RJF IonMetrics Inc. 5-14-07

DMS Operating Point Analysis and the Circuit Design

Background

The existing FAIMS (DMS) cells that we have been referencing have been driven by a waveform formed by summing two sine wave into a Fourier approximation of an asymmetrical square wave with an amplitude of 1000 Volts for approximately .5 micro-sec (usec) and an amplitude of –500 volts for 1 usec. Up to this time we have taken that timing for granted. Now that we are trying to re-invent the waveform the roots of the existing waveform are being reconsidered to see what the boundaries are.

Mobility and Field Strength

Fig 1. below shows the basis for Ion Mobility spectrometry. The upper portion of the curves show the behavior of monomers which exhibit an increased mobility with increased field strength. The bottom curves are for dimers which exhibit a reduction of mobility with increased field strength. The field strength is given in Townsends which are defined so that 1 Td = 10^{-17} Volt-Cm^2. Since the field is divided by number density to arrive at Townsends, it is convenient to note that at STP 80 Td represents a field strength of approximately 21,300 Volts/Cm.

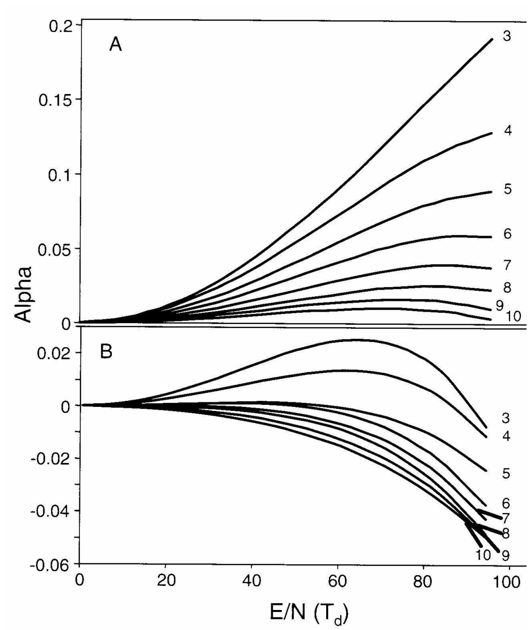

Fig 1. Mobility coefficients for various ions vs. field strengths.

From the spreading of the curves it is proposed that mobility separation occurs at fields greater than 10 Townsends and operation anywhere between 10 and 40 TD seems reasonable. Note that at a spacing between the electrodes of 1 mm, 10 TD represents 267 volts. The design of the circuit requires that we keep the length of the up pulse as long as possible in order to keep the average power low. This then poses the question as to how long can the pulse be. We need to be either at a low enough voltage, or a short enough time or a great enough spacing so that the ion does not strike the electrode before the field reverses and changes the direction of the ion away from the electrode. Since the field strength needs to be kept high to get the separation the only option at a certain number of Townsends is to keep the pulse length short. If the average location of the incoming ions is assumed to be in the center, then we need to know how long it takes, at the maximum field, for an ion to travel S/2, where S is the spacing between the electrodes.

The velocity of an ion is given as K*E where K is the reduced mobility in CM^2/Volt sec. For large molecules the reduced mobility lies between 2 and .5 so the worst-case velocity is less than 2 times the field strength.

$$V =< 2*E$$

Then the time to reach crash is S/2 divided by 2*E or:

$$T=S/4*E$$

For the instruments now being tested they use about 40 Td. This is 10,500 Volts/Cm and the time to crash is S/4*10,500. In this case they assumed that S= 0.1 Cm

Therefore: $T=.1 /42000=2.3$ usec.

In our case we have been planning on .5 mm spacing and therefore keeping the same field strength in the worst case of 40Td we would use 500Volts up. Then we would need the same up time and 2 usec should be OK. It is really not necessary to work at 40 TD. One could make a case always for higher separations, but the device should work down to 125 volts up if needed. Two effects should be expected, however, if the voltage is reduced.

1. There is less difference in mobility between the up and down so the compensation is less thereby decreasing resolution to some extent.
2. The ions go thru smaller steps, therefore the wrong ions should hang around longer and thereby requiring more time to get to equilibrium minimums.

Power Considerations

The energy to charge a capacitor is V^2C no mater how fast the charging rate. If we have V_1 up and V_2 And noting that the average power is the sum of the energies divided by the total time:

$$\text{Power} = (2*V_1^2C+2V_2^2C) /(T_1+T_2)$$

We know we need equal energies to keep the ions approximately in the center so $V_1T_1 = V_2T_2$
Then finally the average power is given by:

$$P=2CV_1^2/(T_1+T_2)\ [1+(T_1/T_2)^2]$$

The case for making T_2 long is clear in this equation. I should now be also obvious that instead of having circuitry place a compensating voltage on the electrodes it can be accomplished by adjusting T_2 on the fly.

For the circuit currently under development a rough calculation for T_1=2 usec, T_2= 8 usec, $V_{1=}$400 volts and a capacitance in the FETs of 70 pico-farads we get an average power calculated as 2.8 Watts. This is in fair agreement with the simulation data for the prototype circuit currently under assembly.