A novel architecture for MIMO transmission and reception of filterbank multicarrier (FBMC) modulated signals under strong frequency selectivity is presented. The proposed system seeks to approximate an ideal frequency-selective precoder and linear receiver by Taylor expansion, exploiting the structure of the analysis and synthesis filterbanks. The resulting architecture is implemented by linearly combining conventional MIMO linear transceivers, which are applied to sequential derivatives of the original filterbank. The classical per-subcarrier precoding/linear receiver configuration is obtained as a special case of this architecture, when only one stage is fixed at both transmitter and receiver. An asymptotic expression for the resulting intersymbol/intercarrier (ISI/ICI) distortion is derived assuming that the number of subcarriers grows large. This expression can in practice be used in order to determine the number of parallel stages that need to be implemented in the proposed architecture. Performance evaluation studies confirm the substantial advantage of the proposed scheme in practical frequency-selective MIMO scenarios.