The time-spectral method (TSM) offers the advantage of increased order of accuracy compared to methods using finite-difference in time for periodic unsteady flow problems. Explicit Runge–Kutta pseudo-time marching and implicit schemes have been developed to solve iteratively the space-time coupled nonlinear equations resulting from TSM. Convergence of the explicit schemes is slow because of the stringent time-step limit. Many implicit methods have been developed for TSM. Their computational efficiency is, however, still limited in practice because of delayed implicit temporal coupling, multiple iterative loops, costly matrix operations, or lack of strong diagonal dominance of the implicit operator matrix. To overcome these shortcomings, an efficient space-time lower–upper symmetric Gauss–Seidel (ST-LU-SGS) implicit scheme with multigrid acceleration is presented. In this scheme, the implicit temporal coupling term is split as one additional dimension of space in the LU-SGS sweeps. To improve numerical stability for periodic flows with high frequency, a modification to the ST-LU-SGS scheme is proposed. Numerical results show that fast convergence is achieved using large or even infinite Courant–Friedrichs–Lewy (CFL) numbers for unsteady flow problems with moderately high frequency and with the use of moderately high numbers of time intervals. The ST-LU-SGS implicit scheme is also found to work well in calculating periodic flow problems where the frequency is not known a priori and needed to be determined by using a combined Fourier analysis and gradient-based search algorithm.