

# Frequency Response Testing of amplifiers, February 2013.

During construction of any amplifier, there is always a need to plot the frequency response graph and to examine the stability with transient input signals. What is always wanted is that all power amplifiers have a flat frequency response between at least 20Hz to 30kHz with no more than -1dB attenuation across this range, and we wish that the response below or above this range has no peaks exceeding +3dB, regardless of the load which may be any possible pure resistance, or with any possible combination of R plus inductance L or capacitance C. All amplifiers must be able to remain unconditionally stable ( free of any oscillations ) even without any load connected at all.

To achieve the response and stability required, we need to have suitable test equipment

including the following items :-

1, Sine wave signal source from 2Hz to 200kHz with THD < 0.5%, with up to 3Vrms amplitude.

2, Square wave signal source for at least 4 frequencies between 100Hz to 500kHz, and

preferably with 12 frequencies, and 3 F per decade and with rise time of at least 50V/uS.

3, Wide bandwidth Vac volt meters for measuring of large voltages between 1Vrms

and 500Vrms, with medium accuracy for F between 2Hz and 2MHz.

4, Wide bandwidth Vac volt meters for measuring voltages between 1mVrms and 1,000Vrms

between F 2Hz to 2MHz with high accuracy. I have several analog Vac meters for measuring

anode voltages and other high level signals over a wide range of F.

I do have several digital meters which are accurate for Vac up to only 1kHz.

5, Radio variable 2 gang tuning capacitor giving C between 50pF and 800pF, and combined

with good quality 25k linear potentiometer in series to make a Zobel network that can have

its R and C varied while observations are made with oscilloscope and

with square wave.

6, Analog old style oscilloscope ( aka Cathode Ray Oscilloscope, CRO ), with 2Hz to 2MHz

bandwidth. Preferably a dual trace unit capable of DC to 15MHz is used.

7, A variable dummy resistance load capable of full power testing for several minutes.

R load values should be selectable between 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14, 16 ohms,

and possibly more ohms up to 32 ohms by adding yet more series connected high watt R.

8, Capacitor loads need only be rated to take the expected amplifier voltages. They normally

do not heat up when subjected to considerable signal voltage, but the amplifier will heat up due to current flow.

9. Power amp speaker cables with low resistance. 15 amp rated mains cabling is fine,

with 4mm banana plugs each end to connect from amp to dummy loads fitted with 4mm banana sockets.

10, Interconnect RCA cabling of normal high C of say 100pF and 1 metre long plus others

500mm long with less than 20pF.

What makes a useful sine wave and square wave generator? Usually, many people use

what is called a function generator which puts out sine waves, square waves, triangular

waves and has such extra abilities as AM and FM and variable square wave intervals

between even spaced +/- waves peaks, and has DC offset adjustment. In fact, only sine

and square waves are needed. Low distortion in sine waves is not critically important for

response measuring as it is when measuring THD, so anything with THD < 0.5% is OK.

Square waves need only a rise time of 50V/uS with no benefits of having say 500V/uS.

Signal generators should have maximum output resistance of 600 ohms to ensure the input

resistance of amplifiers has little effect on the output level of the signal generator.

I am presently using a sine/square gene with 1.8k potentiometer at its output which means

its maximum approximate  $R_{out} = 600$  ohms and surprisingly, with a normal high capacitance

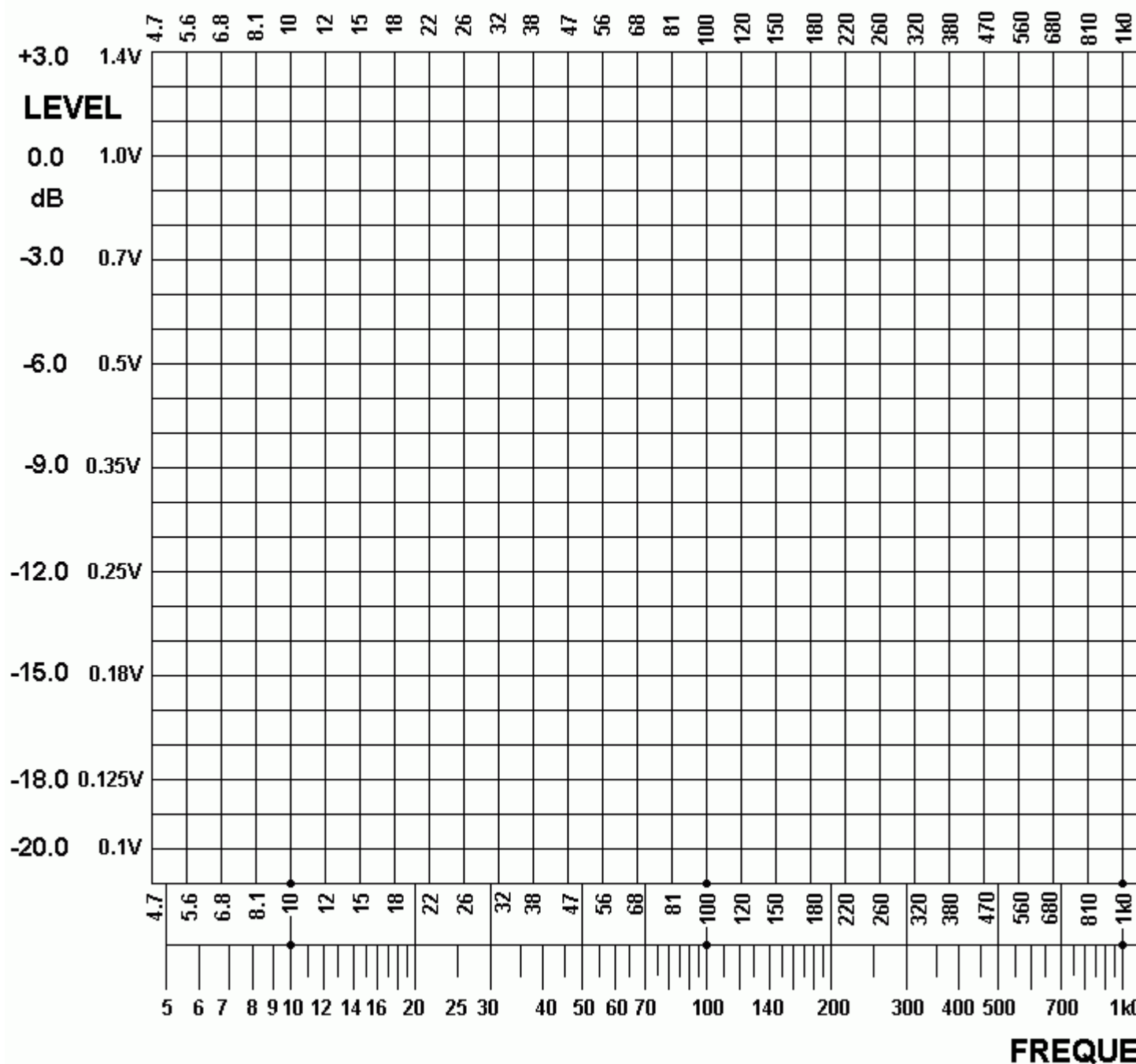
RCA cabling to my CRO, there is considerable reduction of rise time of square waves.

But at least all F up to 500kHz are unattenuated from the gene.

Better signal genes have  $R_{out} = 50 \text{ ohms}$ , which means the gene would need to have a buffered output using a pair of complementary npn and pnp source follower mosfets after the attenuator pot inside the sig gene. But unless otherwise stated, assume all measurements are done with sig gene of  $R_{out} < 600 \text{ ohms}$ . To make a graph of F response between say 1Hz and 1MHz, one can use the oscilloscope ( CRO ) as a volt meter. Suppose you have a 32W amp which makes a maximum  $V_o = 16.0V_{rms}$  into  $8r0$ . The response with a pure

$8r0$  load can be examined with the amp running at  $16V_{rms}$  at 1kHz and the trace on the CRO is set so peak to peak waves occupy  $1/2$  the screen height, and centered. If the  $V_o$  increases by +6dB the sine wave will occupy the whole screen height, and if -6dB it occupies  $1/4$  of the screen height. This method will show small  $V_o$  changes of only  $\pm 1\text{dB}$ , when  $V_o$  will be  $1.12 \times 16V_{rms}$  or  $0.89 \times 16V_{rms}$ . A scale drawn on masking tape may be put on each side of the screen to offer logarithmic calibration so you know levels of  $\pm 3\text{dB}$ ,  $\pm 6\text{dB}$ ,  $-9\text{dB}$ ,  $-12\text{dB}$ . Practice with the CRO stops your confusion. The CRO should have 10MHz BW, and for best LF  $V_o$  measurement, always use the DC option on switch for DC or AC. The amp secondary winding on OPT should have one end taken to 0V. To record your measured response with sine waves at the frequencies produced by oscillators below, you can make a printed paper copy of a response sheet then plot  $V_o$  levels with a pencil. Clever Dicks among you will use a PC program but usually they are limited to 20Hz to 20kHz, and you NEED to measure a much wider response. Here is a sample response sheet which you may copy....

**Graph 1.** Blank sheet for F response recording.



This may be extended at left side down to 1Hz or raised on right side to 1Mhz,  
 and I leave YOU to decide how big you want it to be a printed A4 page.  
 Once you get the page you want, many copies can be made. I spent many  
 hours getting  
 the logarithmic scales just right as I could. One sig gene I have has same  
 switched F  
 output as the vertically written numbers 4.7, 5.6, etc. The spacing is even  
 along the logarithmic  
 scale. Once a row of dots have been penned on the graph sheet, just join the  
 dots with

a smooth curve where response changes, and you have a very good idea of the response.

Measuring the response can tell you all about your mistakes. It is hard disciplined work to properly measure an amplifier. Response levels should be measured at 0dB, which would

be 16Vrms for a 32W amp with 8 $\Omega$  load, and then at -6dB = 8Vrms and at -12dB = 4Vrms.

The best indication of stability and HF and LF behaviour and especially with pure C loads

between 0.1 $\mu$ F and 2 $\mu$ F is done at the -12dB level where it will be safe to test up to 100kHz

with 2 $\mu$ F connected, and where this 2 $\mu$ F has  $Z = 0.8\Omega$ , which is nearly a short circuit.

Don't test at 0dB with 2 $\mu$ F. Don't leave the amp running for long at high  $P_o$  when testing below

20Hz and there is distortion caused by OPT core saturation. The response you wish to

understand is that where THD < 2%, which you can see on the CRO as sudden appearance

of very distorted waves due to core saturation at LF, or appearance of triangular waves at HF

known as slew rate distortion, ie, some stage in the amp becomes overloaded at HF.

Therefore you may find the response for  $V_o = 0$ dB may have -3dB poles at  $F_1 = 20$ Hz,  $F_2 = 40$ kHz. But at  $V_o = -6$ dB,  $F_1 = 12$ Hz,  $F_2 = 80$ kHz, and at  $V_o = -12$ dB,

$F_1 = 5$ Hz,  $F_2 = 60$ kHz.

There will always be peaks in the response at LF if the open loop phase shift is high and you

have not used LF gain shelving. Similarly, peaked response occurs with a pure C load usually

above 15kHz. and to minimize the peaking there must be zobel networks applied carefully within

the amp. The idea is to get the widest 0dB response with a pure R load which is the correct load

for the amp, yet not have peaking any more than +3dB at any F regardless of pure C load use.

The response with zero load at all should not be measured above the 0dB  $V_o$  reference level

for the R load. It can be measured at any level below 0dB. The amp open loop gain is highest

when there is no load connected. While there may be say 16dB GNFB

connected when an 8r0 load is used, this amount of GNFB depends on the open loop gain, ie,  $V_o$  divided by  $V_{in}$  without any GNFB connected. Without any load, many tube amps oscillate at LF because their open loop gain of the output tubes has perhaps doubled which increases the amount of GNFB applied which may make the amp work at a level above the "margin of stability".

This margin of stability is expressed in dB, and it means the amp becomes unstable if the amount of NFB is increased from the safe level by a certain number of dB. In a real amp with 16dB of GNFB, it may begin to oscillate if GNFB is increased by say 8dB to 24dB. So the margin of stability = 8dB, and you just can't allow GNFB to ever be 24dB, even when the amp is unloaded. It means that you have to apply the gain shelving networks just right because the margin of stability is exceeded first where there are peaks in the sine wave response below 20Hz and above 20kHz. The best amps I built has 15dB GNFB which could be increased to 35dB before oscillations could not be prevented by R&C networks for reductions of open loop gain and phase shift below and above the audio band where the applied GNFB should effectively be reduced because the open loop gain has been reduced. You do NOT want a high amount of GNFB applied at 10Hz or 100kHz. Some years ago I built a signal gene with switched sine wave F and switched square wave F.

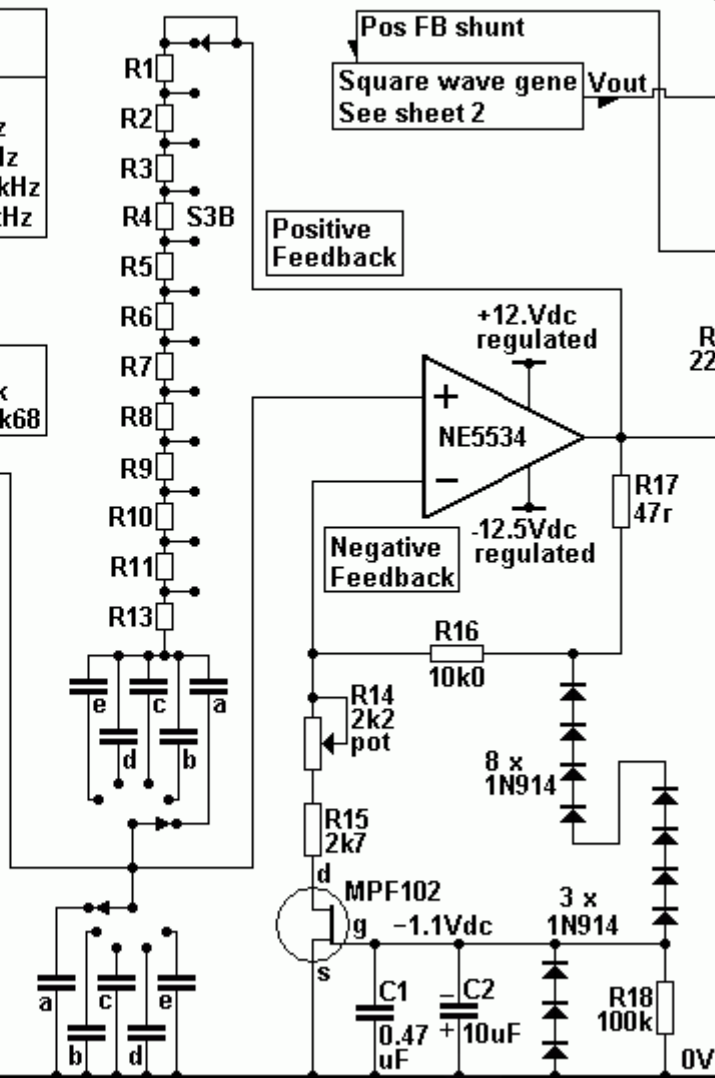
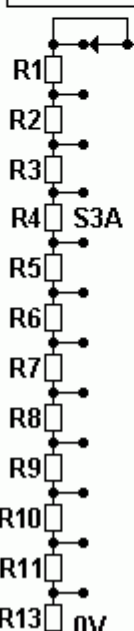
**Fig 1.** Wien bridge oscillator with oppamp.

S4 A&B Freq range  
variable C values  
Ca = 4.7uF 2Hz to 20Hz  
Cb = 0.47uF 20Hz to 200Hz  
Cc = 0.047uF 200Hz to 2kHz  
Cd = 0.0047uF 2kHz to 20kHz  
Ce = 470pF 20kHz to 200kHz

Measured  
Resistances  
and relative  
Frequencies

F = Hertz	R = ohms
201	3,310
250	2,985
321	1,595
379	1,708
469	1,161
556	1,050
680	850
821	748
1,003	682
1,258	584
1,608	412
2,008	1,682

Max total  
R = 16.80k  
Min R = 1k68



S1 ▶ Two output voltage levels  
Low = 0 - 0.47Vpk.  
S2 A&B ▶ Select Sine or Square wave  
S3 A&B ▶ Select 12 Frequencies  
S4 A&B ▶ Select from 5 Frequencies  
2Hz to 200kHz.  
MPF102 = j-fet which operates at low  
resistance controlled by small signal  
Vdc bias generated by rectified sine wave  
and 8 x 1N914. Other diodes are for  
transient V swings when frequency is  
or changing F  
See website for alternative designs and  
other R&C and different components

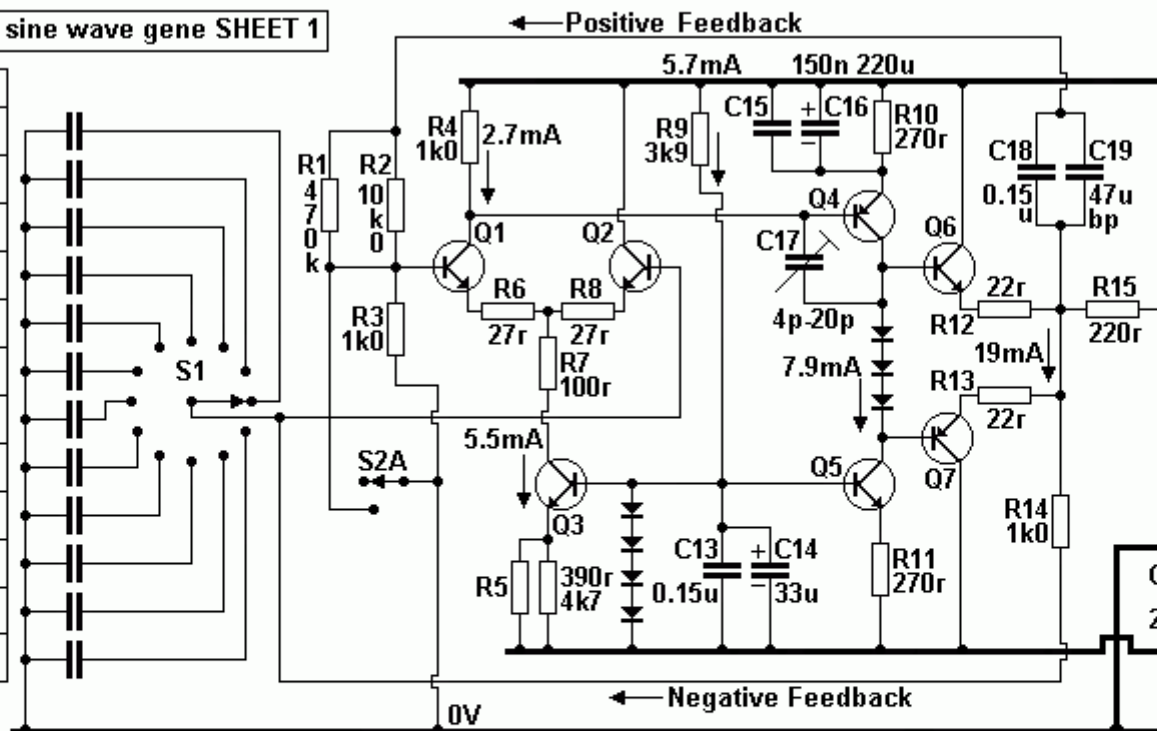
**Fig 2.** Square wave generator with discrete bjt to make op-amp.

# SHEET 2

## Op-amp with 5 bjts, square wave generator -13Feb 20

This used with sine wave gene SHEET 1

Approx CuF and F		
C1	2n8	469kHz
C2	8n0	215kHz
C3	21n5	100kHz
C4	52n6	46.3kHz
C5	113n7	21.5kHz
C6	263n	10kHz
C7	570n	4.63kHz
C8	1u23	2.15kHz
C9	2u67	1.00kHz
C10	5u7	463Hz
C11	12u33	215Hz
C12	26u7	100Hz

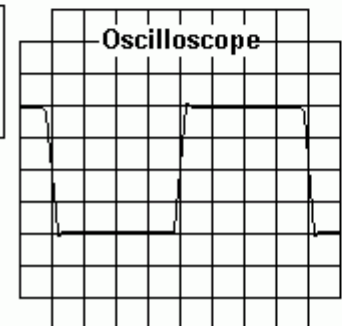


Switched capacitors in negative FB path to vary square wave frequency useful for testing audio amplifiers and transformers.

Q1, Q2, Q3 = 2N2222 npn  
Q4, Q7 = BC327 pnp  
Q5, Q6 = BC337 npn  
Diodes = 1N914

Square wave gene used with sine wave gene with shared PSU with shunt regulated +/- 12.5Vdc rails.

S2A&B to select between sine or square wave gene.  
S2A stops square wave oscillator when using sine wave gene.



Square wave T for 1 v  
Rise time = 59.6V

C17 adjustable  
ringing a

www.tu

**Fig 3.** Wien bridge oscillator with discrete bjts to make op-amp.

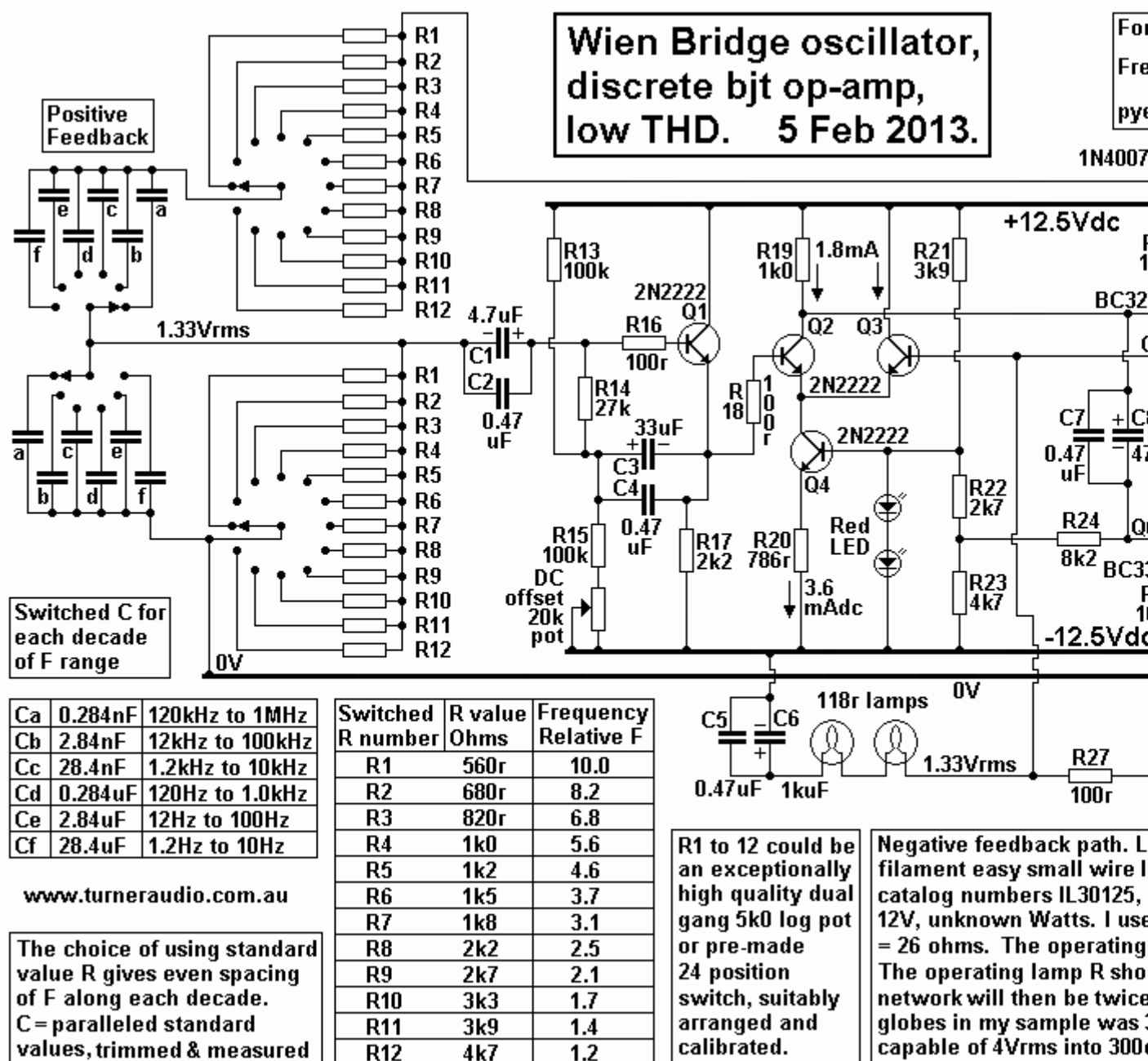


Fig 3 above is another example of a wien bridge sine wave gene.