

Highly Versatile Linearizer for Use in Space

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Abstract--A new highly versatile linearizer front end has been developed for use on next-generation satellites. This linearizer was designed to enable power amplifiers (PAs) to operate over a very wide range of frequencies (> 3 GHz bandwidth) and power levels, yet still maintain optimum linearity and efficiency. The linearizer described here operates with a “Nano” microwave power module (MPM), but can be used with other types of TWTA's and SSPAs for shaped, multibeam, and phased array applications.

Keywords - linearizer, predistortion, space, satellite, power amplifier, TWTA, microwave power module, MPM.

I INTRODUCTION

The space business is in a transition [1]. There is an increasing need for lower-power PAs for low Earth orbit (LEO) satellites and wider-bandwidth PAs for more flexible satellites carrying high-data rate traffic using bandwidth-efficient modulations. Linearity is a prerequisite for these PAs, and in space, highest PA efficiency is a must. Many satellites also require PAs that can be operated efficiently at multiple power levels, that can be changed over time.

High linearity can be achieved by linearization. For wide bandwidths (>1 GHz), analog predistortion linearization (APDL) is the best solution because it provides smaller size, lower complexity, and superior performance over such bandwidths compared to other solutions [2,3]. In this paper an advanced, more highly versatile linearizer front-end (VLFE) is introduced with >3 GHz bandwidth and the ability to correct for variances in PA characteristics, when a PA is adjusted for higher efficiency at different power levels. Figure 1 shows a picture of four versatile Ka-band spaceflight linearizers on a common control board.

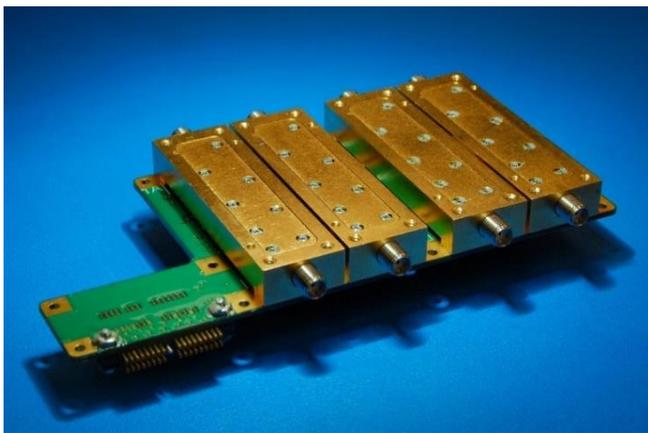


Fig. 1. New 3-GHz Ka-band versatile quad linearizer for space applications.

PA efficiency is normally highest when the amplifier is operated near saturation (Sat). PA linearity is increased when output power (P_{out}) is reduced from Sat to an output backoff level (OPBO). Linearization corrects PA nonlinearity, enabling the PA to operate more efficiently at a given P_{out} . There is a physical limit related to a PA's Sat power level, beyond which its linearity cannot be improved. For the linearity required by satellites, APDL can provide near ideal performance. Many types of PAs can be reduced in P_{out} while maintaining similar efficiency with OPBO. For example, a GaN PA's P_{out} at Sat can be reduced by lowering its drain voltage (V_d), while near constant efficiency is maintained [4].

$$Sat P_{out} = k \cdot V_d \text{ while } E_{ff} \approx \text{constant "k"} \quad (1)$$

When the Sat P_{out} is changed, however, the nonlinearity of the PA is also changed. To maintain optimum linearity, the linearizer must be adjusted. The limits on the linearity from an ideal or perfectly linear PA are shown in Figure 2. If a noise power ratio (NPR) of 15 dB is required, the PA's OPBO cannot be less than about 3 dB. If a linear P_{out} of 10 watts is required, the V_d can be adjusted for a Sat power of 20 watts and the linearizer adjusted to maintain optimum linearity with the new transfer characteristics.

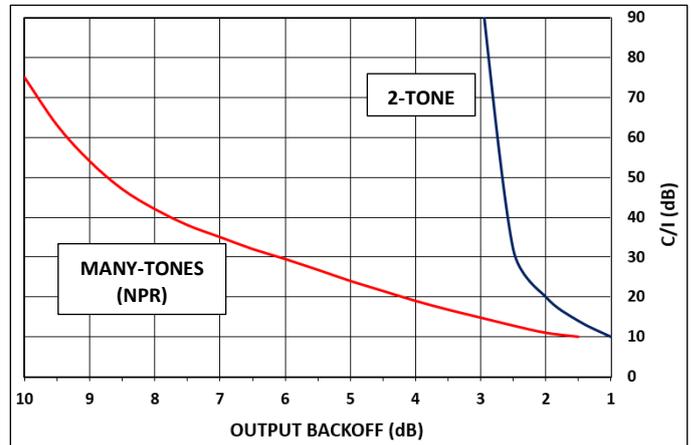


Fig. 2. Linearity limits on an ideal amplifier.

Predistortion linearization (PDL) is the only linearization method that offers the efficiency and bandwidth required for SATCOM. The predistorter (PD) must correct for the nonlinearity of the PA in gain and phase over frequency and power levels. The goal is for the linearized PA is to maintain a

II VERSATILE LINEARIZATION AND EFFICIENT PAS

constant gain and phase with input level, to the point of maximum PA P_{out} , and hold the output level beyond.

Analog and digital technology are used to generate PD. The very wide bandwidths required today make digital PDL (DPDL) impractical for most satellite applications. PDL requires a correction bandwidth 3-to-7 times the transmission bandwidth, which for DPDL must be digitally generated. Digital processing of large bandwidths is doable today, but too costly for many applications in terms of both DC power and economics [5]. Furthermore, when multiple signals are to be amplified, they cannot be linearized individually and then combined. The signals must be moved down to baseband, combined, and then digitized again for up-conversion. Most importantly, a PDL must produce varying nonlinear gain and phase characteristics across frequency that are electrically controllable for the purpose of matching the variations of different PAs. The PD has to not only generate two transfer curves versus input level, but two surfaces with frequency as the third parameter. Figure 3 shows how gain and phase can change with frequency and power level when viewed as surfaces [3]. The versatile linearizer has to generate multiple surfaces (two for each operating level) to compensate for the variation of PA characteristics with bias voltages for optimum performance at different operating levels.

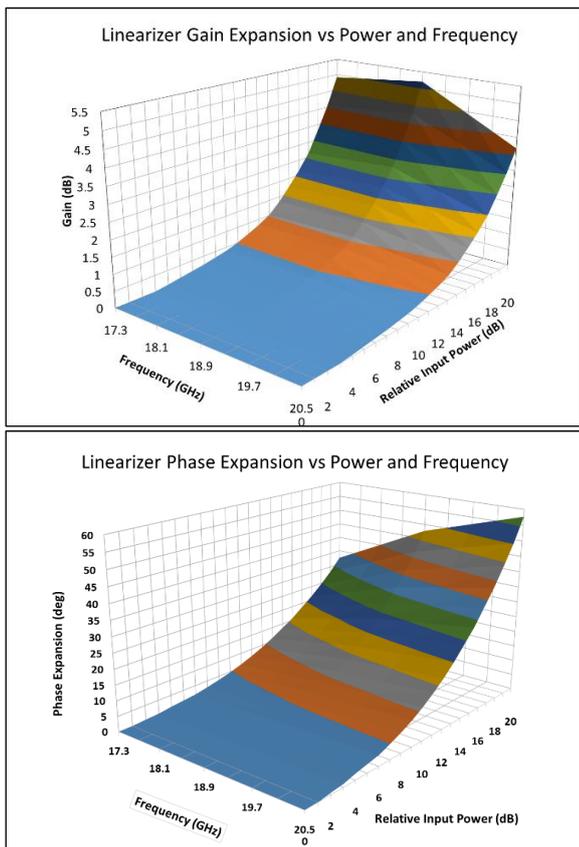


Fig. 3. PA phase surfaces as a function of frequency and power.

PA nonlinearity varies with frequency. Thus, a narrow-band DPDL must vary its nonlinear characteristics with frequency. These changes require even more complex processing that

further limits the DPDL’s capacity to handle wideband signals, and DPDLs adaptively change characteristics to compensate for this degradation over frequency. At higher frequencies, the additional hardware (low-distortion down-conversion to baseband) adds significantly to DPDL complexity and cost.

APDLs are designed to produce a gain/phase surface as a function of input level and frequency. This technology has been demonstrated to 100 GHz with instantaneous bandwidths of >5 GHz [6]. The PD design used for the versatile linearizer described here is based on an open-loop inline active FET PD and employs HEMTs embedded in circuitry that is biased to provide the desired nonlinear transfer responses.

III NANO MPMS

The linearizer discussed here was designed to work with a NanoMPM™ at Ka satellite band (downlink) over a 3-GHz bandwidth. Figure 4 is an example of a MPM is a microwave PA (non-space grade) that integrates a solid-state driver amplifier with a miniature TWT and an electronic power converter (EPC) into a single housing [7]. A NanoMPM™ is a remarkably small MPM designed for low power and high efficiency that is ideally suited for use in space [8]. They offer improved power density and power conversion efficiency comparable or superior to those of SSPAs [9]. Similar to GaN SSPAs, the bias voltages of a TWTA can be varied to reduce output power while maintaining optimum efficiency.

In space, bandwidth is in high demand. Satellites have moved to higher frequencies to take advantage of the greater available bandwidth. V-band is already in use, and MPMs offer the ability to operate to >100 GHz over multi-GHz bandwidths.



Fig. 4. Example of a non-space NanoMPM™*. NanoMPMs very small PAs with integrated miniature TWT and EPC. Photo courtesy of Stellart Systems (formerly L3Harris Electron Devices, * NanoMPM is a registered trademark of Stellart Systems Inc)

IV ADVANTAGE OF LINEARIZATION.

Today’s SATCOM services require high linearity. Linearization is used on virtually all satellites to improve PA linearity and efficiency. The NanoMPM™ VLFE described here includes low-level RF amplification, gain attenuator control, and limiting attenuator controls followed by the

versatile adjustable PD section. The predistorter needs to be flexible to accommodate the family of TWT AM/AM and AM/PM variances across the operating frequency band. A broadband RF amplifier chain follows the PD. An attenuator provides RF drive output level control and an RMS output detector is provided for telemetry. DC power and control lines for the linearizer are provided from the electronic power conditioner (EPC) control electronics. A RF block diagram of the linearizer is shown in Figure 5.

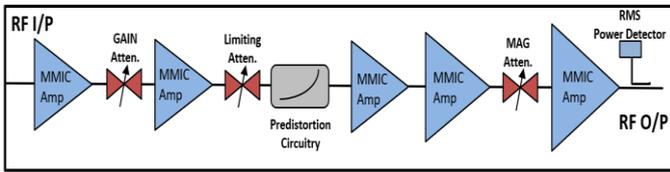


Fig. 5. Block diagram of the VLFE.

In space, PAs are operated as close to saturation as possible to maintain efficiency, while still providing acceptable linearity. A linearity metric frequently used for satellite applications is noise power ratio (NPR), which gives an indicator of linearity with multi-carrier traffic [10]. NPR measurement involves the use of bandpass-filtered noise to simulate multi-carrier traffic with a notch removed at the center where the distortion is measured.

Typical satellite (downlink) NPR requirements are on the order of 14-16 dB. These levels are lower than those specified for terrestrial applications, but still can be significantly improved by linearization. Figure 6 shows that linearization of an MPM can result in an increase of about 2 dB in P_{out} , while maintaining an NPR of 16 dB. This increase in output power corresponds to an increase in DC efficiency of about 35%.

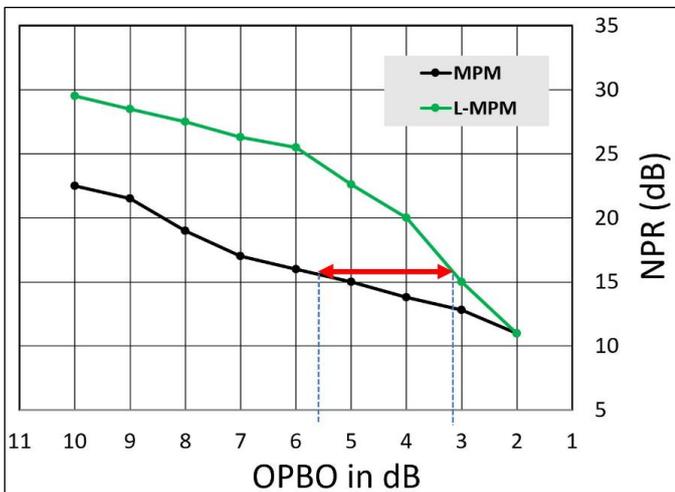


Fig. 6. At an NPR of 16 dB, a linearizer can provide a >2-dB increase in P_{out} and a nearly 35% increase in DC efficiency.

Because of the demand for wideband satellite systems, PAs often must not only operate across a full satellite band but must also support large *instantaneous* bandwidths. The ability of linearizers to support such large instantaneous bandwidths is therefore a major concern. In theory, NPR is independent of the

bandwidth of the noise pedestal. To show the ability to operate with wide instantaneous bandwidth traffic, NPR measurements were made with a pedestal 2 GHz in bandwidth. The results verified that APDL delivers comparable NPRs to those in Figure 6 with signals of very wide instantaneous bandwidths. Figure 7 shows a notch in the center of the 2 GHz wide noise pedestal used for the wideband NPR testing.

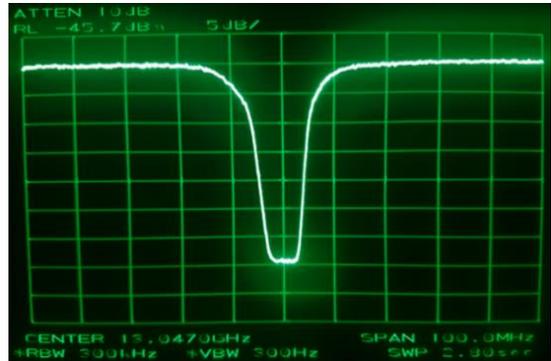


Fig. 7. 35-dB notch at center of 2-GHz pedestal used for NPR measurements.

V VERSATILE OPERATION

For spaceflight applications, linearity at a single operating point is not enough. In wideband applications such as phased arrays, the maximum output power of PAs must be adjusted for different operating points, while maintaining optimum linearity across the frequency range of operation. A new class of versatile linearizers with these capabilities has been developed for integration with PAs. The first units have been designed and are in production for Nano MPMs at Ku and Ka band. A VLFE module for Ku-band is shown in Figure 8. It measures 21 mm (W) x 70 mm (L) x 10.5 mm (H) and weighs 35 grams.

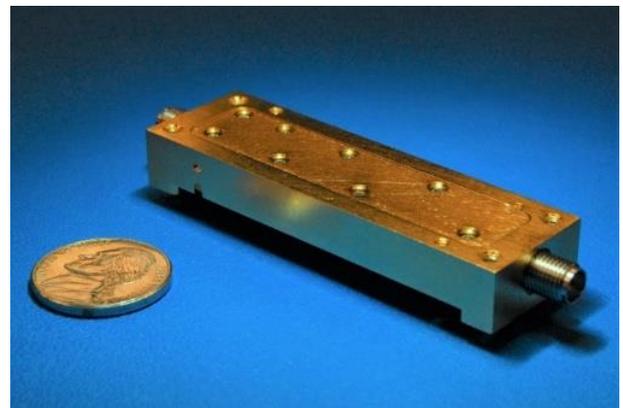


Fig. 8. Versatile Ku-band (downlink) satellite linearizer module with more than 2 GHz bandwidth and more than 6 dB of dynamic range.

The VLFE performance has been excellent and has met all our design goals. Figure 9 shows the Ka-band downlink operating frequency gain and phase change versus small and large signal input drive. Figure 10 shows the VLFEs transfer curves for AM/AM and AM/PM compensation versus input power at the center of the operating band. The linearizer

provides 3.5 dB of gain correction and 22 degrees of phase correction when driven from small signal to large signal.

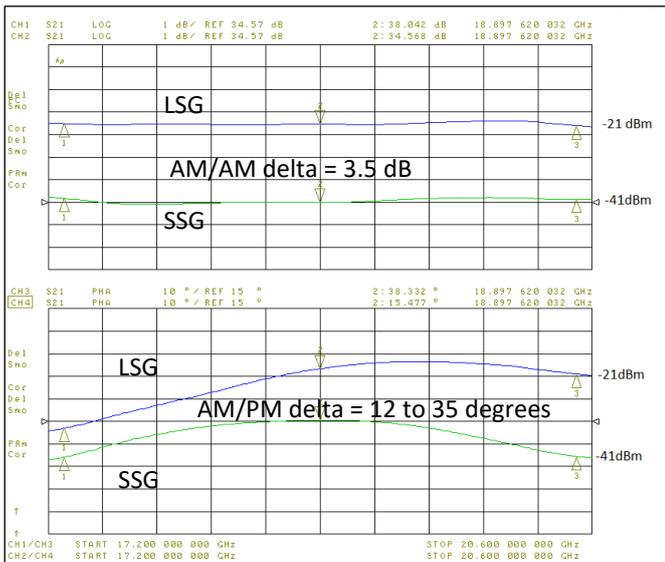


Fig. 9. Frequency and input power versus gain and phase response over the Ka downlink frequency band.

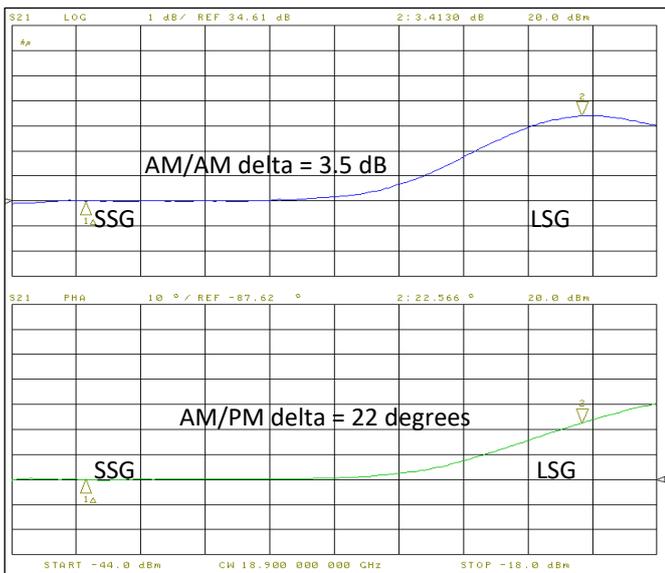


Fig. 10. Phase and gain compensation provided by the linearizer versus input drive at center frequency.

Any change in Nano operating point is communicated to the VLFE, which adjusts its characteristics for the needed response. Figure 11 shows three variants of the AM/AM and AM/PM transfer curves generated by the versatile linearizer.

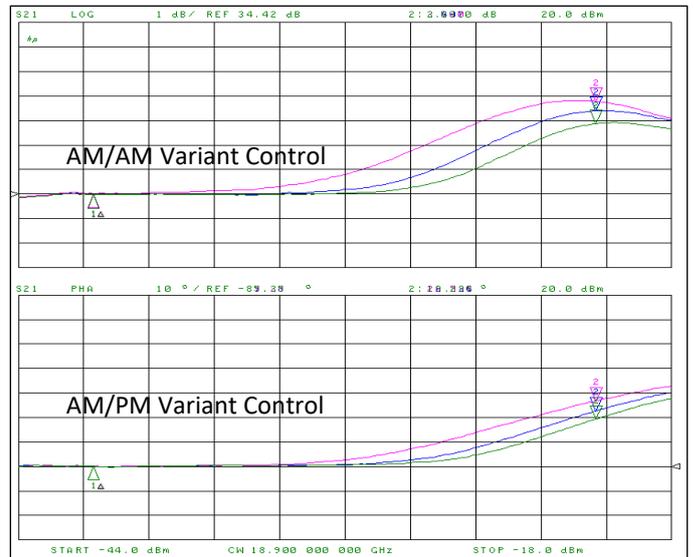


Fig. 11. The phase control provides many variants of the required transfer characteristic needed for TWTs at low and max output power.

Once the VLFE is aligned with the NanoMPM™ the following performance can be achieved. Figures 12 and 13, respectively, show that gain and phase linearity are maintained at the high and low ends of the power range. In both cases the 1-dB gain compression point is moved within 1.5 dB of Sat, and the phase is reduced to < 1 degree. This performance is achieved over a bandwidth of 3 GHz and a dynamic range of adjustment of >6 dB. The use of the versatile linearizer can provide a reduction in prime power on the order of about 35%.

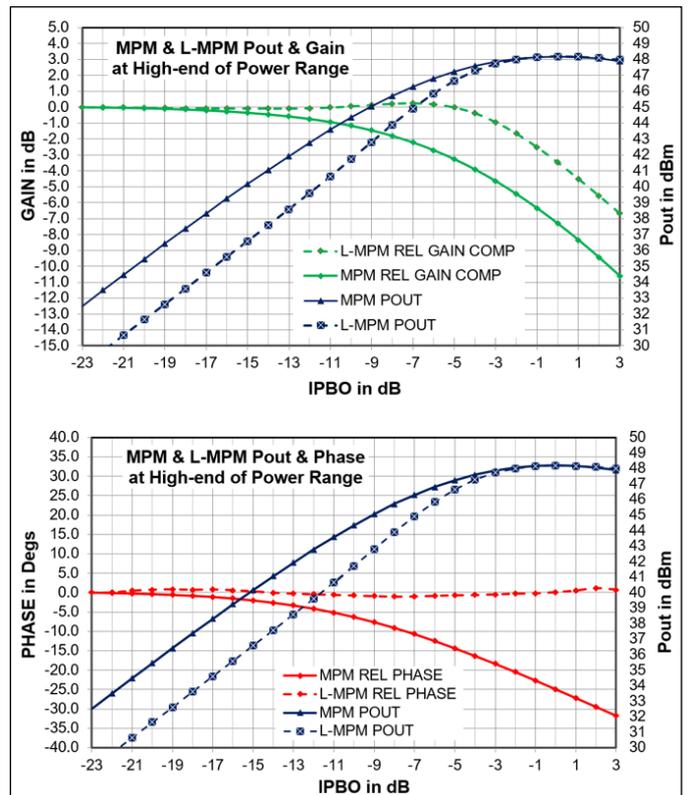


Fig. 12. NanoMPM™ and linearized NanoMPM™ at 18.9 GHz, high power.

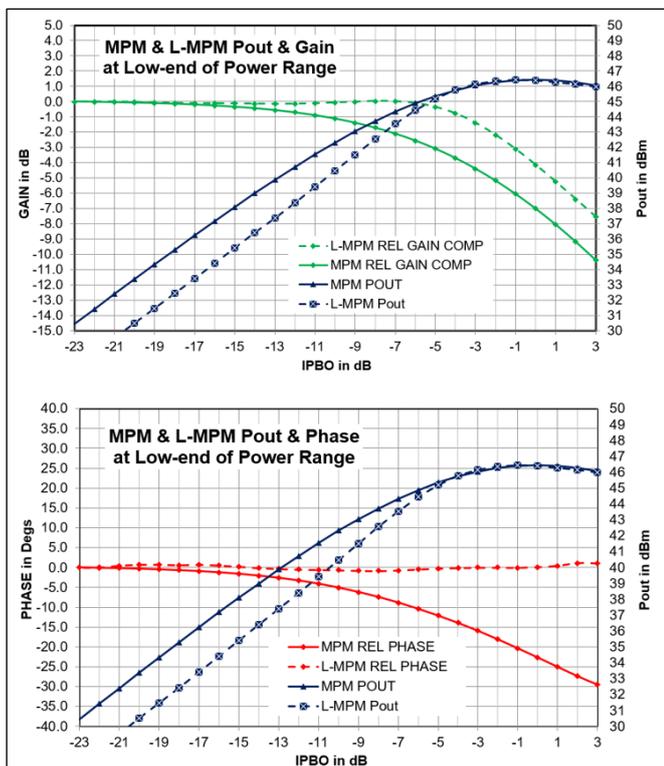


Fig. 13. NanoMPM™ and linearized NanoMPM™ at 18.9 GHz, low power. The VLFE when integrated with a NanoMPM™ can provide 30 Watts of linearizer power and an NPR of 15 dB at an DC efficiency of 35%. A K-band quad space linearized NanoMPM™ is shown in figure 14.

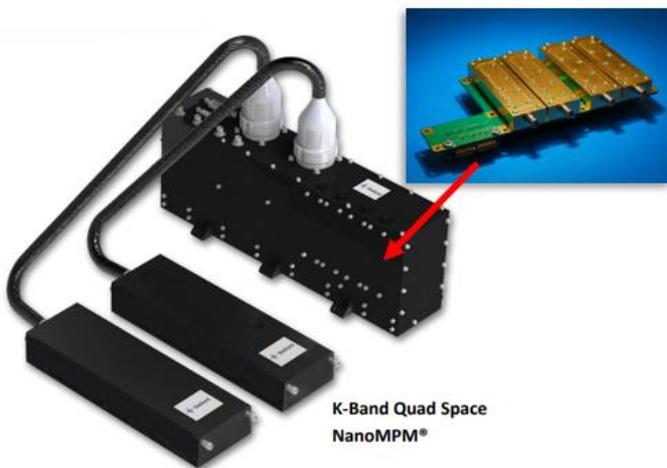


Fig. 14. A K-Band Quad Space NanoMPM™. Photo courtesy of Stellant Systems.

VI CONCLUSION

This paper clearly illustrates the value of implementing versatile linearization of satellite PAs. The results with newly developed Nano MPMs for space have been excellent. These new, smaller, and more efficient MPMs, when combined with

a VLFE, offer the optimum solution for many applications where small size, minimal DC power, and wideband operation are required of PAs. APDL is required for full satellite band operation and the instantaneous bandwidths (demonstrated at 3 GHz and below) necessary for high data rate transmission. The use of linearization can provide about 2 dB more output power and a 35% increase in efficiency for typical SATCOM applications. These new and more VLFEs enable PAs to maintain high efficiency and linearity at multiple operating points, important for phase array and multibeam operation.

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