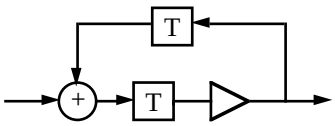
7.3 In this case we have: $T_{min} = \frac{1}{2}(T_{add} + T_{mult})$. The critical path is $T_{add} + T_{mult}$. In order to reach the maximal sample rate we will have to either use interleaving or pipelining.

a) **Unit time processors**

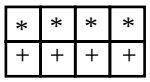
Here we assume that $T_{add} = T_{mult} = 1$ t.u. The minimal sample period, T_{min} is 1 t.u. and the critical path 2 t.u.

Pipelining

After pipelining the critical path is split in two sections of equal length. We can start a new addition and a new multiplication in each sample interval. The schedule for processors is shown below.
We will need only one processor of each type and their degree of utilization is 100%.



Pipelined filter.



Schedule for pipelined filter.

Interleaving

Interleaving of resources must be done if the critical path (adder — multiplier) is indivisible. We will have to start a new set of addition-multiplication every sample period. The schedule for processors is shown in the figure to the right.
Now, we need two adders and two multipliers. More processors are needed since the processing is sequential. Further, their degree of utilization is only 50%.

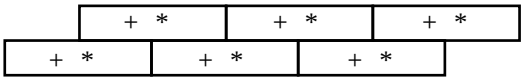
Schedule using interleaving of resources.

b) **Non unit time processors**

Now, assume that $T_{mult} = 3\ T_{add}$ and $T_{add} = 1$ t.u. The minimal sample period will be $T_{min} = 4/2 = 2$ t.u. and the critical path 4 t.u.

Interleaving

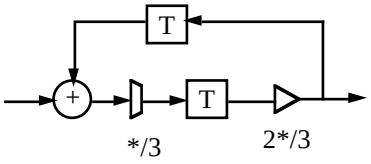
If the adder and the multiplier are indivisible we will have the schedule shown below. We need two processors of each type which will be utilized to 25% and 75%, respectively.



Schedule using interleaving of resources.

Pipelining

If we pipeline, the critical path will have to be split in two parts of length 2. This is assuming that the multiplier can be split into two parts. The pipelined filter is shown to the right while the operation schedule for this is shown below.



Pipelined filter with multiplier split into two parts. The first part has an execution time of 1/3 while the second has an execution time of 2/3 of a complete multiplication.

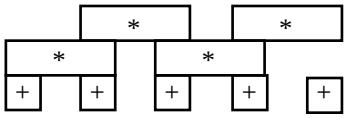
2*/3	2*/3	2*/3	2*/3
+*/3	+*/3	+*/3	+*/3

Schedule for filter with multiplier split into two parts.

Here we have one processor performing +*/3 and one 2*/3. They are both used 100% of the time.

Pipelining and interleaving

In many cases we can not divide a processor in two parts. If we do not divide the multiplier but still pipeline as much as possible, i.e., move one delay element so that the critical path is split into one 1 t.u. section and one 3 t.u. section, we get the schedule shown below. Here we have, one adder which is utilized to 50% and two multipliers utilized 75% each.



Schedule for not fully pipelined filter

Conclusions

It is desirable to have equal processor execution times. Pipelining will improve the processor utilization.