1's location (see text), to avoid damaging IC6. Use heatshrink tubing with all four wires to avoid shorts.

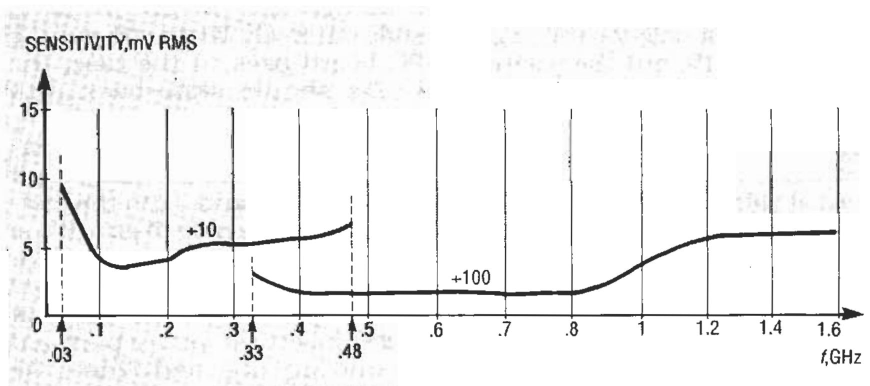


FIG. 10—SENSITIVITY CURVES FOR BOTH the ÷10 and ÷100 ranges. The ÷10 range covers 30–480 MHz, and the ÷100 range covers 330 MHz–1.6 GHz.

the faceplate with nylon washers and a nonconductive spacer. Solder the center pins and lugs for J1 and J2; use two lugs for J1, and one for J2. When the PC board is attached to the faceplate, maneuver the LED's as before, solder and trim.

If you have no SMD tools, hold the SMD in place with a small, sharp knife, a pencil, or a probe. Tack solder one side to hold it in place so you can solder the remainder with both hands; then, resolder the first side. There are kits of SMD tools available that can make working with the devices easier.

Solder creme is powdered solder mixed with flux. With a gun dispenser, place a very tiny spot on each SMD solder pad, and position the SMD with a vacuum tool; it should stick to the solder creme. Heat the foil, and the solder creme should melt; never heat the solder creme directly.

Figure 8-*a* shows side A of the cabinet-mounted prototype, and Fig. 8-*b* shows side B. In Fig. 8-*a*, IC7 has been folded over to lie on its heatsink pad. You can't bolt the heatsink to the PC board in the prescaler, since DSP1 is in the way, but even if you could, it's unnecessary. The center pins of J1 and J2 are on side A; both the threads and center pins were separately soldered. In Fig. 8-*b*, IC6 has been folded over like IC7, but also needn't be bolted down. The header pins protrude through from side A, and are soldered to holes 1–10 on DSP1 on side B; the plastic separator is on side A.

Figure 9 shows side A of the

PARTS LIST

All resistors are ¼-watt, 5%, carbon-composition or film, unless otherwise noted.

R1, R2—150 ohms carbon-composition
R3—30 ohms, SMD
R4—unused
R5—470 ohms, SMD
R6—1.5 ohms
R7, R8, R10—1100 ohms, SMD
R9—120,000 ohms, SMD
R11, R12—2000 ohms, 1%
R13—470 ohms
R14—150 ohms, 10%
R15—91 ohms, 10%
R16–R18—5000-ohm, 4-turn, subminiature, PC-mounted potentiometer
R19—240 ohms
R20—10 ohms
R21—2700 ohms
R22—2700 ohms, SMD

Capacitors

C1, C2—820 pF, SMD
C3—12 pF, SMD
C4, C5, C16—1 µF, tantalum, SMD
C6, C11, C20—0.0033 µF, SMD
C7—10 µF, tantalum, SMD
C8–C10, C13, C14—560 pF, SMD
C12, C17—10 µF, tantalum, axial leads
C15—100 µF, electrolytic, axial leads
C18, C21–C23, C28–C30—0.1 µF, monolithic ceramic, axial leads
C19—0.0018 µF, SMD
C24—330 µF, 25-volt, electrolytic
C25—1000 µF, 10-volt, electrolytic
C26—4.3 pF, SMD
C27—1 µF, 16-volt, tantalum

Inductors

L1, L2—6.5 µH, SMD
L3, L4—18 µH, SMD

Semiconductors

D1, D5–D7—1N4007 silicon diode
D2, D3—FH-1100 diode
D4—Motorola MPN3401 PIN diode
DSP1—Three-Five Systems TSM3915 10-segment LED bargraph display
LED1, LED2—subminiature red LED
IC1, IC2—Avantek MSA-0104 MMIC amplifier
IC3—NEC UPB582C MMIC divide-by-4 prescaler
IC4—Motorola MC12009P ECL two-mode prescaler
IC5—TI 74S196 presettable binary/decade counter
IC6—LM317T adjustable 1.25–37-volt DC regulator
IC7—LM340T-5 or 7805 fixed 5-volt DC regulator

Other components

S1—SPDT PC-mount slide switch (used in the cabinet-mounted version)
S2—4PDT right-angle PC-mount slide switch (used in the cabinet-mounted version)
S2—4PDT PC-mount slide switch (for the panel-mounted version)
PL1—Centronics 50-pin male plug with hood
J1, J2—UG1094-U female BNC socket (see text)
J3—2.1-millimeter coaxial power jack

Miscellaneous: Case for the cabinet-mounted version (two-piece anodized aluminum, four machine screws, with specially punched and printed front), red lens for DSP1 (0.03 × 1 × 3-inches), front panel (optional for the panel-mounted version), three BNC socket solder lugs, 4-40 × 0.25-inch black Phillips pan head screws (for the cabinet-mounted version enclosure), two 6-32 × 0.5-inch black Phillips pan head screws, two 8-32 × 0.5-inch black Phillips pan head screws, 4-40 nylon locknut, 4-40 × 0.3-inch threaded spacer, nylon washer, 2 feet of #22 stranded twisted-pair wire, two BNC socket lockwashers, one 10-pin header pin with plastic separator (for both the cabinet-mounted version and the panel-mounted version), two 2-pin header pins with plastic separators (for the panel-mounted version), heatshrink tubing, AC power adapter with an output of 10–12 volts DC at 400 mA.

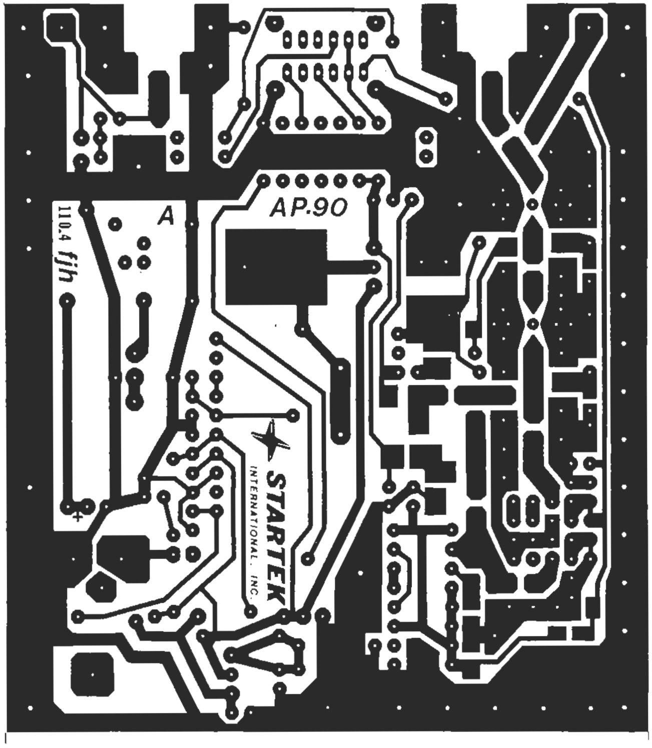
NOTE: The following items are available from STARTEK International, Inc., 5200 N Federal Hwy., Suite #2-1181, Ft. Lauderdale, FL 33308, (305) 783-0008 or (800) 638-8050. A complete set of all parts (#AP-90K) for the cabinet-mounted version is $99.95, an enclosure (#CAB-90) is $25.00, and the AC adaptor (#AC-90) is $9.00. A factory-assembled and tested version with the aforementioned items (#AP-90) is $179.00. The telescoping antenna with BNC plug (#TA-90) is $12.00, and the PC board (#PCB-90) only is $25.00. All seven IC's (#ICS-90), including voltage regulators and DSP1, is $55.00. A complete kit of parts for custom installation of the panel-mounted version into the HP 5245L (#AP-90-HK) is $159.00, and an assembled and factory-tested version (#AP-90-H) is $199.95. A partially assembled kit (SMD components installed) is available. Call Startek or send SASE for information. For SMD tools, a Vac Tweezer pick-and-place tool kit (#VT-1) is $9.50, and a Dot.Maker solder creme dispenser kit containing the Vac Tweezer kit and an assortment of about 20 solder creme caplettes (#DMK-1) is $75.00. Add 5% (a minimum of $4.00 to a maximum of $10.00) for shipping/handling. Visa, MasterCard, C.O.D., cash, or money orders accepted; allow three weeks for personal checks.

panel-mounted prototype. PL1 is connected to the PC board by two twisted pairs and two pairs of header pins. The output fed back into the HP 5245L comes from the header pins at upper left. The upper pin is the output, the lower pin is ground. Power goes into the header pins at lower left; the left one goes to the +13 volts DC from the HP 5245L, and the right one is ground.

The prototype was built before using D5–D7; the anode of a 1N4007 was soldered to pin 13 of PL1, and the cathode to the positive power wire (blocked by the black heatshrink tubing). PL1 is a standard male Centronics plug. Cover both ends of all four wires with heatshrink tubing to avoid shorts. However, one 1N4007 didn't provide a sufficient drop, so D5–D7 were used thereafter.

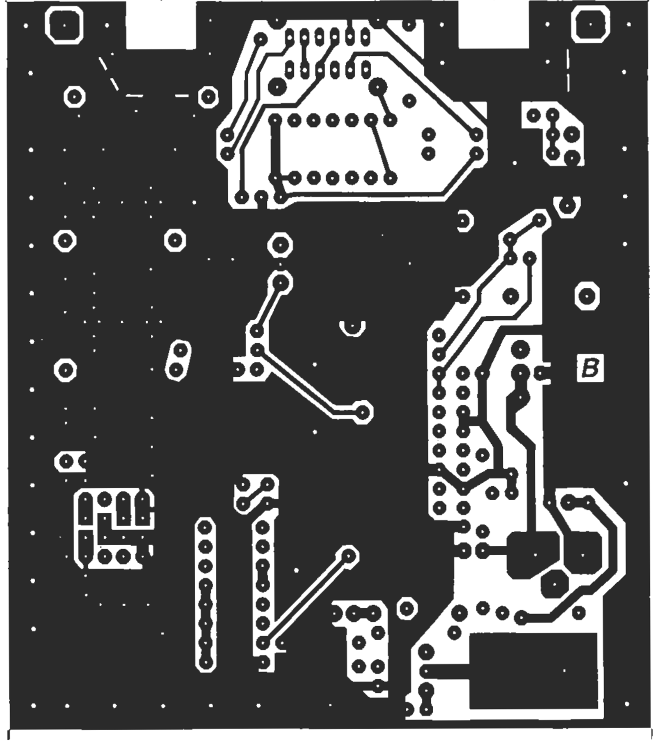
Figures 2, 3, and 6 all show D5–D7; in the panel-mounted version they replace S1, to provide an additional 1.8–2.1-volt DC drop, as mentioned above, to reduce the +13 volts DC from the HP 5245L. IC6 doesn't overheat to the point of exceeding specification. The drops across D1 and D5–D7 reduce the +13 volts DC from the HP 5245L to +10.2–10.6 volts DC, enough to run IC6 with minimum heat dissipation.

To install D5–D7, wrap the cathode of D5 around the anode of D6, and the anode of D7



3.35 INCHES

COMPONENT SIDE OF THE PRESCALER.



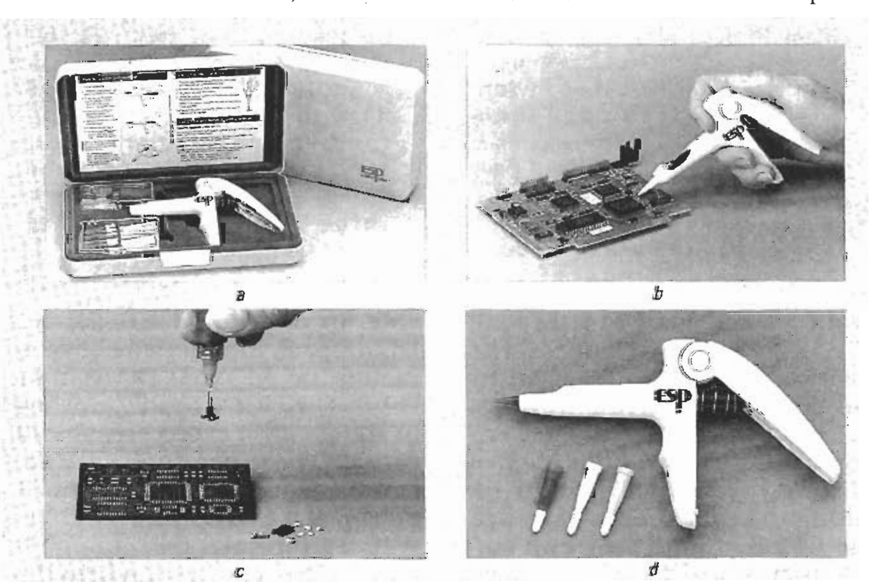
3.35 INCHES

SOLDER SIDE OF THE PRESCALER.

around the cathode of D6, solder and trim. Insert the anode of D5 and the cathode of D7 into their PC board holes, and leave enough lead length on side B to bend D5–D7 flat to the PC board.

In the panel-mount version, install the DSP1 header pins with the plastic separator on side B (the separator is on side A for cabinet installation) to hold DSP1 off the PC board and flush with the red lens and panel.

The PC board and red lens is a precise fit inside the case and shouldn't move around. In the panel-mounted version, the lens is sandwiched between DSP1 and the rear of the faceplate, and has a hole drilled in its bottom for the screw that attaches the PC board to the bottom of the faceplate. The lens goes between the rear of the faceplate and the nylon washer at the base of the nonconducting spacer.



IF YOU WANT SMD TOOLS, (*a*) shows a kit mentioned in the parts list. Solder creme is powdered solder mixed with flux. With the gun in (*b*), place a spot on each pad, and position the SMD with the vacuum tool in (*c*); it should stick to the solder creme. Heat the foil, and the solder creme should melt. In (*d*) a close-up of the gun and three caplettes is shown.

Power-on checkout

Turn the power on, and check for proper voltages:

- At J3, +10–+12 volts DC, input power.
- At the output of IC6, +7.1–+7.3 volts DC (adjust R18).
- At the output of IC7, +4.9–+5.1 volts DC.
- At the outputs of IC1 and IC2, a bias of 4.6–4.7 volts DC (with no input signal).

For the panel-mounted version, J3 is included to let you test it without connecting it to the HP 5245L. If all voltages are right, adjust R16 to zero the bar graph, and R17 for full scale. The two potentiometers interact, but you should get a good setting with a signal generator and some experimenting. The bar graph varies with frequency, but is a convenient relative RF signal strength indicator. With careful assembly, sensitivity should be 1–9 millivolts RMS from 50 MHz–1.6 GHz, consistent with the curves shown in Fig. 10. **R-E**