# Design and Implementation of a Substitute for the SG503
# Peak-to-peak Detector (Part no. 155-0107-00)[†]

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**Introduction**

The Tektronix SG503 is a levelled sine wave generator that provides a regulated, constant-amplitude output into a 50-ohm load. It operates over the frequency range 250 KHz to 250 MHz in nine overlapping bands, with an additional 50 KHz reference band. The SG503 is often used as part of the calibration suite for Tektronix analog oscilloscopes. Unlike its higher frequency cousin, the SG504, the SG503 does not use an external levelling head. Instead, the SG503 leveling circuitry is internal. An excerpt of from the SG503 Service Manual depicting this circuitry is shown below. The red area represents a simplified schematic of the peak-to-peak detector that produces a DC voltage approximately equal to the peak-to-peak voltage of the oscillator output. This DC signal is used to maintain the peak-to-peak amplitude at the leveling point (the R225A/C225C junction), e.g., by increasing the input signal amplitude to compensate for frequency-related reductions in output amplitude. The green area shows the temperature compensation provided for this feedback circuit.
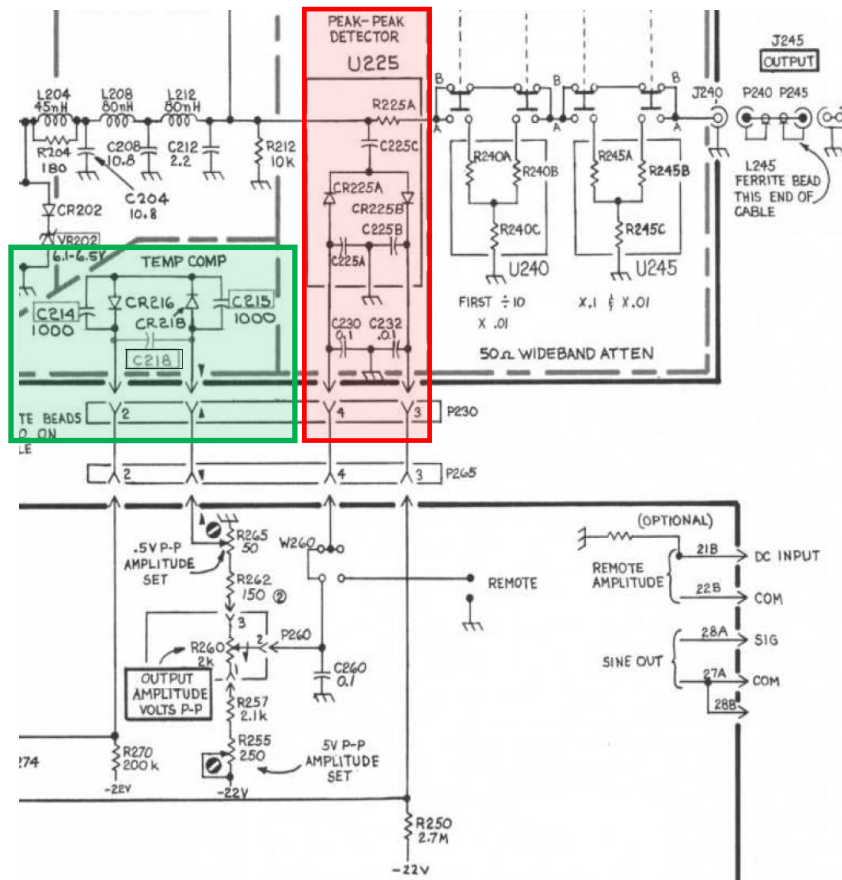


"U225" is a Tektronix ceramic hybrid (Part No. 155-0107-00) that had an internal Tektronix designation of "H204." The H204 "diode leveler" was, according to the Tektronix spec sheet, designed by a Tektronix engineer named Dale Hartman. Online Tektronix records indicate that Mr. Hartman started work at Tektronix in 1958. The H204 specification sheet describes the leveler as follows: "The H204 is a leveling circuit whose DC output is approximately equal to the

peak-to-peak voltage at its leveling point. The H204 circuitry provides frequency response compensation for the SG503 attenuator circuit board and 50 Ω cable." The schematic of the H204 is shown below (note that the input is on right side):
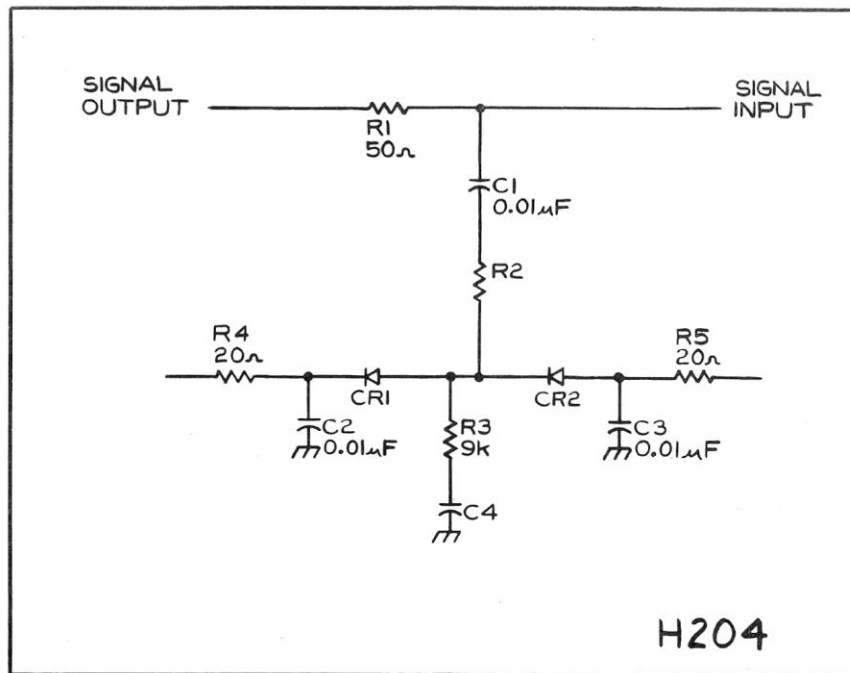


This circuit is implemented on a 1-inch square, 40 mil thick ceramic hybrid, shown below without its plastic cover (also shown is a failed attempt to repair said hybrid). The backside is ground plane cut out for the input and diodes.
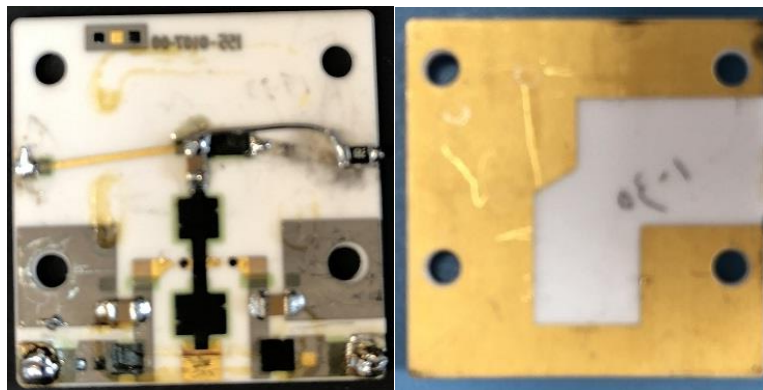


In the photo, Signal Input is on the left; Signal Output is on the right. The dark rectangles are resistors, and the two round dots near the middle are Schottky diodes. Three 1206 capacitors (C1, C2, and C3) can also be seen (the 1206 resistor at the far-right edge was part of the failed repair attempt). C4 is comprised of the approximately 11x11 mil gold foil seen at the bottom middle, and the ground plane (the 40 mil ceramic acts as the dielectric). The measured capacitance of C4 was 25 pf with the hybrid removed from the unit; substantially more capacitance is likely present when installed. R2, also unspecified in the schematic above, is part of a voltage divider, further described below. R2 was measured at 159.2 Ω with a precision ohmmeter. The two diodes and two capacitors that make up the temperature compensation circuit (shown in green above) are located adjacent to U225 on the Output Buffer and Attenuator Board (A3), not on the ceramic hybrid.

An explanation of the P2P detector basic operation is in the SG503 Service Manual on Page 5-1. If the peak-to-peak output amplitude from the oscillator section changes (e.g., the buffer amplifier transistor has lower gain at higher frequency), a corresponding change in detector output produces an error signal that is used to restore the original peak-to-peak amplitude at the leveling point (e.g., by increasing the input signal amplitude to compensate for lower gain). This closed loop feedback establishes a steady state impedance point at the leveling point close to zero ohms. R1 (a

precision 50-ohm resistor) sets the output impedance and reverse terminates the 50-ohm coaxial cable used to connect the SG-503 to other instruments.

The temperature compensation (TC) diodes, and their associated capacitors, are used to differentiate temperature-induced amplitude changes from frequency-induced changes. This is done by passing the two error signals (one from the rectifier diodes, and one from the TC diodes) through an op amp (not part of this circuit). Having the temperature compensating diodes in the same physical package as the rectifying diodes makes the TC work well.

The SG503 P-to-P detector is a relatively common fail point, and the part appears to be unavailable from any of the usual places that sell used Tek parts. I therefore set out to build one using modern parts. I also decided to incorporate the temperature compensation circuit onto the replacement detector.

**Design of the Substitute P2P Detector**
David Partridge's excellent 2009 design of a substitute SG504 external levelling head used the Avago Technologies HSMS-282R diode array, so my first thought was to use the same part. However, it appears to be not readily available (at least in the US), so I went with the Skyworks Solutions SMS3923-081LF. Like the Avago device, the SMS3923 consists of two Schottky diode pairs, but it comes in a bridge quad configuration, instead of the slightly more layout-convenient ring quad configuration. Skyworks also provides SPICE models for their part, which allowed for detailed simulation of the circuit.

In addition to C1's role to decouple the AC signal from the DC portion of the P2P detector, C1, R2, R3 and C4 comprise an AC voltage divider, as shown below.
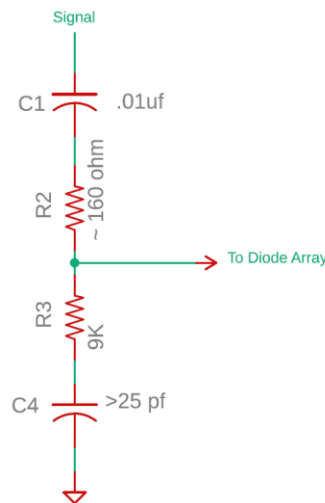


The capacitive reactance of C1 and C4 must be considered when analyzing the behavior of this divider across the frequency range of interest. Capacitive reactance ($X_C$) is determined by capacitance and frequency according to the formula:

$$X_C = \frac{1}{2 \pi f C}$$

where:
$X_C$ = capacitive reactance in ohms,
f = frequency in hertz,
C = capacitance in farads
$\pi$ = 3.1416

The voltage divider should yield the same impedance ratio, regardless of frequency (at least for the frequencies of interest here). R2 and C4 have unspecified values on the original Tektronix schematic, but, armed with our understanding of capacitive reactance, we can determine what their values should be. Consider the following table:

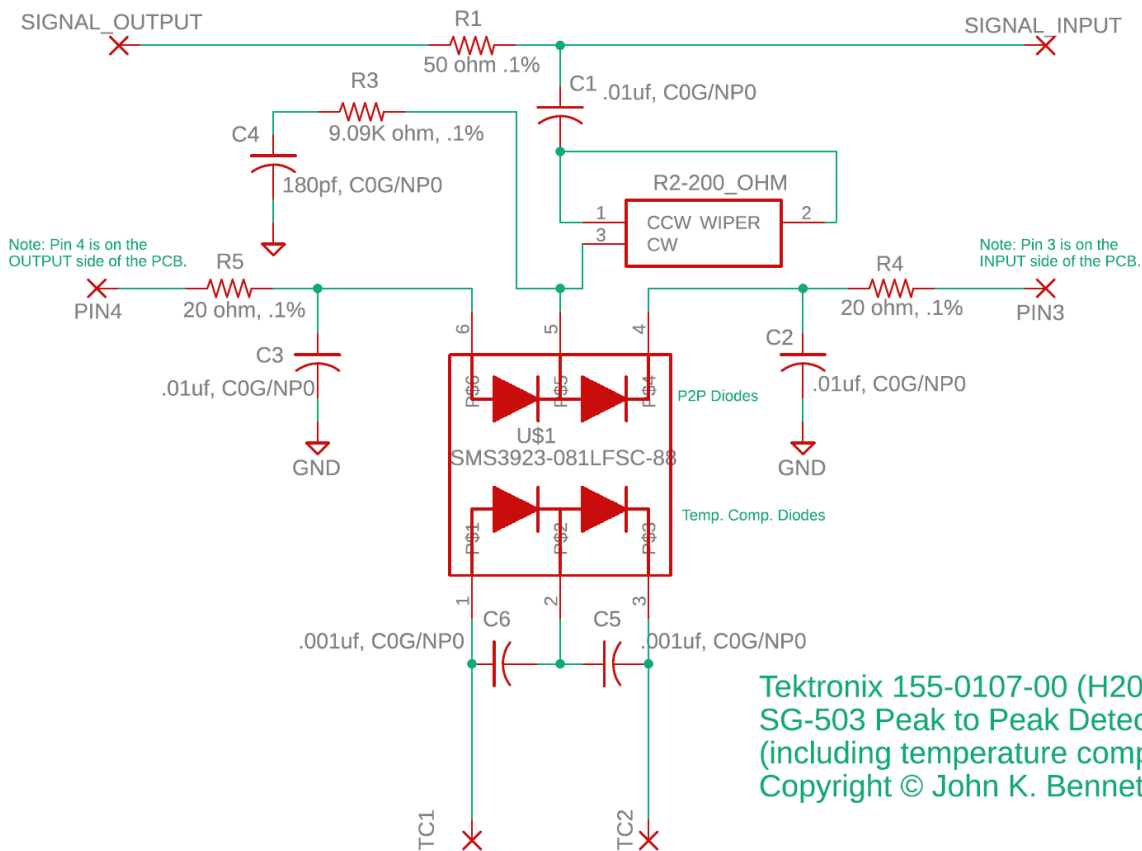| | | f (MHz) | $X_C$ (C1) | $X_C$ (C4) | $X_{C1}$ + R2 | $X_{C4}$ + R3 | $V_D$ | % Diff |
|---|---|---|---|---|---|---|---|---|
| P2P V | 10 | 0.05 | 318.31 | 31831.02 | 478.31 | 40831.02 | 9.8842 | 0.00000 |
| R2 | 160 | 0.25 | 63.66 | 6366.20 | 223.66 | 15366.20 | 9.8565 | -0.28003 |
| R3 | 9000 | 0.5 | 31.83 | 3183.10 | 191.83 | 12183.10 | 9.8450 | -0.39688 |
| C1 (uf) | 0.01 | 1 | 15.92 | 1591.55 | 175.92 | 10591.55 | 9.8366 | -0.48147 |
| C4 (uf) | 0.0001 | 2.5 | 6.37 | 636.62 | 166.37 | 9636.62 | 9.8303 | -0.54554 |
| | | 5 | 3.18 | 318.31 | 163.18 | 9318.31 | 9.8279 | -0.56979 |
| | | 10 | 1.59 | 159.16 | 161.59 | 9159.16 | 9.8266 | -0.58255 |
| | | 25 | 0.64 | 63.66 | 160.64 | 9063.66 | 9.8259 | -0.59041 |
| | | 50 | 0.32 | 31.83 | 160.32 | 9031.83 | 9.8256 | -0.59307 |
| | | 100 | 0.16 | 15.92 | 160.16 | 9015.92 | 9.8255 | -0.59441 |
| | | 150 | 0.11 | 10.61 | 160.11 | 9010.61 | 9.8254 | -0.59485 |
| | | 200 | 0.08 | 7.96 | 160.08 | 9007.96 | 9.8254 | -0.59508 |
| | | 250 | 0.06 | 6.37 | 160.06 | 9006.37 | 9.8254 | -0.59521 |

To construct this table, I assumed the values shown for R2 (~160 Ω, measured) and C4 (100 pf, a guess at this point), and used the original values from the H204 specification sheet for the other components. $V_D$ is the voltage at the diode array connection. The values for $X_C$ were computed using the formula above, and $V_D$ was computed in the usual manner. This table indicates that the error in $V_D$ will grow as frequency increases; we want it to stay flat. We can accomplish this result by increasing the value of C4 to better reflect the original ceramic module in-circuit conditions. We can also take this opportunity to specify readily available component values. This results in the following values: R2 at 160 Ω; R3 at 9.09K, C1 at .01 uf, C4 at 180pf. Now our table becomes:

| | | f (MHz) | $X_c$ (C1) | $X_c$ (C4) | $X_{C1}$ + R2 | $X_{C4}$ + R3 | $V_D$ | % Diff |
|---|---|---|---|---|---|---|---|---|
| P2P V | 10 | 0.05 | 318.31 | 17683.90 | 478.31 | 26773.90 | 9.8245 | 0.00000 |
| R2 | 160 | 0.25 | 63.66 | 3536.78 | 223.66 | 12626.78 | 9.8259 | 0.01488 |
| R3 | 9090 | 0.5 | 31.83 | 1768.39 | 191.83 | 10858.39 | 9.8264 | 0.01947 |
| C1 (uf) | 0.01 | 1 | 15.92 | 884.19 | 175.92 | 9974.19 | 9.8267 | 0.02238 |
| C4 (uf) | 0.00018 | 2.5 | 6.37 | 353.68 | 166.37 | 9443.68 | 9.8269 | 0.02438 |
| | | 5 | 3.18 | 176.84 | 163.18 | 9266.84 | 9.8270 | 0.02510 |
| | | 10 | 1.59 | 88.42 | 161.59 | 9178.42 | 9.8270 | 0.02547 |
| | | 25 | 0.64 | 35.37 | 160.64 | 9125.37 | 9.8270 | 0.02570 |
| | | 50 | 0.32 | 17.68 | 160.32 | 9107.68 | 9.8270 | 0.02577 |
| | | 100 | 0.16 | 8.84 | 160.16 | 9098.84 | 9.8270 | 0.02581 |
| | | 150 | 0.11 | 5.89 | 160.11 | 9095.89 | 9.8270 | 0.02582 |
| | | 200 | 0.08 | 4.42 | 160.08 | 9094.42 | 9.8270 | 0.02583 |
| | | 250 | 0.06 | 3.54 | 160.06 | 9093.54 | 9.8270 | 0.02583 |

This looks a lot better, but the final circuit will be more robust if we build in a way to compensate for as-built conditions. To that end, I made R2 a 200 Ω multi-turn trimmer potentiometer.

Taking all these considerations into account, the final circuit looks like this:

Tektronix 155-0107-00 (H204) Diode Leveler
SG-503 Peak to Peak Detector Substitute
(including temperature compensation)
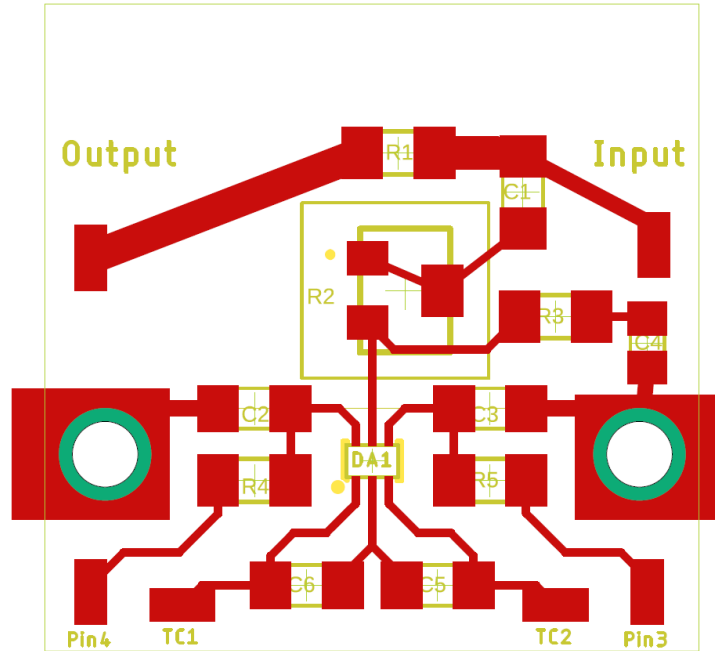Copyright © John K. Bennett 2020

The lower diodes comprise the temperature compensation circuit that was moved onto the P2P detector module. The 200 Ω trimmer is a Bourns PVG5A201C03R00. I used 1206 resistors and capacitors (except for C4), in part because C0G/NP0 capacitors are a little easier to find in 1206, and in part because I have big hands. All the resistors are .1%; all capacitors are C0G/NP0. All parts were in stock at DigiKey. Here is the final parts list:

| | | | | |
|---|---|---|---|---|
| **SG503 Substitute P2P Detector Parts List** | | | | |
| **Quantity** | **DigiKey Part No.** | **Mfr.** | **Mfr. Part No.** | **Value** |
| 3 | 399-11902-1-ND | Kemet | C1206C103JAGAC7800 | .01uf C0G/NP0, 1206 |
| 2 | 399-1218-1-ND | Kemet | C1206C102J5GACTU | .001uf C0G/NP0, 1206 |
| 1 | 399-17434-1-ND | Kemet | C0805C181F5GAC7800 | 180PF C0G/NP0, 0805 |
| 2 | A140045CT-ND | TE Conn. | RQ73C2B20RBTD | 20 Ω, 1206, .1% |
| 1 | 764-1183-1-ND | Vishay | PATT1206E50R0BGT1 | 50 Ω, 1206, .1% |
| 1 | A140822CT-ND | TE Conn. | RQ73C2B9K09BTD | 9.09K, 1206, .1% |
| 1 | 490-2665-1-ND | Bourns | PVG5A201C03R00 | 200 Ω SMT trimmer |
| 1 | 863-1112-1-ND | Skyworks Solutions | SMS3923-081LF | Schottky Diode Array |

**Implementation**

The schematic design and circuit board layout were done using Eagle, but the intended circuit manufacturing target was a Bantam (formerly OtherMill) PCB milling machine. This required a certain amount of special consideration. In particular, the Bantam software tries really hard to keep metal away from the edge of the PCB, so we have to trick it (no doubt there are alternatives to the process I describe, including editing the final G-Code, but this way is simple and fast) by extending areas of metal intended to be at the PCB edge past that edge in Eagle. This technique can be seen below in the top-layer-only depiction of the board layout, where the two holes (implemented as oversize vias to ground so that the ratsnest check would pass) are covered with a polygon and a rectangle copper pour that both extend past the board edge. All traces were 12 mil, except the input (24 mil), output (50 mil), and paths to ground (24 mil). The input and output trace widths match those of the original ceramic module. The board outer dimensions are 1" x 1". The diode

array can be seen in the middle of the PCB. The board was laid out with some attention given to making corresponding signal paths the same length. The low height of R2, the trimmer pot, allows it to easily clear the inside of the RF shield.

The back side of the board is shown below, where the same technique was employed. The amount of overhang is not critical. Using both copper pour and polygon signal paths ensures that the copper areas are not drawn with wires.
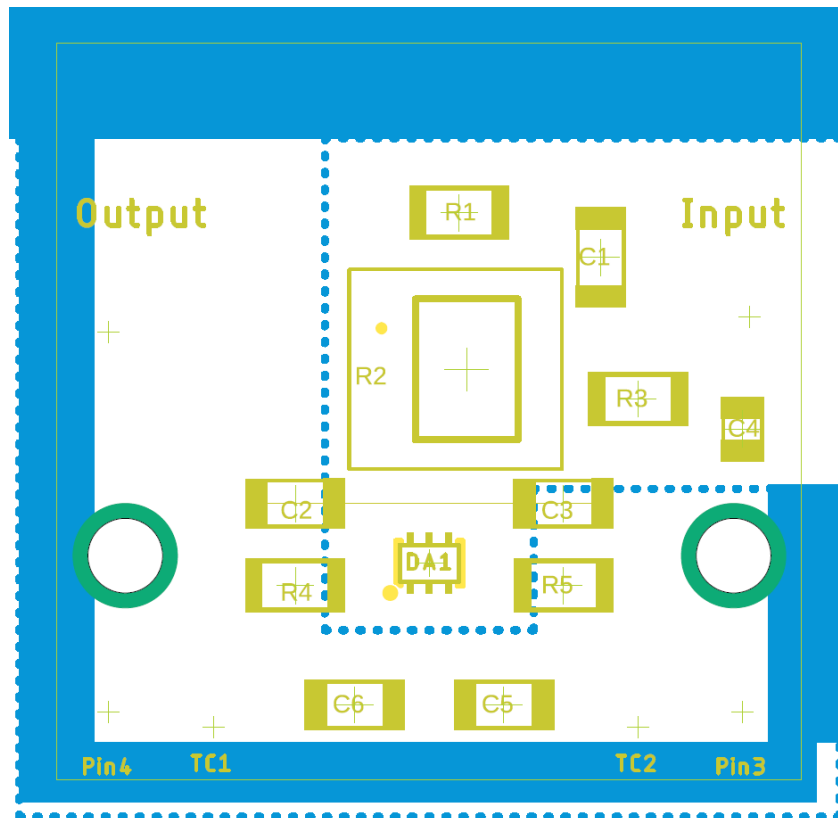
The PCB was routed using easily (and safely) milled two-sided FR-1. Although there is very little data regarding the use of FR-1 in RF circuits, its paper/phenol composition suggests that it would be suitable for use at frequencies up to 250MHz. This proved to be a correct assumption (see the section "Investigating Different PCB Material" below). The milling of the board again required a little trickery. Typically, PCB's routed on the Bantam have a lot of un-connected metal left on the board. This isn't really what we want on a board operating at 250MHz. We can eliminate almost all the unwanted copper by being judicious in the order we use the various end mills used to cut the PCB. Consider the following image from the Bantam Tools software:
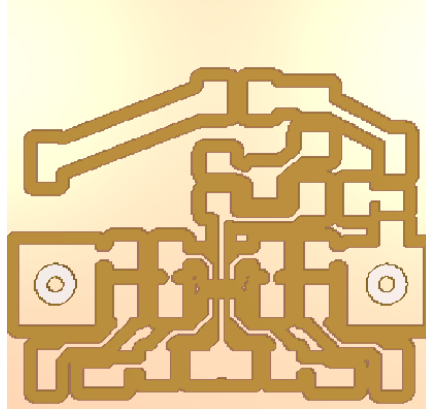


This image shows the board with only a 1/32" end mill, and either a 1/100" end mill, or the PCB .005" engraving bit, selected. This cut (traces and holes only) is the first cut. Notice that a lot of unattached copper remains. Before we deal with this, let's finish up with the 1/32" end mill, so we don't have to change bits as much. Deselect the 1/100" end mill (or PCB .005" engraving bit) and enable only the outline. Let the 1/32" mill make ONE complete trip around AND THEN CANCEL OUT (we will finish the outline cut from the other side). Rehome the machine.
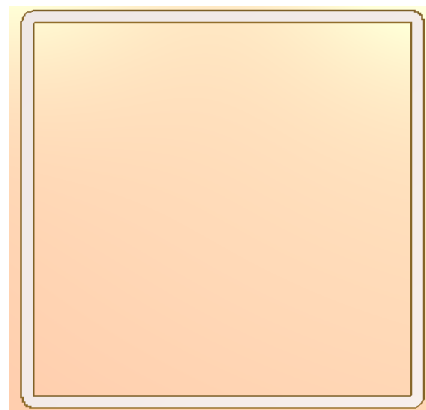


Now, do a cut with a 1/16" end mill (traces only this time):
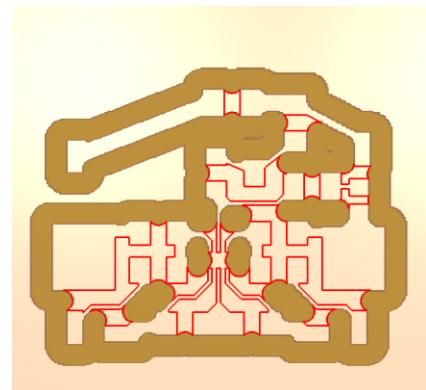


Notice that we have removed a lot of the extra metal. Next, we us a 1/8" end mill (again, traces only) and clear out almost all of the unwanted copper.
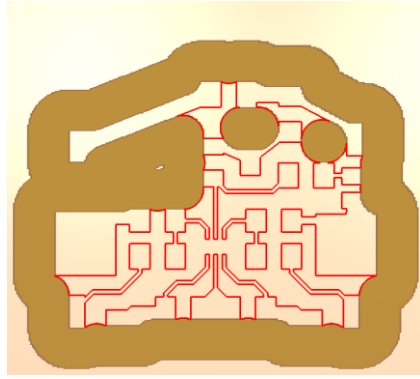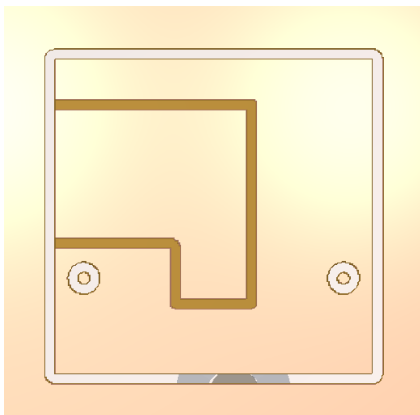
We are done with the front side. Switch to the back side, flip and realign the PCB, and rehome the machine. With the 1/8" end mill still selected, enable traces only and make the cut:



Now, do a cut with only a 1/16" end mill (again, traces only):



Finally, select a 1/32" end mill, and enable traces, holes and outline. Let this cut run to conclusion:

You're done. You may end up with one or two tiny dots of extra metal on the front side, and there will be a rectangular area of extra metal on the back side. Carefully pry up a corner of the unwanted metal with an Xacto knife and peel off with needle nose pliers. The entire process of board production takes about 30 minutes.

**Construction**

Construction of the P2P detector is straight-forward, except for the very fine pitch of the SMS3923. The trimmer also requires a little extra attention. A good rule of thumb is to start with the smallest part and work to the largest. Use care, and only a little solder paste or solder. Clean the board with alcohol before you start. Be sure to tin the connection pads and the screw holes. It is also a good idea to lightly tin the signal input and output traces.

When done soldering, clean with alcohol to remove all flux. Make sure there is no material left under components, especially the diode array. Test the circuit with a low voltage diode checker. You should read ~.34V forward across each diode, ~.68 across each pair (remember, these are Schottky diodes). All diode connections should read open when reversed. All resistance values should be correct, and the input-to-output resistance should be 50 Ω. Capacitors should not be shorted or open.

Now it's time to prepare the SG503. Remove the RF shield on the A3 board and remove the four screws (1-4) that hold A3 down. Remove the two screws (5-6) that hold the RF transistor heatsink bracket to the bottom plate of the SG503. Carefully detach the black attenuator switch extender (7) from the orange selector. Carefully detach the coax (8) and 4-pin connector (9) from A3 and gently remove the A3 board from the SG503. See below for removal locations.
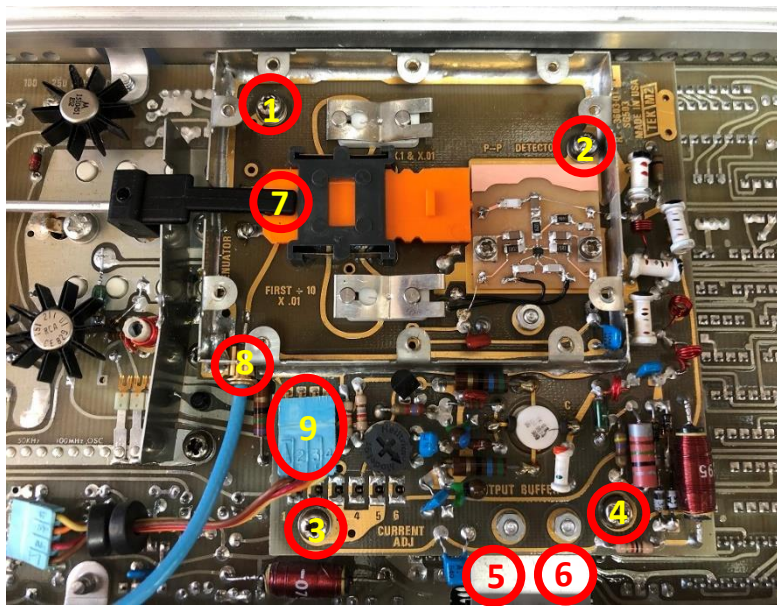


Unsolder the four short wires that connect to the old P2P detector (not shown here) and remove the two screws holding it to A3. Remove the old P2P detector. Remove the old temperature compensation parts (CR216, CR218, C214, and C215) located just below the right end of the orange slide switch. Clear the holes and otherwise prepare for attaching the new detector. Clean the underside of the detector circuit and the corresponding portion of A3. It's a little easier to attach wires to the A3 board before attaching the new detector module. I used 30-gauge wirewrap wire. Strip two short lengths and solder the pads adjacent to the signal input and output points. Then solder four 1.5" insulated and pre-stripped wires to (see picture below; the P2P detector shown was an early prototype, but the connection points are identical to the final version):

1. The former anode of CR218. This should have continuity with Pin 1 of the 4-pin connector on A3.
2. The former cathode of CR216. This should have continuity with Pin 2 of the 4-pin connector on A3.
3. The non-grounded side of C232 (a .1uf ceramic capacitor). This should have continuity with Pin 3 of the 4-pin connector.

4. The non-grounded side of C230 (also a .1uf ceramic capacitor). This should have continuity with Pin 4 of the 4-pin connector (located underneath the mounting flange pictured).
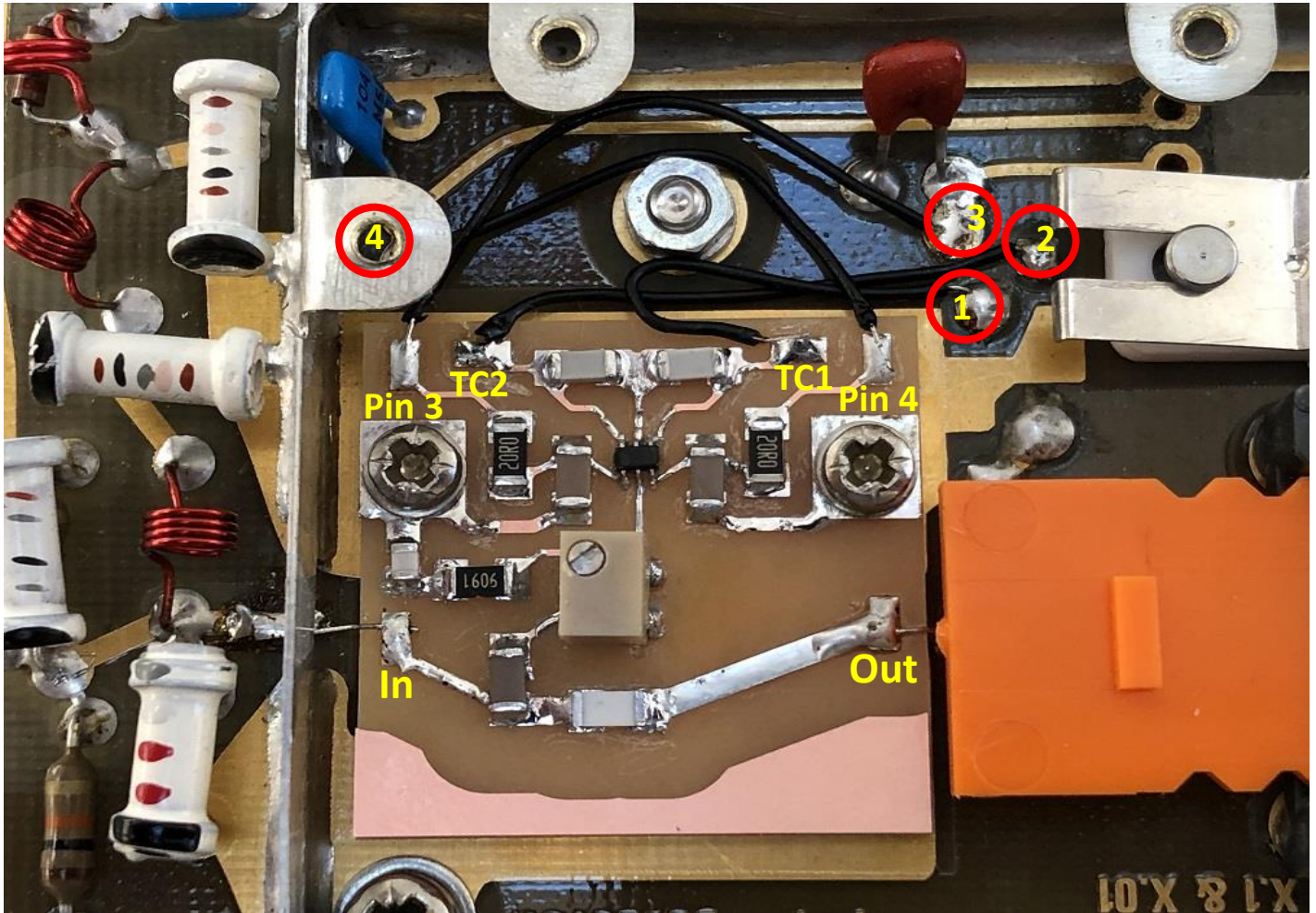


Attach the new detector module with the two screws and tighten. Solder the six wires to the detector as shown:

- 1 to TC1
- 2 to TC2
- 3 to Pin 3
- 4 to Pin 4
- Signal Input to In
- Signal Output to Out (move the attenuation selector to X.01 to make this easier)

Be sure to reattach the attenuation selector to the orange actuator. Leave the RF shield cover off for now.

**Testing**

All SG503's originally came with a "50 Ω Precision Coax," Tektronix part No. 012-0482-00. The characteristics of this cable were analyzed by Dennis Tillman, who demonstrated that this cable is indeed very well made using precision components. This analysis is available on line at https://groups.io/g/TekScopes/topic/31795268 (free registration required). If you don't have this cable, use the best substitute 36" 50 Ω cable available during calibration, and then always use the same substitute cable when the SG503 is in use. Beware of the many on-line sellers (including some major electronics retailers) claiming to have this cable, but who then provide a cheap substitute for a hefty price. If you really want one, the best source is probably eBay. Expect to pay $50-$100, which is a lot for a three-foot piece of coax cable.

Before power-up, verify that things are wired correctly with a diode checker. Pin 1 to Pin 2 of the 4-pin connector should show a Vf of ~.7V. Ditto for Pin 3 to Pin 4. This is also a good time to make sure that the attenuator switches aren't shorted or open. Measure the resistance between the signal output and the coax connector. At X1, you should read < 0.25 Ω. At X.1, you should read around 80Ω; at X.01, around 95Ω. Manually set the value of the R2 trimmer to around 120 Ω (this proved to be the best starting point; if you use Rogers RO4003C PCB material (see below) set it to 130 Ω).

Bring up the SG503 the way you would any piece of equipment after repair: carefully. After warm-up, follow the procedures of Chapter 3 in the Service Manual to check power supply voltages, and then carefully adjust the .5 V and 5 V P-P amplitude set points (this is required). If a PG506 and differential scope is unavailable, you can check amplitudes with a recently calibrated scope with sufficient bandwidth to make frequency-related attenuation a non-issue (1GHz; I used a TDS 7104). If a spectrum analyzer is available, adjust the output buffer current; otherwise leave it alone.

Amplitude flatness is adjusted with R2, the trimmer pot on the new detector, as follows.

1. Set the SG503 to 50 KHz, 0.5V, and X1. Attach one end of the precision coax (or substitute) to the SG503, and the other end to a calibrated high-bandwidth oscilloscope (e.g., a TDS7104). Set the scope input to 50 Ω and 100 mv/div.
2. Allow the SG503 to warm up for at least 20 minutes.
3. Check that the output amplitude at 50 KHz is exactly 5 divisions. If it is not, adjust the 0.5V amplitude until it is. If you change the 0.5V setpoint, be sure to recheck the 5.0V setpoint, as they interact. If the scope has horizontal cursors, the entire process is simplified.
4. Increase the SG503 frequency to 250 MHz. Adjust R2 until the displayed amplitude is >= 5.05 and <= 5.1 V peak to peak. Setting the 250MHz level a little high minimizes undershoot at intermediate frequencies, see "Evaluation" below.
5. Check the flatness at 0.5V, 3.0V, and 5.0V P2P amplitude across the frequency range (see "Evaluation" below) to ensure that the SG503 is operating within specifications. If necessary, readjust R2 slightly, and recheck.

Note: this procedure is intended to ensure the best overall performance. If you only use the SG503 at 5.0V P2P, perform adjustment at that amplitude.
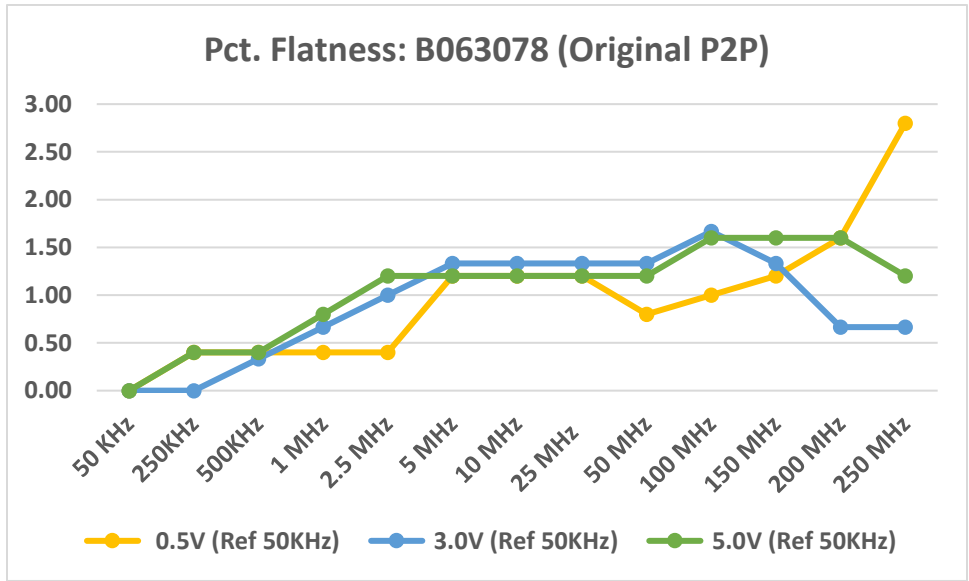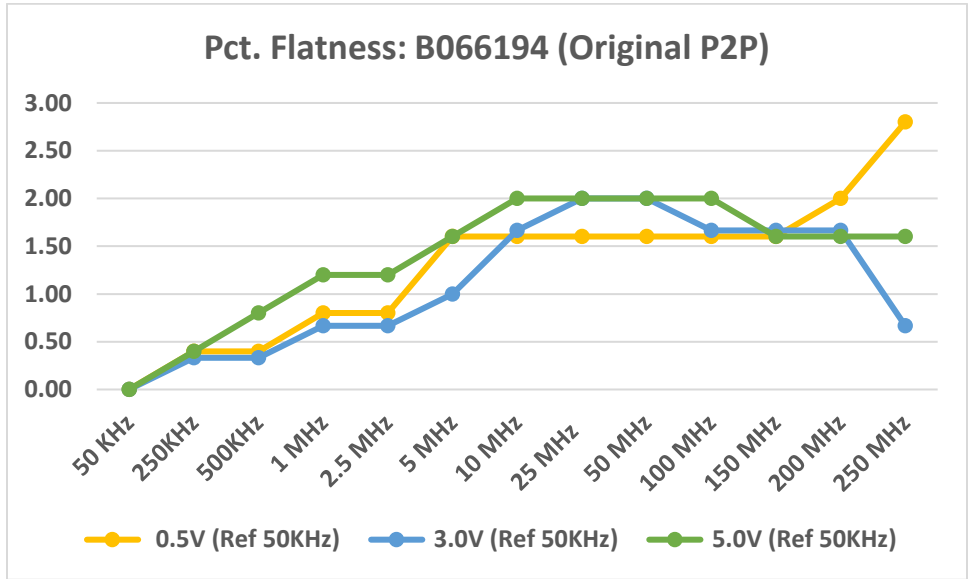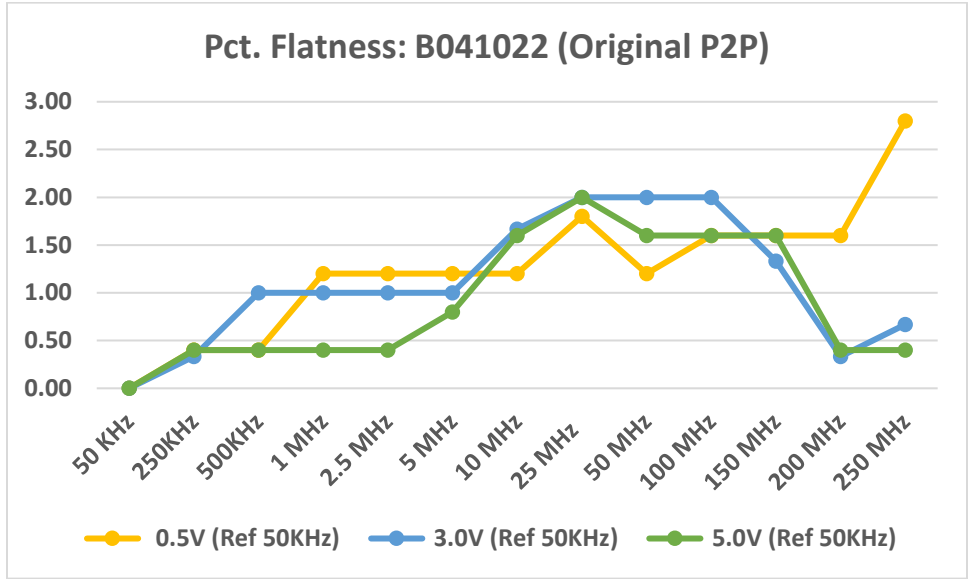
**Evaluation**
The SG503 amplitude accuracy and flatness specifications are as follows (from the Oct 1977 Rev B Service Manual):

| Accuracy | At 50 kHz reference frequency; within 3% of indicated amplitude on X1 range, 4% on X.1 range, and 5% on X.01 range. | Accuracy must be set to within 0.3% on X1 range and checked to be within 2.0% on X.1 and X.01 ranges. |
|---|---|---|

| Flatness (Peak-to-Peak) | | |
|---|---|---|
| Amplitude Multiplier Setting: X1, X.1, X.01 | From 250 kHz to 50 MHz output amplitude will not vary more than 1% of the value at 50 kHz. From 100 MHz to 250 MHz amplitude variation is within 3% of the value at 50 kHz. | |
| Amplitude Multiplier Setting: X1 | 50 MHz to 100 MHz range; output amplitude will not vary more than 1% of the value at 50 kHz. | |
| Amplitude Multiplier Setting: X.1 and X.01 | 50 MHz to 100 MHz range; output amplitude will not vary more than +1.5% and ─1.0% of the value at 50 kHz. | |

These specifications would appear to be met if output amplitude, referenced to the amplitude at 50 KHz, is within 1% below 100 MHz, and within 3% from 100 MHz to 250 MHz.

I tested three calibrated SG503's with the original P2P ceramic detector. An original Tektronix precision cable was used to connect the units to a TDS7104 (50 Ω input impedance). The results were as follows:



Pct. Flatness: B041022 (Original P2P)



Pct. Flatness: B066194 (Original P2P)



Pct. Flatness: B063078 (Original P2P)

The same test was performed with an SG503 modified with the substitute P2P module. This unit was calibrated prior to testing as described above. The results were as follows:



Pct. Flatness: B065314; Substitute P2P (FR-1)

Legend: 0.5V (Ref 50KHz); 3.0V (Ref 50KHz); 5.0V (Ref 50KHz)
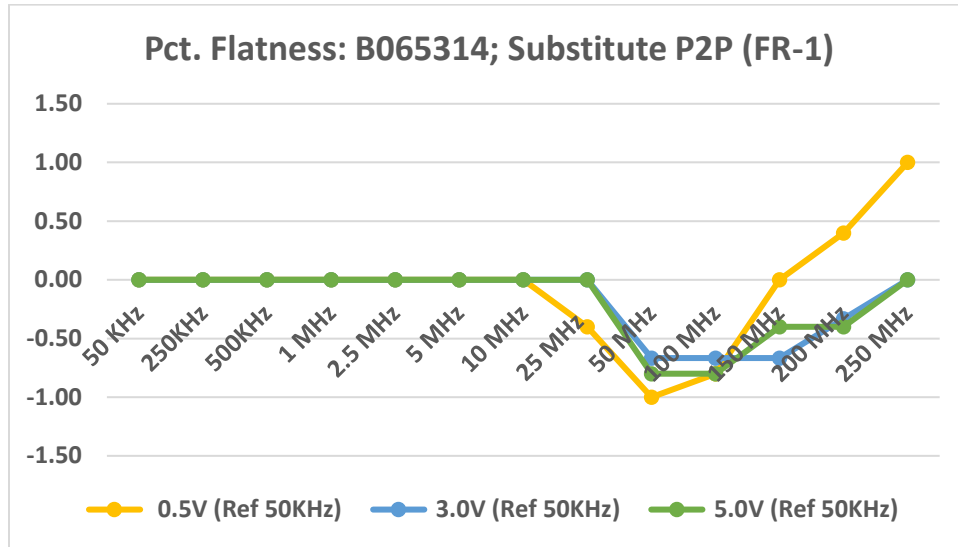
These results indicate that the amplitude flatness of the substitute detector is within specifications, and superior to the (admittedly older) P2P detectors. Note that by varying R2, it is possible to vary the flatness error offset, for example, to ensure that there is no undershoot, thus more closely mimicking original H204 performance.

**Investigating Different PCB Material**
I also investigated the degree to which the choice of FR-1 PCB material impacted performance. One might expect this impact to be significant, given the low cost and modest performance specifications of FR-1. To perform this evaluation, I fabricated a substitute detector on Rogers RO4003C PCB material. All aspects of detector construction were otherwise the same, and it was inserted into the same SG503. The result demonstrated improvement over FR-1, but probably not enough to warrant the extra cost. Discussion follows.
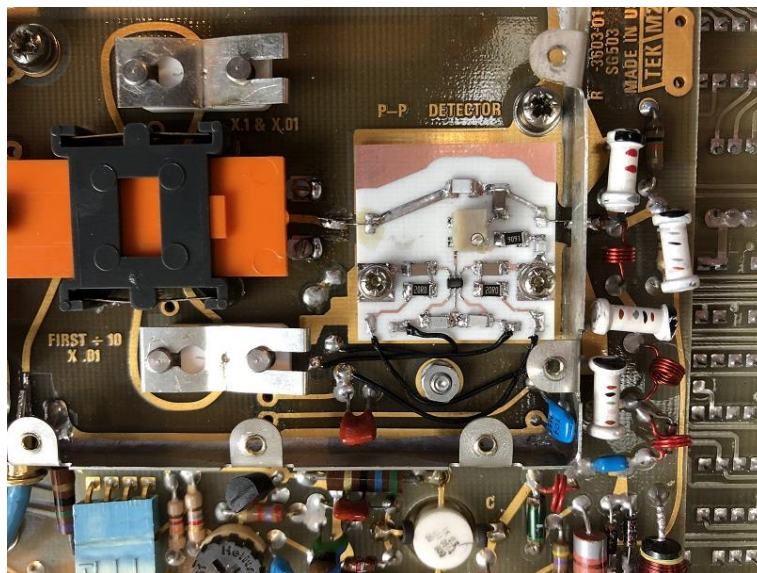


The propagation delay of a PCB trace depends upon, among other things, the dielectric constant (Dk) of the substrate, the dissipation factor (Df) of the substrate, the thickness of the PCB material, and the dimensions of the trace. At very low frequencies, propagation delay is relatively insensitive to frequency changes; at higher frequencies, the impact of these factors on propagation delay becomes more pronounced.

The dielectric constant (Dk) of a PCB laminate material is a measure of the capacitance or energy between copper traces, compared to that pair of traces in a vacuum. The value of Dk for vacuum is 1.0; all other materials have a higher

dielectric constant. A laminate with higher Dk will in general exhibit higher front layer-to-back layer capacitance, and a correspondingly higher propagation delay.

The dissipation factor (Df) of a PCB laminate is a measure of the dielectric material's tendency to absorb some of the AC energy from an electromagnetic field passing through the material. This absorption is sometimes called "insertion loss."

Df and Dk are not the only factors that contribute to circuit losses, particularly at RF frequencies. Other factors include PCB thickness, trace copper thickness, circuit design and board layout, operating frequency, trace smoothness and finish, and trace dimensions, to name a few. In general, cost-conscious board designers will pick the cheapest PCB material that has a Df and Dk appropriate to the expected operating frequency, and then rely on careful design and layout (wider traces spaced farther apart) for everything else.

Consider the following table that depicts Dk and Df for three different substrates: FR-1, an inexpensive prototyping material that is readily available and easily milled; FR-4, the industry standard PCB material; and Rogers RO4003C, a relatively expensive PCB substrate painstakingly designed and manufactured for use in high frequency circuit implementations.

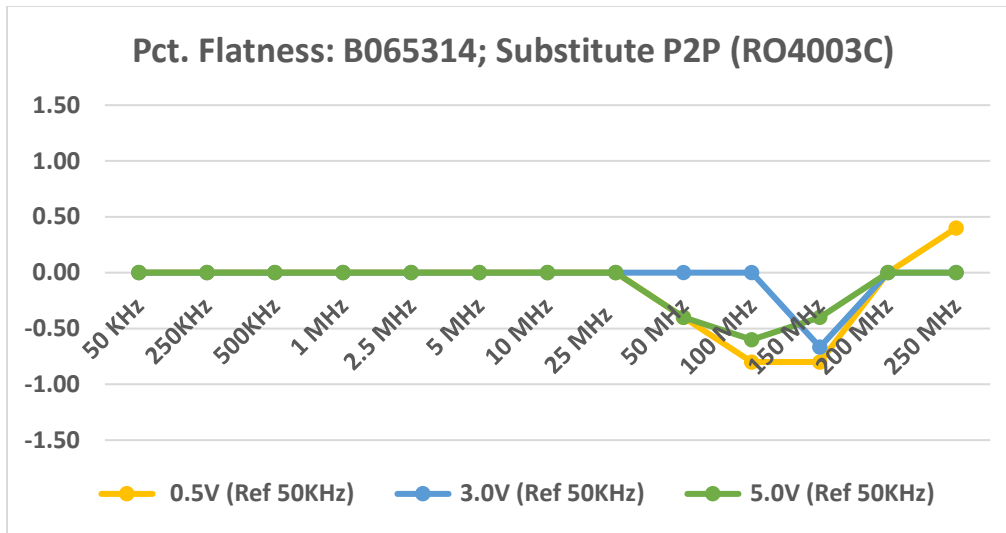|  | $D_k$: Dielectric constant (permittivity) | $D_f$: Dissipation Factor |
|---|---|---|
| **FR-1** | 4.0 - 5.5 @ 1MHz | .045 - .065 @ 1MHz |
| **FR-4** | 4.70 max., 4.35 @ 500 MHz, 4.34 @ 1 GHz | 0.017 - 0.018 @ 1MHz |
| **RO4003C** | 3.38 +/- 0.05 @ 10GHz | 0.0027 @ 10 GHz |

For FR-1 and FR-4, Dk and Df can vary significantly from manufacturer to manufacturer and from lot to lot. In many cases Dk and Df are not specified at RF frequencies (or at all) by some material suppliers. As a reference point, the dielectric constant of ceramic (the material originally used by Tektronix to build the H204 detector) ranges from 5.0 to 9.0, depending upon the composition of the ceramic. Tektronix likely relied on this high Dk to obtain enough capacitance for C4.

A 2012 article in EDN compared PCB trace loss versus frequency for FR-4 and Rogers RO4350B. The following graph is from that article:
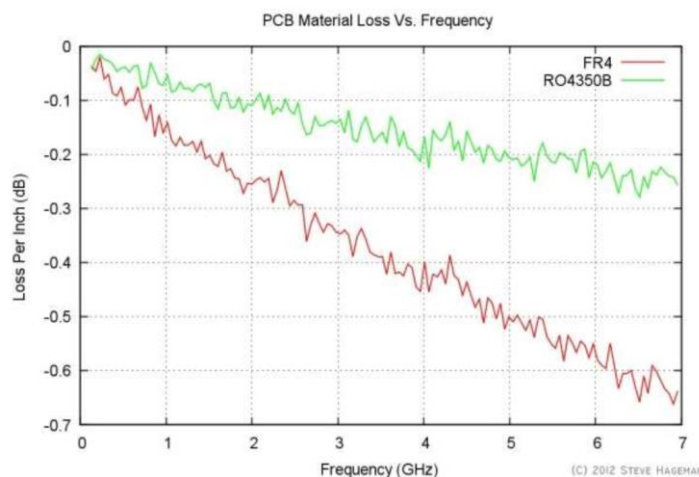


Source: *EDN*, Oct. 19, 2012, **What PCB material do I need to use for RF?**
Steve Hageman, https://www.edn.com/what-pcb-material-do-i-need-to-use-for-rf/

Mr. Hageman's article reports the results of experiments in which he measured loss per inch of trace for the two different PCB materials. His results highlight a key point for our discussion, that there is very little difference in loss (at most .05dB/inch) between FR-4 and RO4350B at 250MHz. Given the table above, one would expect similar results between FR-1 and RO4003C. This expectation is borne out by experiment. The results using RO4003C for the detector substrate are shown below.

Pct. Flatness: B065314; Substitute P2P (RO4003C)

Legend: 0.5V (Ref 50KHz), 3.0V (Ref 50KHz), 5.0V (Ref 50KHz)

These results indicate that the amplitude flatness of the substitute detector fabricated on RO4003C is superior to specifications, the (admittedly older) P2P detectors, and slightly better than the performance of the detector fabricated on FR-1. It is likely that the very small size of the P2P detector PCB makes the design, relative to the original Tektronix SG503 performance specifications, somewhat insensitive to the choice of PCB material. Using either FR-1 or Rogers RO4003C resulted in improvement beyond the original specifications.

Please let me know if you find any of this useful. If there is demand I will post the Eagle files for the detector circuit. Send comments or questions to jkb@colorado.edu.