N87-16343

WEIGHT AND POWER SAVINGS SHAFT ENCODER INTERFACING TECHNIQUES FOR AEROSPACE APPLICATIONS

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Many aerospace applications for shaft angle digitizers such as optical shaft encoders require special features that are not usually required on commercial products. Among the most important user considerations are the lowest possible weight and power consumption. This paper will describe a variety of mechanical and electrical interface techniques that have large potential weight and power savings. The principles to be presented apply to a wide variety of encoders, ranging from 16 to 22 bit resolution and with diameters from 152 to 380 mm (6 to 15 in.).

MECHANICAL CONSIDERATIONS

Mechanical architecture usually keynotes the basic encoder design. There are three basic architectural configurations which may be considered for integration into the user system: housed, unhoused (kit encoder), and cartridge. Schematics of the basic bearing and coupling layouts are shown in Figure 1. A section view of a typical housed or cartridge encoder is shown in Figure 2. A later section will explain the subtle differences between housed and cartridge encoders.

Encoders are characterized by an ultra stable, ultra low runout base and bearing spindle assembly which supports the rotation of the code disk past fixed reading stations. Code disks frequently have patterns of 40 line pairs per millimeter (1000 lines per inch). When photo electrically read out against the fixed slit, diffraction phenomena coupled with readout geometry produces periodic spatial high fidelity sinusoids. One readout period (360 degrees electrical) is produced by rotation through one code cycle. Since phase shifts between reading stations of one or two degrees are readily detected by commonly used processing circuitry, mechanical motions of 1/360 of a code cycle equal to 0.025/360, or about 70 micrometers (3 microinches) are readily inferred. Hence encoder mechanical design is always concerned with creating stable structures such that the observed readout is due to the rotation of the code disc about the axis it is desired to encode, and not spurious bending or deflection of the encoder structure. Given an encoder and another mechanism which must carry the same loads, the encoder structure and bearings are usually considerably oversize and stiffer with respect to their counterparts for general purpose mechanisms.

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A housed encoder (Figure 1(a)) has several advantages, but also several disadvantages. The biggest advantage is that the encoder can be procured, inventoried, and installed as a free standing, self-contained item. The encoder can also be returned to the supplier for repair or modification. The advantages are primarily logistical. The biggest disadvantages are weight and volume penalities.

Inspection of Figure 1 will show that there are duplicate bearings and encoder structure, as well as a shaft coupler. Shaft couplers are required to avoid excessive misalignment loads in the encoder. Couplers capable of transmitting shaft motion to the encoder with under 1.0 second of arc transmission error are often slotted structures in the form of a 100 to 150 mm (4 to 6 in.) diameter by 100 mm long right circular cylinder (19 to 22 bit systems). The coupler can add approximately 100 mm of axial length to the system; larger diameter encoders (250 mm (10 in.) and above) are often provided in a hollow shaft configuration. In some cases part of the through hole can be used to package a coupler (Figure 3) at the expense of using some of the shaft space. Although the hollow shaft configuration may avoid the axial length penalty, it is not a minimum weight configuration. Weight can be reduced to a point by using light weight materials such as titanium and beryllium. However the basic system architecture shown in Figure 1(a) precludes very large savings because the encoder base, shaft, bearings, and shaft coupler are redundant relative to the absolute minimum unhoused configuration shown in Figure 1(b).

In order to eliminate the redundant structural members and their associated weight, some users interface with unhoused kit type encoders such as shown in Figure 1(b). Kit type encoders are characterized by a minimum number of parts. As long as the user can provide a spindle with encoder quality, low runouts over all loads and environments, bearings, encoder structure, and couplers are conserved. The weight and volume savings are an obvious advantage. There are two disadvantages to this technique. First, in some cases it may be impractical to build the user's "power spindle" to the low runout tolerances required by the encoder. Secondly, the encoder is very highly integrated into the user's bearing structure. As a result, the encoder cannot be stocked as a subassembly procured in advance, and the logistics of assembly and repair are often difficult. These encoders are typically assembled either by sending a trained assembler from the encoder supplier to the user's factory or by the user shipping an unencoded spindle to the encoder supplier, which after some time is returned in encoded form.

As an example of what can be done, the encoder shown in Figure 2 was custom designed for a classified application. Following are key parameters:

Resolution	21 bits (0.62 arc sec)
Overall Diameter	381 mm (15 in.)
Shaft Thru Hole Diameter	254 mm (10 in.)
Principal Materials	BE/TI
Bearing Size (DF)	279 mm Bore X 305 mm OD (11 X 12 in.)
Bearing Load Capacity	Approx 115 kg radial and axial (250 lbs.)
Bearing Stiffness	Approx 9 X 10^4 kg/mm (5 X 10^6 lbs./in.)
Starting Torque	0.85 N-m (7.5 in.-lbs.)
Weight	11.4 kg (25 lbs.)
Power	1.5 watts peak
	0.2 watts avg. (200 Hz Update Rate)

By way of comparison, a catalog housed unit of 21 bits resolution in a stainless steel housing and a 203 mm (8 in.) thru hole weighs 32 kg (70 lbs.). A stainless steel shaft coupler weighs an additional 5.5 kg (12 lbs.). In the example shown, the user took responsibility for supplying the bearings for the encoder as well as coordinating the design of a stator diaphragm coupler. The interface was very carefully designed and tolerenced so that the encoder fit the user's structure in a manner that effectively line bored the parts.

The cartridge encoder has the advantage that the encoder may be built and inventoried and shipped as a self contained end item. The user of a cartridge system may field remove the encoder and substitute a spare. In addition, many users of cartridge encoders will procure a "dummy encoder" to support one end of their shaft should encoder removal be required. Compare the logistics with a kit encoder, where the apparatus is so highly integrated that many significant repairs to the user's bearing structure require an encoder teardown/rebuild.

Clearly, the cartridge approach can offer superior minimum weight, minimum volume performance. However, it should be noted that a lot of engineering analysis and coordination are required. This is why usage tends to be restricted to space applications where the engineering costs can be justified in the context of required system performance.

ELECTRICAL CONSIDERATIONS

Encoders are generally classified into two types, incremental and absolute. Incremental encoders are usually two track devices; the two tracks are a main counting track and a once per revolution index track. By zeroing or resetting a counter with the once per revolution index it is possible to dead reckon and derive a multiple bit position word. Absolute encoders on the other hand have many tracks, all of which must be read out and processed.

Incremental encoders have what is termed a volatile output. That is to say if power is ever lost or interrupted, the encoder does not establish a correct position count until the once per revolution index is detected. Absolute encoders on the other hand have data storage in the form of the multiple track code patterns. These encoders are capable of providing a correct readout within a very short time after power is turned on since there is no need to rotate by the once per revolution index.

Some systems, such as high speed scanners, run by the index as often as every few milliseconds; other systems move at Earth's rate. Most systems operate somewhere between these extremes. In many high speed applications an incrementral encoder is satisfactory, while for Earth's rate applications, an absolute encoder is usually required.

Conventional wisdom has been that since the incremental encoder only has two tracks compared with upwards of 15 to 20 in a high resolution absolute encoder, that all things being equal, it would have a much lower power consumption, and if data acquisition times to acquire a current index position were acceptable, it would be the preferred encoder. This is no longer true. It is a fact that most absolute encoders used in space-craft have very low output word data update rates, usually from 20 per second up to about 1000 per second. By using a data acquisition multiplexing and storage system it is possible to design absolute encoders where the encoder is kept mostly unpowered except for a 100 to 150 microsecond interval, when it is desired to update data.

As an example, Figure 5 shows the power consumption profile of a typical 19 bit incremental encoder. Since the encoder depends on pulse counting to maintain the position data current, operation must be continuous. On the other hand, the absolute encoder in Figure 6 can be operated in an Interrogate or sampled data update acquisition mode. A low power "receiver" circuit is kept energized to detect receipt of the user's Interrogate, or Update request pulse. When it is received, a power switch circuit in the electronics unit turns on encoder power, acquires the current shaft position, stores it in memory, and transmits the updated position to the user. When the transmission is completed, the encoder circuits, except for the receiver, are returned to the unpowered state. The cycle is repeated as often as desired.

This pulsed data acquisition has two operating characteristics not common to continuous reading systems. First there is a delay to the user in reading the data. 100 to 150 microseconds is typical. This is not usually serious. The growing use of microprocessors and other computer devices make it possible to easily correct for delay time. Since shaft speed can be reconstructed from the past position data, correcting position to the start of Update is not difficult.

Also, with 100 Hz sampling rates (10,000 μsec period), the acquisition delay is a small percentage of the total updata period. Usually real time servo control is the most demanding application and the effect of 100 to 150 μsec acquisition delay on servo stability is small compared with most servo bandwidths.

A second feature of the Update mode of operation is the power profile, as shown in Figure 6. The power profile is characterized by a low, steady base load (receiver) and an additional pulsed load for data acquisition and transmission. The average power is low, and its function of readout rate is shown in Figure 7. For the example in Figure 6, the average power up to 5000 updates/sec. is lower than the incremental example in Figure 5. If the pulsed currents with a high form factor (ratio of peak to average) are a problem, a filter circuit/energy storage device can be used to smooth out the power profile seen by the user's power supply.

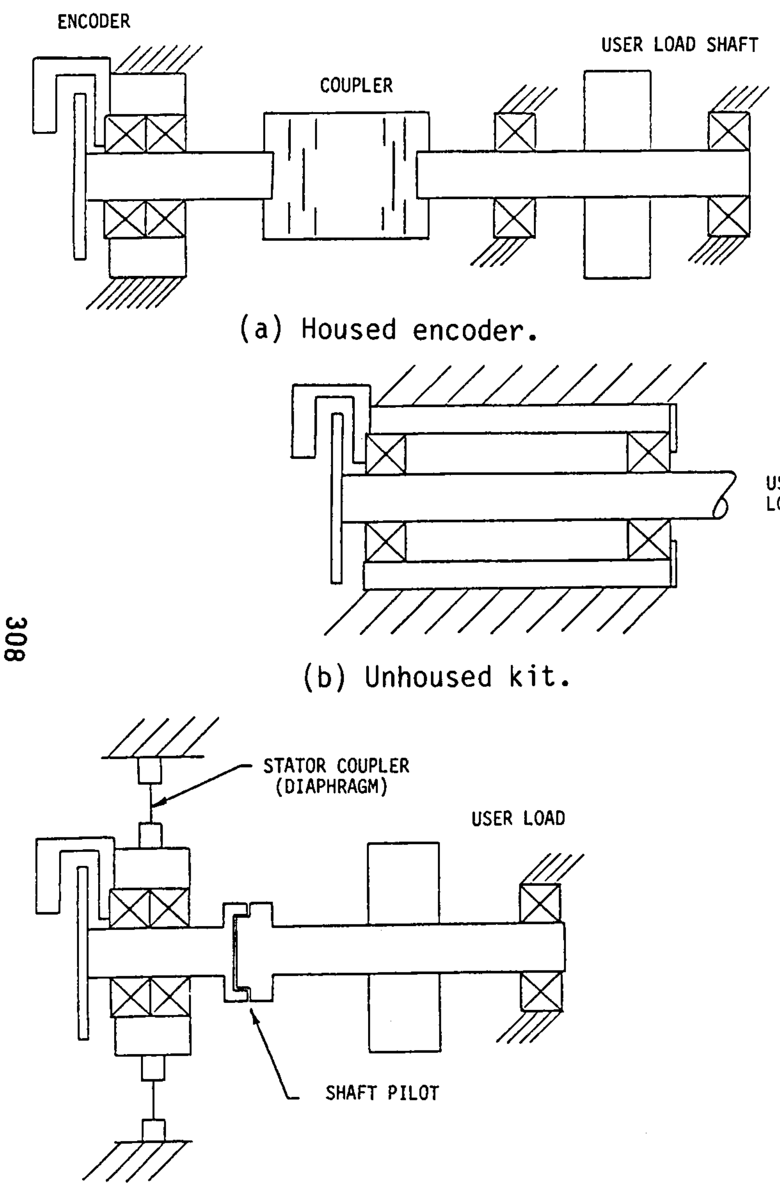
SUMMARY

Basic architectural principles of mechanical and electrical interfacing of encoders have been presented. By understanding the basic principles, users are in a position to interface encoders, selecting those logistic, weight, or power saving techniques that will optimize the encoder for their particular application. Users wishing to study mechanical or electrical interfacing techniques in more detail are referred to two earlier papers by the author.

REFERENCES

1) Installation and Maintenance of High Resolution Optical Shaft Encoders, SPIE Conference Proceedings, Volume 134, Photo and Electro-Optics in Range Instrumentation, March 1978

2) High-Performance Optical Encoders Can Have Small Size, Weight, and Cost, Electro-Optical Systems Design, Cahners Publishing Company, Sept. 1981



(a) Housed encoder.

(b) Unhoused kit.

(c) Cartridge.

Figure 1. - Encoder mechanical interface architecture.

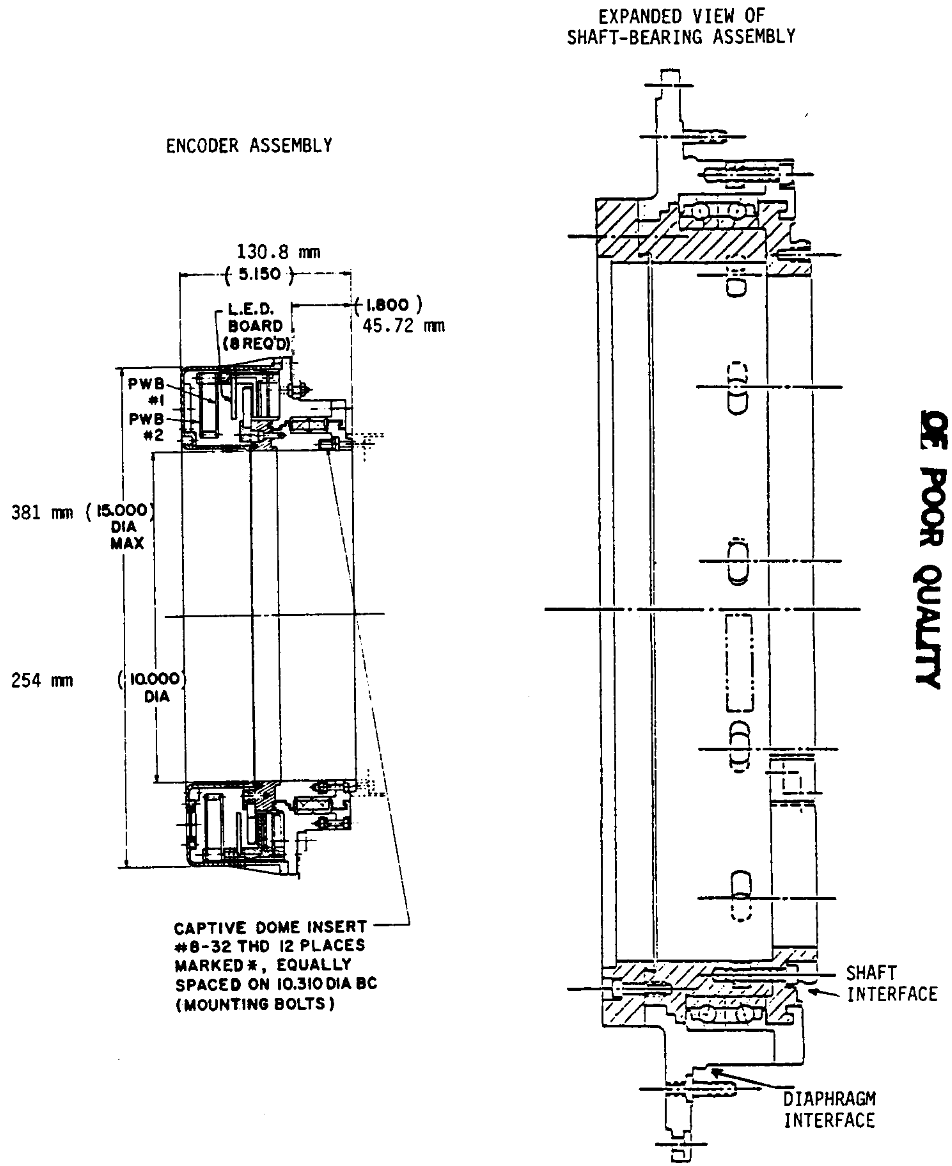
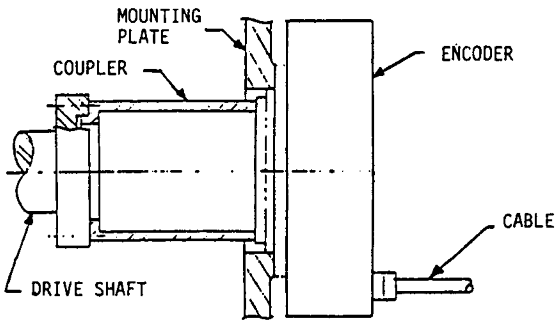
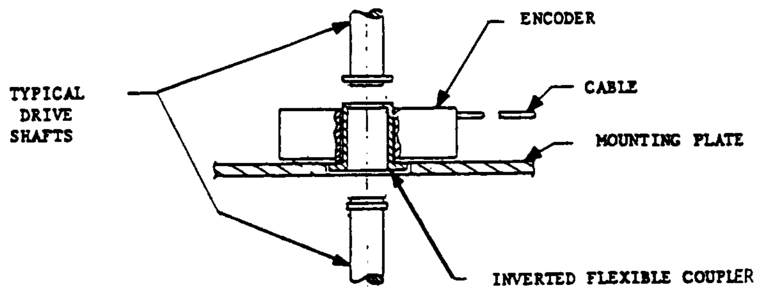


Figure 2. - Section views of a 21-bit cartridge encoder.



(a) External installation outside encoder.



(b) Internal installation inside shaft through hole.

Figure 3. - Shaft coupler installation.

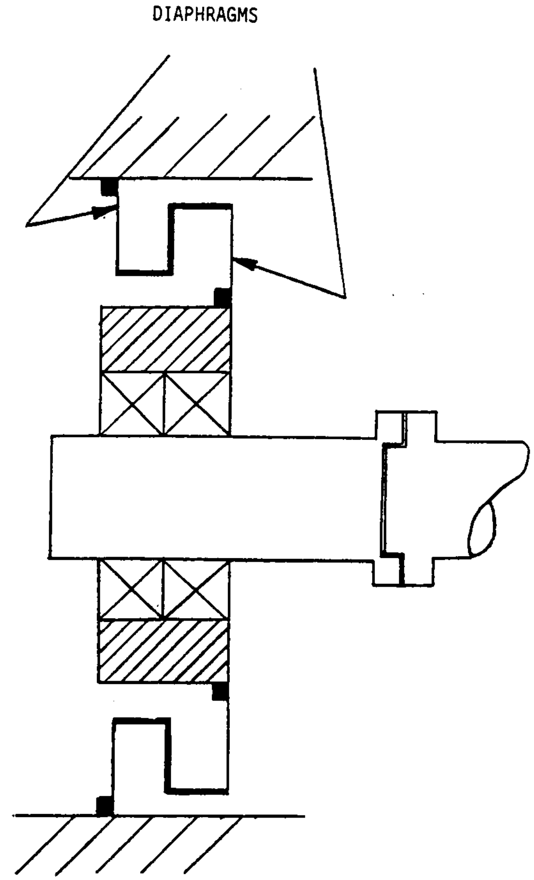


Figure 4. - Stator (body) coupler.

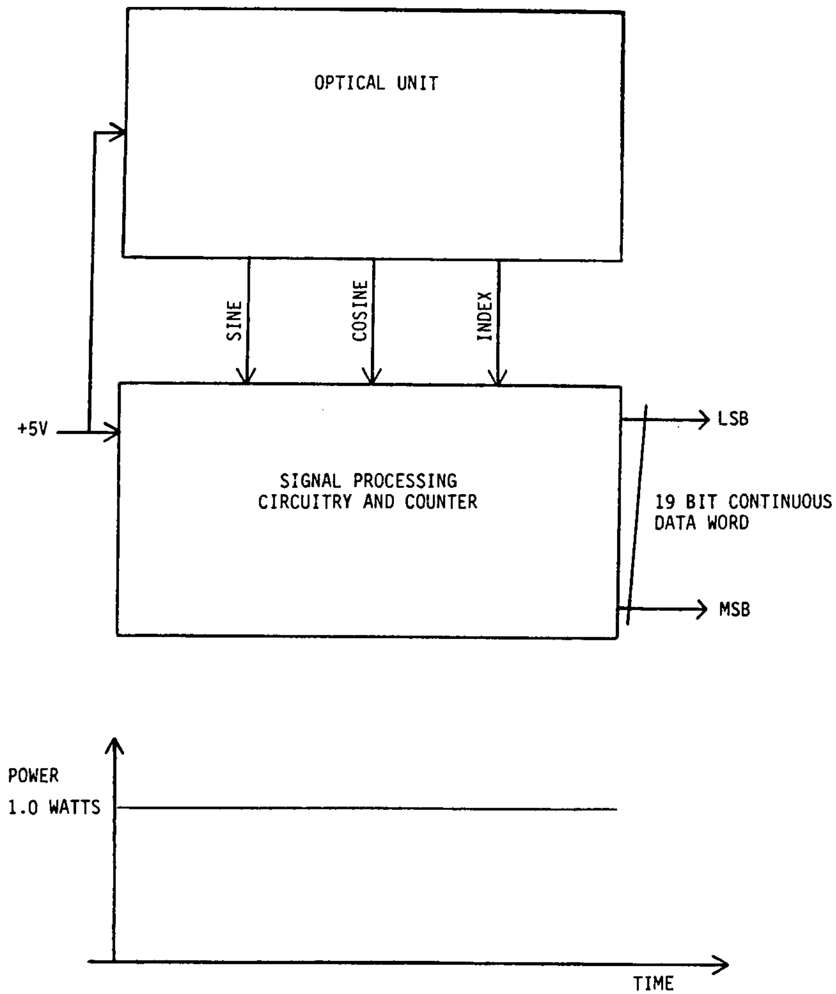


Figure 5. - Block diagram and power profile of 19-bit incremental encoder.

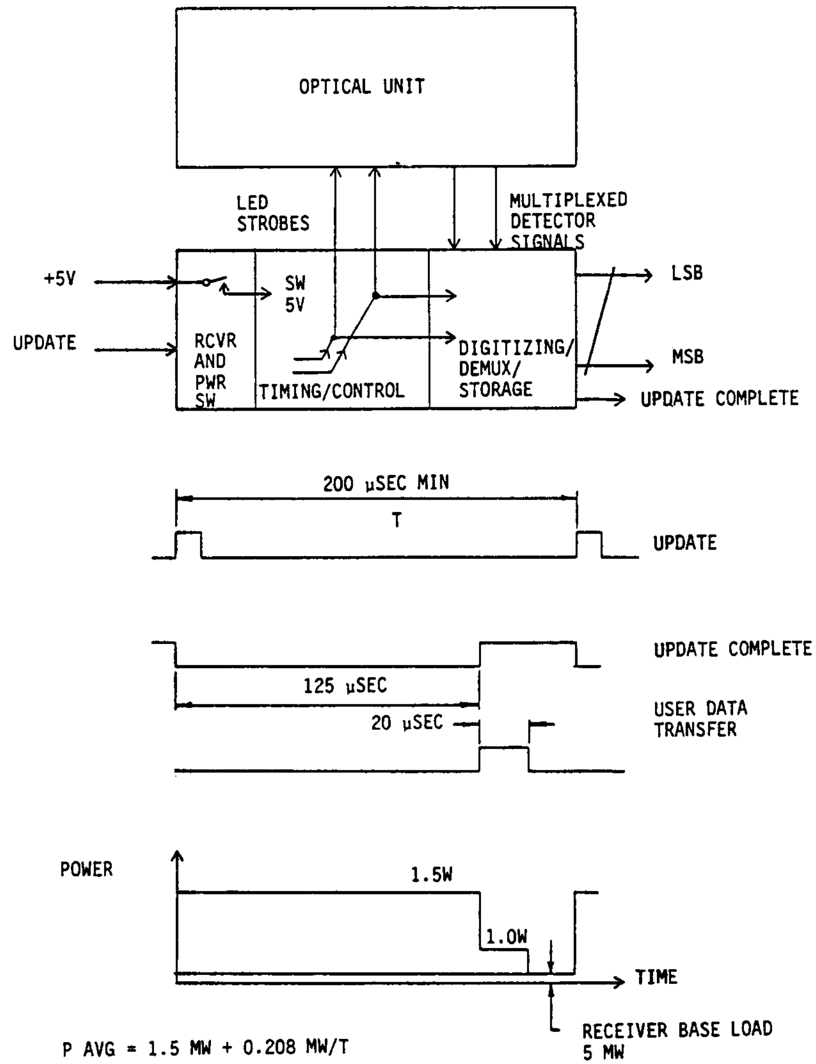


Figure 6. - Absolute, multiplexed encoder simplified block diagram and power profile.

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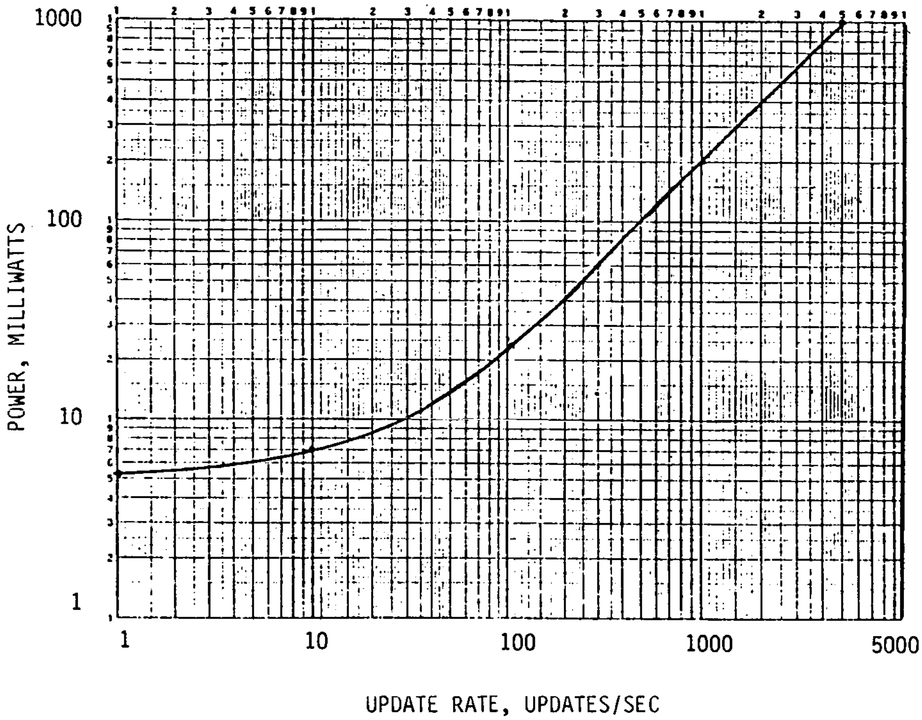

Figure 7. - Average power consumption as function of update rate of encoder shown in Figure 6.