METAMATERIALS 2009 London 30th Aug – 4th Sept http://congress2009.metamorphose-vi.org

A Practical Parametric Magneto-Inductive Ring Detector

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Abstract

A parametrically amplified ring detector for magnetic resonance imaging (MRI) is presented. The system consists of eight coupled PCBs arranged as an octagon. Each carries three L-C resonators, for signal, idler and pump frequencies. Adjacent signal resonators and pump resonators are magnetically coupled, so these two frequencies propagate as magneto-inductive waves; however, the idlers are uncoupled. The signals interact via varactors, allowing amplification of signals from a rotating dipole source by the three-frequency process. Uniform gain is demonstrated in a non-magnetic system suitable for ^{1}H MRI at 1.5T.

1. Introduction

Signals are detected in whole-body MRI using birdcage coils, multiply resonant ring-shaped passive L-C resonators whose primary mode can detect a rotating dipole field [1]. If similar resonators are constructed using purely magnetic coupling [2], the travelling field in the ring may be described as a magneto-inductive (MI) wave [3]. Parametric amplification offers potential advantages in signal detection, since it can provide an effective increase in Q-factor for a loaded resonator. We have been developing a parametrically amplified MI ring detector for MRI, and have demonstrated simple 2- and 3-frequency systems [4, 5]. Here we describe a practical non-magnetic amplifier tuned for 63.8 MHz, the frequency for ^{1}H MRI at 1.5T.

2. Principle

Only a 3-frequency system can provide phase-independent parametric signal amplification. To achieve gain, the frequency matching condition $\omega_S + \omega_I = \omega_P$ must be satisfied, where ω_S, ω_I and ω_P are angular frequencies of signal, idler and pump. If travelling waves are involved, there are further conditions on their propagation constants. Here, we avoid these constraints by propagating only the signal and pump, coupling the relevant resonators magnetically. The three resonators interact via varactors, and if the pump resonators are fed with energy at ω_P, the system can amplify signals near ω_S. A unit cell can be constructed on a PCB as shown in Fig. 1a, and a travelling-wave amplifier from cascaded cells as shown in Fig. 1b. Resonators may be constructed as a polygonal ring of PCBs.

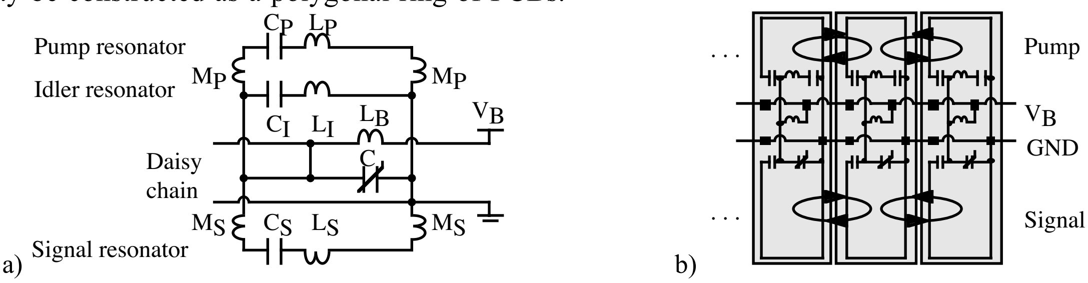

Fig 1: a) Unit cell and b) circuit realisation of a magneto-inductive parametric amplifier.

3. Passive ring

We have constructed passive and active octagonal MI ring resonators entirely using air-cored inductors. Figure 2 shows a passive ring, which contains only a set of coupled signal resonators (each signal inductor is 60 x 180 mm, and has Q ≈ 130 and a coupling coefficient $|\kappa|$ =

$2M_S/L_S > 0.4$). Signals are excited using a rotating RF source based on crossed coils fed by a quadrature hybrid coupler, and running waves are detected using a pair of 90^o inductive taps combined using a second quadrature hybrid. The ring supports five modes as shown in Fig. 3a, with the primary mode tuned to 63.8 MHz. A quadrature system will preferentially detect this mode, and its sensitivity is effectively independent of the radial source position as in Fig. 3b.

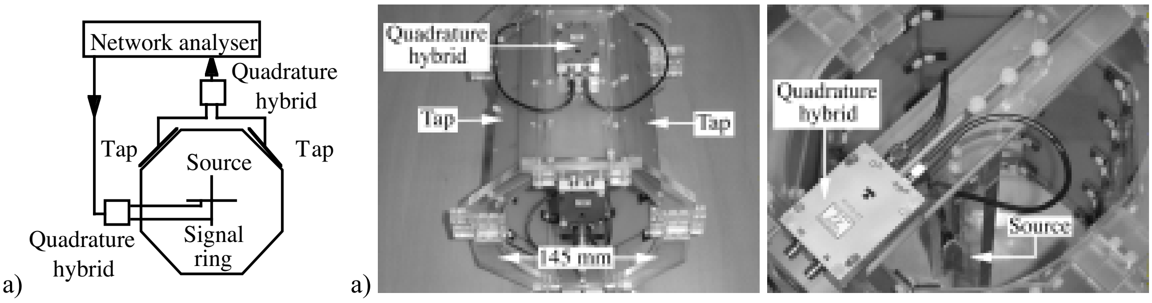

Fig. 2: Passive octagonal magneto-inductive ring: a) configuration; b) experimental realisation.

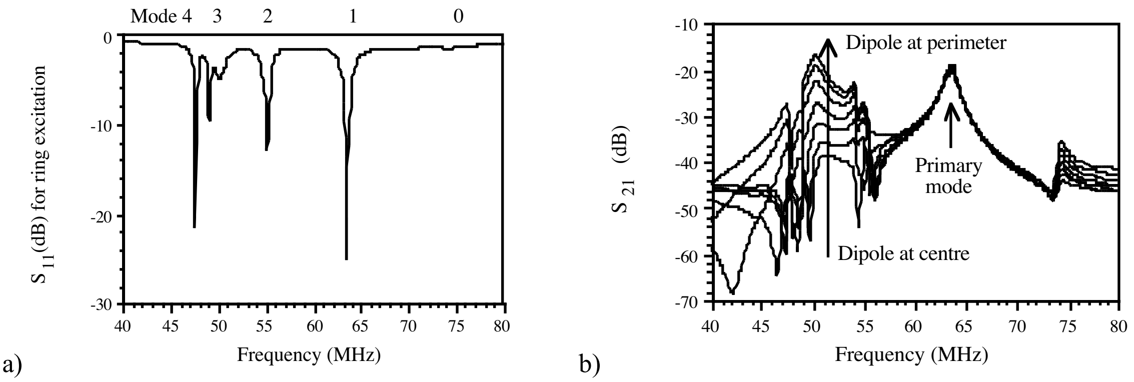

Fig. 3: a) Mode spectrum of passive octagonal ring, and b) detected signal for different source positions.

4. Active ring

Figure 4 shows an active system. The idler is at 35.7 MHz, the pump ring is resonant at a frequency for which the frequency matching condition is satisfied (99.5 MHz), and pump power is injected from a signal generator via 90^o inductive taps fed from a further quadrature hybrid. Because the system is magnetically coupled, inductive detection of spurious idler and pump signals is unavoidable, as shown in Fig. 5a. However, unwanted signals (particularly the pump) may be suppressed using a bandpass filter centred on ω_S, as shown in Fig. 5b. Clean signals are then detected as in Fig. 6a, and > 10 dB gain is routinely achievable without oscillation as in Fig. 6b. Fig. 7 shows frequency variations of detection sensitivity with 6 dB nominal gain, for different radial source positions. Once again, the primary mode signal is almost independent of source position, as shown in Fig. 7b. Consequently, the amplified system appears to exhibit the same advantage as the passive system, namely uniform detection sensitivity.

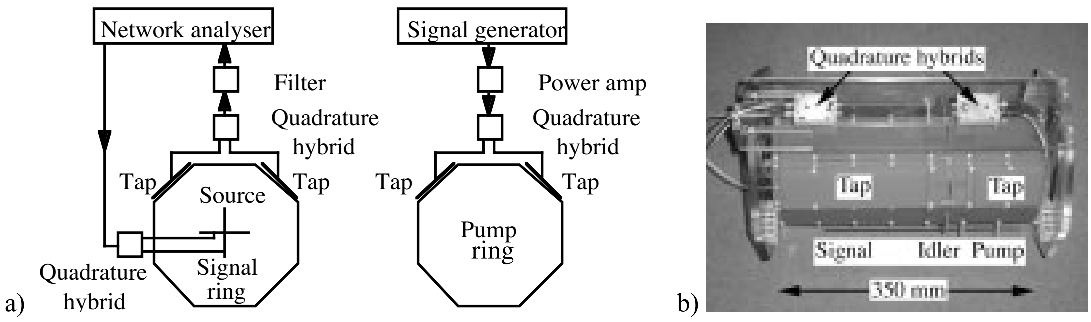

Fig. 4: Active octagonal magneto-inductive ring: a) configuration, and b) experimental realisation.

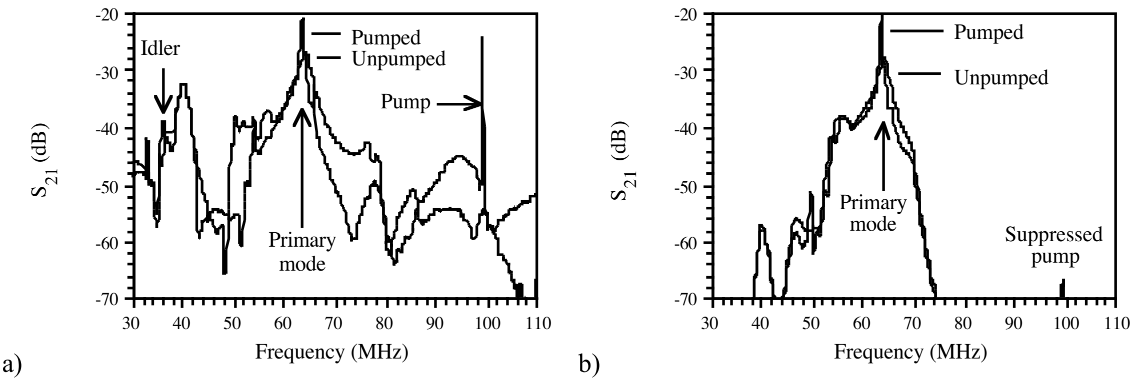

Fig. 5: Frequency variation of the detected signal S_{21} a) without and b) with output filter.

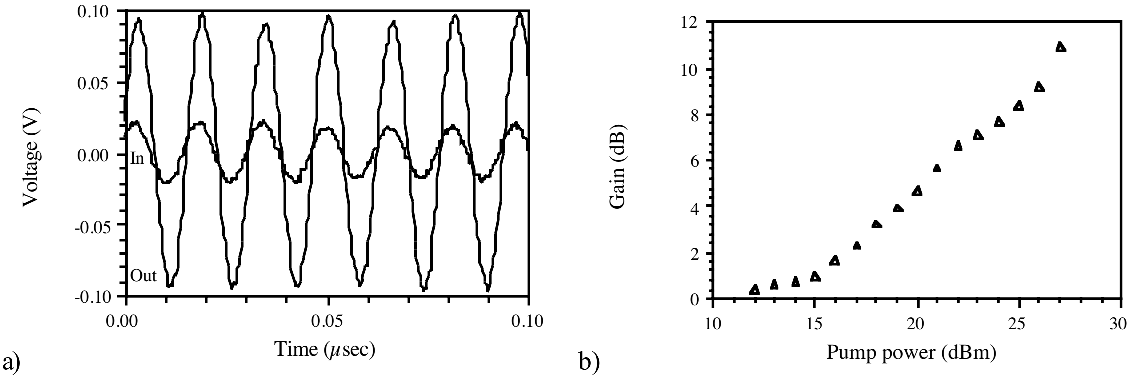

Fig. 6: a) Time variation of input and output signals; b) variation of gain with pump power.

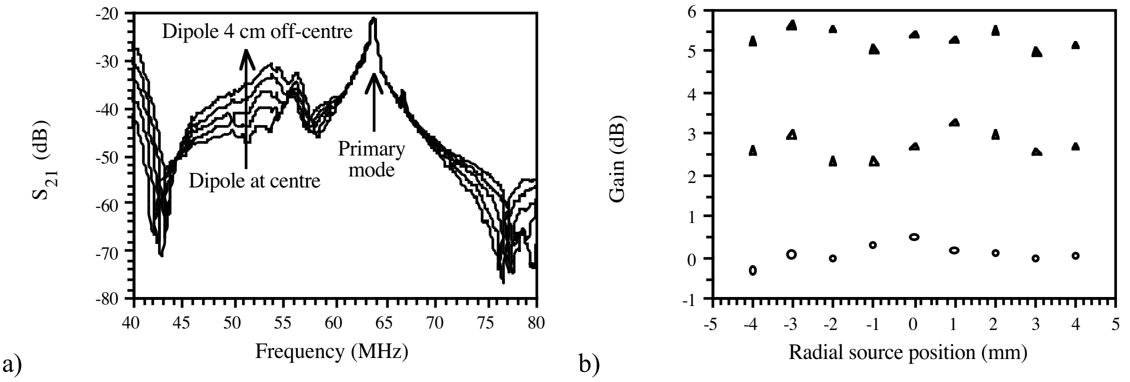

Fig. 7: a) Frequency variation of S_{21} with 6 dB of parametric gain, for different radial source positions; b) variation of gain with source position, for different levels of gain at 63.8 MHz.

5. Conclusions

We have demonstrated a practical detector for magnetic resonance signals, based on parametric amplification of magneto-inductive waves. Further work is required before MRI trials, for example to detune the resonators during the RF transmit pulse. This work is in progress.

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ISBN 978-0-9551179-6-1