Injection Locking in Active Antenna

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***Abstract*—An oscillator type active antenna is designed using two-port microstrip antenna as feedback element for RF BJT amplifier. The injection locking of active antenna is demonstrated in time domain for first time. As per the reported literature active antenna circuit takes some time to lock at the frequency of injection signal. The locking time delay depends on injected power level and difference of active antenna free-running frequency and injected signal frequency. However it is observed experimentally for the first time that the dependency is weak, and only near the edge of the locking band does the locking delay rise sharply.**

***Index Terms*— Active antenna, injection locking, time domain**

I. Introduction

Active Antenna (AA) consists of a passive antenna and an active device integrated on a single chip or substrate to process (amplify / generate / filter /combine / frequency conversion etc.) signal which may be self-generated. AAs are used in RFID, jammer, satellite, biomedical applications, radio astronomy, personal communication systems, wireless local networks etc. [1-2].

Injection locking is an important concept in oscillator circuits where a small signal of nearly same frequency is injected into a free running oscillator. The injected signal forces the oscillator to shift the free running signal frequency to injected frequency. When the phase difference between oscillator signal and injected signal is constant, the injected signal locks the frequency of the oscillator. The oscillator frequency changes with injected signal frequency. As the difference between oscillator's free running frequency and injection frequency increases the phase difference between two also increases and finally the oscillator gets unlocked. The range of injected frequencies for which oscillator is locked is called the locking bandwidth.

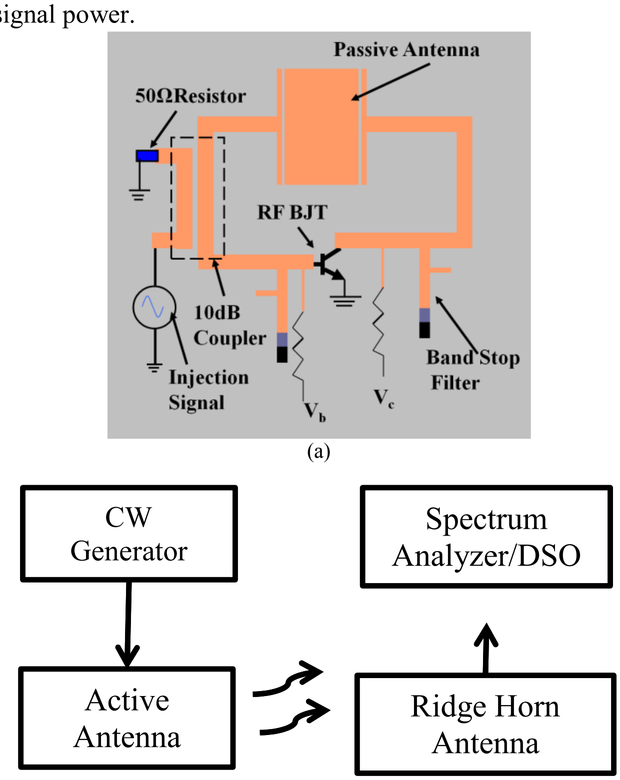
Injection locking of the oscillator type active antenna from [3] is reported here. Several studies on injection locking of active antennas in frequency domain are reported e.g. [4]. The external signal, in this case, is usually injected into the active antenna through a coupler. Time domain measurements are often useful in understanding the delays in any circuit.

In this report we report a systematic study of injection locking in active antennas in time domain. The locking delay is important in communication systems, because a delay of 100 nSec results in missing of 500 cycles at 5GHz. Time domain measurements provide accurate estimation of the locking delay.

II. Injection Locking In Active Antenna

A) Frequency domain study

An active antenna (fig. 1a) is biased at $V_c = 2.15$ V, $V_b = 0.6$ mV and $I_c = 18$ mA. With this a -30 dBm signal at 5.733GHz is received at a UWB horn antenna placed at 85cm from active antenna. The detailed study about this antenna, including radiation properties and use in array is given in [3]. A locking signal (CW) is injected through a 10 dB coupler. The experimental setup is shown in fig. 1b. The frequency and the power of the injected signal are varied. With this, the locking bandwidth achieved is of the order of a few MHz shown in Table I. This experiment supports that injection locking in oscillator type active antenna is possible. It is observed that locking range is proportional to the injection signal power.



(b)
Fig.1. (a) Schematic of the active antenna with injection locking. (b) Block diagram for frequency domain measurements

TABLE I: INJECTION POWER AND LOCKING BANDWIDTH.

Power level (dBm)	Locking frequency range (GHz)	Locking bandwidth (MHz)
-10	5.721 – 5.739	18
-5	5.717 – 5.741	24
0	5.697 – 5.781	84
5	5.684 – 5.833	149
10	5.651 – 5.967	316

As the oscillator type active antenna is biased, this transmits the free running frequency f_s. As shown in Fig. 2a. An external signal of small strength and nearly same frequency f_i as that of of AA is injected through a 10 dB coupler. These two frequencies are distinct as shown in Fig. 2b. As we increase the injection frequency, the AA gets locked to a locking frequency f_l as shown in Fig.2c.

Increasing the frequency of the injected signal results in increase in the amplitude of the locked signal. When $f_s = f_i$, the amplitude of f_l becomes more than the AA as shown in fig. 2d. Further increasing the injected signal frequency decreases the amplitude of the locked signal. Still further increase in injected signal frequency leads to unlocking of AA (Fig. 2e). The range of injection signal frequency (f_{l2}-f_{l1}) for which active antenna is locked is known as the locking bandwidth. Similar locking bandwidth is observed when the frequency of the injection signal is decreased from a higher value than the AA frequency. It is also observed that with increase in strength of the injection signal, the injection bandwidth increases.

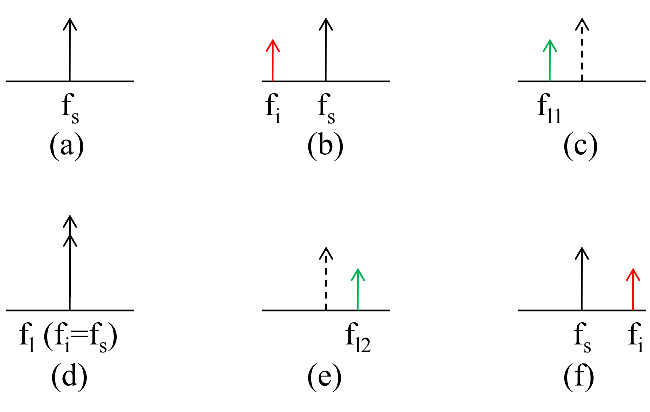


Fig.2 Injection locking in active antenna frequency verses amplitude representation

B) Time domain study

A pulse signal of Vpp=2Volt, 50% duty cycle and 20 MHz / 32bit is modulated with CW carrier of frequency 'fi' (injection frequency). The chopped signal is divided into two; one is injected into the antenna through 10 dB coupler and second is used as reference injection signal in a digital storage oscilloscope (DSO : Agilent Infiniium DSO-X 92504A, 25 GHz) to study injection locking of active antenna signal in time domain. This coupler is made along the active antenna feedback loop. The signal is received by 10dB horn antenna; this signal is sent to DSO through coaxial cable of length 1m. Setup is shown in Fig.3. The lock and unlock frequencies are 5.721 & 5.739 GHz corresponding to injection power of -10 dBm at the coupler input. Hence the difference frequency locking is 18 MHz that is locking bandwidth. Active Antenna's free running frequency is 5.730 GHz. Initially active antenna is a free running oscillator, as frequency of injection signal increases the variation in received signal is observed. Two different frequencies give birth to beat frequency. As injection frequency approaches near to antenna frequency, beat frequency decreases and after that injection signal forces the antenna signal to lock at injection frequency. Further increase in injection frequency just locks the antenna, with some delay. When antenna signal frequency and injection frequency are same the amplitude of locked signal is maximum and locking delay time minimum. As injection signal frequency increases from antenna frequency the locking delay increases and after some value of injection frequency antenna become unlock. Further increase of injection frequency gives birth to beat frequency .The reference injection signal (lowest trace), receiver antenna signal (middle trace) and processed signal (upper trace) are shown in Fig.4. The processed signal is 500MHz low pass filter output of product of reference injection signal and receiver antenna signal. The processed signal obtain DC level in locked condition and sinusoidal signal in unlocked condition, The frequency of this sinusoidal signal is equal to beat frequency and amplitude is function of frequency difference. The locking delay is measured 1dB down from the maximum value and 1dB up from minimum value as depicted in Fig5.

Fig.3 Experiment setup time domain

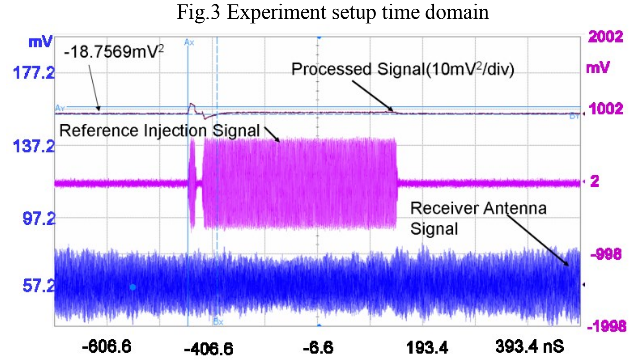


Fig.4. Time domain signals displayed on DSO

III. LOCKING DELAY

As per the reported literatures active antenna circuit takes some time to lock at the frequency of injection signal. The locking time delay depends on injected power level and difference of two frequencies i.e. active antenna and injected signal. When the injected signal frequency is far enough to the active antenna frequency but try to lock the antenna takes more time to lock usually of the order of 100nsec. As the injection signal frequency approaches towards antenna frequency, this locking time reduces. When both frequencies become nearly same the locking delay reduces to minimum and of the order of 16nsec shown in Fig.6.

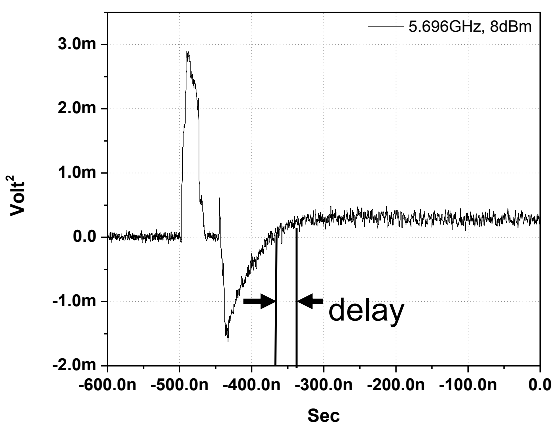


Fig.5. Processed signal for delay measurement

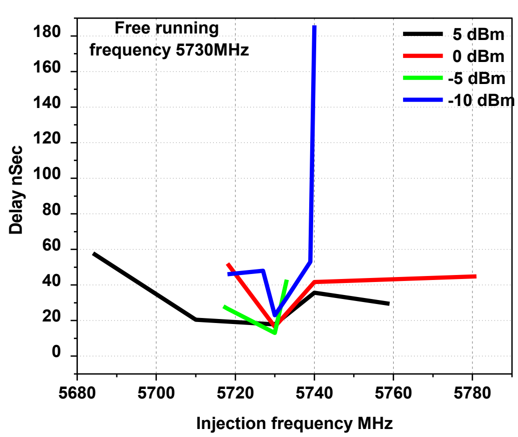


Fig.6. Injection signal frequency v/s locking delay

This may happen because of time require for changing phase of free running signals. Further the injection frequency goes away from free running frequency the locking delay increases and active antenna becomes unlock. Fig.7 shows the graph between injection signal power and locking time delay corresponding to different injection frequencies (5.74, 5.73, and 5.71GHz).

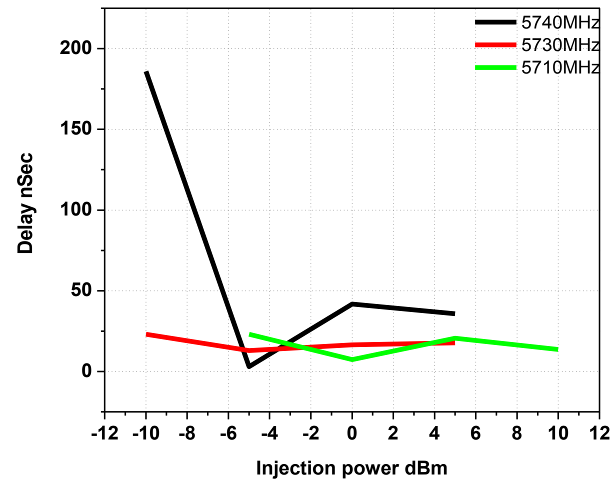


Fig.7. Injection signal power v/s locking delay.

At injection frequency of 5.730GHz as injection power increases locking time delay decreases first then increase. 5740 and 5710 MHz curves also follow this trend but once again the delay decreases because the injection power becomes comparable to active antenna signal power. The low power injection signal unable to lock the free running frequency like at -10dBm injection signal does not lock the active antenna frequency at 5700 MHz while injection signal of 5 dBm strength locks the free running frequency of active antenna. The locking delay as shown in figures includes the propagation delay and delay between receiver antenna and DSO. These delays are approx. 6 nsec. The important observation is that the **locking delay does not depend strongly on either injection frequency or injection power except close to the edges of the locking band where it rises sharply.**

For an efficient communication system the locking delay must be small. To reduce the delay the quality factor Q of the resonator that is antenna should be sufficiently high. Hence two port passive antenna is modeled as series RLC. The passive antenna model has L=30nH, C=0.03pF and R=20.3Ohm and Q=50, Fig. 8. The different sets of series RLC are used to get resonators of different quality factor (Q) at same frequency. Then active antenna using these resonators is simulated in Agilent ADS. *It is observed that delay decreases with increase in Q but at very high Q delay again increases* as shown in Table II.

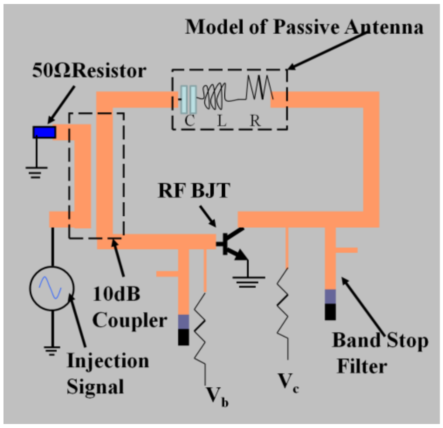


Fig.8 Schematic of injection locking

TABLE II: Quality factor and locking delay

L (nH)	C (pF)	R (Ohm)	Q	Delay (n sec)
15	0.06	20.323	24.6	200.6
30	0.03	20	50	90.8
320	0.003	20.323	508	57
3004	0.00033	20.323	4689	120

Two port antennas of different quality factor are simulated and used for active antenna design. These active antennas of different quality factor are simulated in ADS for studying of injection locking delay. The locking delay does not much depends on quality factor except at the high Q value, where active antenna remains unlocked.

IV. CONCLUSION

Time domain injection locking of an active antenna is studied and novel behavior of the locking delay is brought out through measurement. The locking time delay is expected to depend on injected power level and difference of active antenna free-running frequency and injected signal frequency. However it is observed experimentally for the first time that the dependency is weak, and only near the edge of the locking band does the locking delay rise sharply.

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