distortion meter

The distortion in factory-produced or home-made amplifiers is frequently unknown; designers sometimes give specifications, but these are not always reliable. Since distortion meters are usually expensive, Elektor Laboratories have developed a simple, inexpensive, but effective instrument.

Low frequency pre- and power-amplifiers always produce some distortion. The various kinds are distinguished as follows:

Linear distortion - the departure from a flat amplitude-frequency response curve. An amplifier which is flat within 1 dB from 20-20000 Hz has less linear distortion than another which only does this within the band from 100-8000 Hz.

Intermodulation distortion - when two or more frequencies are fed simultaneously into the amplifier and it produces 'sum and difference' components.

Harmonic distortion. This is real 'visible' distortion; if the input was a sinewave the output signal is definitely 'something else'. The output signal can then be shown to consist of the original sinewave (possible amplified), plus several overtones or harmonics. The ratio of the unwanted components to the total output signal gives the distortion percentage. This measurement can be made with the distortion meter described below.

Design considerations

A distortion percentage of 0.01% means that the fundamental in the output signal is virtually ten thousand times greater than the distortion. Therefore, if the distortion is to be measured the fundamental will have to be attenuated more than 10000 times. This is 80 dB! At the same time, the first overtone (second harmonic) must remain unaffected. This requires an exceedingly sharp filter.

For normal low frequency work it must be possible to measure distortion in the frequency range 100 Hz to 10 kHz. The filter will therefore have to be tunable through this band.

Transistorised power amplifiers frequently produce spikes in the waveform at the zero-crossings as well as the normal distortion components. These spikes can be as short as 10 µs or even less, implying the presence of frequencies in excess of 100 kHz.

After the fundamental has been suppressed the distortion product then appears as in figure 1. The spikes in this trace have an amplitude 1% of the total output! To enable these spikes to be measured the distortion meter will have to pass the high frequencies involved unattenuated. A passband to 500 kHz is therefore by no means an unnecessary refinement.

For a distortion measurement according to DIN standards, the RMS value of the unwanted products - corresponding to their average power-contribution - is what must be determined. This requires an integrating meter. However, since the human ear responds to the amplitude rather than to the power of a signal, a peak-level detector is what is really needed. This will often show a completely different (much 'worse') result!

An example of this is given in figure 2.

Figure 2a is a trace of the distortion product from a reasonably good power amplifier. The RMS and the peak measurements give the same result - 0.18% distortion.

Figure 2b shows the distortion product from a similar amplifier. Along with 'ordinary' distortion however, this one also produces sharp spikes. The two measurement procedures now lead to totally different results: the RMS meter indicates a distortion increase to 0.21% (0.03% more than before). The peak meter on the other hand now indicates 0.95% distortion - an increase of about 0.75%! The latter value is a more accurate indication of the subjective increase of the distortion. Clearly, a universal instrument will have to be able to carry out both procedures.

Finally, the measurement must be unaffected by hum and noise (which can be identified on the 'scope', but may cause a misleading reading on the pointer instrument). The design will therefore include hum and noise filters which can be switched out of circuit.

The filter

The design chosen for the rejection-filter is an unusual one. When two signals having the same frequency, amplitude and phase are presented to the inputs of a good differential amplifier, the output signal is zero. The signals are blocked. The block diagram of a rejection filter can therefore be as shown in figure 3.

The input signal is first passed to a phase splitter (paraphase amplifier, with equal-and-opposite outputs). One of these output signals, the one which is 180° out of phase with the input signal, is applied directly to one input of the differential amplifier. The other output of the phase splitter is in phase with the input signal; it is passed to a phase shifter. This section imposes a phase rotation which, depending on the frequency, lies somewhere between 0° and 360°. For one single frequency (f_O) this shift will be precisely 180°. The output of the phase shifter is now applied to the other input of the differential amplifier. For an incoming signal of frequency precisely f_O which will therefore be rotated exactly 180°, the output of the differential amplifier will disappear - the signal will be rejected. For every other frequency the output signal will be unequal to zero.

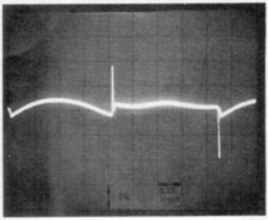
The final step is to provide the required sharpness of the characteristic by means of overall negative feedback.

The great advantage of this arrangement is that it does not require trimming, while at the same time it can be tuned over the entire working range using one stereo-potentiometer. The accuracy of tracking of the two halves of this potentiometer is completely unimportant.

Circuit of the filter

The filter circuit is given in figure 4. The transistors T_1 and T_2 form the phase splitter. The in-phase output signal is developed across R_5, so that the circuit has heavy internal negative voltage feedback like that of an emitter follower (but much heavier in this case). The anti-phase output signal appears over R_4. This circuit is far better-behaved than any single-transistor arrangement and is used at all important points in this design.

The phase shifter is built up around T_3 to T_6. It is actually a cascade of two simple phase shifters, each of which imposes a rotation between 0° and 180°. The frequency for which the total rotation



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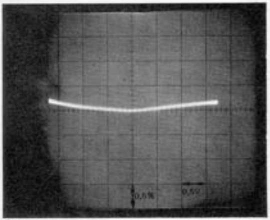

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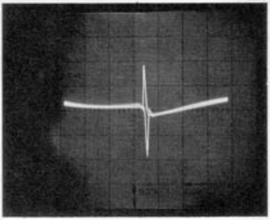

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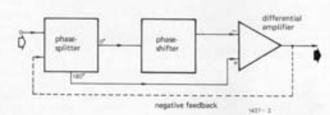

Figure 1. Distortion products from a transistorised power amplifier, viewed after the fundamental has been suppressed.
The fundamental frequency was in this case 1 kHz, the calibration 0.5% per division. The amplitude of the spikes is therefore 1% of that of the fundamental.

Figure 2. Contribution of the spikes to the distortion-percentage according to the DIN standard. Both measurements were done identically:
The X-input is connected to the output of the sinewave generator (frequency 1 kHz); the Y-input is connected to the output of the distortion measuring circuit. The vertical sensitivity of the oscilloscope is set to correspond with 0.5% distortion per division.

Figure 2a shows a trace without spikes; the distortion according to the DIN standard is 0.18%.

Figure 2b shows a trace that does include spikes; the DIN-measurement yields a distortion percentage of 0.21%.

Figure 3. Block diagram of the fundamental suppressing filter used in the distortion meter.

Figure 4. The circuit diagram of the filter. P_1 and S_1 enable calibration of the sensitivity (total signal must read 100%). P_2 and P_3 provide coarse and fine adjustment respectively of the rejection-frequency. P_4 and P_5 provide coarse and fine adjustments of the amplitude balance (maximum rejection). The capacitors C_2 and C_3 must have a high thermal stability.

Figure 5. Circuit of the hum and noise filters and of the x10/x100 amplifier.

amounts to exactly 180°, is f_0. This frequency is adjusted by means of P_{2a} and P_{2b}. A fine adjustment is provided by P_3. The capacitors C_2 and C_3 should have low thermal coefficients.

The switches S_{1a} and S_{1b} enable the circuit to be calibrated, in combination with P_1. When these switches are open the phase shift is 0° for all frequencies; the filter action is defeated and the input sensitivity can therefore be set correctly.

T_9 to T_{13} form the differential amplifier. The impedances in the circuit have been kept low so that it will also behave well at high frequencies. The inverted (180°) signal from the phase splitter reaches the plus-input via R_{15} and P_5. The output of the phase shifter is taken from P_4 and applied to the minus-input. These two signals must have precisely equal amplitudes at f_0 in order to cancel. This can be coarsely and finely adjusted using P_4 and P_5.

The potentiometer P_6 is a preset control for adjusting the DC balance of the differential amplifier, since this depends on the properties of the individual transistors. Set the DC levels at points A and B to be equal (about 4 volts). This is the only trimming point in the whole filter. Overall negative feedback is applied via R_{22}, R_{23} and R_2.

Hum and noise filters

The circuit of these filters is shown in figure 5. They are active filters, containing RC networks in their input, output and feedback paths. The turnover is fairly sharp and the rollof slope is more than 12 dB/octave.

The hum filter is built around T_{15} and can be switched into circuit with S_2. The cut off starts near 250 Hz, the response being more than 20 dB down at 50 Hz.

The noise filter (T_{16}) is switched in by S_3 or S_4 and cuts off at 20 or 200 kHz respectively. Bear in mind that this filter will also suppress any spikes more or less completely. Figure 5 also includes a voltage amplifier (IC_1). This will boost the output signal by 10 or 100, so that a multi-meter can directly indicate distortion at 10% or even 1% fsd. A disadvantage here is that the response of the IC - at a gain of 100 - already starts to roll off at about 20 kHz, so that the output contribution from the waveform spikes is lost.

How to use the meter

Measurements are taken with the equipment arranged as shown in figure 6. The sinewave generator must have very low distortion. We hope to publish a good cheap design shortly.

The measurement procedure is as follows: Set S_1 to 'calibrate'. Switch all filters and the x10/x100 amplifier out of circuit. Adjust P_1 until the meter reading is 1 V; this is equivalent to a distortion of 100%. Set S_1 to 'measure'. Adjust P_2 and P_4 alternately to obtain a minimum reading. S_5 can be set to 'x10' or 'x100' as may be required for a useful deflection. When the adjustment of P_2 and P_4 becomes too

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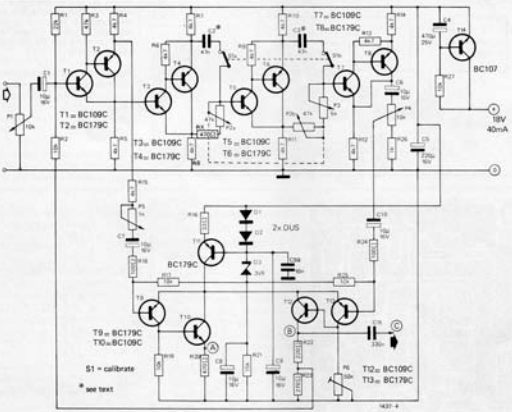

Parts list for the figures 4 and 5.

Capacitors:
C_1 = 10 µ/16 V
C_2,C_3 = 47 n
C_4 = 470 µ/2.5 V
C_5 = 220 µ/16 V
C_6 . . . C_{10} = 10 µ/16 V
C_{11} = 330 n
C_{12} = 6n8
C_{13} = 27 n
C_{14} = 330 n
C_{15} = 3n9
C_{16} = 390
C_{17} = 18 n
C_{18} = 1n8
C_{19} = 47n
C_{20} = 4n7
C_{21} . . . C_{24} = 10 µ/16 V
C_{25} = 10 n

Semiconductors:
T_1,T_3,T_5,T_7,T_{10},T_{12},T_{15},T_{16} = BC 109C
T_2,T_4,T_6,T_8,T_9,T_{11},T_{13} = BC 179C
T_{14} = BC 107
IC_1 = µA 741

Switches:
S_1 = 2x break
S_2 = 1x changeover
S_3 = 3x make
S_4 = 3x make
S_5 = 2x changeover
S_6 = 1x changeover

Resistors:
R_1 = 22 k
R_2 = 10 k
R_3 = 47 k
R_4 . . . R_{15} = 4k7
R_{16} = 33 Ω
R_{17},R_{19},R_{25} = 10 k
R_{18},R_{24} = 100 Ω
R_{20} = 470 Ω
R_{21} = 15 k
R_{22} = 220 Ω
R_{23} = 270 Ω
R_{26} = 1 k
R_{27} = 10 k
R_{28} = 68 k
R_{29},R_{30} = 47 k
R_{31} = 4k7
R_{32} = 15 k
R_{33} = 8k2
R_{34} = 5k6
R_{35} = 560 Ω
R_{36},R_{37} = 220 Ω
R_{38},R_{39} = 47 k
R_{40} = 10 k
R_{41} = 120 k
R_{42} = 1 M
P_1 = 10 k (lin)
P_2 = 2x47k (stereo, log)
P_3 = 5 k (lin)
P_4 = 10 k (lin)
P_5 = 1 k (lin)
P_6 = 50 k (trim, lin)

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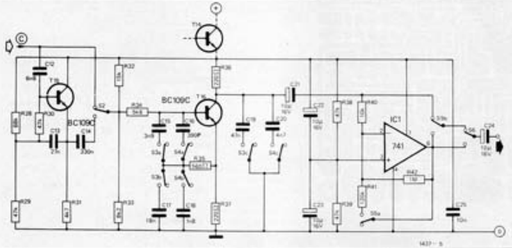

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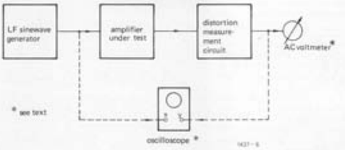

Figure 6. Block diagram of the set-up for distortion measurement. The distortion-measuring circuit is described in this article. It is intended to publish designs for both the sinewave generator and the AC (milli) voltmeter in the near future.

Figure 7. Printed circuit board and component layout for the distortion measuring circuit.

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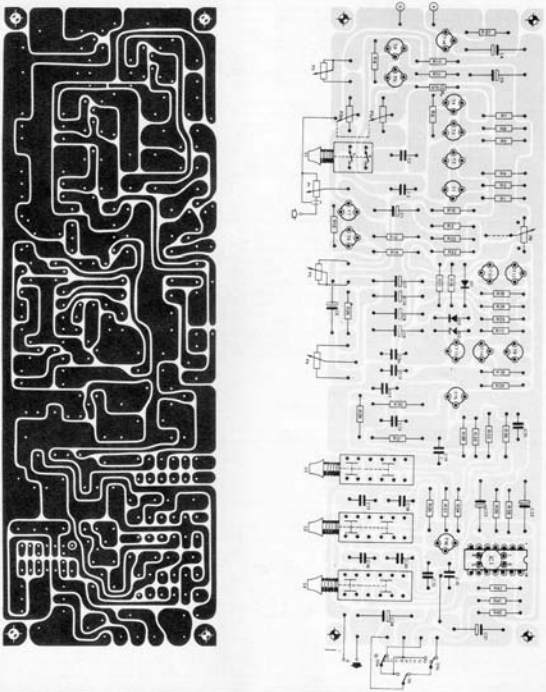

critical, continue fine adjustments with P_3 and P_5. As soon as the minimum output has been found the distortion can be read directly. Just how this is done will depend on the indicating instrument used. If this instrument is a typical multi-meter, the normal harmonic distortion can be read with reasonable accuracy. The 'x100' position of S_5 then corresponds to an fsd of 1% distortion. The contribution of waveform spikes will be lost, while there is no quarantee of the accuracy of the meter at higher frequencies.

A more accurate result can be obtained if a good AC millivoltmeter is available. Set S_5 in this case to 'x1', otherwise the integrated amplifier with its early rolloff will be in circuit.

Both of these methods have the objection that the indicating instrument integrates, so that its reading corresponds to the RMS value of the distortion.

The amplitude of the distortion products can be measured using an oscilloscope. Connect this as shown in figure 6. The original signal from the sinewave generator is applied to the X-input and the output from the distortion measuring circuit (at 'x1' gain!) is applied to the Y-input. The trace will now be of the kind shown in figure 2.

Set the 100% level, during calibration, to indicate 3 volts peak-to-peak. 3 mV in the trace now corresponds to 0.1% distortion-amplitude.

It may be possible to improve the readability of the trace by using the hum or noise reduction filters. Remember, however, that the noise filters will also suppress any spikes.

Finally, a very good indicating instrument is an AC millivoltmeter that can be switched to operate as an RMS or as a peak detector. Beware of instruments that use a peak detector but have a scale calibration reading 0.707x the peak value - they only read the RMS level of a pure sinewave. The meters required here use some kind of square-law detector RMS value of the distortion.

level). With such an instrument distortion can be read either according to the DIN standard or as a 'genuine' distortion-percentage.