Slewing Induced Distortion: Part 2b

Phase II: Two-tone Intermodulation Distortion Tests for SID

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FIG. II-1

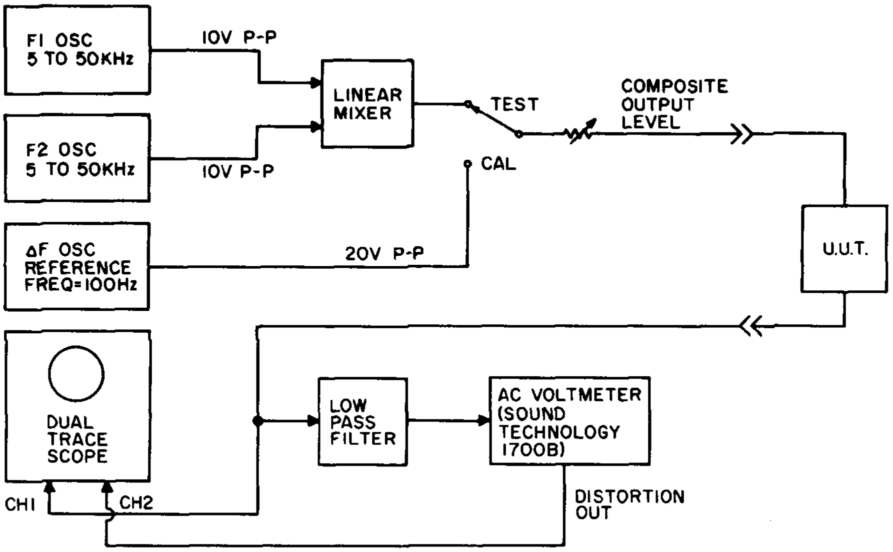


Fig.II-1: Block diagram , two-tone IM test setup.

THE TWO TONE, 1:1 high frequency IM tests (hereafter referred to simply as IM tests) were performed on some, but not all, the IC op amps tested in the Phase I THD tests. One main objective at the outset was to determine whether or not a clearly demonstrable correlation exists between slew rate and two tone IM tests; and also between the IM and THD data.

Once this objective was met, I tested more selectively, generally those devices which had proved superior in THD tests, with data of certain units selected to illustrate the pattern. Overall the results correlate quite well, as devices which perform well in THD tests also do well in IM tests. I discovered many subtleties during the tests, however, which provide further information and food for thought.

Our IM test set was especially assembled for this study, and can most honestly be described as a breadboard. We spent considerable time, however, in ensuring that the measurements were reasonably valid and repeatable. A self-calibration feature was built into the test setup as a means of guaranteeing this, and a fair degree of effort expended with the lash-up in minimizing noise and spurious error sources. Although a breadboard, the setup does allow repeatable measurements, and consistent results. Therefore, while the test setup may lack some desirable features (mainly from the standpoint of convenience) it does yield results which are valid in my estimation.

The test setup consists of the equipment shown in Fig.II-1. Some of this is standard lab equipment, but a fair portion was built specifically for the task. In basic concept, the two tone HF IM test linearly mixes two sine wave sources with a close frequency spacing, and applies the composite signal to the U.U.T. (unit under test). The U.U.T. output will contain (ideally) only the original two tones, and no intermodulation products. If IM is present in the test device, it will appear as sum and difference frequencies. In the case here we are interested in the difference frequency only, which was maintained (for convenience, mostly) at 100Hz.

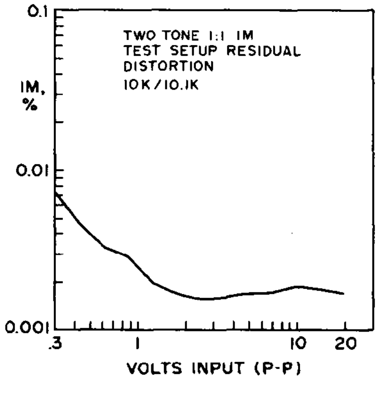
A low pass filter with sufficient HF rejection can be used to separate the original tones from the IM components, and the resultant IM measured rather simply with an AC voltmeter (suitably calibrated).

Factors critical to the success of this method are the mixing stage, which (if active) must not generate any IM of its own. The low pass filter must have a very sharp cutoff between the Δf frequency and the *lowest* two tone frequency used, otherwise the leakage of the tones through the filter will contaminate the readings as residual IM.

In the test setup here, a four-pole Chebyshev filter design was used with a rejection of $\geq$80dB at 5kHz, allowing a basic limiting resolution of 0.01% at 5kHz and greater above. Shielding, screening, and appropriate grounding must also be used to eliminate hum and other noise components as contamination sources. Finally, both the f1 and f2 oscillators must be very clean in terms of hum and low frequency disturbances within the passband of the LP filter.

Before taking any readings, I did various tests to demonstrate a minimum of errors due to the above factors. In summary, our test set can be demonstrated as free of residual IM to the extent of at least 0.01% (or less), at levels as low as 100mV RMS at 10kHz (worst case). This factor is shown by the residual distortion plot of Fig.II-2.

FIG. II-2



Operation of the test set is relatively simple. The two tones f1 and f2 are manually set to the desired frequencies, and the resulting envelope adjusted (by trimming either f1 or f2) for the desired Δf repetition rate. Both f1 and f2 levels are 10V p-p. When mixed this yields a 20V p-p composite waveform. This can be scaled downward as desired, by the COMPOSITE OUTPUT LEVEL. The Δf reference oscillator is also set to a 20V p-p level, and the output can be switched between either Δf, or f1+f2.

For calibration, the Δf oscillator is fed through the U.U.T. and the low pass filter, which has unity gain at 100Hz. By monitoring the output of the U.U.T. with the scope, its drive is then adjusted for the desired p-p output @ the Δf frequency. Simultaneously, the AC voltmeter is adjusted for a 100% full scale reading. To read 80dB below 100mV RMS, a high resolution voltmeter is required; in the test set here the Sound Technology 1700B was used for metering and the f1 oscillator.

With a 100% reference level at 100Hz established through the U.U.T. and filters, the setup is calibrated and now ready for an IM tests. We accomplish this by switching to the f1-f2 source, and increasing the voltmeter sensitivity until we obtain a reading. At the same time, the DISTORTION OUT signal is monitored to observe the IM. The level of the IM is read in either dB or as % of full scale, with the 100% reference level being the 20V p-p (or lower, as adjusted) f1+f2 signal.

The U.U.T. is operated again here in a unity gain inverter with (unless otherwise noted) unity gain compensation. The test circuit is a duplicate of Fig.I-4 (page 9).

Test Results

As I mentioned, one of my first IM testing goals was to establish a correlation between slew rate and the resulting IM, as I did in the THD tests. Fig. II-3 is one test which served as the first indicator of this.

Here two previously tested op amps were selected for an identical bandwidth but with close to a *10/1 difference in* slew rate. One is a 741 which slewed at 0.5V/µS, the other the AD540 which slewed at 5.7V/µS. The results are quite dramatic, indicating that the higher slew rate device generates almost negligible amounts of IM at either 10 or 20 kHz, over the range of levels shown.

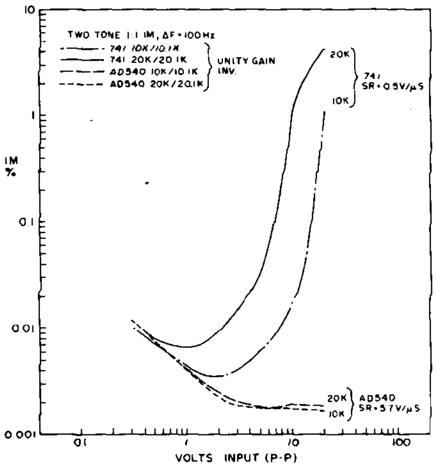
In distinct contrast, the 741 generates large amounts of IM at either 10 or 20kHz, particularly at high levels. The 20kHz curve is higher in level for a given frequency, or, viewed another way, for a given percentage of distortion the level difference between 20 and 10kHz is a factor of two. This same sort of pattern is generated in the THD tests, indicating a relationship to the output voltage rate of change, or slew rate. It is not surprising that the 741 performs poorly in this test, but what is interesting is the apparent close relation of IM percentage to the voltage rate of change as presented by the two tone IM signal.

Our next test was a similar sort at 20kHz, on a device with adjustable slew rate, the 2720. Fig.II-4 plots the results of this test for output levels of 100mV to 7V RMS (±10V) of output. At a low slew rate setting a great deal of IM is generated, but it decreases progressively for greater slew rates. These curves are apparently similar (or would be if complete), with equidistant spacings, but since the lower two cannot be traced completely to dynamic range limitations, a different sort of measurement perspective is needed, one which stresses the device's voltage rate-of-change tracking fidelity more completely.

Fig.II-5 shows the same device in a different form of IM test, full output level (±10V), with a frequency sweep of 5 to 50kHz. With this form of data the performance relationships become more evident. Here the 0.5V/µS and 1.6V/µS curves are virtually identical in shape and separated in frequency (at the 1% distortion level) by a factor consistent with the ratio of the slew rates. The 5V/µS curve appears to start on the same trajectory, but is limited by the upper sweep frequency limit of 50kHz. In the data range which is present, its form also resembles the 1.6V/µS curve.

Now we are able to make an extremely interesting observation, if we compare these data with the 2720's THD data (Fig.I-17b, p.13), as we notice the family of curves are quite similar in shape. If we take the 1.6V/µS curves as similar condition *examples*, we can see that not only are they similar in general shape, but the data points *almost coincide*, with the IM data being slightly less sensitive. With this information, the correlation seems to be established without major reservations.

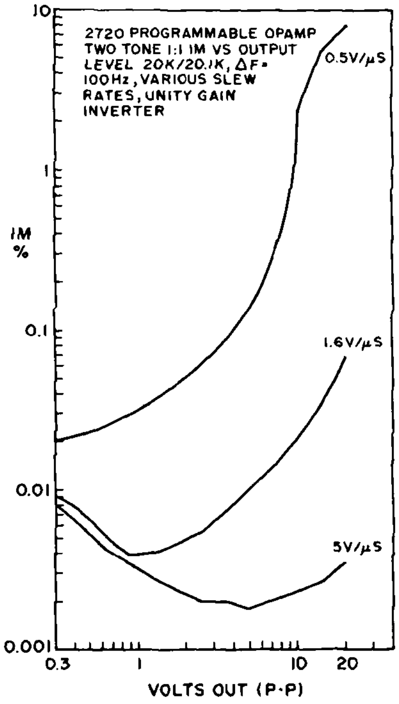
FIG. II-3



If the data do support the IM/THD correlation, is it possible for us to rank amplifiers by slew rate in terms of IM? In fact, we can do so, within reasonable limits, as Fig.II-6 shows. These data, which are also swept IM from 5k to 50k at full voltage output, begin with the 0.5V/µS 741 for reference. If it was not apparent from the slew rate data, perhaps these IM data will establish that a low slew rate device such as this is simply not adequate for high (or even moderate) quality use.

Next in performance comes the 4136 sample, which slews at 1V/µS. Although it is a different device from the 741, the 1% IM frequency intercept is roughly twice that of a 741, or the ratio of slew rates. Lower down on this curve we can note that the 1V/µS 4136 curve is roughly similar to the 535 slew enhanced device, indicating that the 535 would possibly slew in the 1V/µS range were it unenhanced. In other respects, the 535 data cannot be compared directly or ranked by its slew rate.

FIG. II - 4



Next in terms of performance is a 2V/µS 709 which is very closely paralleled but somewhat bettered by a 2.5V/µS 1456. Again (for the 709) the 1% intercept is four to five times that of the 741, roughly the ratio of slew rates.

Going further, we see the 356, the asymmetric slewing device. Close to it but definitely superior in this instance is a x100 comp 709, which slews at 6.7V/µS. Here is a case which clearly reiterates the necessity of symmetrical slewing, as the 709 is operating with 40dB less feedback, but generates less IM. An even better demonstration is the 8007 which slews at 3.6V/µS, but is far superior to the 356 in IM performance.

Between the 536 and the AD540 we have an anomaly as far as slew rate ranking is concerned, but as you may recall, the 536 behaved somewhat peculiarly in one regard in its THD list. The AD540 is a quite attractive unit, with less than 0.005% IM all the way out to 50kHz. Also interesting is the slew enhanced 531 @ x10 comp, which again emphasizes the value of high natural slew rate.

The lowest extremity of the curves is the residual distortion level of the test setup, over the 5k-50kHz range. Below 10kHz, as may be noted, the leakage through the filter becomes the limit of performance measurement for most of the devices, so comparisons in this range should be taken with a grain of salt.

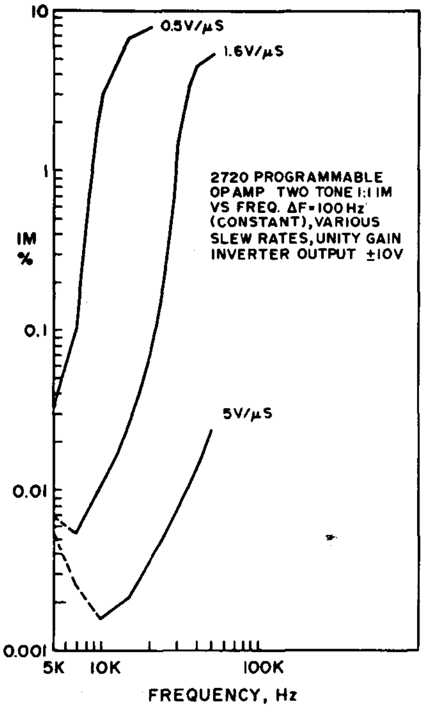
Above 10kHz, the residual is less than 0.002% and, as is noted, a great number of devices simply sat down in this area in terms of IM: namely, the 318, 1034, 2620, OP-01, 301A (FF), 2525, 3140, and TL084. However, THD tests separated most of these devices in terms of performance, although admittedly their differences are of a somewhat subtle nature. This indicates that of the two tests THD is the more strenuous and demanding of a device, and will serve as a more complete indicator of ultimate performance, at least between the types of tests as performed here.

The IM tests would perhaps be more complete and revealing if continued to 100kHz, and with resolution extended below 10kHz. I hope such equipment improvements can be made within the near future. However, the overall data indicate the THD tests to be more sensitive, and definite (similar) patterns emerge from both tests.

As I mentioned, performance of several devices could generally be predicted from slew rate alone. The TL084, for instance, was observed to slew very symmetrically, and at 7V/µS. With the device's 3MHz bandwidth, this is almost a sure guarantee of good IM performance, as in fact it did indeed turn out. I hazarded a similar observation on the OP-01 prior to tests, on the basis of its slew rate and bandwidth: my prediction was borne out by performance measurement.

Ideally, if a strong correlation is established between slew rate and THD/IM test results, it might be possible to predict qualitatively a given device's performance just by oscilloscope observation of its slewing behavior. This obviously simplifies testing and proves

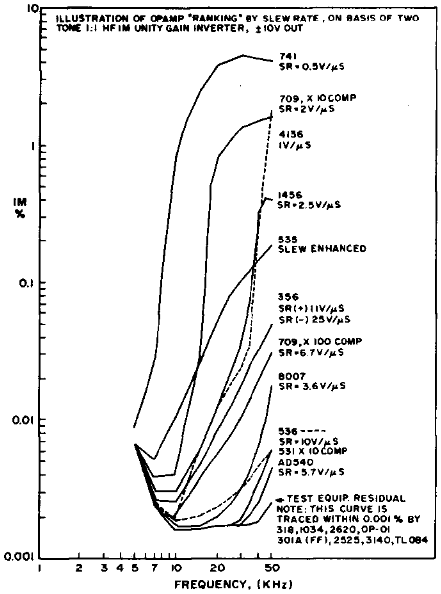
FIG. II-5



true on the TL084 and the OP-01.

Unfortunately, however, this procedural assumption could be dangerous for at least two reasons. One is the behavior

FIG. II-6



of slew enhanced devices which, as we saw, appear to be superlative in slew rate terms, but are less than superior in THD/IM tests. Reason two is simply one of prudence and/or conservativism.

It is unwise to make all-inclusive statements such as, "If it slews fast and symmetrically, it will measure well." While I observed this to be true in about 90% of the cases tested, I also saw exceptions. These may or may not be slew rate related, but since they are yet undefined they cannot be ignored.

In general, however, it can be stated that an amplifier which slews fast and symmetrically will be a good performer, and as such will eliminate the major sources of SID. Since this form of distortion has been shown to be overwhelmingly predominant in most IC op amps, it can hardly be argued that a fast and symmetrically slewing device is *not* a significant improvement.

As a final argument for the rigor and completeness of the THD and IM tests, we found other forms of distortion in several devices, although they were admittedly small by comparison. A device could be entirely free of SID, for instance, and yet have non-linearities in its output stage. These would never show up by doing an analysis of slew rate and bandwidth, but could easily place a limit on the device's ultimate performance.

More than one example of such an IC op amp exists, and I measured some in this study but deleted them from the discussion for such reasons. But you'd never discover such anomalies without making the measurements, and this is but one way in which those of us searching for the truth can be fooled.

Next time we'll move to Phase III, testing for SID by the TIM method.

Please turn to page 36 for the references for this segment.