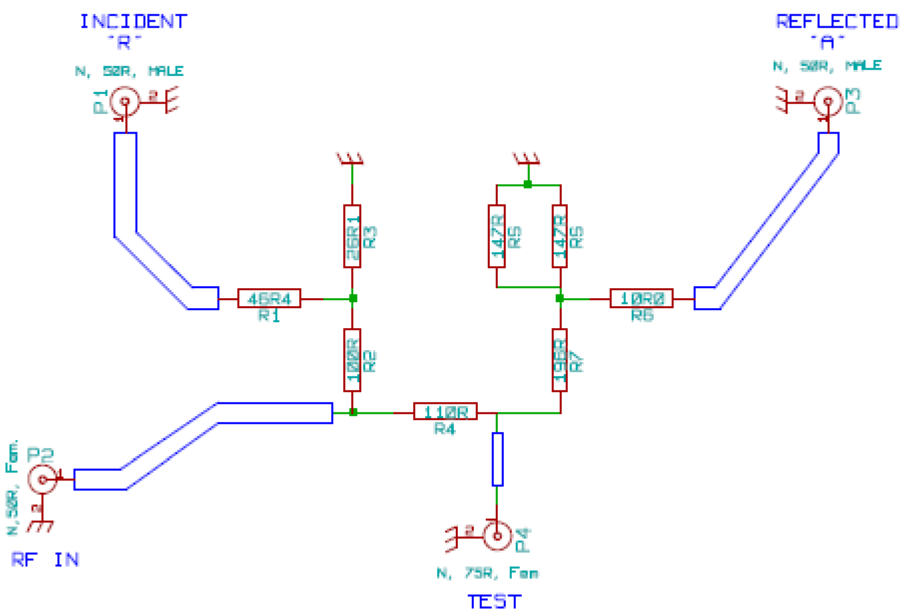
HP87512B (or HP35676B) Sanity Check and Redesign

Source: https://www.eevblog.com/forum/testgear/cloning-the-hp35676a-reflection-transmission-test-set-for-the-3577ab-vna/msg3126264

Schematic HP87812B



Parallel resistance function

$$\parallel(R1, R2) := \frac{1}{\frac{1}{R1} + \frac{1}{R2}}$$

Resistor values

$R1 := 46.4\Omega$ $\quad R2 := 100\Omega$ $\quad R3 := 26.1\Omega$ $\quad R4 := 110\Omega$

$R5 := \frac{147\Omega}{2} = 73.5\,\Omega$ $\quad R6 := 10\Omega$ $\quad R7 := 196\Omega$

$R_w := 50\Omega$ $\quad R_t := 75\Omega$

Sanity check

Ref resistance to GND $\quad R_{X1} := R1 + R3 \parallel (R2 + R4 + R5 + R7) = 71.153\,\Omega$

In resistance to GND $\quad R_{X2} := (R2 + R3) \parallel (R4 + R5 + R7) = 94.65\,\Omega$

A resistance to GND $\quad R_{X3} := R6 + R5 \parallel (R2 + R3 + R4 + R7) = 72.815\,\Omega$

Out resistance to GND $\quad R_{X4} := (R2 + R3 + R4) \parallel (R5 + R7) = 125.848\,\Omega$

Initial analysis

Resistance at X1, Ref $\quad R_{S1} := R1 + \left[R3 \parallel \left[R2 + \left[R_w \parallel \left[R4 + \left[R_t \parallel \left[R7 + \left[R5 \parallel \left(R6 + R_w\right)\right]\right]\right]\right]\right]\right]\right] = 68.36\,\Omega$

Resistance at X2, In $\quad R_{S2} := \left[R2 + \left(R1 + R_w\right) \parallel R3\right] \parallel \left[R4 + \left[R_t \parallel \left[R7 + \left[R5 \parallel \left(R6 + R_w\right)\right]\right]\right]\right] = 69.92\,\Omega$

Resistance at X3, A $\quad R_{S3} := R6 + \left[R5 \parallel \left[R7 + \left[R_t \parallel \left[R4 + \left[R_w \parallel \left[R2 + \left[R3 \parallel \left(R1 + R_w\right)\right]\right]\right]\right]\right]\right]\right] = 66.56\,\Omega$

Resistance at X4, Out $\quad R_{S4} := \left[R7 + \left[R5 \parallel \left(R6 + R_w\right)\right]\right] \parallel \left[R4 + \left[R_w \parallel \left[\left[\left(R1 + R_w\right) \parallel R3\right] + R2\right]\right]\right] = 88.92\,\Omega$

T attenuator resistance at X2 $\quad R_{X2G} := \left(R_w + R1\right) \parallel R3 + R2 = 120.54\,\Omega$

T attenuator resistance at X4 $\quad R_{X4G} := \left(R_w + R6\right) \parallel R5 + R7 = 229.03\,\Omega$

Insertion loss R_t terminated
$$A_{X24} := 20\text{dB}\log\left(\frac{2}{\frac{R_w}{R_{S2}}+1}\cdot\frac{1}{\frac{R4}{R_{X4G} \parallel R_t}+1}\right) = -8.05\cdot\text{dB}$$

Insertion loss X4 open
$$A_{X24o} := 20\text{dB}\log\left(\frac{2}{\frac{R_w}{R_{S2}}+1}\cdot\frac{1}{\frac{R4}{R_{X4G}}+1}\right) = -2.07\cdot\text{dB}$$

Note: The insertion loss X2 to X4 calculated above is based on the voltage ratio. Due to the fact that the nominal X4 port load is $R_t = 75\cdot\Omega$, while the X2 input power is based on $R_w = 50\cdot\Omega$, the voltage ratio must be adjusted by k_t. to obtain the actual insertion loss as the power ratio X2 to X4 in [dB].

Power at R_w and R_t
$$P_w = \frac{{U_L}^2}{R_w} \qquad P_t = \frac{{U_L}^2}{R_t}$$

Correction factor R_w - R_t
$$k_t = 10\text{dB}\log\left(\frac{P_t}{P_w}\right) := 10\text{dB}\log\left(\frac{R_w}{R_t}\right) = -1.76\cdot\text{dB}$$

Power loss R_t terminated
$$A_{pX24} := A_{X24} + k_t = -9.814\cdot\text{dB}$$

T attenuator X2 - X1
$$A_{X21} := 20\text{dB}\log\left[\frac{1}{\frac{R2}{\left(R1 + R_w\right) \parallel R3}+1}\cdot\frac{1}{\frac{R1}{R_w}+1}\right] = -21.07\cdot\text{dB}$$

T attenuator X4 - X3
$$A_{X43} := 20\text{dB}\log\left[\frac{1}{\frac{R7}{\left(R6 + R_w\right) \parallel R5}+1}\cdot\frac{1}{\frac{R6}{R_w}+1}\right] = -18.4\cdot\text{dB}$$

Redesign

To calculate the 7 resistance values the following 7 conditions shall be meet:

1. the resistance R_{S1} at X1 shall be R_w when X2, X3 and X4 are loaded with R_w
2. the resistance R_{S2} at X2 shall be R_w when X1, X3 and X4 are loaded with R_w
3. the resistance R_{S3} at X3 shall be R_w when X1, X2 and X4 are loaded with R_w
4. the resistance R_{S4} at X4 shall be R_w when X1, X2 and X3 are loaded with R_t
5. the insertion loss A_{X24} of the signal path from X2 to X4 shall be 10dB-k_t = 8.2dB when X1and X3 are loaded with R_w
6. the attenuation A_{X21} of the T attenuator from X2 to X1 shall be 21dB when X3 and X4 are loaded with R_w
7. the attenuation A_{X43} of the T attenuator from X4 to X3 shall be 18dB when X1and X2 are loaded with R_w and R_t, respectively

Given

Condition 1: $R_{X1} = R_w$

$$R_w = R1 + \cfrac{1}{\cfrac{1}{R3} + \cfrac{1}{R2 + \cfrac{1}{\cfrac{1}{R_w} + \cfrac{1}{R4 + \cfrac{1}{\cfrac{1}{R_t} + \cfrac{1}{R7 + \cfrac{1}{\cfrac{1}{R5} + \cfrac{1}{R6 + R_w}}}}}}}}$$

Condition 2: $R_{X2} = R_w$

$$R_w = \cfrac{1}{\cfrac{1}{R2 + \cfrac{1}{\cfrac{1}{R1 + R_w} + \cfrac{1}{R3}}} + \cfrac{1}{R4 + \cfrac{1}{\cfrac{1}{R_t} + \cfrac{1}{R7 + \cfrac{1}{\cfrac{1}{R5} + \cfrac{1}{R6 + R_w}}}}}}$$

Condition 3: $R_{X3} = R_w$

$$R_w = R6 + \cfrac{1}{\cfrac{1}{R5} + \cfrac{1}{R7 + \cfrac{1}{\cfrac{1}{R_t} + \cfrac{1}{R4 + \cfrac{1}{\cfrac{1}{R_w} + \cfrac{1}{R2 + \cfrac{1}{\cfrac{1}{R3} + \cfrac{1}{R1 + R_w}}}}}}}}$$

Condition 4: $R_{X4} = R_t$

$$R_t = \cfrac{1}{\cfrac{1}{R7 + \cfrac{1}{\cfrac{1}{R5} + \cfrac{1}{R6 + R_w}}} + \cfrac{1}{R4 + \cfrac{1}{\cfrac{1}{R_w} + \cfrac{1}{R2 + \cfrac{1}{\cfrac{1}{R1 + R_w} + \cfrac{1}{R3}}}}}}$$

Condition 5: $A_{X24} = 8.2\text{dB}$

$$10^{\frac{-8.2}{20}} = \frac{2}{R_w\left(\frac{1}{R2+\frac{1}{\frac{1}{R1+R_w}+\frac{1}{R3}}}+\frac{1}{R4+\frac{1}{\frac{1}{R_t}+\frac{1}{R7+\frac{1}{\frac{1}{R5}+\frac{1}{R6+R_w}}}}}\right)+1} \cdot \frac{1}{R4\left(\frac{1}{\frac{1}{\frac{1}{R_w+R6}+\frac{1}{R5}}+R7}+\frac{1}{R_t}\right)+1}$$

Condition 6: $A_{X21} = 21\text{dB}$

$$10^{\frac{-21}{20}} = \frac{1}{R2\left(\frac{1}{R1+R_w}+\frac{1}{R3}\right)+1}\,\frac{1}{\frac{R1}{R_w}+1}$$

Condition 7: $A_{X43} = 18\text{dB}$

$$10^{\frac{-18}{20}} = \frac{1}{R7\left(\frac{1}{R6+R_w}+\frac{1}{R5}\right)+1}\,\frac{1}{\frac{R6}{R_w}+1}$$

solved for resistor values

$$R_v := \text{Find}(R1,R2,R3,R4,R5,R6,R7) = \begin{pmatrix} 37.69 \\ 65.15 \\ 14 \\ 86.66 \\ 59.01 \\ 3.18 \\ 180.92 \end{pmatrix}\Omega$$

E96 factor

$$e_{96} := 10^{\frac{1}{96}} = 1.024$$

Function to convert to E96 values

$$R_N(R) := \text{round}\left(100 e_{96}^{\text{round}\left(\frac{\ln\left(\frac{R}{10\Omega}\right)}{\ln\left(e_{96}\right)}\right)}\right) 0.1\Omega$$

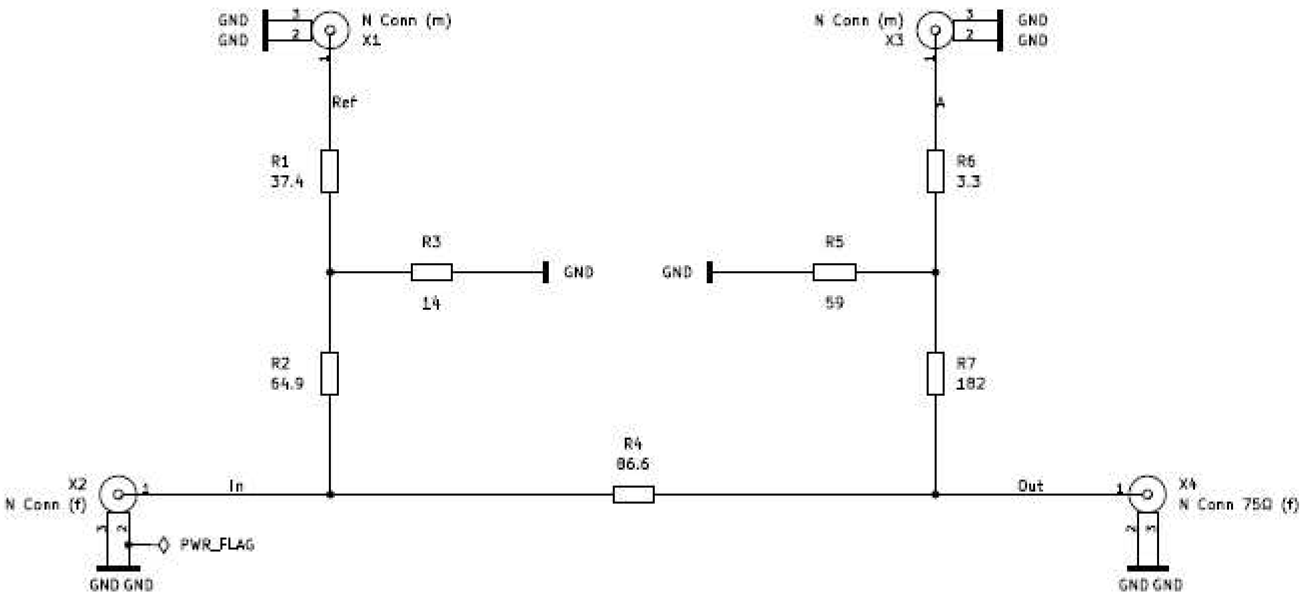
New resistors R1, R2 $\quad R1 := R_N\left(R_{v_0}\right) = 37.4\,\Omega \qquad R2 := R_N\left(R_{v_1}\right) = 64.9\,\Omega$

New resistors R3, R4 $\quad R3 := R_N\left(R_{v_2}\right) = 14\,\Omega \qquad R4 := R_N\left(R_{v_3}\right) = 86.6\,\Omega$

New resistors R5, R6 $\quad R5 := R_N\left(R_{v_4}\right) = 59\,\Omega \qquad R6 := R_N\left(R_{v_5}\right) = 3.3\Omega$

New resistor R7 $\quad R7 := R_N\left(R_{v_6}\right) = 182\,\Omega$

Analysis with redesigned resistor values



Resistance at X1, Ref
$$R_{S1} := R1 + \left[R3 \parallel \left[R2 + \left[R_w \parallel \left[R4 + \left[R_t \parallel \left[R7 + \left[R5 \parallel \left(R6 + R_w\right)\right]\right]\right]\right]\right]\right]\right] = 49.71\,\Omega$$

Resistance at X2, In
$$R_{S2} := \left[R2 + \left(R1 + R_w\right) \parallel R3\right] \parallel \left[R4 + \left[R_t \parallel \left[R7 + \left[R5 \parallel \left(R6 + R_w\right)\right]\right]\right]\right] = 49.9\,\Omega$$

Resistance at X3, A
$$R_{S3} := R6 + \left[R5 \parallel \left[R7 + \left[R_t \parallel \left[R4 + \left[R_w \parallel \left[R2 + \left[R3 \parallel \left(R1 + R_w\right)\right]\right]\right]\right]\right]\right]\right] = 50.06\,\Omega$$

Resistance at X4, Out
$$R_{S4} := \left[R7 + \left[R5 \parallel \left(R6 + R_w\right)\right]\right] \parallel \left[R4 + \left[R_w \parallel \left[\left[\left(R1 + R_w\right) \parallel R3\right] + R2\right]\right]\right] = 75.11\,\Omega$$

T attenuator resistance at X2
$$R_{X2G} := \left(R_w + R1\right) \parallel R3 + R2 = 76.97\,\Omega$$

T attenuator resistance at X4
$$R_{X4G} := \left(R_w + R6\right) \parallel R5 + R7 = 210.08\,\Omega$$

Insertion loss R_t terminated
$$A_{X24} := 20\text{dB}\log\left(\frac{2}{\frac{R_w}{R_{S2}} + 1} \cdot \frac{1}{\frac{R4}{R_{X4G} \parallel R_t} + 1}\right) = -8.2\cdot\text{dB}$$

Insertion loss X2 - X4 open
$$A_{X24o} := 20\text{dB}\log\left(\frac{2}{\frac{R_w}{R_{S2}} + 1} \cdot \frac{1}{\frac{R4}{R_{X4G}} + 1}\right) = -3.01\cdot\text{dB}$$

Power loss R_t terminated
$$A_{pX24} := A_{X24} + k_t = -9.96\cdot\text{dB}$$

T attenuator X2 - X1
$$A_{X21} := 20\text{dB}\log\left[\frac{1}{\frac{R2}{\left(R1 + R_w\right) \parallel R3} + 1} \frac{1}{\frac{R1}{R_w} + 1}\right] = -20.94\cdot\text{dB}$$

T attenuator X4 - X3
$$A_{X43} := 20\text{dB}\log\left[\frac{1}{\frac{R7}{\left(R6 + R_w\right) \parallel R5} + 1} \frac{1}{\frac{R6}{R_w} + 1}\right] = -18.05\cdot\text{dB}$$