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ON CLIPPED-DIGITAL PROCESSING TECHNIQUES

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1. Introduction

The great majority of signal sensors or transducers give analogue outputs. When feeding digital processing systems, a stage must be included where the signals are changed to digital form. Decisions have to be made as to the number of levels in which to quantise the signal amplitudes, the cost of the hardware being roughly proportional to the number chosen. A related operation which can give rise to significant difficulties is that of signal normalisation; if the number of amplitude levels is small, a higher performance may well be required of the normalisation system than is perhaps usual with analogue systems.

Infinite clipping of a signal waveform, where only the polarity information is retained, is a very widely used technique. Its convenience is obvious, but it is only by considering the alternative schemes of normalising, encoding, etc that the true extent of the hardware and system simplifications become apparent.

Although the operation of an infinite clipper has been the subject of an extensive theoretical investigation, starting with the classic paper of Van Vleck (ref.1) and continuing to the present day, it is fair to say that there remain areas which are as yet ill-understood. This paper is based on some recent work at AUWE whose object was to gain an overall insight into the mechanisms underlying clipper-normalisation, and to investigate the rules governing the amplitude-suppression suffered by small signals in the presence of large signals or noise. The emphasis here will be on the results which have emerged rather than on the analysis itself.

2. LINEAR & CAPTURED clipped systems

Ref.2 has argued the case for dividing clipped systems into two separate categories, LINEAR & CAPTURED, according to the S/N ratio at the clipper input. Briefly, the suggestion was as follows:

In CAPTURED clipped systems the input S/N ratio must always be maintained above some minimum or threshold value, usually in excess of 0dB. The correct operation of such systems requires the wanted signal to capture the phase of the clipper output square-wave, so that the clipper is performing what is essentially a maximum-component selection operation. A familiar example of a system using a clipper in its CAPTURED mode is frequency-modulated communication. The Digital Sonar System developed at Birmingham University also falls into this category.

In LINEAR clipped systems the S/N ratio at the clipper input must never exceed an upper limit of about -6dB. Under these small-signal conditions, it is known that the clipper output components are linearly related to their inputs and that a normalisation process similar to that of a fast a.g.c. amplifier is present. Examples of LINEAR clipped systems are polarity-coincidence correlators, and the shift-register beamformers used in the DIMUS technique.

Whereas the above paper dealt principally with CAPTURED clipped systems, this note will be concerned with the mechanisms behind the role played by the clipper in its LINEAR mode.

3. The Operation of an Infinite Clipper in its LINEAR mode

In its LINEAR mode, a clipper can be regarded as a device having a constant output power which it "shares out" amongst its inputs, according to their relative strengths. The approach adopted here will be to examine the rules governing this energy partition for the simple narrowband case of only two tones at the clipper input. By exploiting the narrow-band restriction, the analysis is then extended to cover one tone plus noise. Although the analysis treats only the narrow-band case the results are in good agreement with those measured using a clipped replica correlator under broadband conditions. Since the principal aim is to gain some insight into the mechanisms at work, the emphasis here will be on the interpretation of the results.

TWO TONES AT CLIPPER INPUT: Fig.1 illustrates the case where an infinite clipper has a sinusoid f_A at its input together with a weaker sinusoid at a slightly different frequency f_B. The output is seen to be a squarewave of repetition rate f_A; the presence of the weaker f_B input is seen to impart only a phase-modulation or phase-jitter onto this output, whose magnitude is dependent only upon the relative A and B input amplitudes. The diagram shows that the mean clipper output of 1 volt r.m.s. is not altered by this jitter. Its main effect is to divert some of the power from the f_A output to produce an output component at f_B.

Fig.2 shows an arrangement which could be used to investigate how the clipper output components at f_A and f_B vary as a function the relative A and B input amplitudes. These components are measured after selection by suitable filters, for various values of input amplitude ratios. In the event, the outputs were evaluated by analysis on a computer. Briefly, the f_A component is found by correlating the output squarewave with a sinewave of frequency f_A

$$A_o = \frac{1}{T_r} \int_o^{T_r} S_q(t).\ \sin(w_A t)dt. \qquad \ldots\ldots\ldots \qquad (1)$$

where T_r is a suitable interval containing an integral number of cycles of f_A and f_B.

It is possible to write

$$A_o = k\ \{ 1-2\cos(w_A T_1) + 2\cos(w_A T_2) - \qquad \ldots\ldots\ldots\ \} \qquad (2)$$

where T_1, T_2, ... T_r are the instants where the square wave crosses the axis. Finally, A_o becomes

$$A_o = k \{ 1 + 2 \cos \phi_1 + 2 \cos \phi_2 + \ldots\ldots + \cos\phi_r \} \quad \ldots \quad (3)$$

The narrow band restriction can now be exploited to evaluate the ϕ_r terms using simple phasor geometry.

Fig.3 shows the results for the above analysis. The 0dB of the output scale is the value attained by one component when the other is absent. That the outputs should cross when input f_A = input f_B is not surprising, although it is somewhat unexpected that this output level should be at -4dB rather than -3dB.

There are three main points which can be made from the curves in fig.3:-

(a) The absolute levels of the output components are dependent only on the relative input levels. This transition from relative to absolute levels is of course to normalise.

(b) With the 2-tone case shown, the weaker tone has suffered an amplitude suppression relative to the stronger, in passing through the clipper. For example when B is -2dB down on A at the input, its output is -5.4dB down on output A. This relative suppression of weak signals can reach a maximum of -6dB.

(c) For small input levels, say B/A always less than -3dB or so, the transfer characteristics of the clipper are approximately linear with respect to these signals, i.e. a 2dB change in input B produces a similar change in output B. It is this property which has made it possible for an overall system to be linear (if noisy) whilst containing a grossly non-linear clipper.

ONE TONE IN NOISE: Narrow band gaussian noise can be regarded as a sinewave whose amplitude (and phase) vary slowly. For the purposes of calculating the suppression which it would exert upon a small signal, the noise can be replaced by a series of constant amplitude sinewaves, the amplitudes of the series following the envelope (Rayleigh) distribution. The above results can then be used to find the small signal output level for each member of this series, and the average signal output level found by averaging those of the individual series members. When this is done for gaussian noise, the small signal suppression is found to be assymptotic to only 1.1dB, compared to 6dB for masking by a constant amplitude sinewave of the same average power. A figure of 1.1dB is close to that generally accepted as being the loss in gain of a clipped replica correlator compared to a full analogue correlator.

The fact that the degree of amplitude suppression suffered by a small signal is dependent on the amplitude statistics of the dominant component at the clipper input is not too surprising; in the extreme, a waveform made up of a widely spaced series of large impulses could have any required power yet exert virtually no suppression upon the other inputs. In general it is seen that

$$\text{Small signal suppression} \propto \frac{1}{\text{masking waveform "peakiness"}}$$

SUMMARY: The mechanisms underlying the signal processing function of a clipper operating in its LINEAR mode have been investigated for the narrow band case. From a consideration of how the fixed clipper output power is shared between two input tones, an approximate model for the processing function has emerged: the clipper can be regarded as an a.g.c. amplifier whose gain is controlled by the largest input component, and whose response is quite linear - except with respect to this largest component. The latter is given a "bonus" depending upon its amplitude statistics, and can range from just over +1dB for gaussian noise to as much as +6dB for a constant amplitude sinusoid.

These deductions are in good agreement with measured behaviour, even without the narrowband restriction.

Acknowledgements

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References

1. "Threshold Signals", Lawson & Uhlenbeck, Dover Publications.

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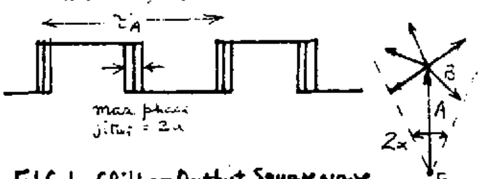

FIG 1 Clipper Output Squarewave

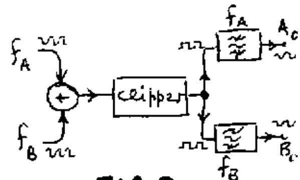

FIG 2

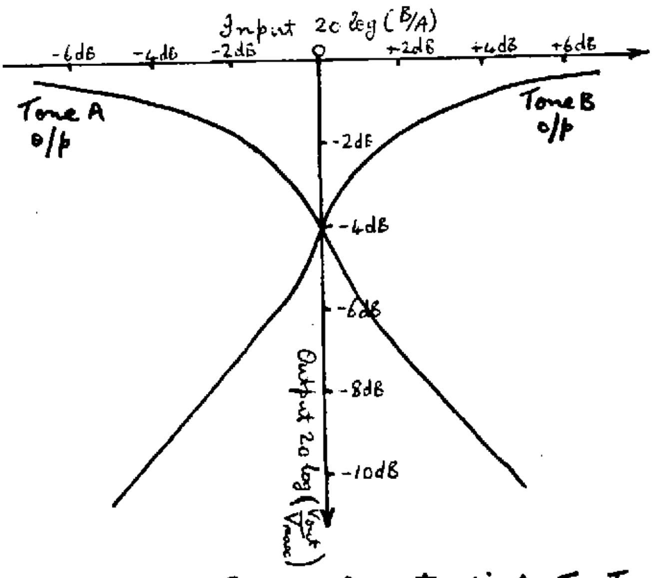

FIG 3 Clipper Transfer Characteristics for Two Tone Case