Analog Design
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Bipolar Amplifier Design
Part 2
Amplifier Distortion

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Abstract

This paper leads on from paper 1, basic bipolar analog design. It addresses general distortion and signal handling issue of bipolar amplifier design.

The fundamental issue here is that if a basic amplifier has no overall feedback such that its net input voltage is very small, that without an emitter resistor, it is all but useless for the majority of applications!

If you cannot follow the entire math, don't worry, the final answer is very simple.

Distortion

In paper 1 it was stated that the emitter current as a function of base emitter voltage is given by:

$$I_e = I_o e^{\frac{V_{be}}{V_t}} \quad -1$$

Suppose that the input voltage is a small signal superimposed on to a dc bias voltage:

$$V_{\mathrm{be}} = V_{dcbe} + V_p \sin(\omega t) \quad -2$$

Then equation (1) becomes:

$$I_e = I_o e^{\frac{V_{dcbe}+V_p \sin(\omega t)}{V_t}} \quad -3$$

$$I_e = I_o e^{\frac{V_{dcbe}}{V_t}} e^{\frac{V_p \sin(\omega t)}{V_t}}$$

But the first term is just the bias, or emitter, current for a constant Vbe dc bias voltage, hence:

$$I_e = I_{edc} e^{\frac{V_p \sin(\omega t)}{V_t}} \quad -4$$

There are some powerful mathematical techniques for handling this equation, such as by the use of Bessel functions, but a simplified approach will achieve much the same result.

In any basic calculus text it can be shown that the exponential function may be expanded as:

$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + + \ldots \quad -5$$

Therefore 4 can be expanded as:

$$I_e = I_{edc}(1 + \frac{\frac{V_p \sin(\omega t)}{V_t}}{1!} + \frac{\frac{V_p{}^2 \sin^2(\omega t)}{V_t}}{2!} + \frac{\frac{V_p{}^3 \sin^3(\omega t)}{V_t}}{3!} + + \ldots) \quad -6$$

If Vp is small the later terms can be ignored. For simplicity, only terms up to 2nd order are examined in this paper, so that:

$$I_e = I_{edc}(1 + \frac{V_p}{V_t}\sin(\omega t) + \frac{V_p{}^2}{2V_t^2}\sin^2(\omega t)) \quad -7$$

using the trig identify:

$$\sin^2(x) = \frac{1}{2}(1 - \cos(2x))$$

Equation (7) can be expressed as:

$$I_e = I_{edc}(1 + \frac{V_p}{V_t}\sin(\omega t) + \frac{V_p{}^2}{4V_t^2}(1 - \cos(2\omega t))$$

$$I_e = I_{edc}((1 + \frac{V_p{}^2}{2V_t^2}) + \frac{V_p}{V_t}\sin(\omega t) - \frac{V_p{}^2}{4V_t^2}\cos(2\omega t)) \quad -8$$

Since by assumption, Vp is small, i.e. Vp < 25mV,, it can be seen that the first term represents a very small increase in the static bias current. The 2nd term is the main signal term, and the last term represents a 2nd harmonic distortion term. The ratio of the 2nd harmonic to fundamental is given by:

$$D2 = \frac{D2^{nd}}{1^{st}} = -\frac{\frac{V_p{}^2}{2V_t^2}}{\frac{V_p}{V_t}} = \frac{V_p{}^2}{4V_t^2}\frac{V_t}{V_p}$$

$$D2 = \frac{V_p}{4V_t} \quad -9$$

Sticking in Vt = 25mV and letting Vp be in mv and converting to % gets:

$$D2 = \frac{V_p(mv)}{4 \times 25mv} \times 100\%$$

$$D2 = V_p(mv)\% \quad \text{-10}$$

So, there you have it. The 2nd harmonic distortion is equal to the input signal in mv. So a 1mv signal will generate 1% distortion, at least! 10mV giving 10% distortion is about your limit if the output is to resemble the input at all.

Reducing Distortion

The simplest way to reduce this distortion is to insert an emitter resistor. This does two things. It reduces the signal to the base emitter junction, and it also generates negative feedback. Negative feedback reduces distortion itself, and is addressed in another paper, only the result will be used here.

In paper 1 it was shown that the signal to the base emitter is given by a potential divider effect as:

$$V_{be} = \frac{r_e}{r_e + R_e}$$

The effect of negative feedback can also be shown to reduce the distortion by this same factor, hence the emitter resistor circuit distortion is given by:

$$D2 = V_p\left(\frac{r_e}{r_e + R_e}\right)^2$$

When expressed relative to the same input voltage. However, to obtain the same output voltage as was the case without feedback, the input must be increased by the attenuation factor, resulting in the principal of

$D2 = V_p\left(\frac{r_e}{r_e + R_e}\right)$ as the real effective distortion. This is covered in more detail in

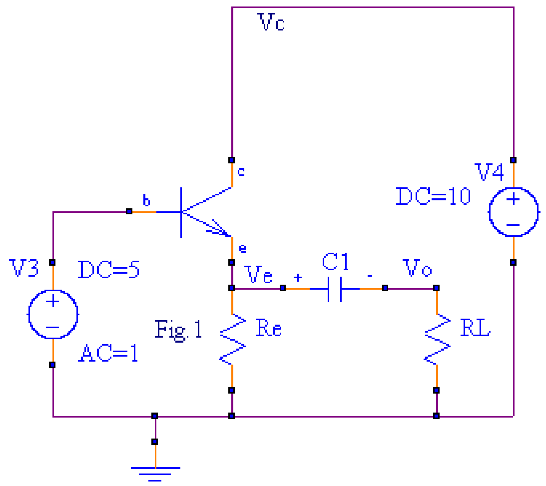
[DistortionFeedback.xht]

An example shows the improvement. Say the emitter resistor is 1k, at a bias current of 1ma so that re is 25 ohms, then D2 for an input of 1V or 1000mv would be = 0.595%.

This is a very large improvement. A disadvantage is that the emitter resistor adds noise.

Emitter follower clipping

Fig. 1



It was shown in paper 1 that the emitter follower has a low output resistance re. Whilst this is indeed the case, it can lead to the erroneous idea that an ac coupled emitter follower can drive a low load resistor. This is not the case for large signals, as will be explained here.

Suppose the emitter current is 5ma such that re is then 5ohms. If a load is hen placed at Vo in Fig.1 of 100 ohms, then the output voltage should drop by a ratio of (Re/(Re + re)) or 100/105. For small signals this is still the case. However for large signals the negative half cycle will be clipped as follows:

The bias voltage at Ve, in Fig.1 will be at around 4.3V. This means that C1 will be charged to 4.3V. For 5ma, Re will be 4.3/5m = 860 ohms. If the input signal swings say, 1V negative from the bias point, C1 will have to supply this negative load current via Re. However, the maximum current available can only be the voltage stored on C1 divided by Re, which in this case is 5ma. This current across a load resistor of 100 ohm is only 0.5 volts. Therefore, the output will clip at this value.

Summary

The 2nd harmonic distortion of a simple bipolar amplifier is given by:

$$D2 = V_p(mv)\%$$

The 2nd harmonic distortion of a simple bipolar amplifier with an emitter resistor is given by:

$$D2 = V_p\left(\frac{r_e}{r_e + R_e}\right)^2$$ Relative to input and

$$D2 = V_p\left(\frac{r_e}{r_e + R_e}\right)$$ Relative to same output level

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