BANDPASS SAMPLING FOR SOFTWARE RADIO

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ABSTRACT

The design of a software radio is based on two simple design goals. First, the analog-to-digital and digital-to-analog converters should be placed as near the antenna as possible, in the chain of RF front-end components. Second, the resulting samples should be processed on a reconfigurable digital domain via digital signal processors or field programmable gate arrays. One way to achieve this is by direct downconversion of the desired RF signal band(s) to baseband frequency using bandpass sampling. This significantly relaxes the requirement on the analog-to-digital converter sampling rate, as the required sampling frequency depends on the signal bandwidth, rather than on the highest frequency component. This leads to reduced requirement of the associated signal processing capability and power consumption. The bandpass sampling theory for a single RF signal band is well developed in literature, however, its counterpart for two or more RF signal bands is relatively immature. The traditional approach for this case have been to bandpass sample a continuous span of spectrum containing all the desired RF signals. The disadvantage with this approach is that the required sampling rate depends upon the span of spectrum, which is ($f_{u2}-f_{l1}$) for two signal bands, with the assumption that the second signal band (f_{l2}, f_{u2}) residing at higher frequencies than the first signal band (f_{l1}, f_{u1}). However, for two signal bands, the theoretical lower limit of valid bandpass sampling frequency is given by $2(B_1 + B_2)$. Now, for two narrowband signals residing far apart from each other in frequency domain, the value of ($f_{u2} - f_{l1}$) may be quite larger than that of $2(B_1 + B_2)$. Hence, the challenge lies in the determination of a valid sampling frequency, closest to $2(B_1 + B_2)$, that will translate all bandpass signals into the sampled bandwidth without causing aliasing, neither the aliasing of a signal onto its own nor into another.
In this paper, we present an algorithm to determine the *minimum* bandpass sampling frequency for direct downconversion of two distinct RF signals. The four basic steps are as follows: (1) select the initial sampling frequency as $f_s = 2(B_1 + B_2)$, (2) check out whether any integer multiple of the chosen $f_s/2$ falls within any of these two bands, if *yes*, then increase the sampling frequency by _f_s and repeat this step, *otherwise* move on to next step, (3) perform bandpass sampling operation of both the bands, with the chosen sampling frequency of step 2, and (4) check out whether the bands overlap over each other in the sampled bandwidth ($0 - f_s/2$), if *yes*, then again increase the sampling frequency by _f_s and go back to step 2, *otherwise* the chosen sampling frequency represents one of the valid sampling frequency for direct downconversion of two RF signals. The efficiency of this algorithm is solely dependent on the value of _f_s that needs to be chosen in step 2 and 4. In general, we can choose a fixed value of _f_s, i.e., increase

the sampling frequency from $2(B_1 + B_2)$ to Nyquist rate uniformly. But then two possibilities can arise, either we may miss the *minimum* sampling frequency, when the value of $\_f_s$ is a large one, or we may get the *minimum* sampling frequency after a large number of iterations, when the value of $\_f_s$ is quite small. Hence, we try to avoid this uniform incremental procedure. Instead, at each iteration, we formulate the required increment $\_f_s$ as a function of the band specifications (f_{l1}, f_{u1}), (f_{l2}, f_{u2}), and the chosen value of f_s at that iteration. Therefore the novel contribution of this algorithm is that, at each iteration, it determines the next minimum value of f_s, to be checked for validity, and thus provides the results at lesser iterations. Extending this idea, in this paper, we present another algorithm, with analytical formulations,
to determine the valid ranges of bandpass sampling frequencies for simultaneous downconversion of two distinct RF signal bands. For better understanding of these algorithm, we also present few simulation results. We considered a hypothetical software radio designing issue, where e want to incorporate the GSM and IS-95 CDMA standards over a single radio terminal, and applied these algorithms for both uplink and downlink bands separately, to compute the valid ranges of sampling frequencies.