

AUTOMATIC TUNING OF ELECTRICAL SMALL ANTENNAS

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Abstract: RF frequency band is widely used for different applications such as RFID and digital radio communication. RFID systems operating at 13.56MHz are used for access control, public transport and credit cards. A 300kHz band centered around 27MHz which has been used for citizen band radio (CB) and is now finding new use for digital radio devices mainly for human interface applications. All these devices use electrically small antennas since electrically proper antennas would have dimensions in meters. Electrically small antennas are in essence LC tanks that project magnetic field (magnetic dipole) or electrical field (electrical dipole) into their surroundings. LC tanks operating as antennas are relatively sensitive to mistuning due to large dimension of coils (in case of magnetic dipole). Proximity of conducting material changes the inductance of the coil due to eddy current generated in the conductive material. Material with different dielectric constant changes coil's parasitic capacitance. Proposed automatic antenna tuning system solves this problem for low power and medium power systems up to 0.5W

The comparison of amplitude and phase criteria of resonance is given in section 2. Section 3 describes the implementation of phase measurement which offers sufficient precision for antenna tuning. The actuation part of the automatic tuning is described in section 4. Added are some practical data gained by implementing this principle in RFID reader for proximity standards on 13.56MHz.

Samodejno uglaševanje električno majhnih anten

Ključne besede: električno majhne antene, uglaševanje anten, meritev faze

Izvleček: Frekvenčno področje RF se uporablja za različne aplikacije, kot so RFID sistemi in sistemi za digitalno brezžično komunikacijo. V tem področju delujejo tudi RFID sistemi z nosilno frekvenco 13.56MHz, ki jih uporabljamo za kontrolo dostopa, plačilo javnega prevoza in tudi za kreditne kartice. 300kHz pas v okolici 27MHz, ki je bil včasih namenjen amaterskim CB postajam pa sedaj pogosto uporabljajo sistemi za bližinsko brezžično digitalno komunikacijo, kot so brezžične računalniške miške ali pa športne ure s tipali. Vse te naprave uporabljajo električno majhne antene, saj bi drugače antene bile bistveno prevelike. Električno majhne antene so LC nihajni krogi, ki v okolico širijo magnetno (magnetni dipol) ali električno (električni dipol) polje. Takšne antene pa so občutljive na razglasitev, saj so dimenzije tuljav (v primeru magnetne dipol antene) relativno velike. Če takšni tuljavi približamo prevodni material, se njena induktivnost zniža zaradi vrtničnih tokov, induciranih v prevodnem materialu. Material z drugačno dielektričnostjo pa spremeni parazitno kapacitivnost tuljave. Predlagana avtomatska uglašitev rešuje te probleme za sisteme z malo in srednjo oddajano močjo do 0.5W.

Primerjava meritve faze in amplitude kot kriterija resonance, je podana v drugem razdelku. V tretjem opišemo izvedbo meritve faze, ki zagotavlja točnost, potrebno za izvedbo avtomatske uglasitve antene. Veže za uglasitev antene pa je opisano v četrtem razdelku. Podani so tudi nekateri praktični vidiki uporabe takšnega sistema v izpraševalniku pametnih kartic delujočem v frekvenčnem področju 13.56MHz.

1. Introduction

Electrical small antennas can be configured as parallel resonance circuit, serial resonance circuit or a combination of both. Pure parallel resonance is used for receiving antenna where high impedance of parallel resonance yields higher receive voltage. Pure serial resonance is best fit for high power transmit antenna where low impedance of serial resonance enables high power at limited supply voltage. Combination of both offers a very versatile solution which can be used for low and mid power transmit systems (from few mW to 1W) and can provide separate connections points for receive and transmit side. Fig. 1 presents eclectically small magnetic dipole antenna employing such configuration. The transmit power amplifier is connected to RF_tran node and the ratio between the serial capacitance Cser and the parallel capacitance composed of the sum of Cpar and capacitor divider C2/C1 defines the impedance on the node RF_tran. This in turn defines the power the amplifier will deliver to the antenna. The power can thus be efficiently defined by the ration of parallel and serial capacitance. Receiving signal is taken

directly from the parallel resonance where the signal is highest. If the transmitter is not active during receive the node RF_out is connected to ground not to change the resonant frequency. If the transmit is active during receive as in case of RFID systems, receive signal level can be adjusted using a capacitive divider (C1/C2 in fig. 1) since the signal amplitude on the coils is typically much higher than the supply voltage of the chip.

2. Basic principle of antenna tuning

It is well known fact that the voltage amplitude on antenna coil connections is highest when the LC tank is in resonance. When in resonance the phase difference between the signal on node RF_tran, where the transmit signal is forced to the antenna, and signal on node ant is 90 degrees. This gives us two evaluation parameters on which the antenna tuning system can be based. Figure 2 presents the dependence of the signal amplitude on node ant as a function of frequency for three different Q factors in canvas one and the phase difference for same frequency span and Q factors in canvas 2. Solid lines are simulation re-

sults for $Q=10$, dashed lines for $Q=20$ and dash-dot lines for $Q=30$.

Phase difference is obviously a much better criterion for evaluation the antenna tuning since it not relative but absolute criteria. In case of amplitude the maximum has to be identified before amplitude can be used as tuning criteria but the phase criteria is absolute. Phase also contains the information if the antenna resonance is to low or too high, while the amplitude does not discriminate between the two sides. In spite of this practically all existing systems use amplitude criteria /1, 2/ for determination the antenna resonance. The amplitude is much easier to measure compared to the phase. The phase measurement is extremely sensitive to the difference in delays in both comparison branches what makes the implementation of phase based calibration more problematic in spite of its obvious advantages as resonance criteria. Solving these problems is the key to an efficient antenna tuning system.

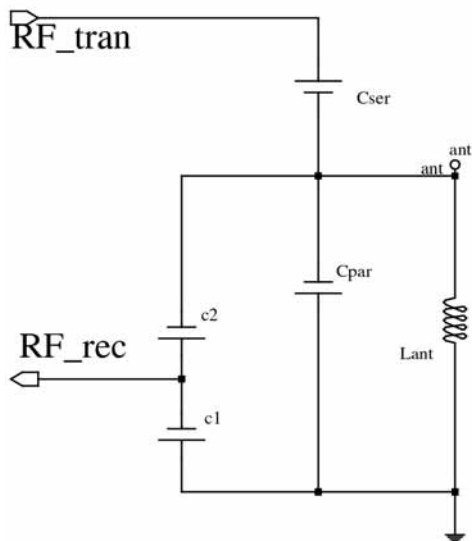


Fig. 1: Electrically small antenna with separate connection nodes for receive and transmit.

3. Phase measurement system

The signal the transmit output is generating is usually square-wave rail to rail signal since this is the most power efficient way to deliver power to the antenna. The antenna LC tank shapes this into sine-wave signal so the signal entering the receive path is sine-wave shaped. The input signal must be scaled to fit the chip's supply rails by a capacitive divider. Using resistor divider would introduce additional phase shift due to the input capacitance of chip's input pin. This means the phase measurement must be done on two signals, one being a square-wave (transmitter output signal) and one being sine-wave, having similar amplitude close to chip supply rails. To use analog down-conversion mixing stage for phase measurement we would need to scale both signals to proper amplitude (~200mVp) and shift their DC levels accordingly using internal voltage

reference /3/. In case of significant variation in receive signal amplitude an automatic amplitude control system would be required /4/. We decided for a less complicated digital mixing system. This means both signals have to be square-wave shaped so the input signal has to be digitized before the digital mixing. The digitizing comparator introduces additional delay in the range of few nanoseconds thus corrupting the measurement since 1ns corresponds to 4 degree in phase at 13.56MHz. To compensate the comparator delay over the complete operational supply voltage and temperature range we introduced same comparator also in the second signal branch although the transmit output signal is already square shaped. The proposed solution is presented on figure 2.

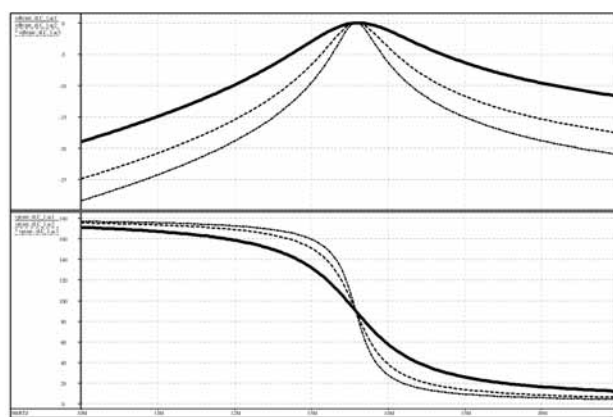


Fig. 2. Dependence of amplitude and phase on the frequency

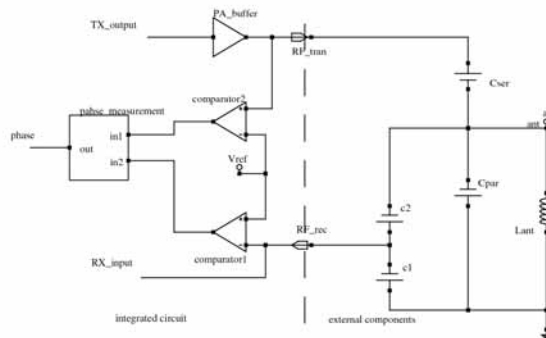


Fig. 2: Compensation of digitizing delay by adding a dummy comparator

Special care was taken to equalize the comparator delay for sine and square shaped signals so that the delay does not differ for more than 0,3ns. Using the capacitor divider to scale the signal and adding the dummy comparator to equalize the delay in both signal paths enables the use of digital mixing stage as presented in fig. 3.

In case of 90 degree phase difference between the two input signals the resulting signal is twice the input frequency with 50% duty ratio. The high frequency is removed with second order passive low pass so that the DC mixing component is presented on the phase output. In case of 90

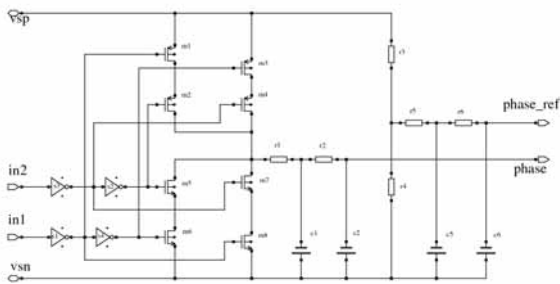


Fig. 3: Digital mixing circuit with improved PSRR

degree phase difference the DC level is equal to half of supply level. This means the absolute value of the phase output also dependant on supply level resulting in extremely poor PSRR. To improve PSRR the output was made differential with half of supply as the reference voltage. PSRR stability owner frequency was improved additionally by introducing the same second stage low pass filtering used in signal path is also in the reference voltage path. The result is high and frequency stable PSRR.

4. Implementation of antenna tuning

Once we have reliable criteria of antenna resonance like phase measurement the antenna tuning can be performed by changing the inductance or capacitance of the LC tank. The implementation can be done either by parallel elements or serial elements. To use serial elements for tuning low resistance switches have to be used not to degrade the quality factor of the LC tank. These switches would shunt part of the inductance or serial capacitance so all the currents in LC tank would flow through them. The voltage amplitude of the LC tank is typically much higher (10Vp to 100Vp for mid power systems) than the supply voltage of the integrated circuit so shunting even 15% of the inductor or capacitor would require capability to handle voltages far above the supply rail of the chip together with the demand for low on resistance. As a rule high voltage and low resistance are conflicting demands for switch deign. For practical realization the use of parallel elements (parallel capacitors) proved to be more feasible to realize with simple CMOS technology. The simplest high voltage element to be implementing in standard CMOS technology flow is a high voltage NMOS transistor where only the drain can be exposed to high voltage. Such transistors can be used to switch the parallel capacitors to the LC tank thus changing the effective resonance capacitance. When the switch is off the drain of high voltage transistor is exposed to similar maximum voltage equal to peak-to-peak voltage on the LC tank, since the drain of high voltage transistor cannot swing below the low supply of the integrated circuit so the serial capacitor charges to a DC voltage equal to one half of peak-to-peak amplitude. When the switch is on the resistance of the switch is not so critical since only a minor portion of the current in LC tank flows through it. The on resistance can be an order of magnitude higher compared to the serial trimming topology and thus much easier to implement.

The simplified schematic of actual realization is presented in figure 4.

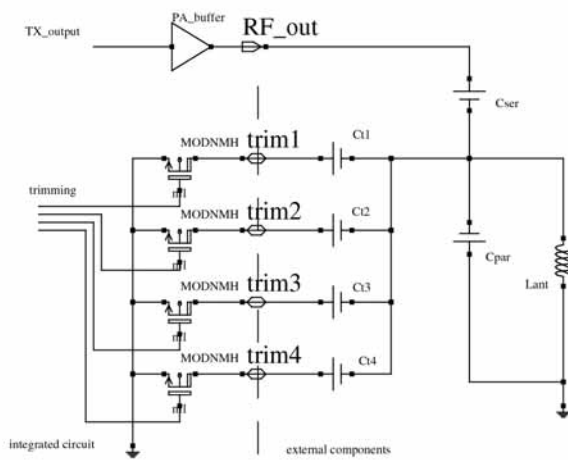


Fig. 4: Implementation of trimming using high voltage NMOS transistors.

The automatic calibration loop was implemented using 4 bit counter which was controlled by the output of phase measurement system. When the automatic calibration is initiated the counter is preset to a mid value and the phase measurement is switched on. Following a delay required the by the settling behavior of the system the output is evaluated by a window comparator. The result is either resonant frequency low, resonant frequency high or resonant frequency inside the desired limits. If the resonant frequency is to low or too high the counter controlling the switches is increment of decremented depending on the phase measurement result. The measurement period is repeated and the counter value changed till the phase measurement yields a result inside desired limits.

5. Conclusion

In practical application a +- 15% trimming range of capacitance resulting in +-7.5% resonant frequency trimming range already proves to be sufficient. It suffices to compensate the effects of mistuning due to temperature changes, aging and the proximity of conductive objects. The main advantage of system equipped with automatic antenna tuning is that for the lifetime of the product there is no need for service intervention which is often required in other systems due to mistuning of the antenna LC tank.

The main limitation of this principle is the maximum voltage the high voltage NMOS switches can handle. The maximum voltage allowed directly limits the transmit power. For this reason we used differential drivers and differential antenna configuration thus doubling the ration between the antenna peak-to-peak voltage and the maximum voltage NMOS switches are designed for. Using differential topology and antenna coil geometry which minimizes the inductance value the antenna trimming system can operate with 400mW reader output power. Applications with higher

power are possible, but they need a capacitive divider for the signal connected to the trimming capacitor bank limiting the peak-to-peak voltage to 30V. The penalty paid is a reduced trimming range.

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