Efficiency of Charge Pump Inverter.

Peter Sladek, Czech Republic, 23rd of June 2004. ASIX Ltd. async@centrum.cz

One pump stage: supply plus bulky capacitor.

Imagine connection: DC supply – switch(R_{SW}) – capacitor(C_{bulk}) – load(constant current sink).

During charging (switch ON) bulky cap is connected to supply with resistor (i.e. MOSFET's Rdson). Current thru switch is given by: $i(t) = I_{max}.e^{\frac{-t}{\tau}}$

Dissipated energy (which must be wasted to heat because of principle of operation and toplogy) is (finished transition):

$$E_{DIS} = \int_0^\infty R_{SW}.i^2(t)dt = R_{SW} I_{max}^2 \int_0^\infty e^{\frac{-2t}{\tau}} dt =$$

$$= R_{SW} I_{max}^2 \left[-\frac{\tau}{2} e^{-2t/\tau} \right]_0^\infty = R_{SW} I_{max}^2 \frac{\tau}{2} = \frac{R_{SW}^2 I_{max}^2 C_{bulk}}{2}$$

DC supply gives $U + \Delta U$ voltage, C_{bulk} was charged to voltage U thus $I_{max} = \Delta U / R_{SW}$. After charging is complete capacitor is charged to $U + \Delta U$.

Switch OFF: discharging bulky cap with constant current load I_{AV}.

$$\Delta U = \frac{I_{AV}}{C_{bulk}} \Delta t$$

$$I_{max} = \frac{I_{AV}}{C_{bulk} R_{SW}} \Delta t$$

Thus ($C_{bulk} \equiv C$)

$$E_{DIS} = \frac{I_{AV}^2}{2C} \Delta t^2 = \frac{I_{AV}^2}{2C f^2}$$

Approximation (I_{max} falls to 10% of initial value):

$$P_{DIS} = \frac{I_{AV}^2}{2Cf}$$

Transfered energy to C (finished transition):

$$E_{TRD} = \int_0^\infty i(t)u(t)dt = \int_0^\infty I_{max}.e^{\frac{-t}{\tau}} (U + \Delta U(1 - e^{-t/\tau}))dt =$$

$$= I_{max} U \int_0^\infty e^{\frac{-t}{\tau}} (1 + \tilde{r}(1 - e^{-t/\tau}))dt$$

ripple $\tilde{r} = \Delta U / U$

$$\int_0^\infty e^{\frac{-t}{\tau}} (1 + \tilde{r}(1 - e^{-t/\tau}))dt = \int_0^\infty e^{-t/\tau} + \tilde{r} \int_0^\infty e^{-t/\tau} dt - \tilde{r} \int_0^\infty e^{-2t/\tau} dt =$$

$$= \tau + \tilde{r}\tau - \frac{\tilde{r}\tau}{2} = \tau(1 + \frac{\tilde{r}}{2}) = R_{SW}C(1 + \frac{\tilde{r}}{2})$$

$$E_{TRD} = I_{max}U\tau(1 + \frac{\tilde{r}}{2}) = I_{AV}U\Delta t(1 + \frac{\tilde{r}}{2}) = \frac{I_{AV}U}{f}(1 + \frac{\tilde{r}}{2})$$

Energy transfer efficiency ε:

$$\varepsilon = \frac{E_{TRD}}{E_{TRD} + E_{DIS}} = \frac{(1 + \frac{\tilde{r}}{2})}{(1 + \frac{\tilde{r}}{2}) + \frac{I_{AV}}{2fCU}} \approx \frac{1}{1 + \frac{I_{AV}}{2fCU}}$$

One cap storage stage achieves 99% efficicency if $fCU \geq 50I_{AV}$