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A preconditioned MINRES method for block lower triangular Toeplitz systems with application to solving all-at-once systems of linear time-dependent PDEs

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In this study, a novel preconditioner based on the absolute-value block α-circulant matrix approximation is developed, specifically designed for nonsymmetric dense block lower triangular Toeplitz (BLTT) systems that emerge from the numerical discretization of evolutionary equations. Our preconditioner is constructed by taking the absolute value of a block α-circulant matrix approximation to the BLTT matrix. To apply our preconditioner, the original BLTT linear system is converted into a symmetric form by applying a time-reversing permutation transformation. Then, with our preconditioner, the preconditioned minimal residual method (MINRES) solver is employed to solve the symmetrized linear system. With a properly chosen α, the eigenvalues of the preconditioned matrix are proven to be clustered around ±1 without any significant outliers. With the clustered spectrum, we demonstrate that the preconditioned MINRES solver for the preconditioned system has a convergence rate independent of system size. Our preconditioner can be implemented in a parallel-in-time manner. The efficacy of the proposed preconditioner is corroborated by our numerical experiments, which reveal that it attains optimal convergence.

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