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Measurement of Efficiency Degradation Due to External Detuning of a Tunable Patch Antenna

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Abstract—Realistic deployment scenarios for narrow-band mobile terminal antennas can place the antenna in close proximity to sources of detuning such as the user’s hand. Undesirable side-effects can include frequency shifts off-resonance and degraded impedance matching, reducing the overall system efficiency. Here, 3D radiation patterns and radiated efficiency measurements were used to evaluate the ability of a tunable matching network to preserve system efficiency in a patch antenna detuned with a hand phantom. The results indicated a trend for improving tuner benefit as a function of increasing severity of detuning. However, the transducer efficiency of 69%—which is a major issue in system evaluation—was too low to justify the improved impedance matching with the degree of detuning examined here.

I. INTRODUCTION

Space constraints in mobile terminal design often require antenna placement at the edge of the handset, increasing the risk of antenna detuning caused by proximity to the user’s hand. The associated frequency shifts are more significant for narrow-band antennas as a shift of a few MHz can be enough to move the resonance out of band [1]. Various works suggest tunable matching networks may be beneficial under certain detuning conditions [1], [2], but none are known to have measured the realized system efficiency (combining radiative and tuning effects) for an antenna matched with a practical tunable pi-network under the given detuning scenario. The gap was addressed in this work by fabricating and validating a hand phantom for detuning, followed by an examination of the ability of the tuner to preserve the overall system efficiency through measurements in an anechoic chamber.

II. EXPERIMENTAL DISCUSSION

A. Hand phantom fabrication

The hand phantom was fabricated from anhydrous “TX151” powder, polythene powder and water mixed to yield a 600 gram detuning block with a measured relative permittivity $\epsilon_r = 40$, measured using a permittivity probe and Vector Network Analyzer (VNA) [3]. When positioned in front of the 2-GHz patch antenna at various distances d (Fig. 1), the differences in impedance given by the hand and the phantom were found to be small (mean deviation $0.2\% \pm 3.0\%$ of $|Z|$), validating the impedance shifting effect of the phantom.

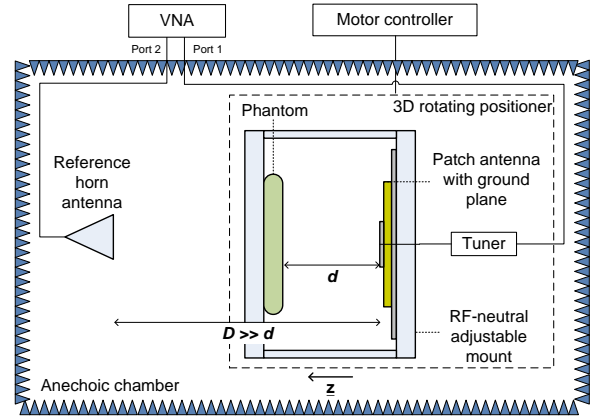


Fig. 1: Detuning setup in an anechoic chamber.

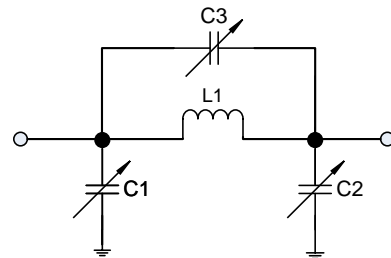


Fig. 2: Tunable pi-network.

B. RF MEMS impedance tuner

The in-line impedance tuner was based on a WiSpry WS1050 chip, providing three digitally tunable capacitances each of nominal value between 0.5 and 6.0 pF, and a 5 nH air-core inductor (Fig. 2) with topology described in [4]. The tuner offered 60^3 tuning states, with Smith chart coverage dependent on the frequency and inductance L_1 . A tuning state for each distance d was chosen to maximise over-the-air forward transmission (OTA S_{21}) from an exhaustive set of measurements recorded with a setup similar to Fig. 1, limited to operation on bore-sight.

C. Detuning effects

Total-power radiation patterns were measured for each case described in Table 1, with or without the presence of the tuner

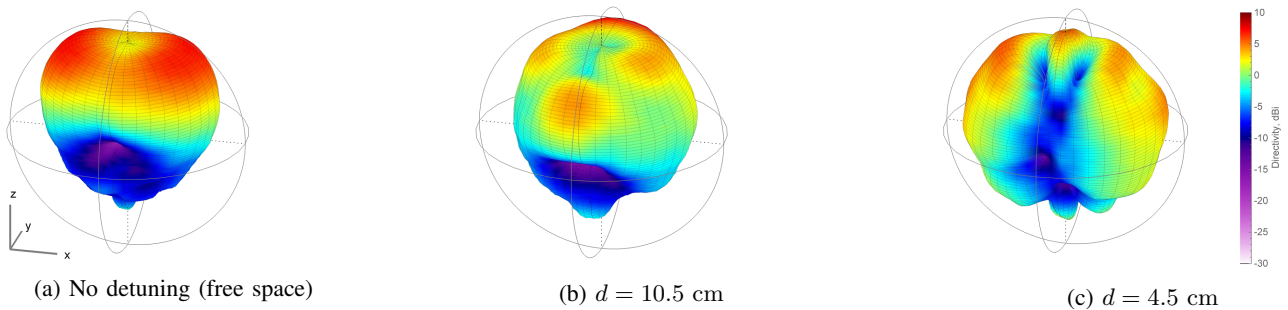


Fig. 3: Total power radiation patterns with tuner. Antenna aligned in xy -plane.

(Fig. 3). The patterns demonstrated clear variation due to the increasing proximity of the phantom (reduced separation in the z -axis) causing some blocking of the signal.

The system efficiencies $\eta_{\text{sys}(T/N)}$ were measured relative to a reference monopole known to have efficiency greater than 98% at 2-GHz using the technique described in [5]. This definition of system efficiency includes all sources of loss described (1), where T and N denote “tuner” and “no-tuner” configurations:

$$\frac{\eta_{\text{sys}(T)}}{\eta_{\text{sys}(N)}} = \frac{\eta_{\text{match}(T)} \cdot \eta_{\text{trans}(T)} \cdot \eta_{\text{rad}} \cdot \eta_{\text{phantom}}}{\eta_{\text{match}(N)} \cdot \eta_{\text{trans}(N)} \cdot \eta_{\text{rad}} \cdot \eta_{\text{phantom}}} \quad (1)$$

where η_{match} is the matching efficiency into the combined tuner/antenna block, and η_{rad} is the radiation efficiency accounting for conductor and dielectric losses (independent of the tuner). η_{phantom} accounts for loss caused by the phantom, defined such that absence of the phantom gives $\eta_{\text{phantom}} = 1$. η_{trans} denotes the transducer efficiency, with $\eta_{\text{trans}(N)} = 1$ in the non-tuned configuration. The product $\eta_{\text{rad}} \cdot \eta_{\text{phantom}}$ in both tuned- and non-tuned configurations for fixed d is equal, thus taking the ratio of measured system efficiencies yields the transducer efficiency of the tuner, $\eta_{\text{trans}(T)}$ (2):

$$\eta_{\text{trans}(T)} = \frac{\eta_{\text{sys}(T)} \cdot \eta_{\text{match}(N)}}{\eta_{\text{sys}(N)} \cdot \eta_{\text{match}(T)}} \quad (2)$$

The measured system efficiencies reduced in both detuning cases compared to the free space scenario due to the combined increase in phantom loss and detuning (Fig. 4). The transducer efficiency was observed to be relatively constant with a mean value of 69% (Table 1), nonetheless the tuner did not provide any system efficiency improvements in this narrow-band example. However, the relative gradients of the two data sets suggest a general trend for the tuner benefit to improve with increasingly severe detuning. An intercept point is apparent at which the performance degradation due to detuning exceeds the insertion loss of the tuner. Below this intercept distance, the tuner may yield a performance advantage.

III. CONCLUSION

Previous works reported that tunable matching networks may yield an improvement in mobile terminal performance under hand-detuning scenarios. This work highlights that despite

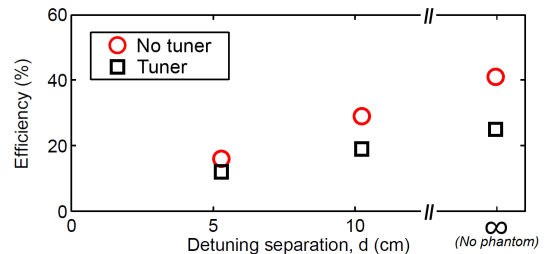


Fig. 4: Measured efficiencies (Table 1).

TABLE I: Efficiency percentages under detuning

Case	Matching (%)	Transducer (%)
$d = 4.5$ cm, no tuner	98	-
$d = 4.5$ cm, tuner	97	72
$d = 10.5$ cm, no tuner	93	-
$d = 10.5$ cm, tuner	89	67
No phantom, no tuner	98	-
No phantom, tuner	96	67

improved impedance matching, improved system efficiency is not an inevitable outcome even with transducer efficiencies in excess of 65%. The matching efficiency without the tuner may be degraded more severely in an antenna with higher Q such that the tuner becomes more advantageous, thus future work should examine a combination of higher Q antennas and more extreme detuning to determine the maximum acceptable insertion loss of such an impedance tuner.

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