CPI Communications & Power Industries

CPI Gen IV operating cost savings – Return on Investment Analysis

The CPI Gen IV KPA has been universally accepted by customers since introduction, and today enjoys an overwhelming position as the amplifier of choice for new or replacement KPAs. There are many features that are essential when considering the purchase of a new KPA, such as reliability, ease of maintenance, and user-friendly interface. However, in the end, it is a cash profit calculation that drives people towards a decision to purchase the Gen IV that has convinced even the most frugal of users. The analysis will show how you can obtain a minimum return of **20 to 50% annual ROI** on your capital investment, plus another **87%** if you are constructing a new facility with UPS and backup generators.

This paper will discuss in basic terms how much energy is actually saved, what is the estimated cash savings, how much does the MSDC technology cost, and what is the return on investment. The result is quite dramatic, with an easy decision to use MSDC in almost any application. This is because MSDC technology reduces energy input to the Klystron by up to **82%.**

First of all, we must compute the baseline-operating mode. For many earth stations, KPAs are run 24 hours a day, 7 days a week, in full beam power mode. The Klystron is powered at full rated voltage; even though the RF demand from the system may be only a few hundred watts compared to the CW rating of 2 to 3 kW depending on band. This mode offers the most flexibility for sudden demands for more carriers or EIRP in case of rain fade. This is the Classic model, as described in addendum #2, "Comparison of Satcom Klystron Performance Under Typical Ground Station Conditions."

In a modified version of this baseline mode, the Classic Power Saver, the Klystron is run at reduced beam voltage, which is still sufficient to allow linear performance at high backoff levels, typically 100W. If more power/headroom is required, the beam voltage can be raised back to full ratings typically within several seconds. This allows power to be conserved over a majority of the time, as full power for rain/peak demand may only be 5% or less of the time.

When the MSDC technology is used, you achieve all the energy-saving benefits of the Classic Power Saver mode, without having to wait several seconds for the voltage to recover during a peak RF demand. MSDC technology permits the Klystron to operate anywhere from zero to full rated RF *without* changing any power supply settings, and still save a significant amount of energy. The Klystron collector automatically redistributes energy to the proper electrode to maximize efficiency. A significant side benefit is that heat is greatly reduced, which improves Klystron life and reliability. (Preliminary results of 700 Gen IVs in the field are showing MTBF of over 100,000 hours, and increasing).

MSDC Klystrons can also be used with Power Saver, resulting in even more energy conservation. There is the drawback of waiting to ramp the voltage up and down during surges, but if this is acceptable, another large improvement in efficiency can be obtained.

The typical Klystron power draw for the four modes are (for C band operating at 100W) are:

A. Classic without power saver	9985W	0% savings
B. Classic with Power saver	4128W	59% savings
C. MSDC without power saver	4127W	59% savings
D. MSDC with power saver	1762W	82% savings

These values do not include the power supply/fan overhead, which adds roughly an 800-1000W constant drain regardless of mode. However, this comparison does show that the basic tube efficiency can be dramatically improved, with the best mode being MSDC Power Saver by a significant margin.

To calculate the savings specifically attributed to MSDC technology, one must compare similar cases, with or without Power Saver. Therefore, Case A must be compared with Case C (both without power saver); Case B must be compared with Case D (both with power saver):

1) Case A - Case C = **5.8 kW saved** with MSDC technology, without Power Saver active

2) Case B – Case D = **2.3 kW saved** with MSDC technology, with Power Saver active

Now we are ready to calculate the savings in cash. With operation 24 hours/day, we will run 8760 hours per year. Using $0.10/kW-hour, (you may get charged more or less):

Therefore, 8760*$0.10 = **$876/year/kW saved**

In comparison 1), this results in savings of **$5,131/year** per amplifier. In comparison 2), the savings are still **$2,073/year** per amplifier.

If you are constructing a new facility, you can save even more on the UPS and generator costs. UPS costs approximately $1,000 per kVA with 5 minute battery capacity, plus generators are around $500 per kVA. You must size the UPS/generator for the worst case full power mode (no Power Saver), since the site very likely will lose power during a storm when the rain fade is maximum, and you need full RF. So, MSDC technology will save money right from the beginning:

(5.8 kW/ 0.95 typ Power factor=6.2 kVA)*$1,500/ kVA = **$8,787 in capital savings**

Is MSDC technology right for you? MSDC technology is mature, but costs more (actual amount varies with frequency band) per KPA. The minimum return on investment, even in the Power Saver Case, is at least **20% per year**. In the non-Power Saver case, the ROI is over **50% per year**. In addition, if you throw in the UPS/generator savings, this is over **87%** return at day one! This beats almost any investment you can make, and is virtually risk free. For most of us, we will put our money on the MSDC Gen IV KPA and collect an excellent return on investment year after year. CPI is available to calculate your exact savings depending on your facility and electrical power rates.

Addendum 1

Explanation of typical operating modes

MODE A
GEN III **POWER 9.9kW**
CLASSIC KLYSTRON **BASELINE**
Standard equipment in use we classify, for comparison, as the baseline-operating mode. Many earth stations run 24 hours a day, 7 days a week, in full beam power mode. The Klystron is powered at full ratings; the RF output capability is 2-3 kW (depending on band) but the RF demand may be only a few hundred watts. This standard mode has provided, until now, the most flexibility for changing demands. This is the Classic model, as described in the CMP paper, “Comparison of Satcom Klystron Performance Under Typical Ground Station Conditions.”

MODE B
COMPACT KLYSTRON POWER AMPLIFIER (CKPA) **POWER 4.1kW**
CLASSIC KLYSTRON **59% SAVING**
The CKPA with Power Saver, operates the Classic Klystron at reduced beam voltage, allowing linear performance at high backoff levels, typically 100W. If more power/headroom is required, the beam voltage can be raised to full ratings within 30 seconds. This allows power to be saved most of the time; full power for rain/peak demand may only be needed for up to 5% of the time.

MODE C
GEN IV HIGH EFFICIENCY AMPLIFIER **POWER 4.1kW**
MSDC KLYSTRON **59% SAVING**
When the CPI MSDC Klystron technology is used, you get all the benefits of the Classic Power Saver mode, without having to reset the beam voltage. MSDC allows the Klystron to operate anywhere from zero to full rated RF without changing any power supply setting. The Klystron automatically redistributes energy to the proper collector electrode to maximize efficiency. A significant side benefit is that waste heat is greatly reduced, improving equipment life and reliability. (Preliminary results of 700 Gen IVs in the field are showing MTBF of over 100,000 hours, and increasing).

MODE D
GEN IV, POWER SAVER **POWER 1.7kW**
MSDC KLYSTRON **82% SAVING**
Using Power Saver results in even more saving. By managing the voltage up and down when demand requires, another large improvement in efficiency can be obtained. Delays of up to 30 seconds may be experienced during uplink power control adjustments.

Addendum 2

CPI Communications and Medical Products Division MSDC White Paper

Comparison of Satcom Klystron Performance Under Typical Ground Station Conditions.

Richard Dobbs, Senior Engineer, CPI Canada Inc. **October 2002**

Abstract

The past few years have seen significant advances in both Klystron and KPA Technology. This provides the end-user with more options than ever before when choosing an uplink system, and the scheme under which to run it.

This paper examines the major two advances, MSDC Klystron Technology and the Power Saver operating scheme. It is shown that MSDC Klystron Technology represents dramatic power savings compared to the Classic Klystron, and the combination of MSDC and Power Saver gives the best performance for a typical ground station application.

Introduction

MSDC Klystron Technology is now available in commercial satcom amplifiers. The MSDC (Multi-Stage Depressed Collector) Klystron employs state of the art collector technology to recover energy from the electron beam once it has passed through the RF section of the device, and recycle this energy to the power supply. MSDC Klystrons are available in the common Ku, DBS and C-band uplink frequency bands.

Power Saver Technology is available in a modern KPA (Klystron Power Amplifier). This was developed to save energy costs when running a Classic (Single, un-depressed collector) Klystron in a typical uplink scenario, where relatively low output power (100 W or so) is required most of the time.

This paper examines the performance of CPI klystrons under each condition, and compares the Prime Power performance of each scheme. The discussion is based on the C-Band Family of devices, but the results are directly scalable to the other frequency bands.

Classic Klystron

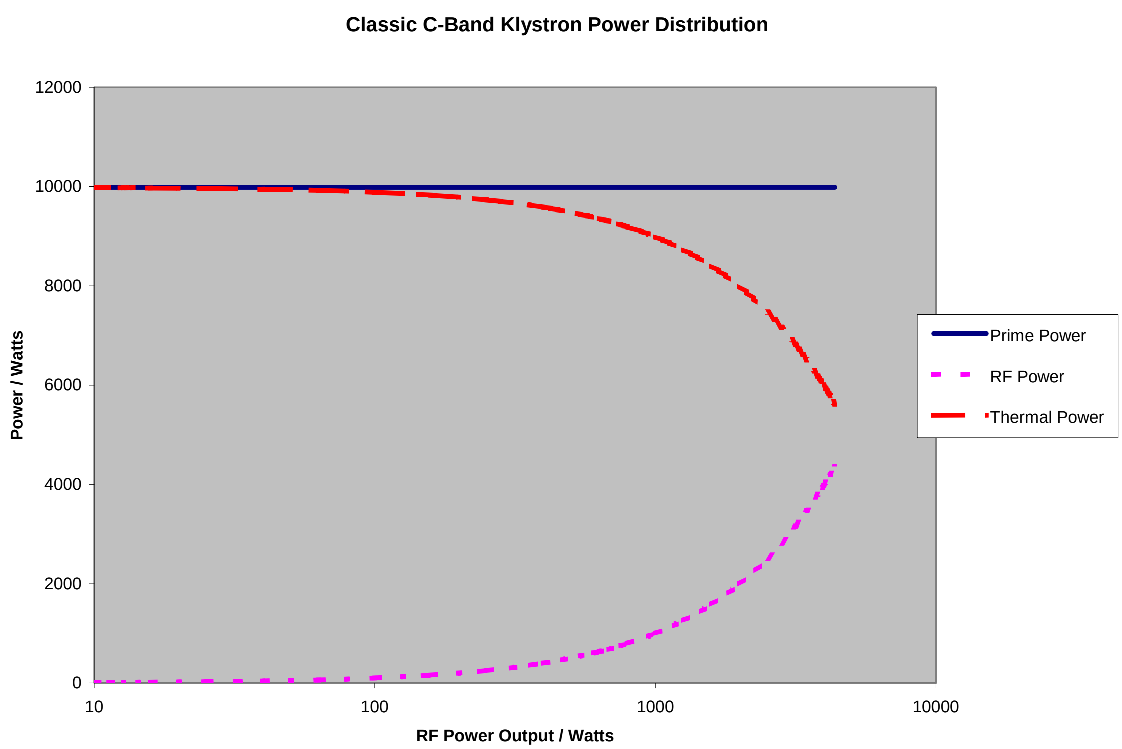
Calculating prime power draw (power drawn from the wall) for a Classic, un-depressed klystron is quite simple. The product of the Beam Voltage and the Beam Current will give you the total power draw of the device. In a classic klystron, this power is either converted into RF energy, or dissipated in the collector as thermal energy. With a constant Beam Voltage setting the power draw is constant, only the distribution between RF and Thermal energy will change.

Example 1, C-Band Classic Klystron

Eb = 8600 V; Ib = 1161 mA; Power Draw = 9985 Watts

RF output=0 , *Thermal dissipation = 9985 Watts*
RF output=3400W, *Thermal dissipation = 6585 Watts*

Prime Power Draw is constant.



MSDC Klystron

In the case of the MSDC, much more care needs to be taken in the calculations. Due to the design philosophy of the device, the power input into the klystron via the beam is the same as in the Classic case, and can be calculated from the beam voltage and current. However, this is not equivalent to the Prime Power Draw.

The Depressed Collectors recover a significant part of the unused energy in the beam, which can be recycled to the beam supply. This recovered energy must be taken into account when calculating total power draw. If only the beam parameters are used, as the beam remains constant, the power calculations will appear the same as the Classic Klystron case. However, once the energy recovery of the collectors is taken into account, the true value of the MSDC can be seen. For each collector segment, the Power Dissipated is equal to the DIFFERENCE between the Beam Potential and the Collector potential, multiplied by the current landing on that collector.

Example 2, C-Band MSDC Klystron, No RF Output

Eb = 8600 V;	*Ib = 1161 mA;*	*Beam Power = 9985 Watts*

RF output = 0

Ec1 = 0V,	*Ic1 = 23mA;*	*Power C1 = 198 Watts*
Ec2 = 2860V,	*Ic2 = 164mA;*	*Power C2 = 941 Watts*
Ec3 = 5730V,	*Ic3 = 975mA;*	*Power C3 = 2798 Watts*

TOTAL POWER DRAW = 3927 Watts

When you compare this to the Classic Example, with the same beam parameters, the MSDC klystron will only draw 39% of the power from the KPA. This can also be stated as a collector efficiency of 61% (The collector recovers 61% of the power input into it).

Under RF Conditions, the calculations are the same, however the interpretation gets somewhat more complicated.

As the energy distribution of the electrons in the beam changes with RF output, the power recovery will change with RF drive. The Prime Power Draw will rise approximately linearly with the RF output. The physics of the beam dynamics in the collector will cause the slower electrons to be collected nearer to ground potential, reducing the overall power recovery of the MSDC system.

Example 3, C-Band MSDC Klystron, Rated RF Output

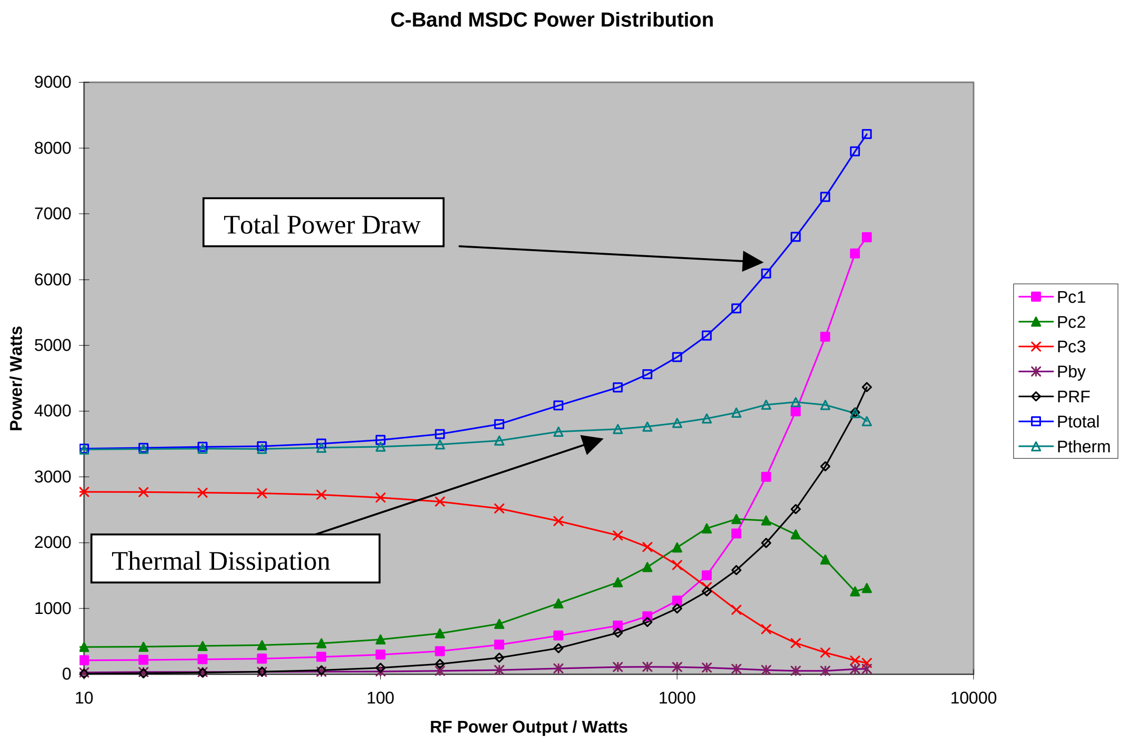
Eb = 8600 V;	*Ib = 1161 mA;*	*Beam Power = 9985 Watts*

RF Output = 3365 Watts

Eby = 0V;	*Iby = 13mA;*	*Power body = 112 Watts*
Ec1 = 0V,	*Ic1=703mA;*	*Power C1 = 6045 Watts*
Ec2 = 2860V,	*Ic2 = 316mA;*	*Power C2 = 1814 Watts*
Ec3 = 5730V,	*Ic3 = 74mA;*	*Power C3 = 212 Watts*

TOTAL POWER DRAW =8183 Watts

The Total Power Draw is the sum of the Thermal dissipation and the RF output power. As the thermal dissipation is approximately constant, then the Total Power Draw will change linearly with the RF output. This dynamic power draw will happen with no user intervention – it is a function of the physics of the device. The following chart illustrates the power draw over the full operating range of the klystron:



P total = Pc1 + Pc2 + Pc3 + Pby
Ptotal = Ptherm + P RF

Another important point is that electrical power dissipation on any particular collector stage is not equal to the thermal dissipation. For instance, under RF conditions, collector one accounts for the majority of the electrical power drawn, but does not dissipate very much thermal energy.

The mechanism for power dissipation from the beam is conversion of kinetic energy of the electrons into thermal energy in the collector. The measure of current is a measure of the number of electrons per second hitting the collector, but does not measure their kinetic energy. In the instance of collector one, under RF conditions, this is known to account for the majority of the electrical energy drawn, but little thermal energy. The reason for this is that the collector one current is mainly made up of slow, low kinetic energy electrons that have given up their energy to the RF output.

To make these calculations properly, all of the above parameters must be known. In a typical KPA, full monitoring of the collector currents and voltages is not done normally. Therefore the danger is that calculations are based on the Beam parameters, not the true power draw.

If this metering is not available, then the best way to quantify prime power draw is to measure the power going into the KPA from the wall.

Power Saver

Classic Klystron

One of the best ways in which to save prime power with a Classic Klystron, is to set up the Beam parameters tailored for the particular application in question. This is done by reducing the Beam Voltage so that the required output power (with any backoff provision for linearity) is available. This can greatly reduce the prime power draw.

Example 4, C-Band Classic Klystron with Power Saver

Eb = 6000V, Ib = 688mA; Power Draw = 4128 Watts

Nominal Available Power Output = 700 Watts

MSDC Klystron

The MSDC Klystron is fully compatible with the Power Saver concept. The MSDC collector will still recover energy from the spent beam that would be wasted in the Classic case.

Example 5, C-Band MSDC Klystron

Eb = 6000 V; Ib = 688 mA; Beam Power = 4128 Watts

RF Output = 0 Watts

Ec1 = 0V,	*Ic1=16mA;*	*Power C1 = 96 Watts*
Ec2 = 2000V,	*Ic2 = 110 mA;*	*Power C2 = 440 Watts*
Ec3 = 4000V,	*Ic3 = 563mA;*	*Power C3 = 1126 Watts*

TOTAL POWER DRAW =1662 Watts

Again, the MSDC Collector only draws 40% of the power compared to the Classic Design.

Example 6, C-Band MSDC Klystron

Eb = 6000 V; Ib = 688 mA; Beam Power = 4128 Watts

RF Output = 676 Watts

Eby = 0V;	*Iby = 0mA;*	*Power body = 0 Watts*
Ec1 = 0V,	*Ic1=141mA;*	*Power C1 = 846 Watts*
Ec2 = 2000V,	*Ic2 = 324 mA;*	*Power C2 = 1296 Watts*
Ec3 = 4000V,	*Ic3 = 200mA;*	*Power C3 = 400 Watts*

TOTAL POWER DRAW =2542 Watts

Which is only 60% of the power draw compared to the Classic Design .

C-Band Klystron Operation In a Typical Ground Station

Klystron Type and Operating Scheme	*Output Power / W*	*Available Output Power/ W*	*Power Draw @ 100W output /W*	*% Power Savings*
Classic	100	3400	9985	0%
Classic Power Saver	100	700	4128	59%
MSDC	100	3400	4127	59%
MSDC Power Saver	100	700	1762	82%

MSDC Power Draw calculated by adding 100W RF output onto DC power draw figures

It can be seen that the MSDC klystron when used in a normal (full beam voltage) mode, has an equivalent power draw to the Classic klystron used in a power saver mode. MSDC has the advantage that not only is full rated power available instantaneously at any time, simply by increasing RF drive, but other subtler but nevertheless critical parameters such as linearity are preserved.

When Power Saver is applied to the MSDC, then the power savings become even more pronounced, and the full benefits of both power reduction schemes can be realized.