= Staggered tuning =

Staggered tuning is a technique used in the design of multi @-@ stage tuned amplifiers whereby each stage is tuned to a slightly different frequency . In comparison to synchronous tuning (where each stage is tuned identically) it produces a wider bandwidth at the expense of reduced gain . It also produces a sharper transition from the passband to the stopband . Both staggered tuning and synchronous tuning circuits are easier to tune and manufacture than many other filter types .

The function of stagger @-@ tuned circuits can be expressed as a rational function and hence they can be designed to any of the major filter responses such as Butterworth and Chebyshev . The poles of the circuit are easy to manipulate to achieve the desired response because of the amplifier buffering between stages .

Applications include television IF amplifiers (mostly 20th century receivers) and wireless LAN .

= = Rationale = =

Staggered tuning improves the bandwidth of a multi @-@ stage tuned amplifier at the expense of the overall gain . Staggered tuning also increases the steepness of passband skirts and hence improves selectivity .

The value of staggered tuning is best explained by first looking at the shortcomings of tuning every stage identically . This method is called synchronous tuning . Each stage of the amplifier will reduce the bandwidth . In an amplifier with multiple identical stages , the 3 dB points of the response after the first stage will become the 6 dB points of the second stage . Each successive stage will add a further 3 dB to what was the band edge of the first stage . Thus the 3 dB bandwidth becomes progressively narrower with each additional stage .

As an example , a four @-@ stage amplifier will have its 3 dB points at the 0 @.@ 75 dB points of an individual stage . The fractional bandwidth of an LC circuit is given by ,

<formula>

where m is the power ratio of the power at resonance to that at the band edge frequency (equal to 2 for the 3 dB point and 1 @.@ 19 for the 0 @.@ 75 dB point) and Q is the quality factor .

The bandwidth is thus reduced by a factor of <formula> . In terms of the number of stages <formula> . Thus , the four stage synchronously tuned amplifier will have a bandwidth of only 19 % of a single stage . Even in a two @-@ stage amplifier the bandwidth is reduced to 41 % of the original . Staggered tuning allows the bandwidth to be widened at the expense of overall gain . The overall gain is reduced because when any one stage is at resonance (and thus maximum gain) the others are not , unlike synchronous tuning where all stages are at maximum gain at the same frequency . A two @-@ stage stagger @-@ tuned amplifier will have a gain 3 dB less than a synchronously tuned amplifier .

Even in a design that is intended to be synchronously tuned , some staggered tuning effect is inevitable because of the practical impossibility of keeping all tuned circuits perfectly in step and because of feedback effects . This can be a problem in very narrow band applications where essentially only one spot frequency is of interest , such as a local oscillator feed or a wave trap . The overall gain of a synchronously tuned amplifier will always be less than the theoretical maximum because of this .

Both synchronously tuned and stagger @-@ tuned schemes have a number of advantages over schemes that place all the tuning components in a single aggregated filter circuit separate from the amplifier such as ladder networks or coupled resonators . One advantage is that they are easy to tune . Each resonator is buffered from the others by the amplifier stages so have little effect on each other . The resonators in aggregated circuits , on the other hand , will all interact with each other , particularly their nearest neighbours . Another advantage is that the components need not be close to ideal . Every LC resonator is directly working into a resistor which lowers the Q anyway so any losses in the L and C components can be absorbed into this resistor in the design . Aggregated designs usually require high Q resonators . Also , stagger @-@ tuned circuits have resonator components with values that are quite close to each other and in synchronously tuned circuits they can be identical . The spread of component values is thus less in stagger @-@ tuned circuits than in aggregated circuits .

= = Design = =

Tuned amplifiers such as the one illustrated at the beginning of this article can be more generically depicted as a chain of transconductance amplifiers each loaded with a tuned circuit .
where for each stage (omitting the suffixes)
gm is the amplifier transconductance
C is the tuned circuit capacitance
L is the tuned circuit inductance
G is the sum of the amplifier output conductance and the input conductance of the next amplifier .

= = = Stage gain = = =

The gain A (s) , of one stage of this amplifier is given by ;
<formula>
where s is the complex frequency operator .
This can be written in a more generic form , that is , not assuming that the resonators are the LC type , with the following substitutions ,
<formula> (the resonant frequency)
<formula> (the gain at resonance)
<formula> (the stage quality factor)
Resulting in ,
<formula>

= = = Stage bandwidth = = =

The gain expression can be given as a function of (angular) frequency by making the substitution s = i? where i is the imaginary unit and ? is the angular frequency
<formula>
The frequency at the band edges , ?c , can be found from this expression by equating the value of the gain at the band edge to the magnitude of the expression ,
<formula>
where m is defined as above and equal to two if the 3 dB points are desired .
Solving this for ?c and taking the difference between the two positive solutions finds the bandwidth ?? ,
<formula>
and the fractional bandwidth B ,
<formula>

= = = Overall response = = =

The overall response of the amplifier is given by the product of the individual stages ,
<formula>
It is desirable to be able to design the filter from a standard low @-@ pass prototype filter of the required specification . Frequently , a smooth Butterworth response will be chosen but other polynomial functions can be used that allow ripple in the response . A popular choice for a polynomial with ripple is the Chebyshev response for its steep skirt . For the purpose of transformation , the stage gain expression can be rewritten in the more suggestive form ,
<formula>
This can be transformed into a low @-@ pass prototype filter with the transform
<formula>

where ? 'c is the cutoff frequency of the low @-@ pass prototype .

This can be done straightforwardly for the complete filter in the case of synchronously tuned amplifiers where every stage has the same ?0 but for a stagger @-@ tuned amplifier there is no simple analytical solution to the transform . Stagger @-@ tuned designs can be approached instead by calculating the poles of a low @-@ pass prototype of the desired form (e.g. Butterworth) and then transforming those poles to a band @-@ pass response . The poles so calculated can then be used to define the tuned circuits of the individual stages .

= = = Poles = = =

The stage gain can be rewritten in terms of the poles by factorising the denominator ;

<formula>

where p , p * are a complex conjugate pair of poles

and the overall response is ,

<formula>

where the ak = A0k?0k / Q0k

From the band @-@ pass to low @-@ pass transform given above , an expression can be found for the poles in terms of the poles of the low @-@ pass prototype , qk ,

<formula>

where ?0B is the desired band @-@ pass centre frequency and Qeff is the effective Q of the overall circuit .

Each pole in the prototype transforms to a complex conjugate pair of poles in the band @-@ pass and corresponds to one stage of the amplifier . This expression is greatly simplified if the cutoff frequency of the prototype , ? 'c , is set to the final filter bandwidth ?0B / Qeff .

<formula>

In the case of a narrowband design ?0 ? q which can be used to make a further simplification with the approximation ,

<formula>

These poles can be inserted into the stage gain expression in terms of poles . By comparing with the stage gain expression in terms of component values , those component values can then be calculated .

= = Applications = =

Staggered tuning is of most benefit in wideband applications . It was formerly commonly used in television receiver IF amplifiers . However , SAW filters are more likely to be used in that role nowadays . Staggered tuning has advantages in VLSI for radio applications such as wireless LAN . The low spread of component values make it much easier to implement in integrated circuits than traditional ladder networks .