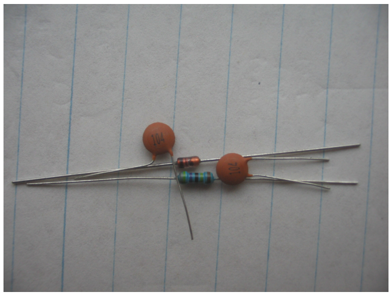
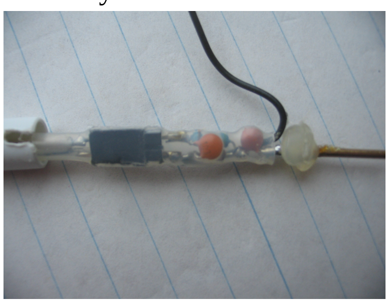
Diode Probe
&
10:1 Divider

for WA1WA Project by K1TRB


Parts Layout

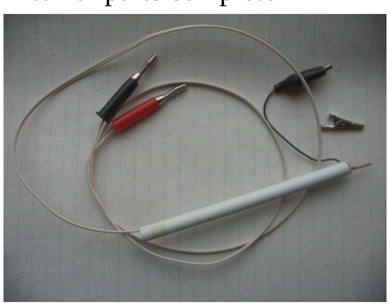
Probe Parts:

a. 1m twin banana plug / alligator clip lead pair.
b. 2 .01uF disc capacitors
c. 1 4.7M 1/4w resistor
d. 1 1N4148 diode
e. 4" black stranded ground wire
f. Copper nail
g. BIC ball point pen barrell
(solder, hot melt glue)


Internal parts complete

Probe Assembly Instructions

1. Twist the banded end of the diode around an end of the 4.7M resistor.
2. Twist one end of a .01uF capacitor around the same end of the 4.7M resistor.
3. Solder and trim the connections in 1 and 2.
4. Cut the head off a copper nail. Solder the cut end of the nail to the free .01uF capacitor lead (connected in 2 above).
5. Twist the ends of a .01uF capacitor around the ends of the 4.7M and diode (opposite the ends used in 1 and 2). The capacitor will bridge between the diode and 4.7M resistor.
6. Solder and trim the capacitor leads.


Assembled Probe

7. Remove the alligator clips from the test lead set.
8. Solder the black and red lead to the diode at the bridge capacitor.
9. Solder a 4" black ground wire to the joint of the diode and red and black lead.
10. Trim the connection in 8.
11. Solder the red lead to the 4.7M at the bridge capacitor. Trim the resistor lead. Wrap the joint with a dab of black electrical tape so it will not contact the connection of 8.

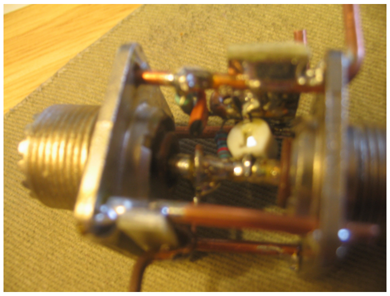
12. Remove the barrell from a BIC ballpoint pen.
13. Melt a groove for the ground wire in the barrell.
14. Opposite the groove, put the ground wire into the barrell and pull the nail and probe circuit into the barrell. Pull it through until the nail point extends out the barrell. Put the ground wire into the groove in the barrell.
15. Position the circuit correctly in the barrell.

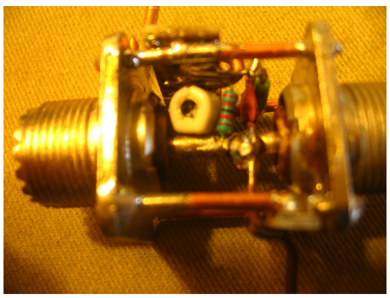
16. Put the black alligator clip cover onto the ground wire. Solder the clip onto the ground wire. Pull the clip cover over the alligator clip.

17. Remove the red cover from the alligator clip. Crimp the clip onto the nail so that it will slide off and on

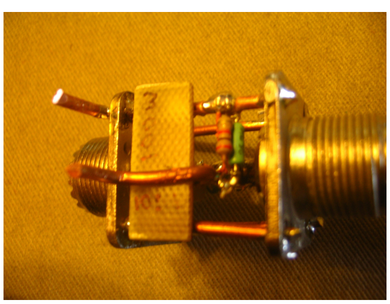
the tip and hold with friction.
18. Test the probe.
19. Put hot melt glue into both ends of the barrell to securely hold the probe together.

10:1 Divider Parts:


Divider: backside of capacitor


Divider: frontside of capacitor


Divider: 1:1 tap

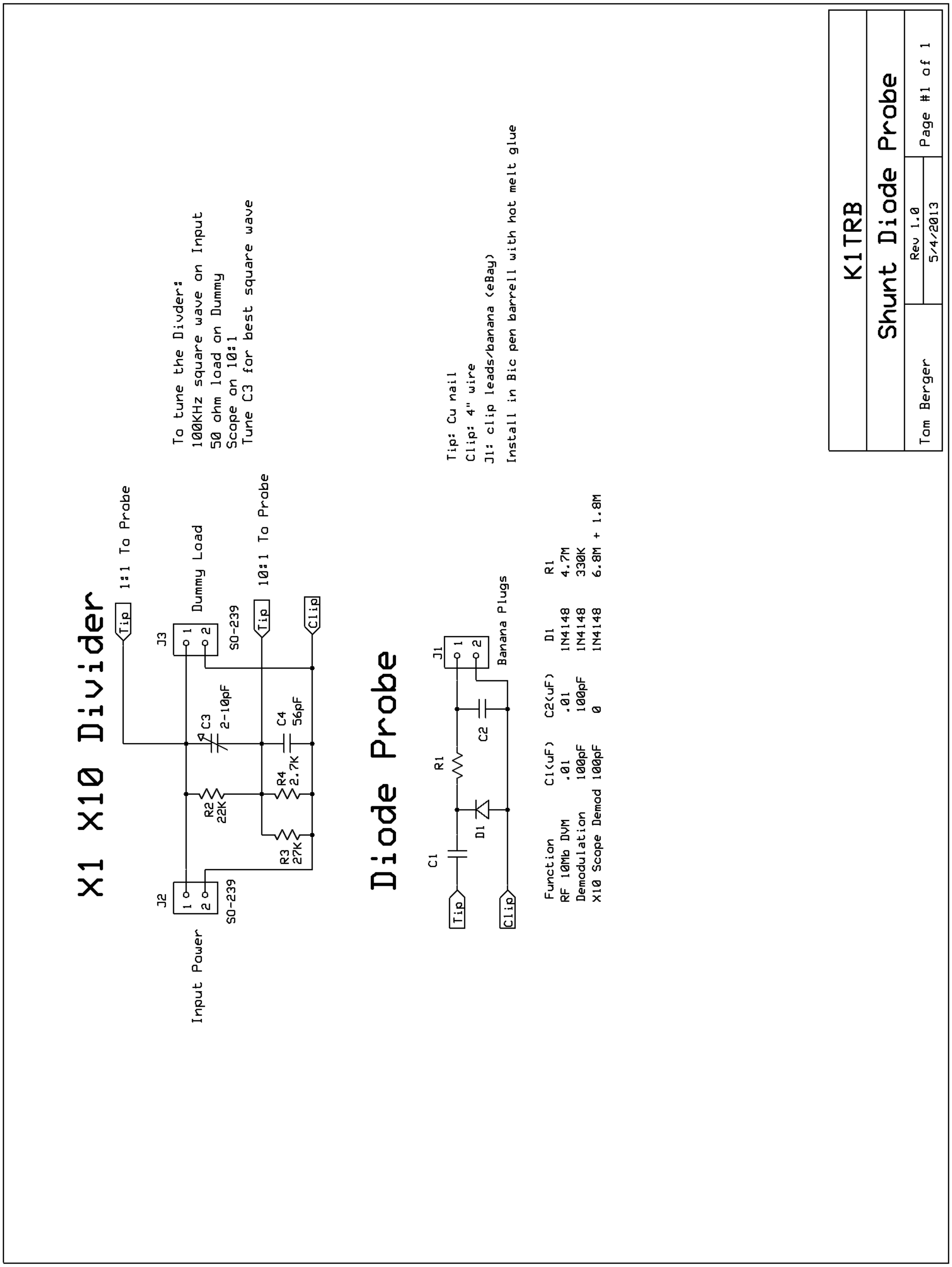

Divider: 10:1 tap

a. 2 SO-239 female coax fittings
b. 3 1-1/4" bare #12 wire (frame)
c. 1 1-3/4" bare #12 wire (tap & frame)
d. 2 1" bare #12 wire (tap)
e. 1 1" bare #20 wire (tap)
f. 1 3/4" bare #14 wire (center)
g. 2 etched 1"x 3/8" PCB (tap support)
h. 2-10pF trimmer
i. 56pF capacitor
j. 22k 1/4w resistor
k. 27k 1/4w resistor
l. 2.7k 1/4w resistor

Divider Assembly Instructions

1. Using the 3/4" #14 wire join the two center conductors of the two so-239 fittings. Solder.
2. Position the two fittings so they are parallel and will sit flat on a table.
3. Solder a 1-1/4" #12 wire to join two corners of the fittings.
4. On an adjacent corner, solder the 1-3/4" #12 wire between the two fittings. Bend the longer end away from a fitting at a right angle so as to form a tap attachment point to ground.
5. Put a 1" wire through a PCB, bend and crimp it as shown in the diagram. Solder it into place. Prepare the second PCB in the same way.
6. Solder the PCB to bridge between the two #12 wires near the fitting. The ends of the board are soldered and the inner rectangle makes no contact. The wire of 5 should point outward. The wire bend around the board should be away from the fitting side of the board.
7. Both the 2-10pF trimmer and 22k resistor will go from the center conductor of the SO-239 to the tap point on the PCB. With this in mind, solder the 22k from the center conductor to the tap point.
8. Solder the 2-10pF trimmer from the center conductor to the tap point. It will probably be necessary to bend the tabs of the trimmer at right angles with long nose pliers.
9. Put the 27k, 2.7k, and 56pF in parallel. Twist the leads of the 27k and 56pF around the leads of the 2.7k and solder. Leave the leads of the 2.7k but trim the others.
10. Solder the parallel combination of 9 to the tap point and to the crossing #12 support wire.
11. Insert the remaining two 1-1/4" #12 wires into the remaining corner holes of the SO-239 and solder.
12. Position the remaining PCB on these two wires and solder as in 6.
13. Bend the #20 wire around the center conductor. Run it up to the tap of
14. Bend it over beside the tap. Solder the tap and the center conductor.

Schematics



X1 X10 Divider
Tip
1:1 To Probe
J3
Dummy Load
SO-239
Tip
10:1 To Probe
Clip
C3
2-10pF
C4
56pF
R4
2.7K
R2
22K
R3
27K
J2
SO-239
Input Power
To tune the Divder:
100KHz square wave on Input
50 ohm load on Dummy
Scope on 10:1
Tune C3 for best square wave
Diode Probe
C1
D1
R1
C2
J1
Banana Plugs
Tip
Clip
Tip: Cu nail
Clip: 4" wire
J1: clip leads/banana (eBay)
Install in Bic pen barrell with hot melt glue
Function C1(uF) C2(uF) D1 R1
RF 10Mb DVM .01 .01 1N4148 4.7M
Demodulation 100pF 100pF 1N4148 330K
X10 Scope Demod 100pF 0 1N4148 6.8M + 1.8M
K1TRB
Shunt Diode Probe
Tom Berger
Rev 1.0
5/4/2013
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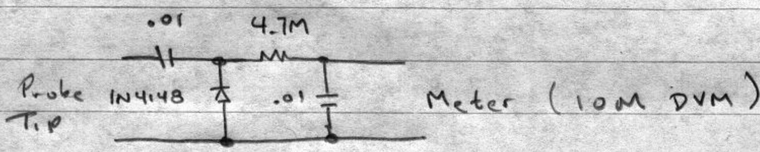
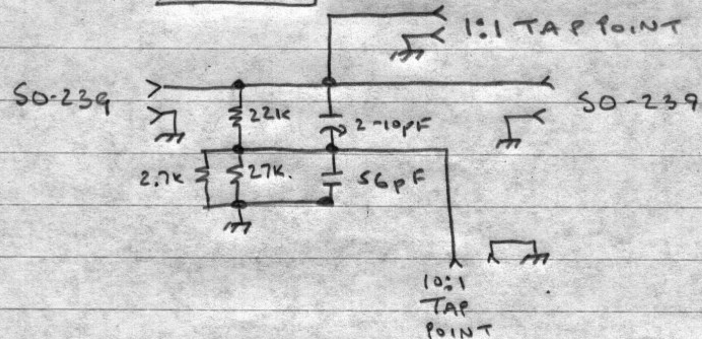
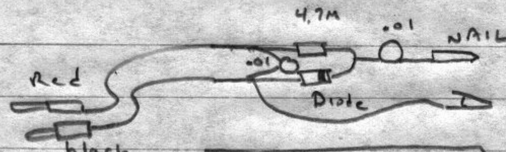


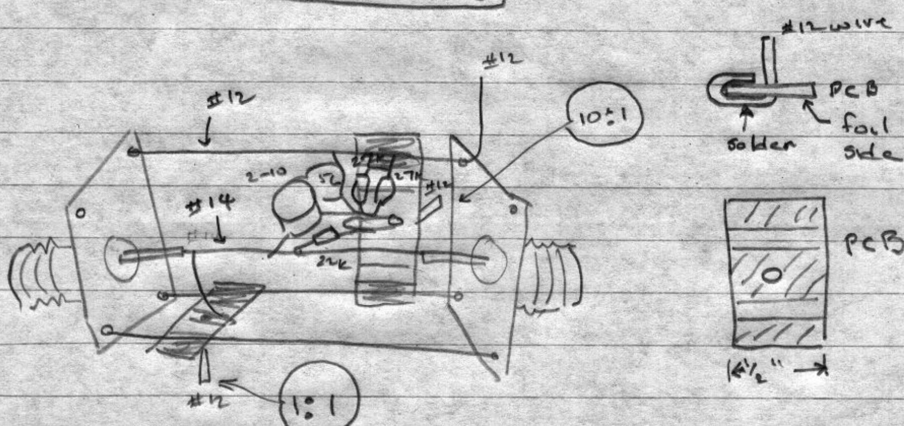
PROBE



10:1 VOLTAGE DIVIDER



Probe Wiring



TAP CONSTRUCTION

Calculations

Maximum Voltage

Do not measure voltages over 20 volts with this probe. Use the 10:1 divider to measure higher voltages.

At 35 volts, both the diode and input capacitor are at their maximum rating. Somewhere over this voltage, the diode will blow out. (I blew out a diode at 38 volts.) With a 1:1 SWR, 100 watts generates 71 volts on the line. If the SWR is not 1:1 the voltage can be higher. At 35 volts the power is 24.5 watts. At 20 volts the power is 8 watts. Assuming a two times safety factor, 20 volts is a good maximum to set for the probe.

Here is how these voltages arise. Imagine a 10 volt peak sine wave. Thus, the probe would measure 7.07 volts. This voltage will swing between -10 volts and +10 volts during a cycle. Here is what happens to the diode and capacitor at the probe tip during a cycle.

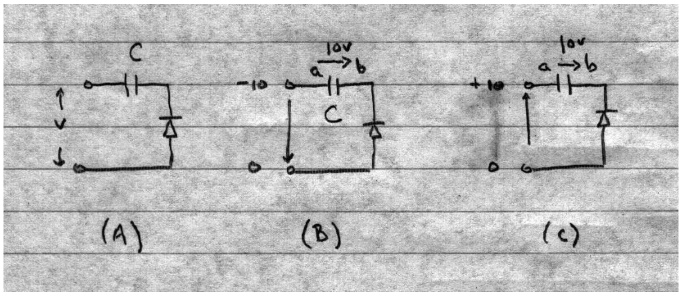


Figure A shows the probe with the sine wave voltage V connected. On the negative cycle swing, Figure B shows the voltage at -10 volts. The anode (pointer) end of the diode is more positive than the cathode (bar) end so the diode conducts. (Arrows have been drawn to show the voltage sense.) The capacitor C charges and side b of the capacitor is 10 volts more positive than side a. (Side a is at -10 volts and side b is at 0 volts.)

Figure C shows the voltage when the cycle has swung the other way. The anode of the the diode is at 0 volts. Point a of the capacitor is at +10 volts since the sine wave is at +10 volts. The capacitor is charged to +10 volts so this adds to the +10 volts of the sine wave. The cathode of the diode is now at +20 volts. This is twice the peak voltage of the sine wave.

In this probe, the diode must withstand twice the peak voltage of the sine wave. The 1N4148 diode has a peak reverse voltage rating of 100 volts. Thus the maxiumum sine wave peak would be 50 volts. The RMS voltage that has this peak is about 35 volts. Therefore, the diode will blow out at some voltage over 35 volts. To be safe: **Don’t measure over 20 volts.**

It might seem like the probe should measure this 20 volts instead of the RMS value of 7 volts that the meter shows. The calculations above are instantaneous values. The meter measures average values. Point a of the capacitor has an average value of 0 volts since it swings rapidly between +10 and -10 volts. Point b, therefore has an average value of +10 volts since the capacitor is charged to 10 volts.

The 4.7M resistor and the 10M DVM input resistances divde this 10 volts down to 7 volts (the RMS value). Since the capacitor charges to the peak voltage, a diode probe is a peak detecting device. This is reduced to the RMS value by a divider. This divder only works correctly for sine waves. If the wave shape is not a sine wave, it is likely the DVM will be reading the wrong RMS voltage. When transmitting CW, the wave is a very pure sine wave. (If it weren't, the FCC would quickly be on your case for spurious emissions.)

Measuring Power

Power should be measured while connected to a good dummy load. If the SWR is greater than 1:1 then voltage along the line varies as the probe is inserted at different points along the line. There are two conclusions from this:

> First, since the power is constant, this means the power calculation from the probe will be inaccurate (i.e. garbage).
> Second, if the SWR is high, even at low power, the voltage can grow large enough to blow out the diode requiring the probe to be rebuilt with a new diode.

So *measure voltages with the transmitter connected to a dummy load (i.e. SWR = 1:1).*

Hypothetically, the diode can withstand 100 volts of peak reverse voltage. However, I have blown a diode with 38 RMS volts. So I advise that voltage be kept below 20 volts. This is easy to do with the 10:1 divider.

So: *Do not measure voltages in excess of 20 volts.*

So: *Measure first with the 10:1 divider. Switch to the 1:1 divider only if the voltage is less then 2.0 volts on the 10:1 divider.*

To measure transmitter power, connect the transmitter to the divider and then to the dummy load. Set the transmitter for CW mode. Set the DVM to the 20 volt range. Put the clip on the probe tip. Connect the probe tip to the 10:1 divider and the ground clip to the divider ground.

Key the transmitter. If the voltage is less then 2 volts, switch the probe tip from the 10:1 divider to the 1:1 divider. Key the transmitter and record the voltage. If the clip is connected to the 10:1 divider, then the voltage on the line is 10 x the DVM voltage. Thus if 2.3 volts appears on the meter then the line voltage is 23 volts. (Actually, the line voltage is closer to 25 volts as will be explained.)

The power is now read from the tables.

P1:1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	2	3	4	5	6	7	8
V1:1	2.04	2.96	3.67	4.28	4.8	5.28	5.72	6.12	6.52	6.85	9.8	12	13.9	15.6	17.1	18.5	19.8

P10:1	5	10	15	20	25	30	35	40	45	50
V10:1	1.38	2.04	2.54	2.96	3.32	3.67	3.98	4.28	4.54	4.8
P10:1	55	60	65	70	75	80	85	90	95	100
V10:1	5.05	5.28	5.5	5.72	5.92	6.12	6.3	6.52	6.7	6.85

The power is given by (R = 50 is the line impedance)

$$P = V^2/R.$$

Therefore, if the 10:1 divider reads 2.3 volts on the DVM then the power is

$$P = (10 \times 2.3)^2/50 = 10.6 \text{ watts.}$$

But wait, this is not exactly correct. A diode junction has a built in voltage drop. You may recall that for a silicon diode, .6 volts is taken as this drop. Measurements indicate that with this probe, after the RMS division is applied, a correction of .2 volts is more accurate. Therefore, whatever the DVM reading is, add .2 volts. So the above calculation redone this way gives

$$P = [10 \times (2.3 + .2)]^2/50 = 12.5 \text{ watts.}$$

Suppose the probe is on the 10:1 divider and 6.9 volts is on the DVM. The power is

$$P = [10 \times (6.9 + .2)]^2/50 = 101 \text{ watts.}$$

The probe is within about 5% so the power is about 100 watts. *Do not connect the probe to the 1:1 divider for this measurement. The diode will blow. Switch to the 1:1 divider when the 10:1 divider reads 2.0 volts or less.*

Suppose the voltage is 1.9 volts on the 1:1 divider. The power would be

$$P = (1.9 + .2)^2/50 = .09 \text{ watts.}$$

The power is not too far from 100 mW. Accuracy suffers because of the diode junction drop. There is no "multiply by 10" because the probe is on the 1:1 (not the 10:1) divider.

The lower the voltage on the DVM, the more that the diode drop influences the answer. Further, the correction of + .2 volts also changes. Therefore, the probe accuracy goes down with the power. For lower powers, the 1:1 divider should be used. The probe is reasonable accurate to powers down to 1/2 watt or so. On the high end with the 10:1 divider, powers up to 100 watts can be measured. Above 100 watts, the divider resistors will heat up, become inaccurate, and may burn out.

The Probe

The input capacitor C on the probe charges to the peak voltage. The diode rectifies that voltage. Thus, the diode has the peak voltage appearing across it. For power measurements, an average voltage is needed. The correct average is RMS voltage. For a sine wave, the RMS voltage is .707 times the peak voltage. Therefore, the diode probe should incorporate a .707 divider.

The input resistance of a standard DVM is 10M. If 4.7M is put in series with this 10M there is a voltage division of

$$10M/(4.7M + 10M) = 10/14.7 = .68$$

which is very close to .7 (the right division ratio).

The input capacitor C blocks DC from the diode and holds the charge for a peak reading probe to work.

The output capacitor holds the voltage for a time constant of

$$R\,C = (4.7 \times 10^{6}) \times (.01 \times 10^{-6}) = .047 \text{ seconds}$$

thus this capacitor makes a low pass filter, taking out frequencies above

$$1/.047 = 21\text{Hz}.$$

The drop-off of this filter is very slow. The probe reads reasonably well down to 100Hz or so. Therefore, this probe is pretty useless as a demodulating (or detector) probe. It is a probe good for measuring sine wave RMS voltage.

The RF part of the probe is so compact that this probe should work well on 6m. Above this the resonant frequency of the .01pF capacitor becomes a problem. But the probe may give resonable readings on 2m.

The Divider

First, decide what maximum power will be measured in order to get a wattage on the parts. The decision, in this, case was ¼ watt resistors used to divide 100 watts on a 50 ohm line. At 100 watts, the voltage on the line will be given by

$$P = V^2/R : \qquad 100 = V^2/50 : \qquad V^2 = 5000 \qquad V = 70.7.$$

The divider will have a total resistance of Ro. The power should not exceed ¼ watt. Therefore

$$P = V^2/R : \qquad 1/4 = V^2/Ro : \qquad Ro = 5000/(1/4) = 20{,}000.$$

The divider should be designed to use more than 20k ohms or so. The next larger standard value is 22k. Therefore, that will be the big divider resistor. R_1 = 22k will be put in series with a value of R_2 so that the division ratio is

$$1/10 = R_2 / (R_1 + R_2) = R_2/(22k + R_2) \qquad R_2 = 2.44k$$

This is not a standard value. The next larger standard value is 2.7k. Put a resistor in parallel with a 2.7k resistor to drop it near 2.44k. The value needed is given by

$$1/2.44k = 1/2.7k + 1/R_{par} \qquad R_{par} = 25.7k$$

A nearby standar value of 27k is chosen. The parallel combination gives

$$1/R_2 = 1/2.7k + 1/27k \qquad R_2 = 2.45K$$

which is very close. R_2 is 2.7k in parallel with 27k.

The resistor divider is now designed.

This divider works great at DC but internal capacitances of the circuit screw everything up for RF. So a capacitive divider is put in parallel with the resistors. Since the capacitance of the circuit is not known, one capacitor in the divide is made variable so that the capacitive divider can be adjusted for best frequency response.

A little math shows the right choices are given by

$$R_1\,C_1 = R_2\,C_2$$

where C_1 is in parallel with R_1 and C_2 is in parallel with R_2. The capacitor C_2 is chosen arbitrarily: 56pF was chosen in this design. The capacitor C_2 must be chosen large enough that the capacitor C_1 is not too small to achieve. The capacitor C_2 must not be chosen so large that at higher frequencies the impedance of the divider affects the impedance of the line.

With a choice of 56pF the equation is

$$R_1\,C_1 = R_2\,C_2 \qquad 22k \times C_1 = 2.45k \times 56pF \qquad C_1 = 6.2pF$$

A 2 - 10pF trimmer will work. Some of the capacitance occurs in the circuit, the rest comes from the trimmer.

A reality check should be done to see if this divider will affect the line impedance at the highest frequency (30MHz). The total resistance is 22K + 2.45k = 24.45k. The total capacitance is given by

$1/C_{tot} = 1/C_1 + 1/C_2$ $\quad$ $1/C_{tot} = 1/6pF + 1/56pF$ $\quad$ $C_{tot} = 5.4pF$

The capacitive reactance is

$X_c = 1/(2 \times Pi \times f \times C_{tot})$ $\quad$ $X_c = 1/(2 \times 3.14 \times 30MHz \times 5.4pF)$ $\quad$ $X_c = 982$

Both the resistive and reactive values are more than 10 times the line impedance so the divider will not affect the line impedance much at all.

The divider will do ok for all the HF bands: 160m through 10m, for powers from 8 watts to 100 watts. Below this from .1 watt to 8 watts, the 1:1 divider may be used.

Ordering Information

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Parts Order (10 probe/dividers)
Rounding up: $6.00 per probe + 10:1 divider

Tayda each  @10
22k   .01   .10
27k   .01   .10
2.7k  .01   .10
4.7M  .01   .10
56pF  .01   .10
2-.01uF     .02   .20
1N4148      .01   .10
total       .80

Shipping(guess)   5.00
Subtotal                     5.80

eBay
clip/lead/plug set      1.68  16.80
2 SO-239          20@   23.49
2-10pF trim cap   10@    4.24
Subtotal                     44.53

Radio Shack
PC board                      4.81

Home Depot
Copper Nails                  1.81

total 10 probe/dividers      56.95

Rounding up:  $6.00 per probe/divider

All other bits needed come from stuff people have.
#12 house wire, #14 house wire, 4" ground wire, hot melt glue, BIC pen barrel, sol-
der.
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