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Frequency multiplication

This topic examines the process of frequency multiplication employing techniques outlined in an article by Stanislaw Alechno in Applied Microwave and Wireless (March 2000).

The frequency multiplication process can be applied to both narrow band and wideband sources.

Narrowband sources could include crystal oscillators or direct digital synthesisers. Applications for narrow band very high purity requirements are found in design and development reference oscillators, production test equipment, specialist narrow band transmitter/receiver applications and communication satellite downconverters.

Wideband applications would include the multiplication of wide range low frequency sources applied to upconverting transmitters (base stations), test equipment and swept frequency calibration sources.

The topic is the result of having had the requirement, for RF test purposes, to design low noise, VHF and UHF frequency sources.

In this example, a voltage controlled crystal oscillator is analysed (although as stated wideband multiplication can also be performed).

As is frequently the case, commercially available products either did not quite fulfill a target specification, or are too expensive for the particular application. As a result most requirements are fulfilled by the process of thinking of an approach, sketching a circuit, CAD modelling, prototyping, disappointment, re-iteration, success (eventually) then production, i.e. a classical design process.

To fulfill a low noise requirement, VCXO's (voltage controlled crystal oscillators) and multipliers, interspaced with amplifiers and filters are frequently used. The multipliers (for low order) are usually of the classic class AB or Class C stages using discretes or MMICs with tuned outputs.

The designs are difficult to model and success is only achieved by a large amount of empirical (or 'suck it and see') work. However, results are usually acceptable and use low cost components. The downside comes at product test/set-up when multiple stages have to be carefully tuned to maintain an acceptable efficiency, or an acceptable inefficiency!

It was therefore interesting to read Stanislaw Alechno's article on 'The Operation of Low-Order RF Frequency Multipliers' and to test its approach to a practical design. The prime parameters of interest (beside the frequency output!) were those of

spurious content, efficiency and the effect on phase noise. Repeatability and stability of performance over temperature were also required.

What follows are notes on an implementation of a multiplier process using Stanislaws suggested approach and the findings and consequent modification of the approach to produce the required results.

The circuits in the article are referred to as triplers and the quality of the output is shown to depend on the 'idealness' of a 1:1 mark space ratio being applied to a subsequent harmonic filter. This approach enables the 'non-production' of even order products. The article then outlines a 'close to ideal' method of waveform production using a flip-flop. This indeed, using the ACT family, yields very low even order products but has the effect of dividing the input by two. Considering the input to output frequency the overall process should be defined as a 'one and a halfer'. As the frequent objective of the multiplier process is to obtain outputs that are several times the input, a greater number of 'one and a halfer' stages would be required than triplers (and a different band plan). Accordingly a method of obtaining 1:1 ratios direct from sine waves was investigated. The investigation examined both methods and the resulting qualities of waveform squarers, and the influence input waveform quality has on the output. In order to make a valid comparison, the same filter (with appropriate matching) was used in each case.

Again, as the article points out, the performance of flip flops, D types etc becomes a limiting factor as frequencies towards 100 MHz are reached. It is possible to construct higher frequency flip flops from individual gates but a simpler solution to the problem of avoiding even order products at high frequencies was needed.

The investigation was restricted to odd order functions because, as implied in the original article, successful (high performance) even order functions (doublers, quadruplers, etc) are a function of the quality of construction of phasing transformers, diode matching etc. These components are more cost effectively purchased than constructed on the equipment assembly line.

In order to reduce the overall number of stages to a minimum, the design started with as high a frequency as possible.

Using a crystal oscillator as the source, it could either be run in overtone mode or alternatively a harmonic of the fundamental could be picked off (tuned) at the output. As a reasonably large pulling range was required from the oscillator the crystal was not excited in overtone mode. The approach was therefore to run the crystal at it's fundamental frequency and tune for the second harmonic at the output of the oscillator. As the article demonstrates, the good suppression of even order products comes from the attainment of a perfect 1:1 mark space ratio.

The 'doubled' output from the oscillator was then applied to a 74ACT74 to produce the required square wave output. The output (Q) of the D type flip flop was then filtered in line with the method described in the article.

The results obtained gave a suppression of F2 and F4 of approximately -30 dB,

somewhat less than the -75/-78 dB measured in the article.

Further investigation showed that as indicated, the output of the D type contained significant even order product.

Following the signal back to the oscillator/D type interface showed that the problem was occurring because of the difference in amplitude between alternate cycles of the input waveform, ie the presence of the fundamental (half) frequency in the waveform. This gave rise to alternate cycle triggering threshold differences of the D type and hence the repetitive variation in square wave output.

To obtain the figures of -75/-78 dB down (after the filter) required a very pure input waveform to the D type. Providing a greater amount of filtering at this point defeated the object of simplicity.

The option of achieving a direct 'squaring' process from simple gates was considered.

The first approach was to use a NAND (ACT00) gate and as the article points out it is necessary to control the triggering very carefully to achieve satisfactory results. The 'trigger' point is both a function of the AC input and a DC bias applied to the input. The article suggests a high level (~3V) of pure drive with a DC bias adjusted to minimise the F2 and F4 products. This approach did indeed produce the desired output but only over a narrow (+/-15 degree) temperature range. Resetting of the DC was required outside this range in order to re-establish the required performance.

Again, in order to maintain simplicity (ie minimum cost and minimum setting up) a method was tried that has proved successful in the past in similar situations.

The squaring device was replaced with an AC04 - a buffered HEX inverter. The AC was used in preference to an ACT device as the adopted method allowed establishment of linearisation through self biasing.

Self biasing was achieved by using a simple feedback of a 1 meg ohm resistor on a single gate. Two further gates were then connected in series in order to further square up the wave form before filtering.

The configuration represents a high input impedance and so can be simply connected through a low value capacitor to a relatively high Q (hence pure) point in the oscillator output. The F2 F4 suppression, although not reaching the -75/-78 level was better than 50 dB after filtering and maintained this level over -20 to +50 degrees.

The consequent output of this process was a 60 MHz signal derived from a 20 MHz crystal running in fundamental mode. The harmonic suppression was better than -50 dBc over the range -20 to +50 degrees with a frequency pulling range determined by the characteristics of the crystal in fundamental mode.

Next month's **Hot Topic** will consider low cost phase noise measurement techniques.

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