$$s(t) = \cos\left(2\pi f_c t - 2\pi \frac{f_c}{t} \sqrt{x_o{}^2 + (y_o + vt)^2} \right) = \cos\left[\Psi(t)\right]$$

$$f_i(t) = \frac{1}{2\pi} \frac{d\left[\Psi(t)\right]}{dt} = \frac{1}{2\pi} \frac{d}{dt} \left(2\pi f_c t - 2\pi \frac{f_c}{t} \sqrt{x_o{}^2 + \left(y_o + vt\right)^2} \right)$$

$$f_i(t) = f_c - \frac{2 f_c v}{c} \frac{y_o + vt}{\sqrt{x_o{}^2 + \left(y_o + vt\right)^2}}$$