Embedded "Card-Based" receivers are one of the latest innovations in telemetry reception. These products provide substantial power and flexibility in a small form factor (one slot, PC or VME). In many applications they are a cost effective alternative to conventional telemetry receivers. This paper analyzes currently available products with regard to their features, capabilities, and performance, as well as highlighting typical applications.

KEYWORDS
Card-Based, receivers, VME, PC, Diversity Combiner, S-Band, L-Band, baseband, IF, FM, block converter, discriminator, signal strength, deviation.

INTRODUCTION
Systems Engineering & Management Company (SEMCO) introduced the first IBM PC/AT card-based receiver (see Figure 1) at the International Telemetering Conference (ITC) in the fall of 1992. The PCTR-500 telemetry receiver was designed to be a companion product to IBM PC-based telemetry processing systems. The combination of a PC-based receiver, antenna, and portable PC-based telemetry processing system produced a portable Telemetry Ground System. The PC-based receiver was greeted by the telemetry community with both enthusiasm and skepticism. Many people found it hard to believe that a sensitive receiver could be implemented in such a noisy environment as a computer. However, SEMCO's successful demonstration of the receiver's performance, including both its high sensitivity (see Table 1) and low 6 dB noise figure, resulted in the product's first deliveries in the first quarter of 1993. At the
1993 ITC, SEMCO introduced the industry's second card-based receiver (see Figure 2), which supports VME-based telemetry processing systems.

Figure 1. PCTR-500 Telemetry Receiver

Figure 2. VMETR-500 Telemetry Receiver
Table 1. Series 500 Telemetry Receiver Performance Specification

<table>
<thead>
<tr>
<th>Electrical Specification</th>
<th>Performance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range:</td>
<td>VMETR/PCTR-500L: 1435-1540 MHz, up to 210 Channels</td>
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<tr>
<td></td>
<td>VMETR/PCTR-500S1: 2200-2300 MHz, up to 200 Channels</td>
</tr>
<tr>
<td></td>
<td>VMETR/PCTR-500S2: 2300-2400 MHz, up to 200 Channels</td>
</tr>
<tr>
<td></td>
<td>VMETR/PCTR-500S3: 2400-2500 MHz, up to 200 Channels</td>
</tr>
<tr>
<td>Frequency Resolution:</td>
<td>0.5 MHz</td>
</tr>
<tr>
<td>Frequency Selection:</td>
<td>Via Supplied Menu-Driven Program or User-developed application</td>
</tr>
<tr>
<td>Frequency Accuracy:</td>
<td>±0.002%</td>
</tr>
<tr>
<td>Noise Figure:</td>
<td>6 dB</td>
</tr>
<tr>
<td>Sensitivity:</td>
<td>-87 dBm</td>
</tr>
<tr>
<td></td>
<td>@ 20 dB (S+N)/N and 180 kHz deviation with 500 kHz BW</td>
</tr>
<tr>
<td>Maximum RF Input:</td>
<td>+10 dBm (without damage)</td>
</tr>
<tr>
<td>Input Impedance:</td>
<td>50 ohms</td>
</tr>
<tr>
<td>IF Bandwidth:</td>
<td>500 kHz to 20 MHz Standard</td>
</tr>
<tr>
<td>Image &amp; Spurious Rejection:</td>
<td>60 dB Minimum for signal levels below -55 dBm</td>
</tr>
<tr>
<td>Modulation:</td>
<td>True FM</td>
</tr>
<tr>
<td>Frequency Response:</td>
<td></td>
</tr>
<tr>
<td>Start Frequency:</td>
<td>100 Hz ±1.5 dB</td>
</tr>
<tr>
<td>Stop Frequency:</td>
<td>Options from 500 kHz to 20 MHz (Plug-in dependent)</td>
</tr>
<tr>
<td>Deviation:</td>
<td>50 kHz/volt peak to 3.6 MHz/volt (plug-in module)</td>
</tr>
<tr>
<td>Maximum Output Level:</td>
<td>5.0 volts p-p (into 1K ohm load)</td>
</tr>
<tr>
<td>Logic Sense:</td>
<td>Positive</td>
</tr>
<tr>
<td>Output Distortion:</td>
<td>2% Maximum at 250 kHz deviation up to -50 dBm input level</td>
</tr>
</tbody>
</table>

Currently, SEMCO's two card-based receivers are the only products of this type available. They have been used for aerial vehicle testing, flight-line pre-flight tests, factory testing of telemetry data transmitting subsystems, and a variety of other telemetry applications. The success of these two products has shown that there is a future for card-based telemetry receivers. The acceptance of these products has resulted in the development of second generation products from SEMCO, in addition to incentivising other companies to begin the development of similar products. Second generation products will have significantly increased performance, flexibility, and a
DESCRIPTION OF CURRENT PRODUCTS

SEMCO developed the Series 500 family of Receiver-On-A-Card (ROAC) products to provide the telemetry community with a low cost, easily reconfigured telemetry receiver that offers the user a small footprint package and significant functional capabilities. The Series 500 telemetry receivers plug into one full-length IBM PC/AT or 6U VME bus slot and are controlled by the host personal computer. To receive and process telemetry data then becomes a simple matter of attaching the Series 500's RF input port to an antenna and its baseband output to a Bit-Synchronizer. Both IBM PC/AT and VME computer-based Bit-Synchronizers and Decommutators are available from several sources. The advent of this technology, used in concert with the Series 500, now affords the systems designer the capability of assembling powerful, compact, fully functional telemetry reception and processing systems that are truly portable.

The Series 500 products are dual conversion, general purpose, frequency selectable telemetry receivers that have been fully integrated into the computer environment. The Series 500 receivers provide reception and FM demodulation for telemetry signals transmitted on the L and S frequency bands. Four models are available for each computer environment. The model PCTR-500L and VMETR-500L receivers provide reception in the 1435-1540 MHz band. The model PCTR-500S1 and VMETR-500S1 receivers operate in the 2200-2300 MHz band; the model PCTR-500S2 and VMETR-500S2 receivers operate in the 2300-2400 MHz band; and the model PCTR-500S3 and VMETR-500S3 receivers operate in the 2400-2500 MHz band. All S-band receiver models provide up to 200 user programmable channels with 500 kHz frequency resolution. The L-band receiver model provides up to 210 channels with the same frequency resolution. The performance specification for the Series 500 telemetry receiver is presented in Table 1.

The Series 500 receivers offer user replaceable plug-in modules for the 2nd IF Stage, FM Discriminator and Post Detection Amplifier/Filter sections. The receiver is controlled via a simple menu-driven program that is supplied with the receiver, or the control program can easily be integrated into a custom-developed application program.

SEMCO's card-based receivers provide two indicators of their operational status: signal strength and output deviation. These signals are provided in an analog form as well as a digital format. The analog signals are buffered and provided as test points on
a DB-9 connector. The analog signals are converted to digital format by a single multiplexed 8-bit Analog to Digital (A/D) converter that is accessed through the bus. The system's application software can acquire samples of these status signals and create a variety of operator displays (bar charts, numeric readouts, etc.).

Signal strength refers to the level of the desired RF signal at the receiver's input. The signal strength signal as provided from the receiver board is not calibrated. However, using a software routine, signal generator, calibrated directional coupler or power splitter, and a power meter, the signal strength signal can be calibrated. Once calibrated, it can be used as a course indicator of the received power level.

In the receiver's FM demodulator, carrier deviation changes are converted to changes in output voltage levels. The receiver's output deviation signal provides an indication of the AC voltage level at the receiver's output.

Therefore, SEMCO's receivers provide two important indicators. The signal strength indicator can both verify that the receiver is detecting the RF signal and provide relative power level indication, while the output deviation level indicator can both verify the presence of frequency modulation and provide a relative indicator of the receiver's output level.

**PLUG-IN MODULE DESCRIPTION**

SEMCO's Series 500 telemetry receivers can support a wide variety of telemetry applications in the L or S frequency band. To provide flexible receivers at a low cost, the Series 500 employs a modular architecture that enables the user to configure the receiver for a variety of different PCM data rates, IF bandwidths, FM deviation response and signal output voltage levels.

The Series 500 receiver offers replaceable plug-in modules for the 2nd IF Stage, FM Discriminator and Post Detection Amplifier/Filter. Eleven different 2nd IF plug-in modules are available with bandwidths from 500 kHz to 20 MHz. Twelve different FM Discriminator plug-in modules are available with deviation responses from 50 kHz/volt to 3.6 MHz/volt. Fourteen different Post Detection Amplifier/Filter plug-in modules are available for post detect filtering from 50 kHz to 20 MHz.

**OPTIONS**

Several options are available, such as AM, PM, and BPSK Demodulators, By-Directional IF/Tape Converters, Sub-Carrier Processors boards, and Test Transmitter Cards (TTCs). The optional By-Directional IF/Tape Converters can be used with the
receiver and external data recorders to form small portable IF data collection systems. Sub-Carrier Processor boards are used to process FM/FM systems and they can also be used to detect fuze tones or to separate doppler signals. The TTCs provide RF test signals that can be used for a variety of applications.

There are several methods of providing verification of the receiver subsystem's health and status. During factory testing, telemetry system integration, and maintenance exercises, external test equipment can be used to verify the receiver subsystem. However, during pre-mission tests it is best to have a fully integrated self-test capability. S- and L-band VME and PC TTCs are available from both SEMCO and BERG Systems Inc. The TTCs use fully synthesized, FM-modulated signal sources that can be tuned over the same band covered by the receivers.

The TTCs are companion products to the card-based telemetry receiving products. They provide modulated RF test signals that can be used for pre-mission checkout of SEMCO's ROAC systems as well as other telemetry receiving systems. A Telemetry Receiving Verification System (TRVS) is formed by combining a TTC with a portable IBM PC/AT, antenna, and optionally, a PCM Simulator and/or Link-Analyzer. The TRVS is a small portable receiver verification system that can be used in any location.

SECOND GENERATION PRODUCTS

SEMCO began the development of its next generation VME and IBM PC-based Telemetry Receivers and companion Pre-Detect Diversity Combiner in the second quarter of 1994. A full diversity system would consist of three or five 6U VME cards, depending on the location of the receiver's tuner. SEMCO's new design incorporates a remote tuner that either mounts on a single 6U VME card or is externally mounted (normally at the antenna). The antenna-mounted, remote tuner configuration provides superior performance when the antenna must be mounted a significant distance from the signal processing equipment (RF is received at the antenna and lower frequency IF signal is sent through the long cables). The RF Tuner's advanced design has a significantly higher intermodulation distortion level, wider dynamic range, AGC, and a high accuracy LO that locks to an external reference. The output of the RF Tuner is fed into the IF FM Receiver, another 6U VME card.

The IF FM Receiver card contains the second down-converter, AGC circuitry, programmable IF Filters, a variable slope FM demodulator, programmable post-detect filters, and an optional IF/Tape Converter. The primary difference between the current Series 500 receiver and SEMCO's next generation receiver is in the area of programmable flexibility. There are four programmable IF SAW filters that can be switched in over the VME bus. The slope of the FM demodulator (kHz/V) is also
programmable. The user will also have the ability to select one of eight different post-
detect linear phase filters. The computer will have feedback of the receiver's status,
including internal health, signal strength, frequency offset indicator, and output
deviation level. A linear IF output at 70 MHz will be provided to the diversity
combiner card. During a mission, the optional IF/Tape Converter can down-convert
the 70 MHz IF signal and during play-back up-convert to IF frequencies. The IF/Tape
Converter provides amplitude and frequency corrections in both directions. The
IF/Tape Converter also provides frequency offset information to the user via the
computer's bus.

The Pre-Detect Diversity Combiner (PDDC) will also be housed on one 6U VME
card. It will take in the linear IF outputs and low and high speed AGC signals of the IF
FM Receivers and combine them into a composite IF signal. The user can select from
three PDDC operating modes: optimal ratio combining with fast fade rates, highest
level selection (passes only the strongest of the two signals), or manual control (user
selects source). Additionally, an optional IF/Tape Converter can be used to record and
play back raw data.

**WHERE TO USE CARD-BASED TELEMETRY RECEIVERS**

Today's card-based telemetry receivers were designed to be companion products to
both IBM PC-based and VME-based telemetry processing systems. The combination
of a card-based receiver, antenna, and a portable PC/VME-based telemetry processing
system produced a powerful, easy to carry, portable Telemetry Ground System. These
systems can be used for a variety of applications, including;

* Airborne Vehicle Testing
* Ground Vehicle Testing
* Quick-look Data Verification of Complex Telemetry Systems
* Fight-line Pre-Mission Check-Out
* Automatic Test Equipment for Verification of Telemetry Data Transmission
  Systems
* Point-to-Point Fixed Telemetry Data Links

Because of their small size, rugged construction, and light weight, the receivers are
also ideal for Airborne Telemetry Receiving and Processing Systems. These receivers
can also be used independent of the processing system. Several computer chassis are
available with 15 or more user-defined slots. SEMCO has configured systems with up
to 14 receivers in a 19-inch rack-mounted chassis that is just 7 inches in height.
STRENGTHS AND WEAKNESSES

While today's card-based telemetry receivers perform well in a wide variety of applications, they do not fit every receiving requirement. In this section, the strengths and weaknesses of SEMCO's products are examined and key changes in the second generation products are highlighted.

Strengths of currently offered products:

* Low Noise Figures
* High Sensitivity
* Fully Synthesized (Tunable)
* Ability to alter IF Bandwidth, FM Demod Slope, and Post-Detect Filters
* Small size
* Light weight
* Cost (<$10K)

The first generation of card-based telemetry receivers was designed to allow system designers the ability to produce low-cost telemetry receiving and processing systems. Normally, these systems will utilize low-cost, low-gain antennas. To offset the low antenna gain, SEMCO's designers optimized the first generation receivers for both the lowest noise figure (< 6 dB) and highest sensitivity they could achieve. Factory tests have shown that a receiver configured with a 500 kHz IF bandwidth, 100 kHz/volt FM demodulator, and a 500 kHz post detect filter receives 500 kbps data at -96 dBm with a bit error rate of 1X10^-6.

Weaknesses of currently offered products:

* Limited Linear Dynamic Range
* Multi-band Tuners are not currently available
* User must perform physical plug-in change to alter IF Bandwidth, FM Demod Slope, and Post-Detect Filters
* No external reference-lock capability
* QPSK modulation not currently supported
* No Diversity Combiners

The first generation of telemetry receivers from SEMCO has a somewhat limited linear dynamic range. As mentioned above, the receivers were optimized for low noise figure and high sensitivity. Their front-ends are very sensitive, but they go non-linear with an input signal at about -50 dBm. Limited quantity tests have shown that conventional receivers go non-linear at -20 dBm. The non-linear point is defined
herein as the input level of two adjacent channels that have frequency spacing such that the first order intermodulation products (which fall at the receiver's center frequency) are -60 dBc.

These receivers can operate above the linear dynamic range. Both card-based and conventional receiver families provide distortionless demodulated signal at levels up to +10 dBm if the received signal is the only signal present. The received signal will become distorted if two adjacent signals at levels above the linear limit are spaced such that the resulting intermodulation distortion falls directly on the desired signal's frequency. This is one of the reasons that test range frequency management groups are so careful in selecting telemetry transmission frequency assignments.

SEMCO's receivers utilize AFC for their optional PM and BPSK demodulators, but do not offer AFC for the FM demodulator. This does not normally cause a problem because the output of the FM demodulator is AC coupled. Small variations (<100 Hz) in the received signal's frequency will cause the FM demodulator to operate on a different part of its demodulation slope, but the output will remain balanced.

Second Generation Product Highlights:

* Increased Linear Dynamic Range
* Programmable IF Bandwidths, Output Levels, and Post-Detect Bandwidths
* AFC and AGC
* Optional Remote Tuners
* External reference lock
* Pre-Detect Diversity Combiners

CONCLUSION

Card-based telemetry receivers are exciting new products. They are niche products that fill a variety of telemetry receiving and processing system requirements which demand portability, small form factors, low cost, and dedicated performance. Second generation products are soon to be released that will provide increased performance, programmable flexibility, and utility.

NOMENCLATURE

A/D Analog to Digital
AFC Automatic Frequency Control
AGC Automatic Gain Control
AM Amplitude Modulation
<table>
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<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>BPSK</td>
<td>Binary Phase Shift Keying</td>
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<tr>
<td>FM</td>
<td>Frequency Modulation</td>
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<tr>
<td>IF</td>
<td>Intermediate Frequency</td>
</tr>
<tr>
<td>ITC</td>
<td>International Telemetering Conference</td>
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<tr>
<td>LO</td>
<td>Local Oscillator</td>
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<tr>
<td>PDDC</td>
<td>Pre-Detect Diversity Combiner</td>
</tr>
<tr>
<td>QPSK</td>
<td>Quadrature Phase Shift Keying</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>ROAC</td>
<td>Receivers-On-A-Card</td>
</tr>
<tr>
<td>SAW</td>
<td>Surface Acoustic Wave</td>
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<tr>
<td>SEMCO</td>
<td>Systems Engineering &amp; Management Company</td>
</tr>
<tr>
<td>TRVS</td>
<td>Telemetry Receiving Verification System</td>
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