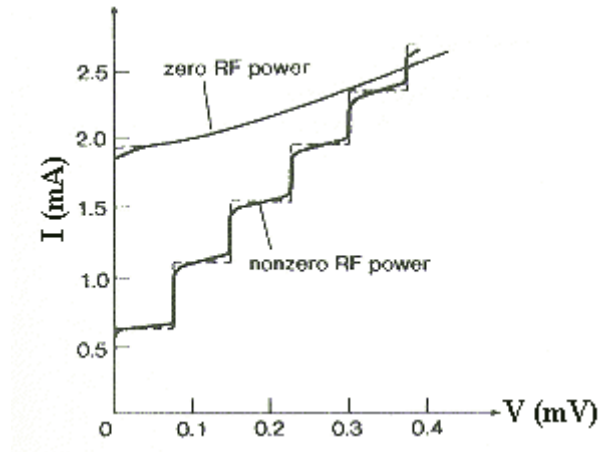5.    *Josephson Tunneling*        Experimental data from a Josephson junction is shown in the figure.  (a)  What is the critical current $I_c$ ?  (b)  When no RF power is applied, what is the phase difference of phase across the junction at I=1.0mA?  (c)  When RF radiation is applied, Shapiro steps are formed.  Judging from the figure, what is the frequency of the microwave radiation?



(a)    Critical current is the maximum current at zero bias (V=0).  Judging from the figure, $I_c \sim 1.85$ mA.

(b)
$$I = I_c \sin\phi \Rightarrow 1 = 1.85 \sin\phi$$
$$\Rightarrow \sin\phi = 0.5405$$
$$\Rightarrow \phi = 32.7^{o}$$

(c)

$$\text{Shapiro step width} = \Delta V = \frac{hf}{2e}$$

Judging from the figure,  width if 5 steps $\approx 0.38$ mV

$$\therefore \Delta V = \frac{0.38}{5} = 0.076 \text{ mV}$$

$$\therefore 0.076 \times 10^{-3} = \frac{6.626 \times 10^{-34} f}{2 \times 1.602 \times 10^{-19}}$$

$$\Rightarrow f = \frac{0.076 \times 10^{-3} \times 2 \times 1.602 \times 10^{-19}}{6.626 \times 10^{-34}}$$

$$= 3.67 \times 10^{10} \text{ Hz}$$
$$\approx 37 \text{ GHz}$$