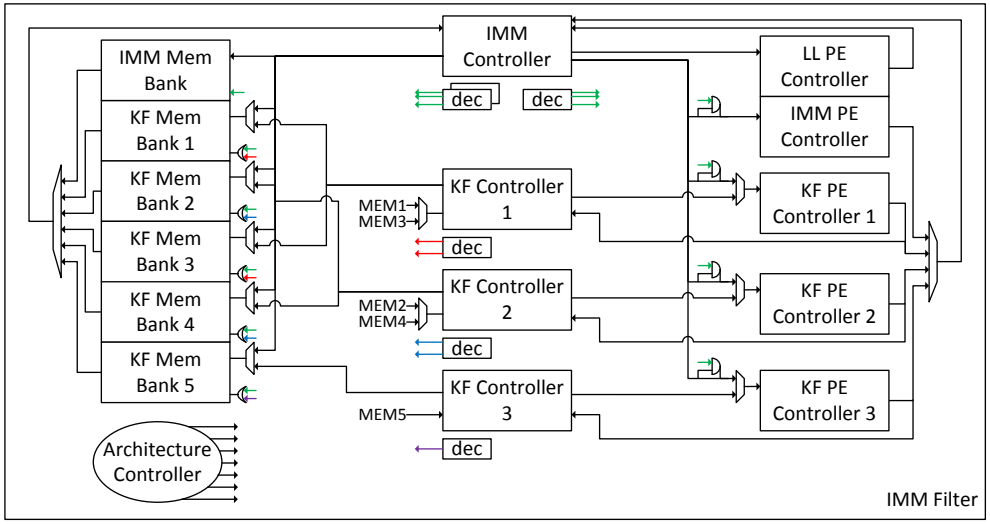
Implementation of a Parameterized Interacting Multiple Model Filter on an FPGA for Satellite Communications



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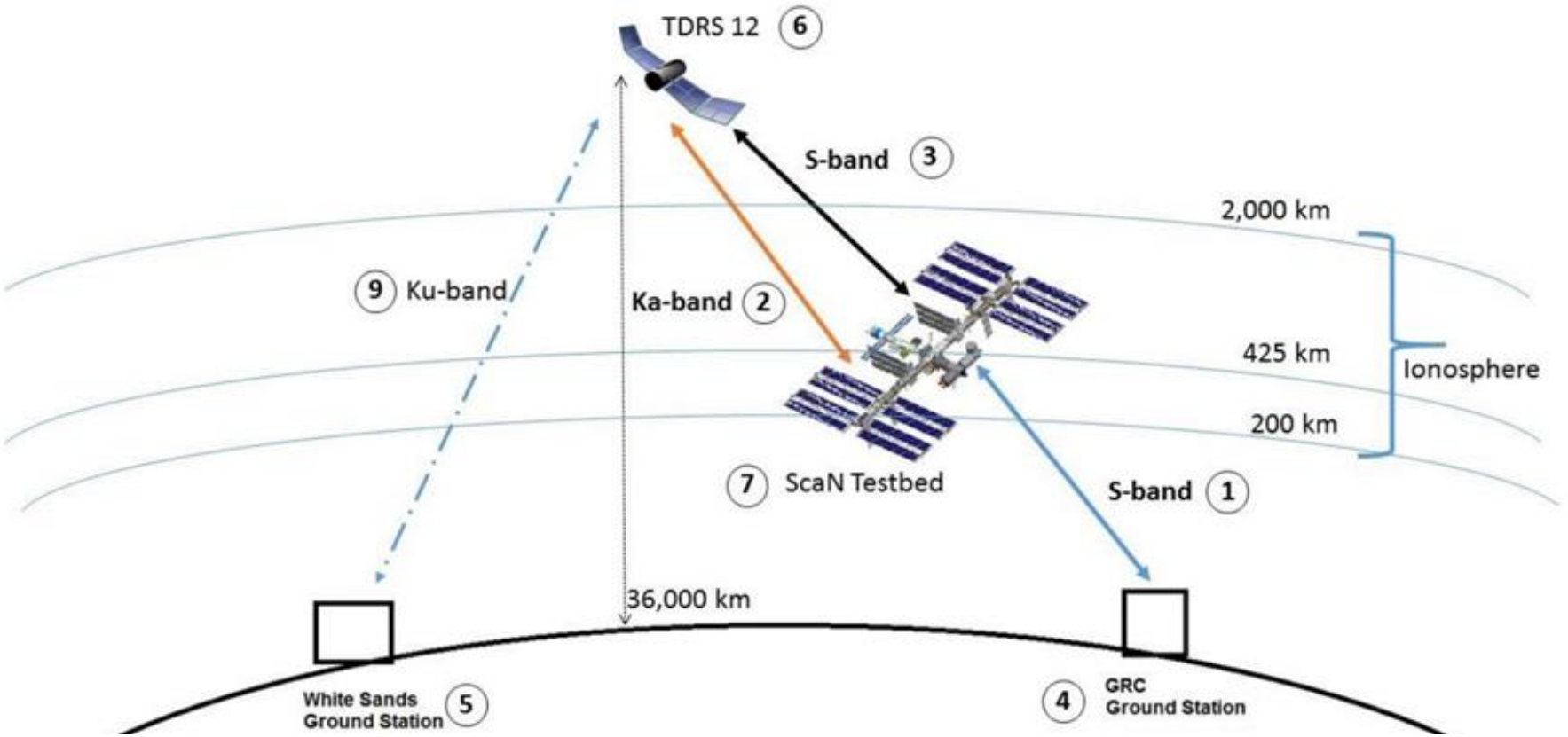
Overview of Research



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Targeted Platform

JPL Radio

- 66-MHz SPARC processor
- 2 x Xilinx Virtex-II FPGAs
- S-band transceiver
- L-Band (GPS) receiver

Picture Source: Reinhart, R., *Wireless Innovation Forum Technical Conference*, 2013

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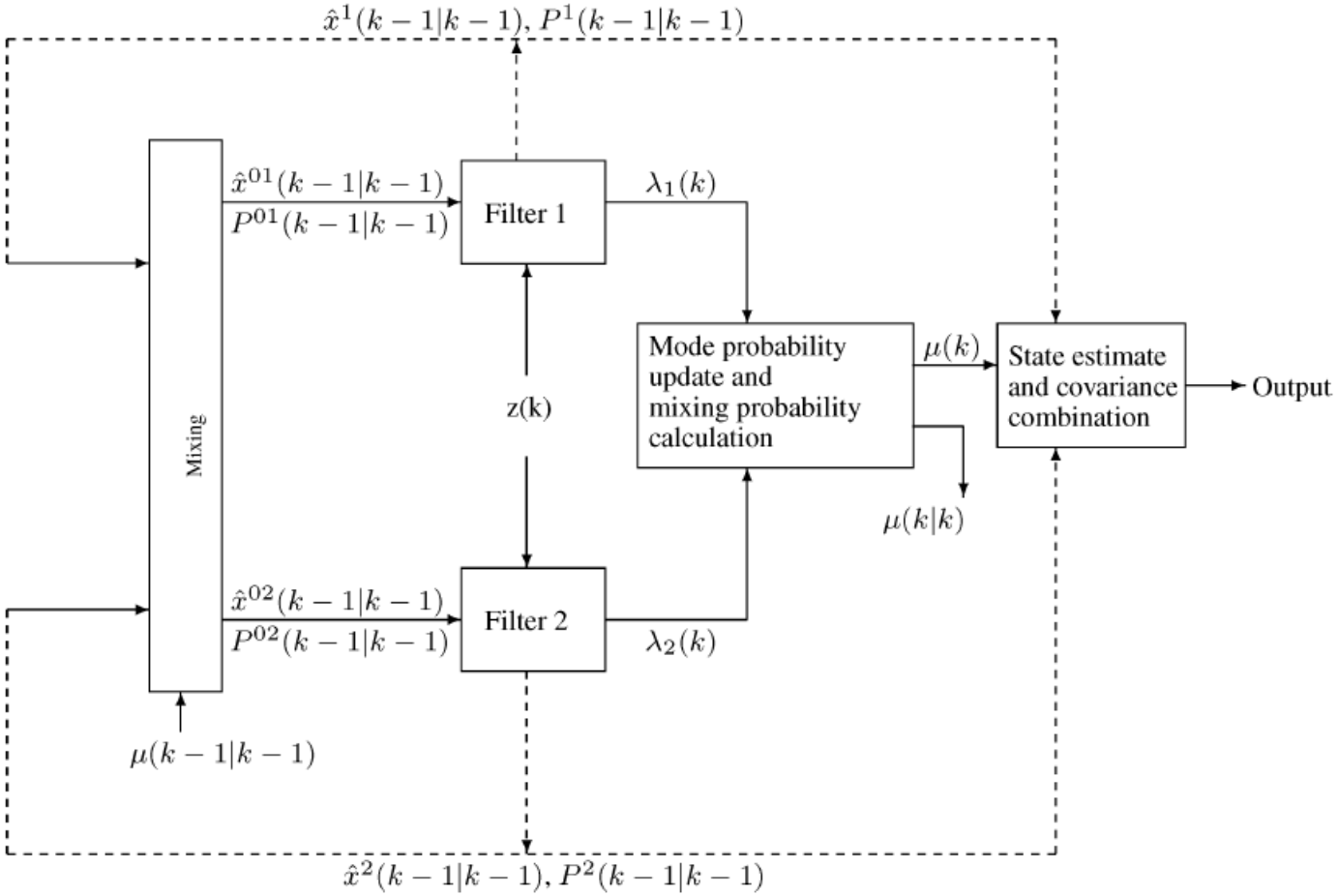
Interacting Multiple Model (IMM) Background



Picture Source: Sathyan, T. and Kirubarajan, T., *IEEE Transactions on Circuits and Systems, 2006*

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Interacting Multiple Model (IMM) Background

Step Number	Step Type	Iterations Needed	Expression Executed
MIX01	SF	1	$\underline{\hat{\mu}}(k+1\|k) = \underline{\mu}^T(k) \times \pi^T$
MIX02	SF	1	$\pi^T \times \text{diag}(\underline{\mu}(k))$
MIX03	SF	1	$\underline{\mu}(k) = (\pi^T \times \text{diag}(\underline{\mu})(k))^T \times (\text{diag}(\underline{\hat{\mu}}(k+1\|k)))^{-1}$
MIX04	SF	1	$\hat{X}_0(k\|k) = \hat{X}(k\|k) \times \underline{\mu}(k)$
MIX05	DF	R^2	$\hat{X}_{j0}(k\|k) - \hat{X}_i(k\|k)$
MIX06	DF	R^2	$(\hat{X}_{j0}(k\|k) - \hat{X}_i(k\|k)) \times (\hat{X}_{j0}(k\|k) - \hat{X}_i(k\|k))^T + P_i(k\|k)$
MIX07	DF	R^2	$P_{j0}(k\|k) = [(\hat{X}_{j0}(k\|k) - \hat{X}_i(k\|k)) \times (\hat{X}_{j0}(k\|k) - \hat{X}_i(k\|k))^T + P_i] \times \text{diag}(\mu_{ij})(k) + G$
KF01	DF	R	$\hat{X}_j(k+1\|k) = F \times \hat{X}_{j0}(k\|k)$
KF02	DF	R	$F \times P_{j0}(k\|k)$
KF03	DF	R	$P_j(k+1\|k) = F \times P_{j0}(k\|k) \times F^T + Q$
KF04	DF	R	$P_j(k+1\|k) \times H_j^T$
KF05	DF	R	$S_j(k+1) = H \times P_j(k+1\|k) \times H^T + R_j$
KF06	DF	R	$K_j(k+1) = P_j(k+1\|k) \times H^T \times (S_j(k+1))^{-1}$
KF07	DF	R	$P_j(k+1\|k+1) = P_j(k+1\|k) - K_j(k+1) \times (P_j(k+1\|k) \times H_j^T)^T$
KF08	DF	R	$e_j(k+1) = \underline{z}(k+1) - H \times \hat{X}_j(k+1\|k)$
KF09	DF	R	$\hat{X}_j(k+1\|k+1) = \hat{X}_j(k+1\|k) + K_j(k+1) \times \underline{e}_j(k+1)$
COM01	DF	R	$\underline{e}_j^T(k+1) \times S_j^{-1}(k+1) \times \underline{e}_j(k+1)$
COM02	SC	R	$-\frac{1}{2} e_j^T(k+1) \times S_j^{-1}(k+1) \times e_j(k+1)$
COM03	SC	R	$\exp(-\frac{1}{2} e_j^T(k+1) \times S_j^{-1}(k+1) \times e_j(k+1))$
COM04	SC	R	$\|S_j(k+1)\|$
COM05	SC	R	$(\|S_j(k+1)\|)^{-\frac{1}{2}}$
COM06	SC	R	$\underline{L}_j(k+1) = (2\pi)^{\frac{Z}{2}} (\|S_j(k+1)\|)^{-\frac{1}{2}} \exp(-\frac{1}{2} e_j^T(k+1) \times S_j^{-1}(k+1) \times e_j(k+1))$
COM07	SF	1	$\text{diag}(\underline{L}(k+1)) \times \underline{\hat{\mu}}^T(k+1\|k)$
COM08	SF	1	$\underline{\hat{\mu}}(k+1\|k) \times \underline{L}^T(k+1)$
COM09	SF	1	$\underline{\mu}(k+1) = (\text{diag}(\underline{\hat{\mu}}(k+1\|k) \times \underline{L}^T(k+1)))^{-1} \times (\text{diag}(\underline{L}(k+1)) \times \underline{\hat{\mu}}^T(k+1\|k))$
COM10	SF	1	$\underline{\hat{X}}(k+1\|k+1) = \hat{X}(k+1\|k+1) \times \underline{\mu}(k+1)$

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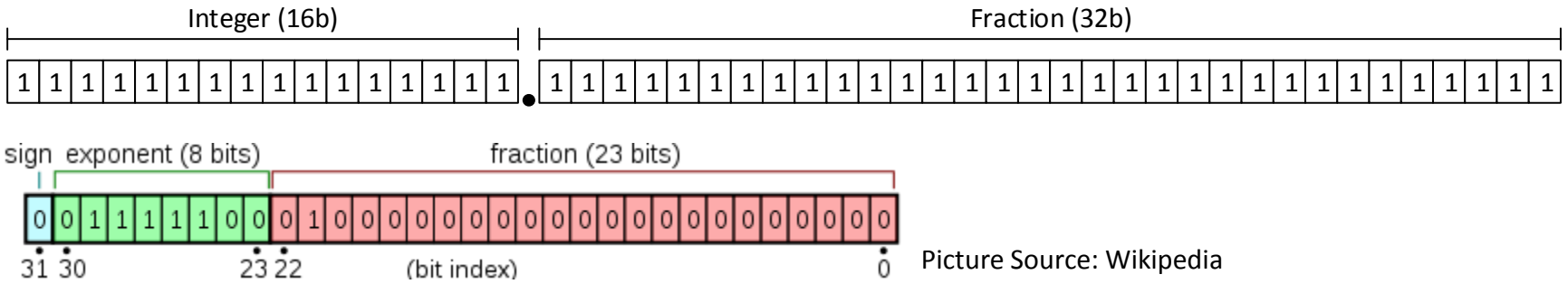
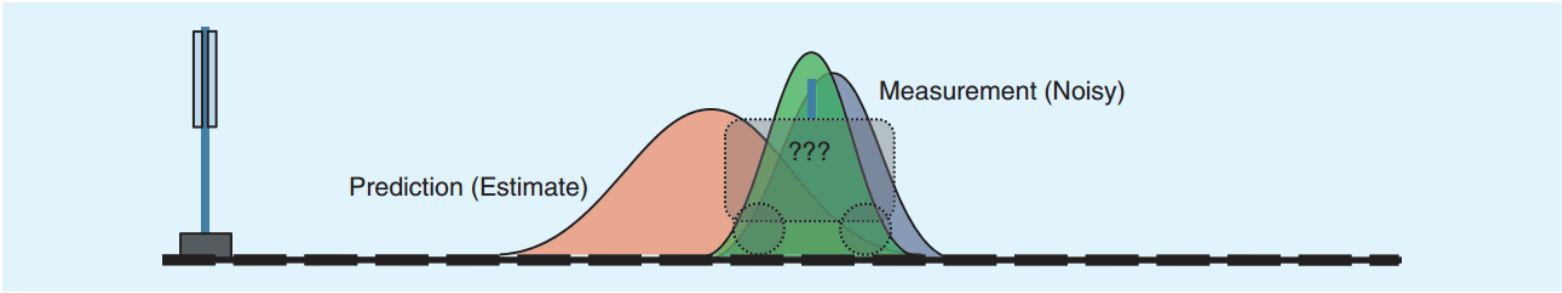
Ferreria, P., Paffenroth, R., and Wyglinski, A., *Wiley International Journal of Satellite Communications and Networking*, 2016

Implementation Trade Studies

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{bmatrix} \qquad A^{-1} = ?$$



Picture Source: Wikipedia



Picture Source: Faragher, R., *IEEE Signal Processing Magazine,* 2012

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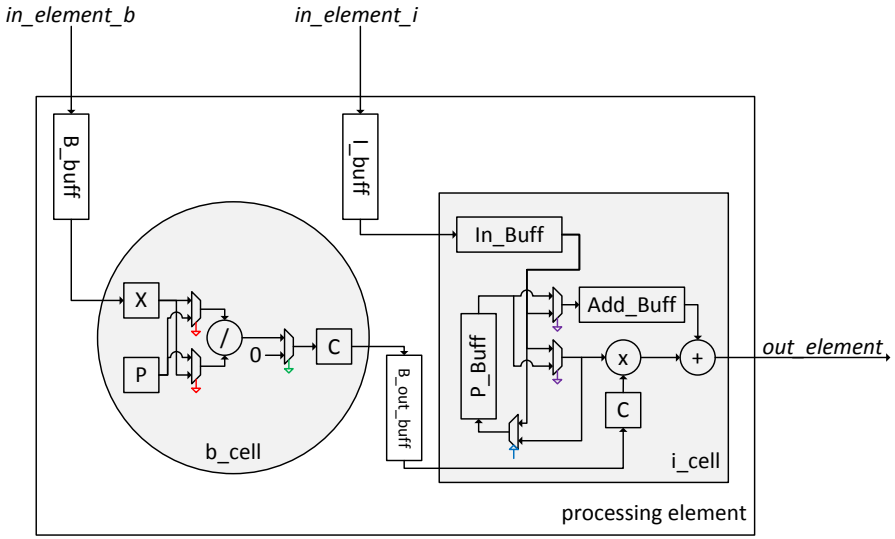
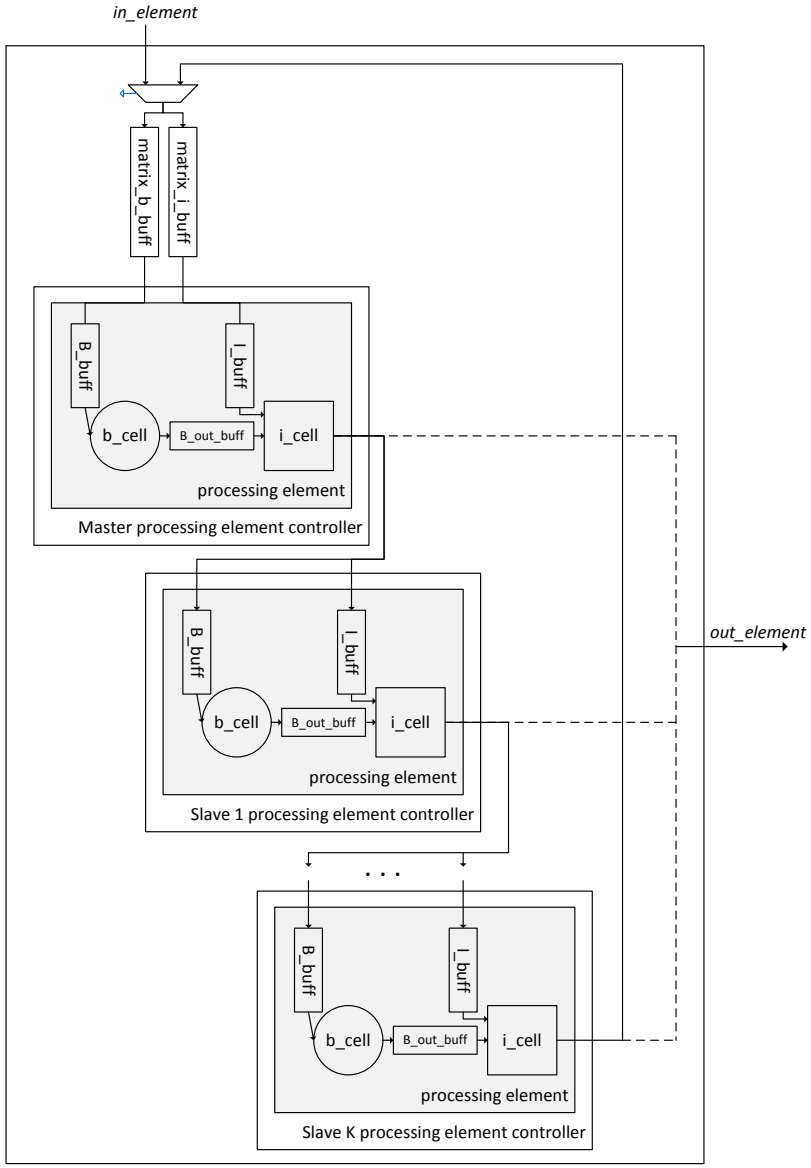
Schur Complement Architecture





Sudarsanam, A. et al., *IET Computers & Digital Techniques*, 2010

Schur Complement Analysis

Multiplier Latency	Addition Latency	Divider Cycles Per Operation	Divider Latency	Occupied Slices	Slice Flip Flops	4-Input LUTs	Max Clock Frequency (MHz)
1	1	14	14	754	541	1299	50.742
3	5	14	14	829	925	1340	133.233
3	7	26	27	849	1090	1328	152.879
6	7	26	27	910	1201	1343	175.389

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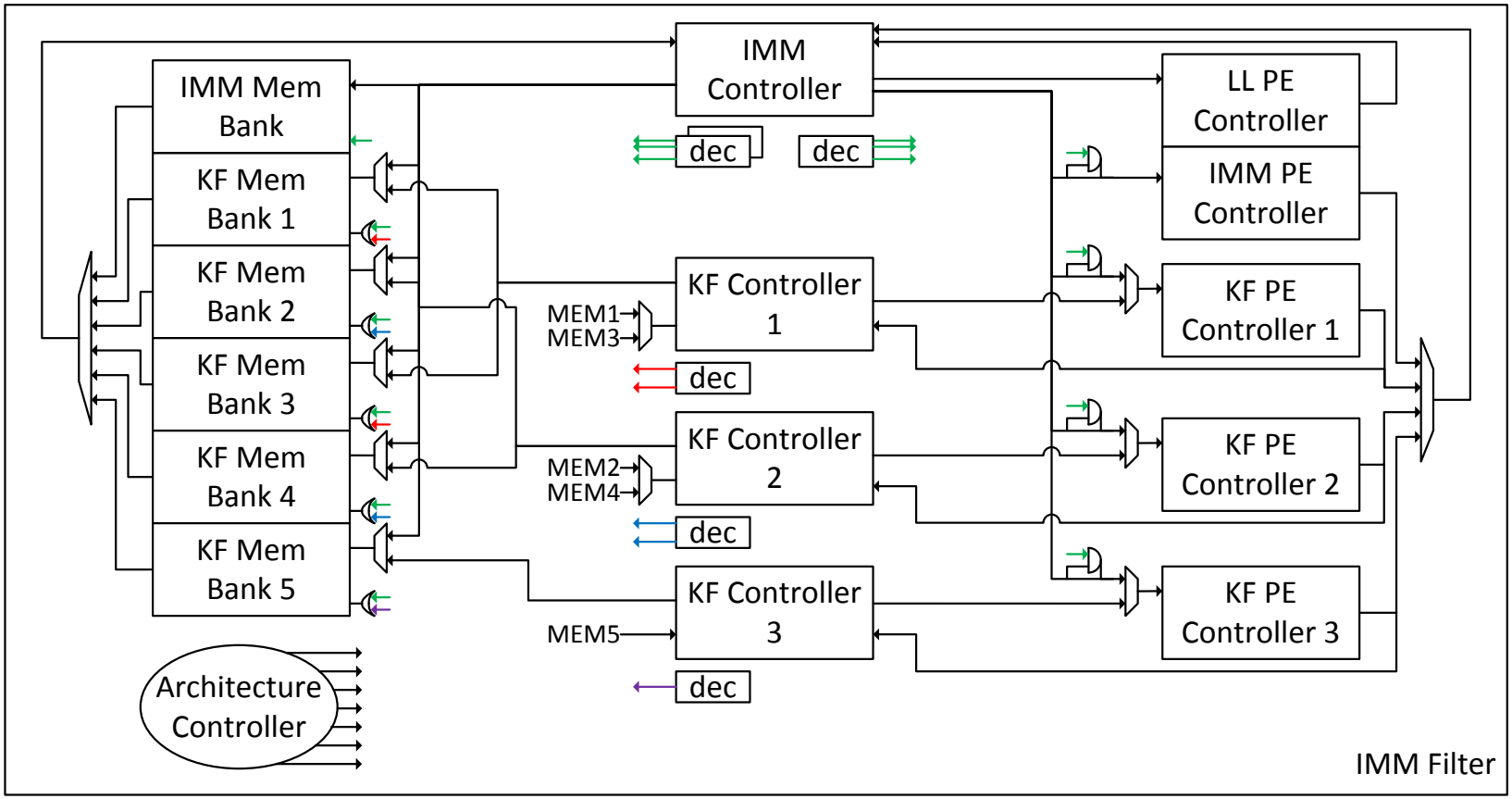
IMM Filter Architecture



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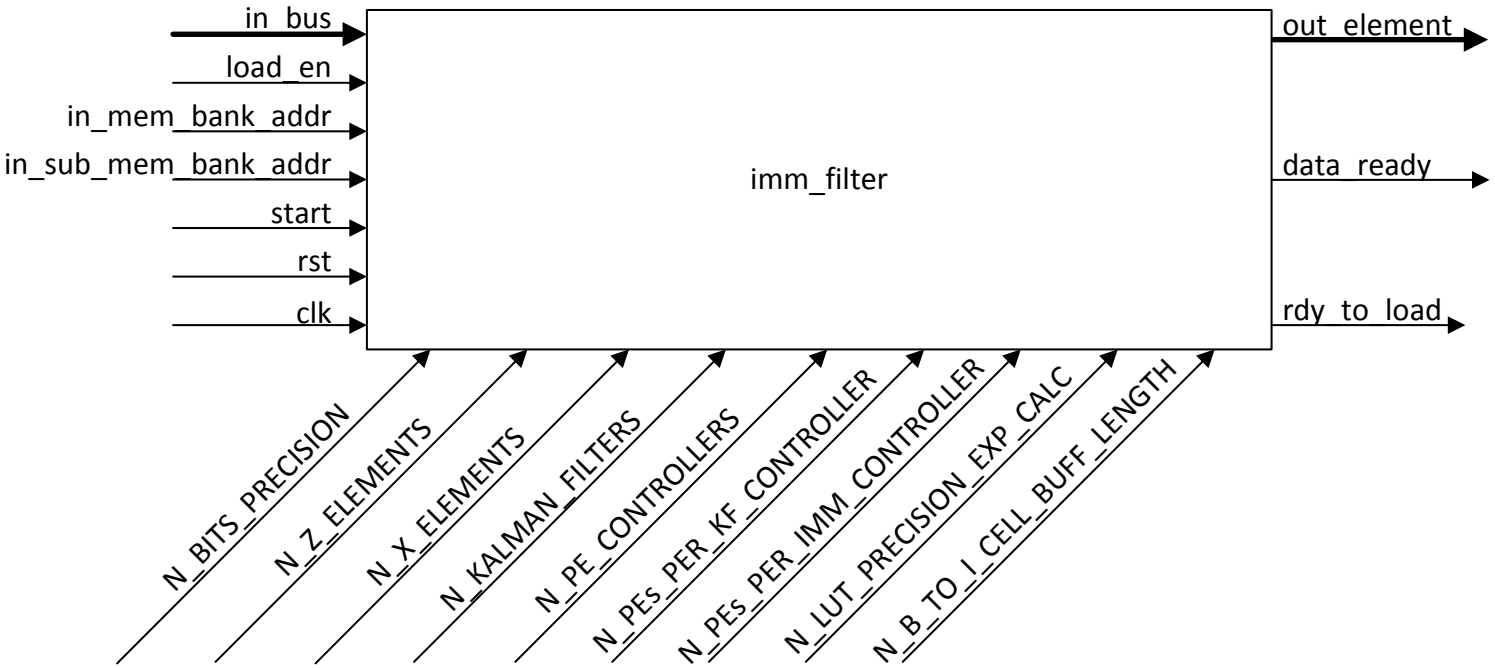
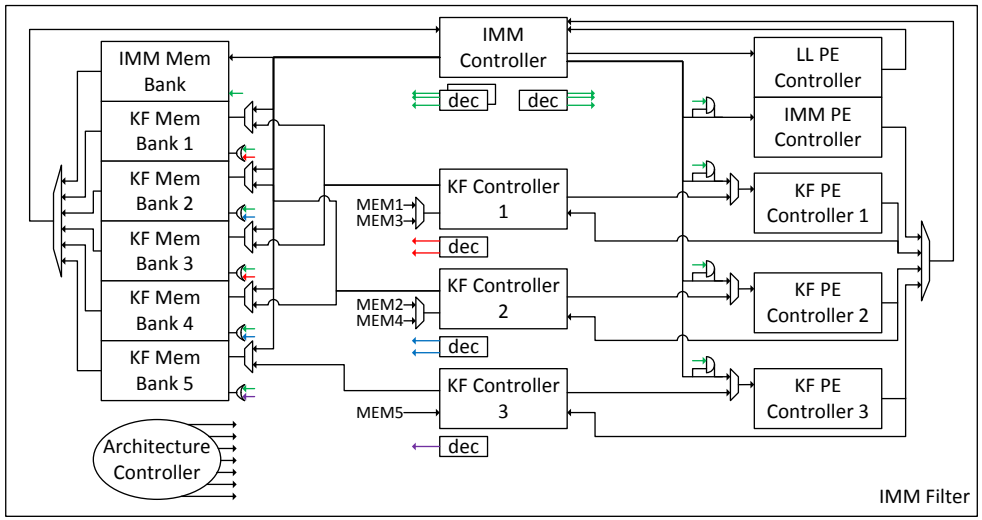
IMM Analysis





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Example Scenario

State Model

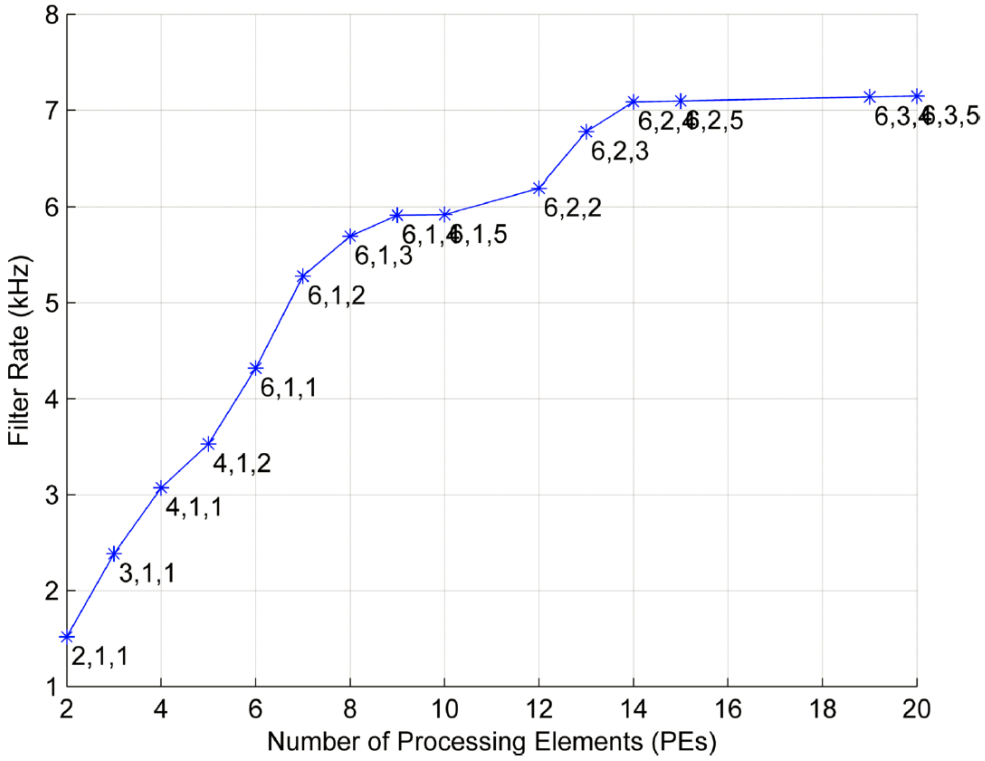
Constant Acceleration Model

Available Measurements

SNR, SIR

System Models

Clear Sky, Rain Fade,
Ionospheric Scintillation,
Tropospheric Scintillation,
Multipath Fading



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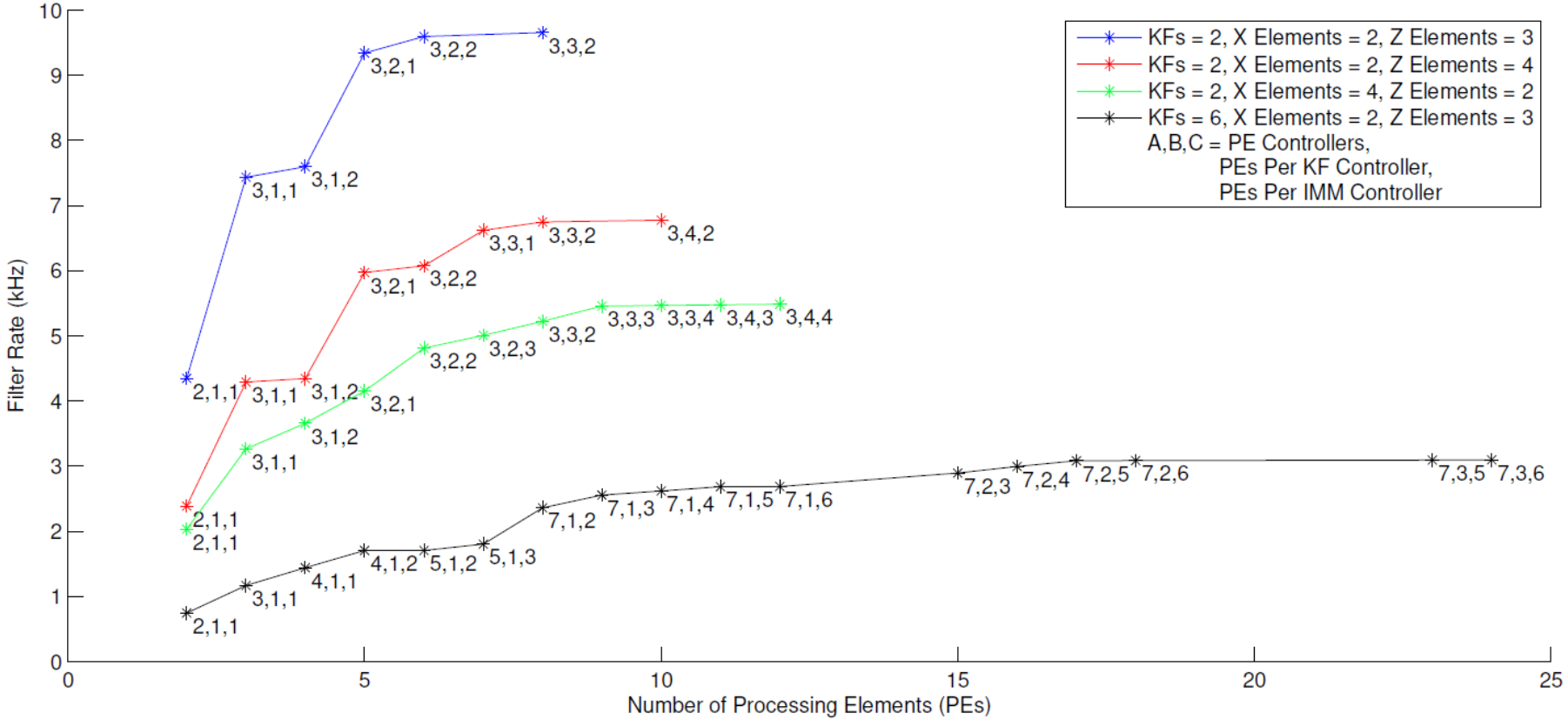
IMM Analysis



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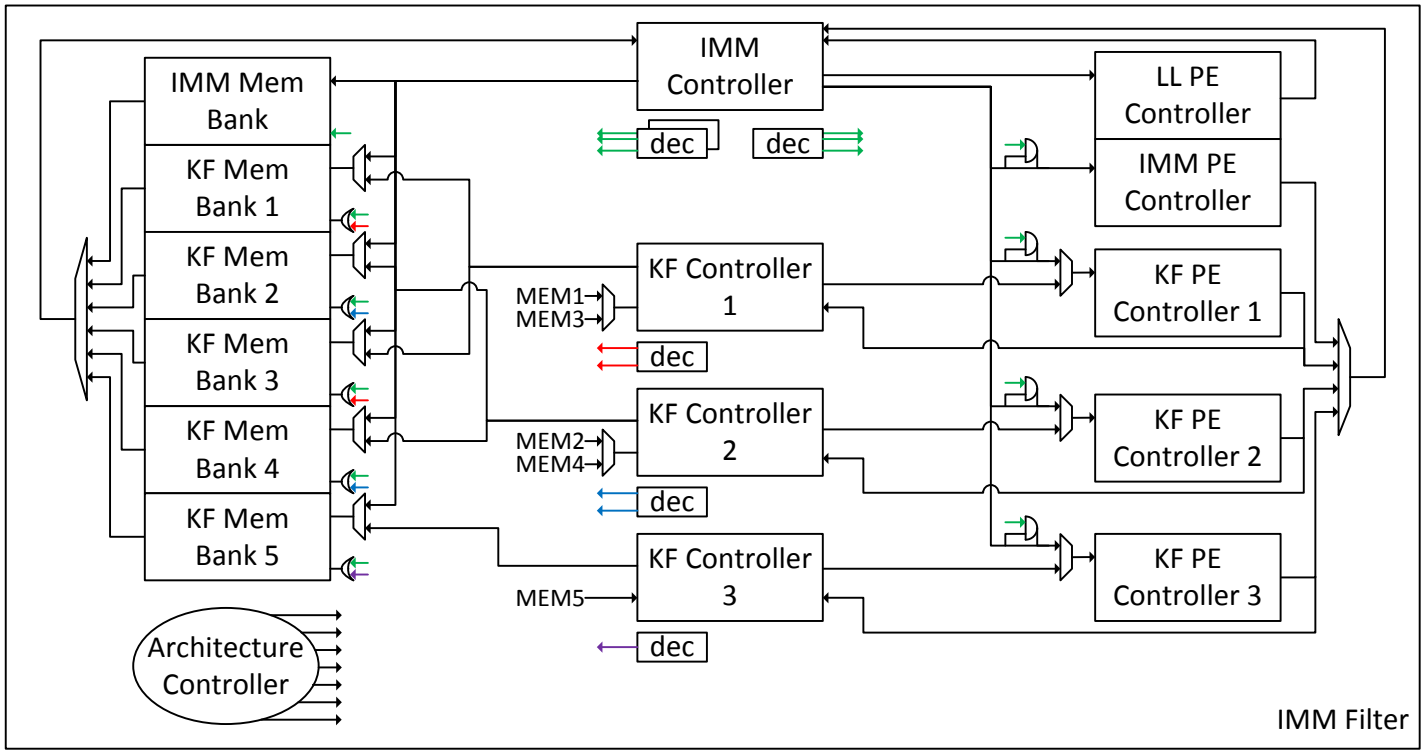
Summary



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