SIMPLE EMITTER-FOLLOWERS.

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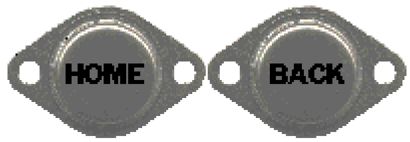


to Discrete Design

THE SIMPLE EMITTER-FOLLOWER.

The simplest discrete circuit-block is the emitter-follower. It acts as a unity-voltage-gain buffer. A buffer is a stage with high input impedance and low output impedance; typically it prevents things downstream from loading things upstream. The simple emitter-follower does not have a gain of exactly one, but it is usually pretty close; this will depend somewhat on the output loading; don't expect the output impedance to be as low as a opamp with plenty of NFB.

Fig 1 shows the simple emitter-follower with emitter resistor Re. This is 2K7, giving a quiescent current of 6mA; this value is also used in the more sophisticated circuitry to come, to allow valid comparisons. Biasing is by a high-value resistor Rb connected to 0V. This is omitted in later diagrams. Note the polarity of the output capacitor; the output will sit at about -0.6V due to the Vbe drop, plus a little lower due to the voltage drop caused by the base current Ib flowing through Rb.

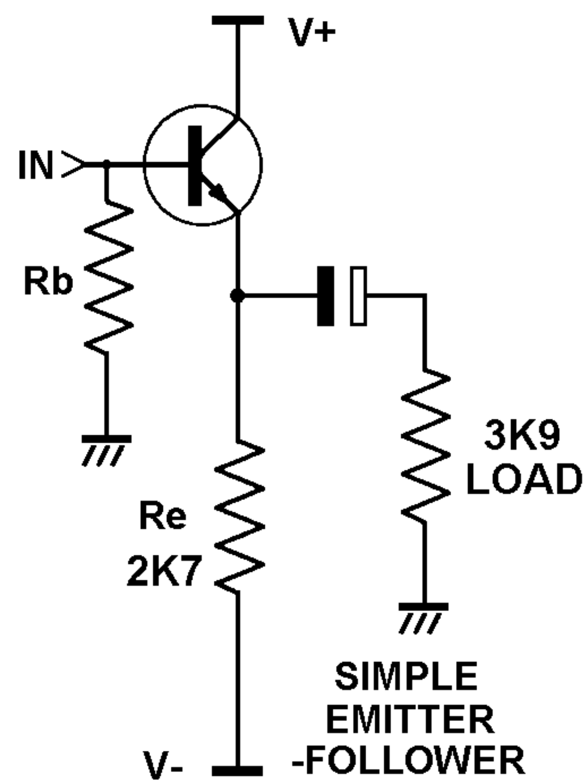
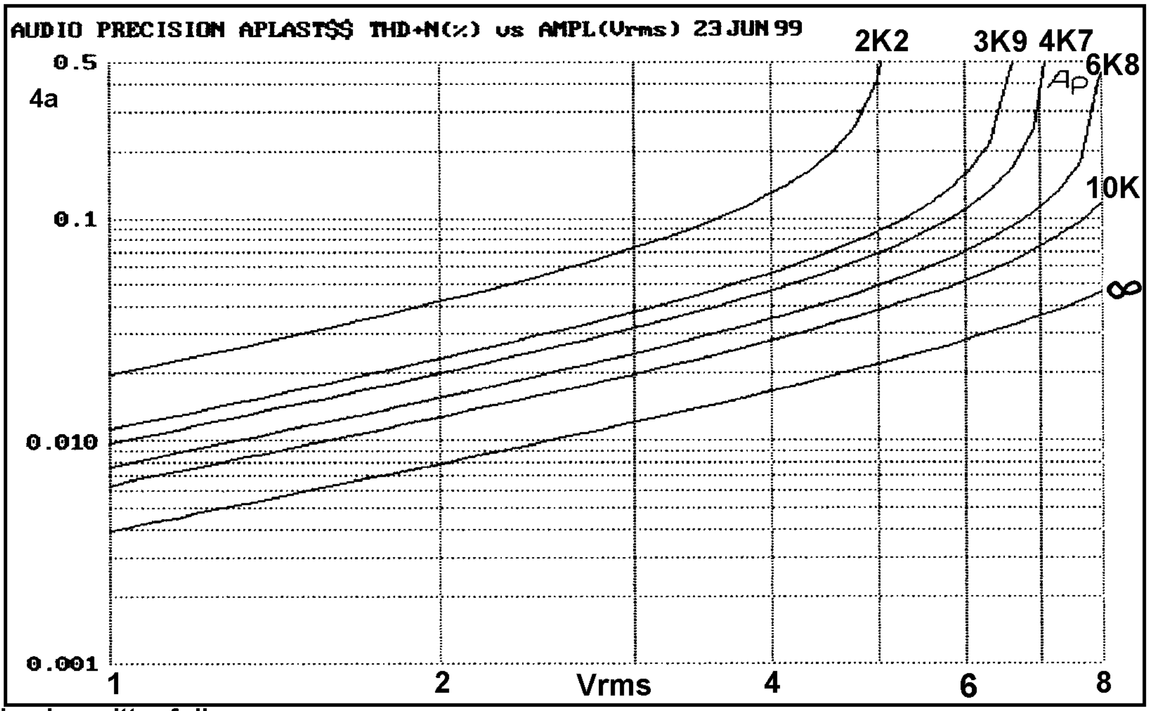


Fig 1: The simple emitter-follower circuit.

The simple emitter-follower has several factors that affect its distortion performance:

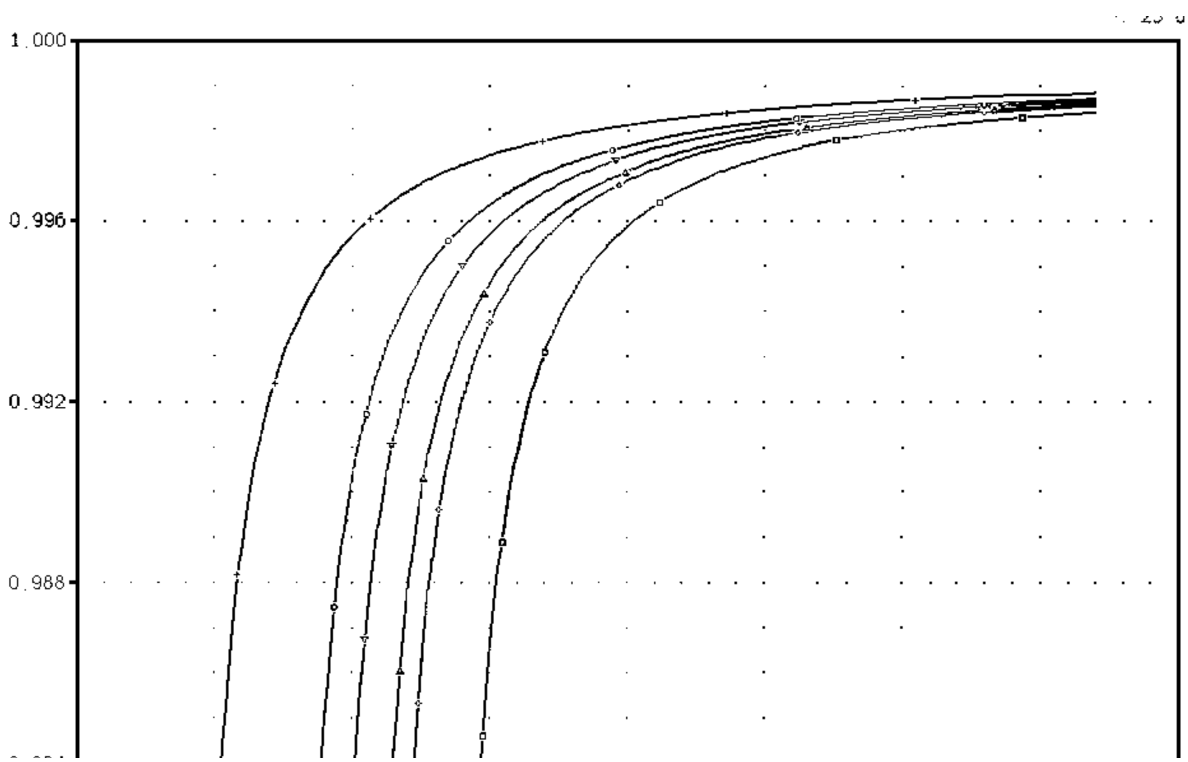
Distortion is reduced as the emitter resistor is reduced, for a given load impedance.
Distortion is reduced as the DC bias level is raised above the mid-point.
Distortion increases as the load impedance is reduced.
Distortion increases monotonically with output level.
Distortion does NOT vary with the beta of the transistor. This statement assumes low-impedance drive, which is often not the case for an emitter-follower.

The distortion generated is mainly second harmonic, except when closely approaching clipping. This is entirely predictable, as the circuit is not symmetrical. Only symmetrical configurations, such as the differential pair, restrict themselves to generating odd harmonics only, and then only when they are carefully balanced. (see power-amp distortion page)
Symmetry is often praised as desirable in an audio circuit, but this is subject to Gershwin's Law: "Ain't necessarily so". Linearity is what we want in a circuit, and symmetry is not necessarily the best way to get it.



Simple emitter-follower

Fig 2 How external loading degrades linearity of the simple emitter- follower.
The distortion is mostly second harmonic, so its level is proportional to amplitude. Distortion (no load) at 2 Vrms is about 0.008%, rising to 0.016% at 4 Vrms; linearity worsens rapidly as the amplitude approaches the clip point.
External loading always makes things worse; THD is more than doubled from 0.029% to 0.070% at 6 Vrms, just by adding a light 6K8 load.
For these tests Re was 2K7, as in Fig 1.



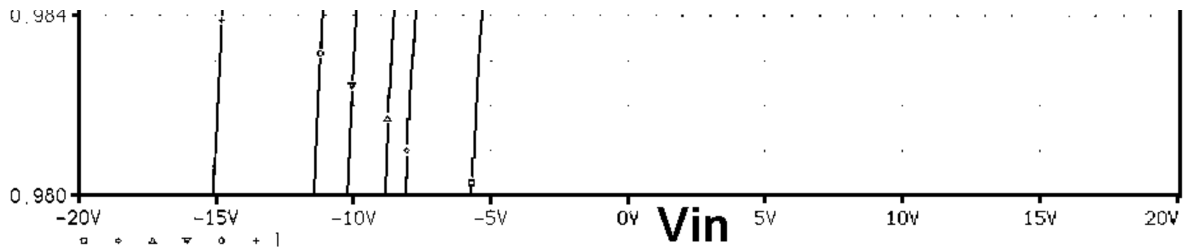


Fig 2a. PSPICE simulation of the circuit in Fig 1, with different loads. The Y-axis shows incremental gain; a distortionless circuit would give a horizontal line.
It can be seen at once that the circuit is more linear on the positive side of 0V, explaining why emitter-followers give less distortion when biased above the mid-point. This trick can be very useful if the full output swing is not required.

The simple emitter-follower can source as much current as the load needs, but its current-sinking capability is limited as the load current must pass through emitter resistor Re, with a resulting voltage drop that causes premature clipping on negative half-cycles.

Most amplifier stages are biased so the quiescent output voltage is at the mid-point of the operating region, to allow the maximum symmetrical voltage swing. However, the asymmetry of the simple emitter-follower's output current-capability means that if there is significant loading, a greater symmetrical output swing is often possible if the stage is biased above the zero point.
If the output is loaded with 2K2, Fig 2 shows that negative clipping occurs at -7.5V, which allows a maximum sinewave amplitude of only 5.3 Vrms. If the bias point is raised from 0V to +5.5V, the maximum is increased to 8.3 Vrms. Compare the unloaded output capability, which is about 12 Vrms.

Fig 3: Biasing the emitter-follower for maximum output swing.

Sorry: Figure 3 not currently available.

THE CONSTANT-CURRENT EMITTER-FOLLOWER.

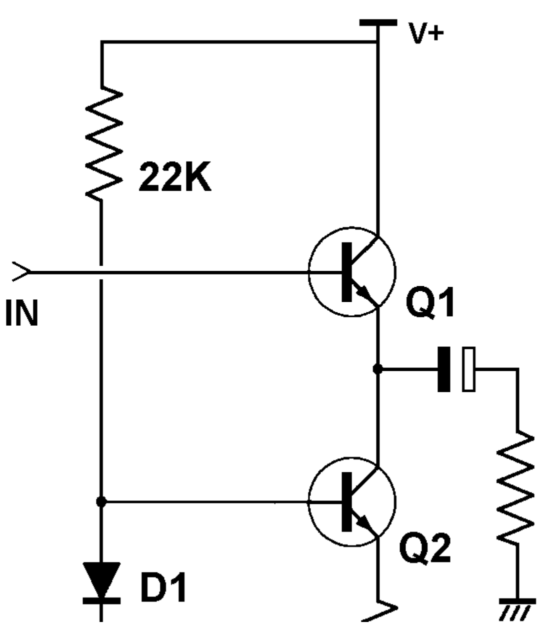
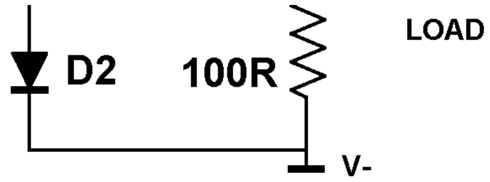
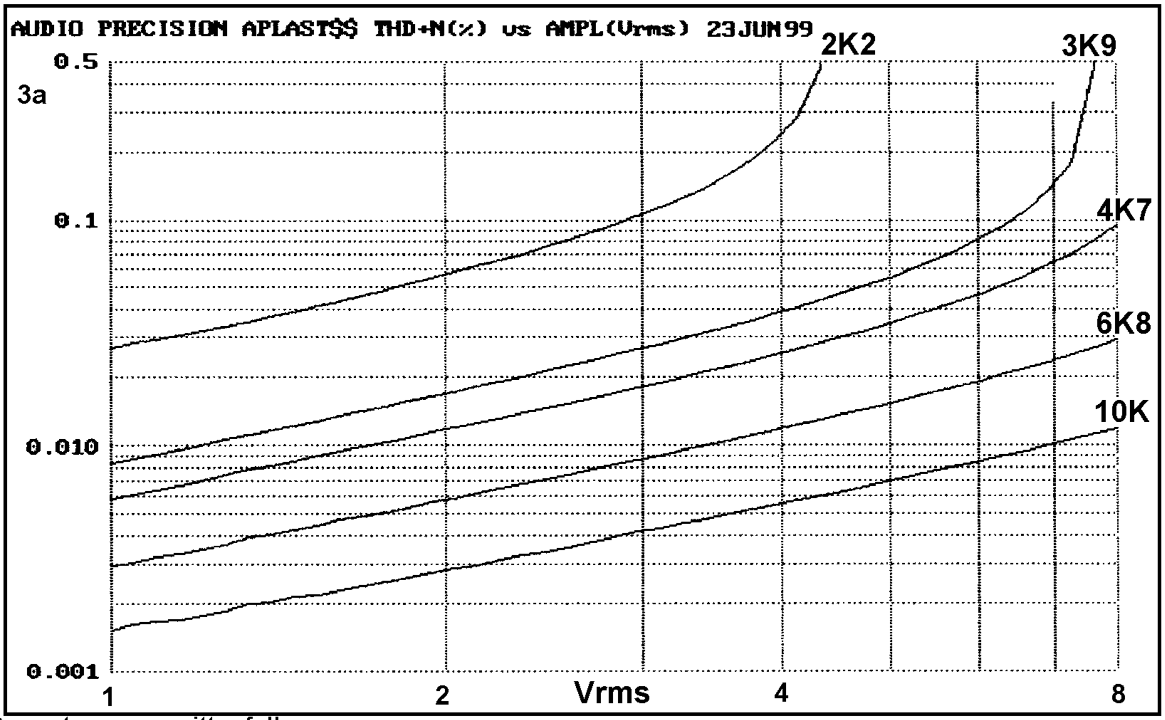


Fig 4 Emitter-follower with constant-current source replacing emitter resistor. (ef2)

The simple emitter-follower can be improved by replacing the sink resistor Re with a constant-current source. The voltage across a current-source does not (to a first approximation) affect the current through it, so if the sink current is large enough a load can be driven to the full voltage swing in both directions.
The current source Q2 is biased by D1,D2. One diode cancels the Vbe drop of Q2, while the other sets up 0.6V across the 100R resistor. This establishes the quiescent current at 6mA. The 22K resistor in turn biases the diodes. It works fine as shown if the supply rails are regulated, but might require filtering if they are not. The 22K value is



non-critical; so long as the current through the diodes exceeds the Ib of Q2 by a reasonable factor (say ten times) there will be no problem.
The linearity of this emitter-follower is still degraded by increasing loading, but to a much lesser extent: see Fig 5 below.



Current-source emitter-follower

Fig 5 How loading degrades linearity of the current-source emitter-follower.
The addition of the current-source means external loading is handled better; THD in the 6 Vrms, 6K8 load condition is reduced from 0.070% to 0.019% at the same quiescent current of 6mA. (3A)

THE PUSH-PULL EMITTER-FOLLOWER.

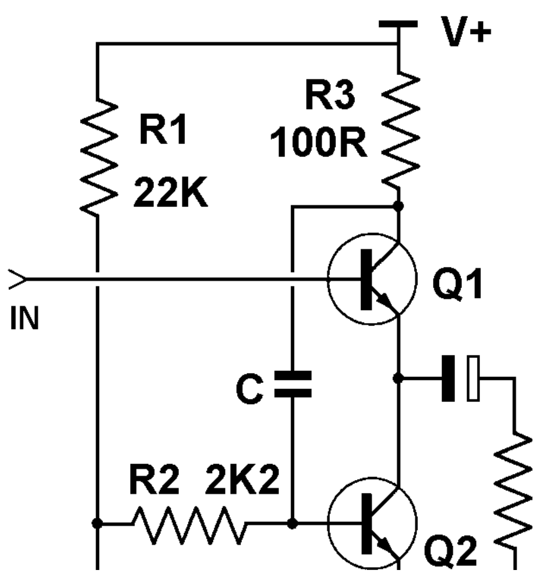
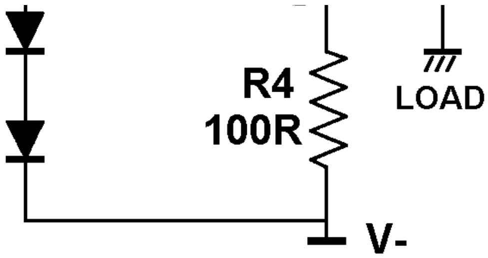


Fig 6 Circuit of push-pull emitter-follower. Quiescent current still 6mA as before, but the load-driving capability is twice as great. (ef3)

This is an extremely useful and trouble-free form of push-pull output; I have used it many times in preamplifiers, mixers, etc. I derived the notion from the valve-technology White cathode-follower, described in a long-ago Wireless World. I'm afraid I have no idea who Mr White was.

When the output is sourcing current, there is a voltage drop through the upper resistor R3, so its lower end goes downwards in voltage. This is coupled to the current-source Q2 through C, and tends to turn it off. Likewise, when the current



through Q1 falls, Q2 is turned on more. This is essentially a negative-feedback loop with an open-loop gain of unity, and so by simple arithmetic the current variations in Q1,Q2 are halved. In other words, this stage can sink twice the current of the constant-constant source version described above, while running at the same quiescent current. The effect of loading on linearity is once again considerably reduced.

Only one resistor and one capacitor have been added to the constant-current version.

This configuration needs fairly clean supply rails to work, as any upper-rail ripple or disturbance is passed directly through C to the current-source, modulating the quiescent current and disrupting the operation of the circuit. A suitable value for C in the circuit as shown is 47uF. Note that the biasing resistor is not shown, to aid clarity.

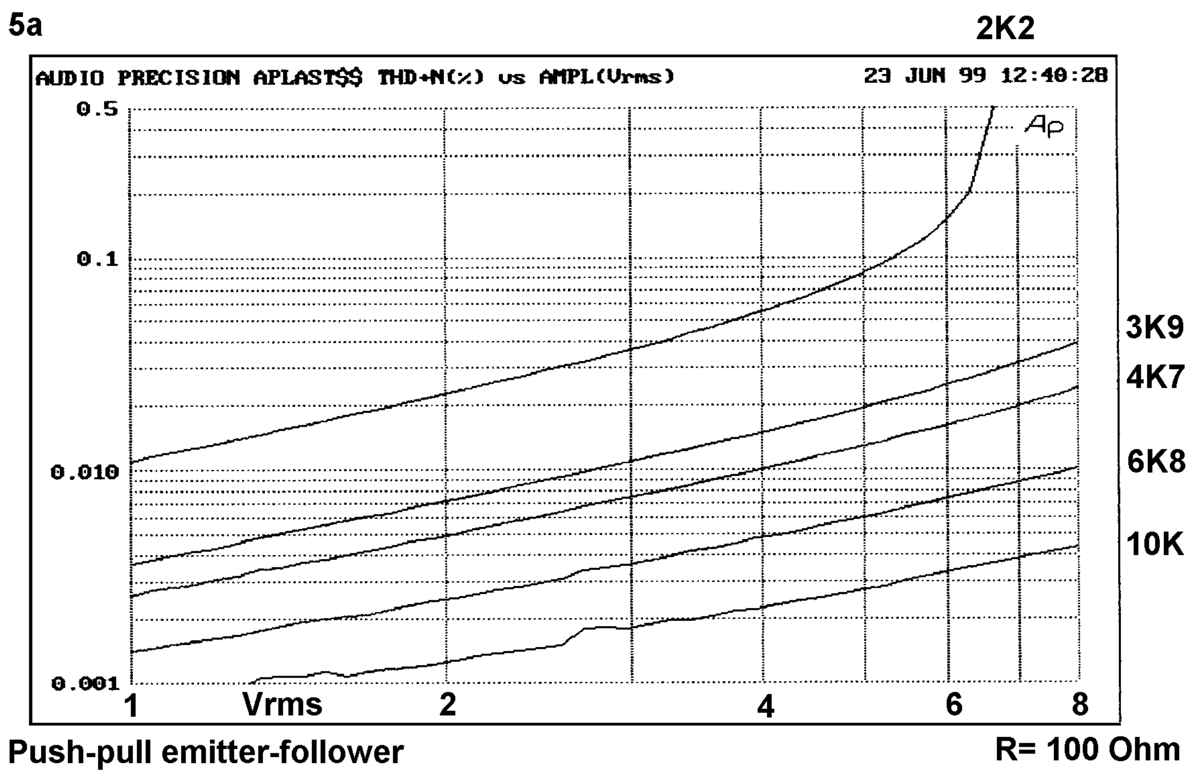


Fig 7 How loading degrades linearity of the pushpull emitter-follower.
Push-pull action further improves the linearity of load driving; THD in the 6 Vrms, 6K8 load condition is reduced from 0.019% to 0.007% at the same quiescent current of 6mA. This is pretty good for such simple circuitry. The quiescent current is still 6mA. (5A)

EMITTER-FOLLOWER STABILITY. *In preparation.*

The emitter-follower is about as simple as an amplifier gets, and it seems highly unlikely that it could suffer from obscure stability problems. However, it can. Emitter-followers are liable to RF oscillation when fed from an inductive source impedances. This oscillation may well be in the VHF region and invisible on the average oscilloscope; however a sure sign is unusually high distortion that varies strongly when the transistor is touched with a probing finger. The standard way to stop this is to put a "base-stopper" resistor in series with the base. This should come after the bias resistor to minimise loss of gain. Depending on the circuit conditions, the

resistor may be as low as 100 Ohms or as high as 2K. The higher values can be an inconvenient source of Johnson noise in low-noise circuitry.

The instability mechanism(s) are not easy to explain quickly. The best source I know for more information on this is a book by Feucht, "The Handbook of Analog Circuit Design" published by Academic Press, 1990.
