An adaptive microstrip patch antenna for use in portable transceivers.

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ABSTRACT

This paper describes an adaptive frequency tunable microstrip patch antenna. The introduction of an adaptive feedback loop enables the patch antenna to optimise the antenna-feed impedance match. As a result, the performance of the antenna is less affected by external disturbances such as coupling to near by objects. Measurements evaluating the performance of the proposed antenna, in terms of transmitted power and bit error rate, are presented.

I. INTRODUCTION

Microstrip patch antennas exhibit features that make them attractive for use in mobile transceivers, such as their low profile, light weight and low cost. The required bandwidth for most of today's mobile communication systems represents the main obstacle for employing conventional microstrip patch antennas fabricated on thin substrates. These have an input bandwidth typically of ~1% for VSWR<2 [1]. For instance, GSM requires a bandwidth of 7.6% to cover both up-link and down-link frequencies. As a result a substantial amount of research has been carried out to improve their bandwidth characteristics. One approach has been to increase the instantaneous bandwidth by employing either multiple patches or a feed matching network. Alternative arrangements have concentrated on improving the frequency agility of microstrip patch antennas, giving a large operating bandwidth while maintaining their narrow input impedance bandwidth. This approach is well suited for most mobile communication systems as the instantaneous bandwidth is perfectly adequate for covering a single channel. This will reduce the KTB noise, and can also relax the filter requirements placed on the front-end of the transceiver. The most popular method for tuning the antenna is to insert a varactor diode between the patch and the ground plane [2] , see Fig.1. By varying the applied bias voltage the resonant frequency can be varied over a considerable range, giving an operational bandwidth (VSWR<2) of > 30%.

Since the microstrip patch antenna has an inherently narrow bandwidth it is susceptible to de-tuning that occurs when the antenna is brought into close proximity with other objects. This can, in the worst case, disable the functionality of the transceiver unit. It has been shown [3] that the introduction of an adaptive feedback loop enables the microstrip patch antenna to counteract any degradation in antenna-feed match caused by external disturbances. Another advantage of employing an adaptive frequency tunable antenna is that the actual antenna dimensions, together with the dielectric permittivity and anisotropy of the substrate, are much less important in determining the input response (hence the resonant frequency) of the antenna. This makes the fabrication of physically-small antennas on high dielectric permittivity material more attractive. It can be seen that to incorporate adaptive frequency tuning into such an antenna element gives the potential of removing local environmental considerations, such as antenna mounting, from the antenna design.

II. CIRCUIT DESCRIPTION

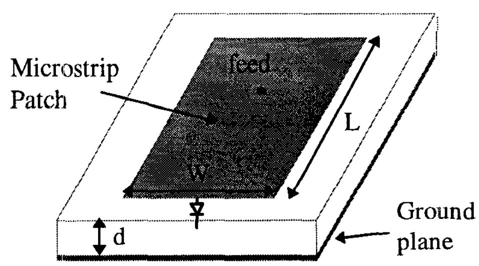

Fig.1 Varactor tunable patch antenna

A rectangular microstrip patch antenna, with dimensions W=40mm and L=53mm, was designed to operate in TM_{01} mode, and fabricated on a 1.59mm thick RT/duroid 5880 substrate (ε_r=2.2). An abrupt-junction varactor diode (Alpha DVH-6733-13) was inserted between one of the radiating edges and the ground plane, Fig.1, in order to give the widest possible tuning range. The resonant frequency could be altered by varying the applied bias voltage on the varactor diode. Fig.2 shows the measured resonant frequency versus applied bias voltage. It can be seen that the antenna has an operational bandwidth of 520 MHz, from 1120 MHz to 1653 MHz. The measured instantaneous bandwidth at each frequency was approximately 0.9%.

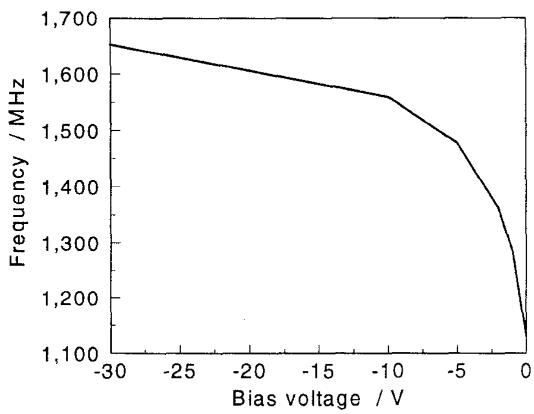

Fig.2 Resonant frequency versus applied bias voltage.

Fig.3 shows the block diagram of the proposed transmitting adaptive microstrip patch antenna. The aim is to monitor the power level of the reflected signal from the antenna- feed junction, and adjust the bias voltage of the varactor diode so as to minimise the reflected power. This achieved by coupling the reflected wave into a power detector (HP 423A), using a -20dB directional coupler with good isolation(<-18dB). It is essential for the directional coupler to have a good degree of isolation, as this will determine the sensitivity of the detector. The output of the power detector was amplified to a level suitable for the analogue-to-digital converter (ADC). A TLC32040 with a 14-bit resolution was used to provide the analogue-to-digital (ADC) and digital-to-analogue (DAC) conversions. A TMS32050 microprocessor was employed to process the sampled data. The digital output of the microprocessor was converted into an analogue signal by the DAC, followed by biasing circuitry that produced a voltage range of 0-12V. This voltage was applied to the diode through the feed. The minimum resolution was mainly dictated by the noise level at the ADC input. For correct operation the change per sample at ADC input had to exceed the noise level.

The algorithm developed for the TMS32050 microprocessor served several purposes. Firstly it allowed the user to access any frequency channel inside the operational bandwidth. Either a look-up table giving the required DAC value for a given channel or using the equation relating applied bias voltage to resonant frequency [3] can be used to select the desired channel. Because of the adaptive feedback only a rough estimation is required, as the system will immediately optimise the antenna-feed match. Secondly, the algorithm also included a maximum de-tuning range, which was determined through experimentation. This enabled the adaptive system to restrict the scanning region, thus giving a quicker response time. Thirdly, when the reflected power exceeded a given threshold, the algorithm forced the microprocessor to continue scanning until the feed-antenna matched status (i.e. reflected power < threshold) was regained. In the matched state, the scanning direction changed only when an increase in reflected power was detected.

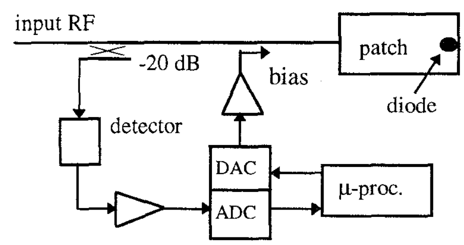

Fig.3 Block diagram of transmitting adaptive frequency tunable antenna.

The receiving adaptive patch antenna is very similar to the transmitting antenna, except the adaptive feedback in this case aims to maximise the monitored power level. The block diagram of the receiving system is shown in Fig.4. The only difference between Figs.4 and 3 is that the received power is monitored after it has been down converted (I.F.), whereas in transmit mode the R.F. power level is monitored. Also a precision peak rectifier instead of the HP 423A was used as a detector in the receiving antenna.

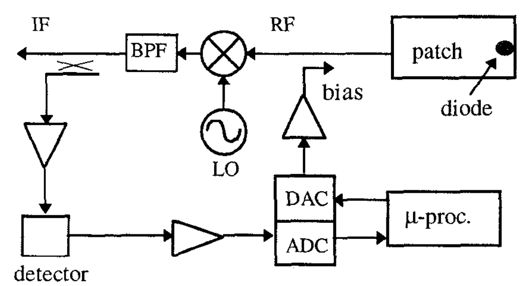

Fig.4 Block diagram of receiving adaptive frequency tunable antenna.

In a typical mobile environment, the user and/or nearby objects are likely to be non-stationary resulting in a time varying received signal strength. For instance, a user who is moving (driving, walking) in a typical urban environment can be subjected to Rayleigh fading [4], and can experience deep signal fades of -20dB. This can cause problems for the adaptive algorithm, as it should be able to distinguish between drops in signal strength due to de-tuning and those from fading.

The sampling rate of the system was 3 kHz and was mainly limited by the rather slow ADC/DAC conversion times associated with the TLC32040. By employing faster ADC/DAC together with parallel communication between microprocessor and ADC/DAC the response time of the adaptive microstrip patch antenna can be greatly improved, as the performance of the adaptive antenna is mainly dependent of the response time of the adaptive feedback.

III. MEASUREMENTS

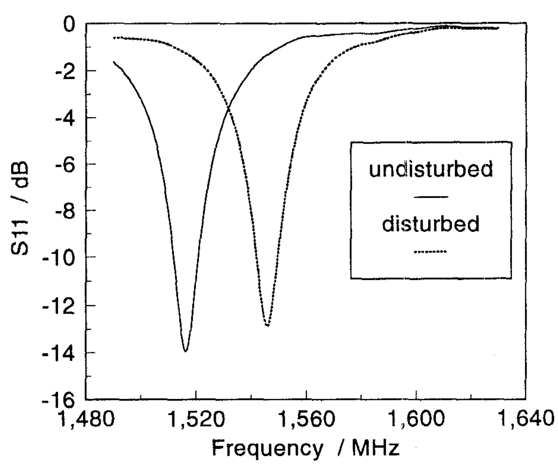

Fig.5 Reflected power versus frequency for undisturbed and disturbed antenna.

Two tests were conducted to evaluate the performances in terms of transmitted power and Bit Error Rate (BER), of a tunable patch antenna with and without adaptive feedback. In both tests the input response of the tunable patch antenna was altered by placing a metal sheet (170x170 mm) 20mm in front of the antenna. This is a particular severe disturbance. Fig.5 shows the effect of the metal plate on the input response of a non-adaptive tunable patch antenna. The resonant frequency increased by 30 MHz from 1516 MHz to 1546 MHz and the reflected power increased 13dB, from -14dB to -1dB, at the original resonant frequency (1516 MHz).

A. Transmitted Power (Transmit mode)

A direct transmission link was established using a HP 8780A Vector Signal Generator and the tunable patch antenna as a transmitter. The receiver comprised of a dipole antenna and a HP 8594A Spectrum Analyser, that was used to measure the transmitted power. Fig.6 shows the transmitted power for adaptive feedback and non-adaptive tunable patch antennas. It can be seen that the maximum transmitted powers when undisturbed were practically equal (~-53dB) for the both non-adaptive and the adaptive antennas, the non-adaptive being slightly larger. When subjected to the disturbance, it can be seen that the adaptive antenna improved the transmitted power by 5 dB, see Fig.7. The transmitted power of the adaptive antenna was slightly higher (~1dB) disturbed than undisturbed, due to the diffraction from the edges of the metal sheet, producing a more narrow beam.

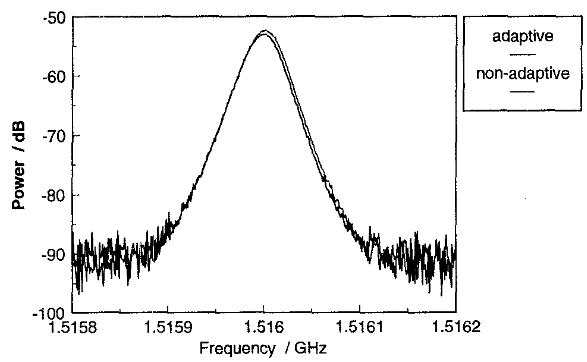

Fig.6 Transmitted power of undisturbed adaptive and non-adaptive antenna.

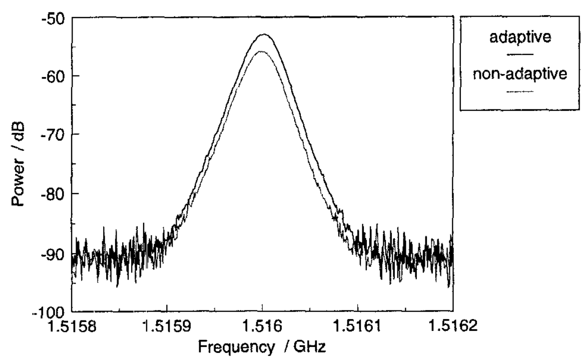

Fig.7 Transmitted power of disturbed adaptive and non-adaptive antenna.

B. Bit Error Rate (Transmit mode)

A complete FSK wireless system (direct link) was used to measure the Bit-Error-Rate. The transmitter consisted of an Anritsu ME520 transmitter using an external generated clock, HP 8780A Vector Signal Generator and tunable patch antenna. The receiver was made up of a resonant dipole antenna, HP 8594A Spectrum Analyser functioning as a FM demodulator and Anritsu ME520 receiver. The transmission rate was set to 10 kbits/s, and the distance between the transmitter and receiver was approximately 2m. The measured bit error rate (BER) for the adaptive and non-adaptive antenna when undisturbed were $6.3x10^{-6}$ and $5.2x10^{-6}$, respectively, Fig.8.

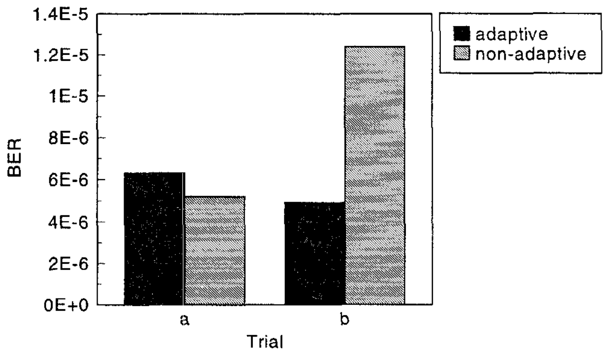

Fig.8 Measured BER of adaptive and non-adaptive antenna a) undisturbed, b) disturbed.

The better performance can be explained by the slightly larger transmit power measured in the previous section (see Fig.5). Next the metal plate was placed in front of the antenna and from fig.8 it can be seen that the adaptive feedback improved the bit error rate from $1.2x10^{-5}$ to $4.9x10^{-6}$. Note that the introduction of the metal did improve the bit error rate for the adaptive antenna. Again, this is consistent with the observation made in section III.A, the increased directivity gain of the antenna.

C. Bit Error Rate (Receive Mode)

A complete FSK system was used to measure the bit-error rate (BER). The transmitter comprised of an Anritsu ME520 transmitter using external generated clock, HP 8780A Vector Signal Generator and the dipole antenna. The receiver was made up of tunable patch antenna, HP 8594A Spectrum Analyser functioning as a FM demodulator and Anritsu ME520 receiver. The IF output port of the HP 8594A was connected to the peak detector of the adaptive feedback. The distance between the transmitter and receiver was approximately 2m. The measured BER, over a 4 minutes period, for adaptive and non-adaptive tunable antennas when undisturbed were $1.1x10^{-5}$ and $1.0x10^{-5}$, respectively. In order to verify the performance of the adaptive feedback the metal sheet was again placed 20mm in front of the antenna to disturb the frequency response of the tunable antenna. Fig.9 shows the measured bit error rate of adaptive and non-adaptive tunable patch antenna. It can be seen that the bit error rate of the adaptive feedback antenna was lower than that of the non-adaptive antenna, namely $1.6x10^{-5}$ compared to $3.1x10^{-5}$. The results show that the adaptive feedback enabled the antenna to improve the bit error rate compared to a non-adaptive antenna, while experiencing changes in its input response.

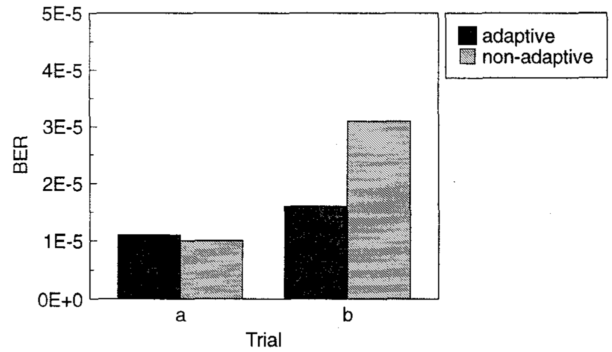

Fig.9 Bit error rate measurements of adaptive and non-adaptive antennas (no Doppler shift) a) undisturbed b) disturbed.

To see how the algorithm coped with fading the transmitted signal was sent through a HP multipath simulator with a 150 Hz Doppler shift. This resulted in a time varying response, as can be confirmed by the time response at the detector output, see Fig.10. The metal sheet was again introduced as a disturbance and the bit error rate readings for the adaptive and non-adaptive patch antennas were measured. Fig.11 shows that the BER for the adaptive antenna were $9.4x10^{-6}$ (undisturbed) and $1.6x10^{-5}$ (disturbed). The measured BER for the non-adaptive antenna was $1.1x10^{-5}$ and $4.1x10^{-5}$ for the undisturbed disturbed case, respectively.

The results presented indicates that there is room for improvements, since ideally, the performance of the adaptive antenna when disturbed should be close to that of an undisturbed non-adaptive antenna. Two main areas for improvement have been identified. When the receiver is operated in fast fading environment the response time of the system becomes crucial. The faster response time means that the system can regain matched state quicker. The response time is mainly determined by the sampling rate, so by increasing the sampling rate the performance of the system should improve. Another approach being considered is the development of a more robust (intelligent) algorithm, which performs better in a time varying environment

A well known method of reducing the effects of fading is the use of diversity reception techniques [4]. The proposed receiving system can easily be modified to accommodate space diversity, assuming the transceiver allows for employment of more than one receiving antenna. This would require no additional hardware as the diversity algorithm can be implemented using the existing microprocessor.

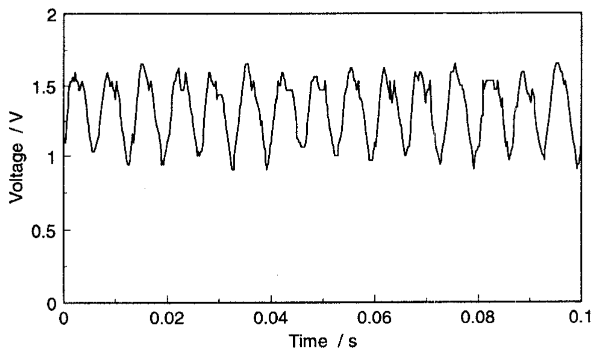

Fig.10 Input to ADC when Doppler shift applied.

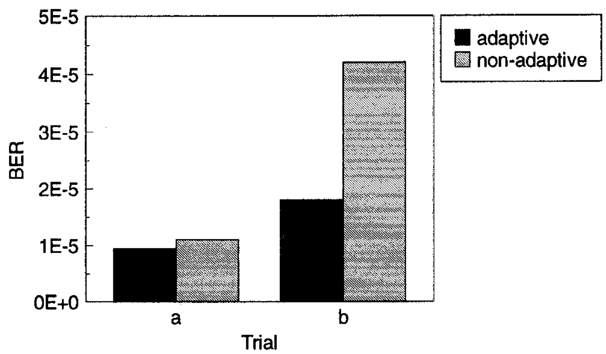

Fig.11 Bit error rate measurements of adaptive and non-adaptive antennas (including Doppler shift) a) undisturbed b) disturbed.

IV. CONCLUSION

An adaptive frequency tunable microstrip antenna which is capable of counteracting any degradation in the antenna-feed match caused by external disturbances has been presented. The performance of the antenna has been evaluated in terms of transmitted power and bit error rate when used in transmit mode, and in terms of bit error rate while being subjected to a time varying received signal in received mode. It has been shown that the performance of the adaptive antenna when subjected to an external disturbance approaches that of an undisturbed non-adaptive antenna.

ACKNOWLEDGEMENT

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