INTRODUCTION: $B_1$ maps are an essential part of most quantitative MRI protocols, including Variable Flip Angle (VFA) $T_1$ mapping. To achieve whole brain quantitative imaging in reasonable scan times, several novel rapid $B_1$ methods have been introduced. Recent works have compared several novel $B_1$ mapping methods used at 3T in simulations, phantom scans, and in vivo. Accelerating $B_1$ mapping can also be done through fast k-space trajectories, such as EPI, but are sometimes dismissed due to the possibility of distortions associated with artifacts, particularly for brain imaging. The aim of this work was to compare VFA $T_1$ maps in white matter (WM) produced with four $B_1$ methods: Reference double angle (DA), Bloch-Siegert, Actual-Flip-Angle Imaging (AFI), and DA using a stock scanner spin-echo EPI readout sequence (EPI-DA).

METHODS: Six healthy adult subjects were scanned with a 3T Siemens Tim Trio MRI using a 32-channel receive-only head coil. Axial slices (2x2x5 mm) were acquired (or extracted from 3D volumes) parallel to the AC-PC line above the corpus callosum. A reference DA $B_1$ map was acquired using a turbo spin echo readout with TE/TR 12/1550 ms and $\alpha=60/120^\circ$. Whole brain 3D optimally spoiled $A^2$ $B_1$ maps were acquired with TE/TR 1 5/100 ms, N = 5, $\alpha=60^\circ$, spoiling gradient moment $A_y=450$ mT·ms/m and RF phase increment $\phi=39^\circ$. Single slice BS $B_1$ maps were acquired with TE/TR 15/100 ms, $\alpha=25^\circ$, 8 ms Fermi Pulse of 500° at ±4kHz off-resonance and $K_{BS}=74.01$ rad/G. Interleaved multi-slice spin-echo EPI-DA whole brain $B_1$ maps were acquired with TE/TR 46/4000 ms, $\alpha=60/120^\circ$, EPI Factor = 9 and echo spacing = 4.18 ms. To further investigate possible distortion artefacts in EPI-DA $B_1$ maps, a left-hemisphere sagittal slice $B_1$ map for both DA methods was acquired for one subject. VFA $T_1$ maps were acquired using an optimally spoiled 3D gradient echo sequence (TE/TR 2.89/15 ms, $\alpha=3/20^\circ$, $A_y=280$ mT·ms/m, $\phi=169^\circ$), and the flip angles were scaled voxel-wise by each $B_1$ map prior to fitting for $T_1$. Whole-brain $T_1$w MPAGE images (1x1x1 mm$^3$) were acquired, and tissue classification maps (WM, GM, CSF) were provided via INSECT with the ICBM-152 atlas. WM tissue masks were resampled to a 2x2x5 mm$^3$ slice using a majority voting analysis; GM and CSF were not included because of partial volume effects due to the voxel size.

RESULTS: Single slice $B_1$ maps and WM $T_1$ maps for a single subject are shown in Fig.1. Figure 2 displays histograms for single slice WM $T_1$ data that was pooled for all subjects. Linear regression analysis of pooled WM $T_1$ for each $B_1$ relative to the reference is shown in Table 1. Figure 3 compares reference DA and EPI-DA sagittal $B_1$ maps for a single subject. No significant $B_1$ maps distortions were observed in axial or sagittal EPI-DA $B_1$ maps.

DISCUSSION: All $B_1$ methods provided comparable $B_1$ and VFA $T_1$ maps. EPI-DA, the fastest of the $B_1$ maps (5 s/slice), had no observable $B_1$ artefacts (Figs. 1 and 3), due to careful sequence planning (low EPI factor, long echo spacing). Strong correlations were observed between VFA $T_1$ maps using flip angles corrected with each $B_1$ map.

Transmit $B_1$ in the brain is typically observed to be a slowly varying function. Interpolating or blurring $B_1$ maps has been used for both transmit and receive $B_1$, and could remove structural information from the $B_1$ maps, particularly for maps measured using novel (BS, AFI) or k-space accelerated (EPI-DA) methods. For multi-site or multi-scanner studies requiring whole-brain $B_1$ maps, EPI-DA could be a good alternative to novel methods, which are not available as stock-sequences on most scanner platforms.

CONCLUSION: All $B_1$ methods resulted in comparable WM $T_1$ maps, and all rapid methods strongly correlated with the reference DA map. EPI-DA, the fastest of the techniques derived from a stock scanner sequence, correlated the best with Ref. DA with no observable distortion artefacts. As $B_1$ maps are expected to be smooth, blurring or spline smoothing could be beneficial at improving $B_1$ maps for quantitative MRI methods (e.g. spline interpolation would remove visible anatomical regions such as the sulci and ventricles in EPI-DA $B_1$ maps (Fig. 1)).