# A High Bit Rate Miniaturized QPSK Modulator for Satellite Data Transmission

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## Introduction

Space communication systems are designed based on the prime requirements of size, weight, on-board power requirements and reliability. Various factors limit the transmission of data from satellites and the design of the system becomes more complex with an increase in data rates.

Indian Remote Sensing (IRS) satellites provide data in a variety of spatial, spectral and temporal resolutions. The data transmission requirement for IRS satellites has increased from 20Mbps to 640Mbps. There is a need to improve the resolution of images and hence there is increase in demand for higher data rate transmitters. This calls for developing new data transmitting systems—the modulator in particular.

Data transmission from space to ground needs to be carried out in the frequency band allotted by International Telecommunication Union (ITU). The S-band is overcrowded and moreover higher data rates cannot be accommodated in the allowable 20MHz bandwidth. The other bands allotted for data transmission from space to ground are X-band and Ka-band with 375MHz and 1500MHz bandwidth, respectively. At present, data transmission from remote sensing satellites is confined to X-band, with data rates as high as 210Mbps on two different carriers using QPSK modulation. The next generation satellite will transmit data rates as high as 640Mbps on a single carrier using dual polarization. If the data rates are increased further, transmission at Ka-band is the only option.

In a digital communication system, especially in satellite links, there is a trade-off between bandwidth efficiency and power efficiency when selecting a suitable modulation scheme. The QPSK modulation scheme, which is optimum in terms of power and bandwidth efficiency, is widely used for high bit rate data transmission for terrestrial as well as satellite communications.

A miniaturized QPSK modulator was designed at X-band using micro-strip line techniques. It was tested for its performance up to a data rate of 800 Mbps. The high data rate ensures the transmission of images acquired by high resolution cameras to ground. Realization of the unit and its test results are explained in this paper.

## Description

The existing on-board QPSK modulator at X-band transmits 105Mbps on a single carrier. The modulator is reflection type consisting of a hybrid, two BPSK modulators and a power combiner. Each BPSK modulator consists of a hybrid ring with switching diodes in two arms. The diodes are switched by data to include or exclude $\lambda/4$ lines to get 0º or 180º phase shift at the output of the modulator. The modulator MIC was realized on a 2" x 2" alumina substrate.

A new miniaturized QPSK modulator at X-band was realized using a 3dB/90° hybrid, two double balanced mixers (HMC 141&142 from M/S Hittite) used as BPSK modulators and a Wilkinson power combiner. It was realized at X-band wherein the BPSK modulator was realized using MMIC double balanced mixers, thus drastically reducing the size. The two double balanced mixers are mirror images of each other and have identical characteristics except for the location of the IF port. These mixers were selected to avoid cross over of the data line over the RF path in the layout.

The use of double balanced mixers gives a wider bandwidth, possibility to operate at higher data rates and better isolation between the input, output and data ports. The double balanced mixer has four diodes connected as a bridge. A pair of diodes conducts at a time depending on the polarity of the applied data signal, thus providing 0° or 180° phase shift. The 3dB/90° hybrid and power combiner were designed using micro-strip line techniques. These were designed to cover a broader bandwidth of 8.0-8.55GHz. The modulator has the benefits of reduced size and high data rate handling capability. The same modulator design can be used for data transmission at X-band as well as the extended X-band for deep space missions.

The block diagram of the QPSK modulator is shown in Fig.1. The un-modulated X-Band carrier is split into two carrier components using a 3dB/90° hybrid coupler. The two double balanced mixers bi-phase modulate the carriers with the I and Q data streams and their outputs are combined using a Wilkinson power combiner to provide QPSK modulated signal.

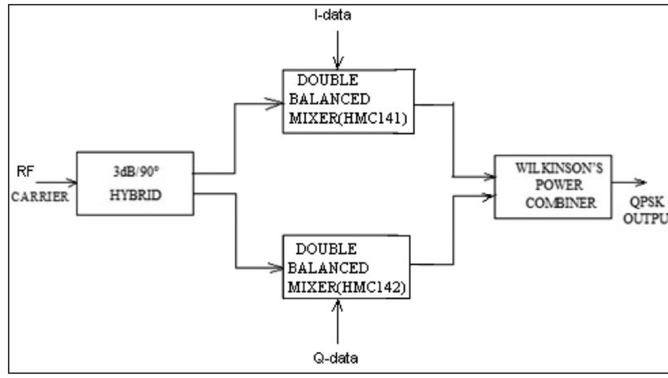


**Figure 1 • Block Diagram of X-band QPSK Modulator.**

## Simulation

The simulated test results of the microstrip elements i.e. the 3dB hybrid coupler and power combiner are presented.

## Hybrid Coupler

The hybrid coupler also known as branchline coupler is a four port device. The input RF carrier power will be

| FREQ-GHZ | DB[S21] HYB | DB[S31] HYB | ANG[S21] HYB | ANG[S31] HYB | DB[S11] HYB | DB[S22] HYB | DB[S33] HYB | DB[S44] HYB | DB[S41] HYB |
|---|---|---|---|---|---|---|---|---|---|
| 8.00000 | -3.164 | -3.085 | -14.931 | -104.938 | -24.144 | -24.268 | -24.268 | -24.144 | -24.703 |
| 8.05000 | -3.137 | -3.089 | -18.236 | -108.253 | -25.959 | -26.115 | -26.115 | -25.959 | -26.640 |
| 8.10000 | -3.116 | -3.093 | -21.550 | -111.567 | -28.243 | -28.334 | -28.334 | -28.243 | -29.064 |
| 8.15000 | -3.100 | -3.097 | -24.871 | -114.880 | -31.326 | -30.956 | -30.956 | -31.326 | -32.155 |
| 8.20000 | -3.088 | -3.102 | -28.197 | -118.192 | -36.082 | -33.492 | -33.492 | -36.082 | -35.592 |
| 8.25000 | -3.082 | -3.106 | -31.528 | -121.505 | -46.047 | -33.980 | -33.980 | -46.047 | -36.133 |
| 8.30000 | -3.081 | -3.110 | -34.861 | -124.818 | -41.568 | -31.822 | -31.822 | -41.568 | -32.907 |
| 8.35000 | -3.085 | -3.114 | -38.196 | -128.133 | -34.205 | -29.145 | -29.145 | -34.205 | -29.666 |
| 8.40000 | -3.093 | -3.119 | -41.531 | -131.450 | -30.203 | -26.820 | -26.820 | -30.203 | -27.113 |
| 8.45000 | -3.107 | -3.123 | -44.865 | -134.770 | -27.463 | -24.892 | -24.892 | -27.463 | -25.085 |
| 8.50000 | -3.126 | -3.127 | -48.198 | -138.094 | -25.378 | -23.275 | -23.275 | -25.378 | -23.425 |
| 8.55000 | -3.149 | -3.131 | -51.527 | -141.422 | -23.694 | -21.893 | -21.893 | -23.694 | -22.029 |

**Table 1**

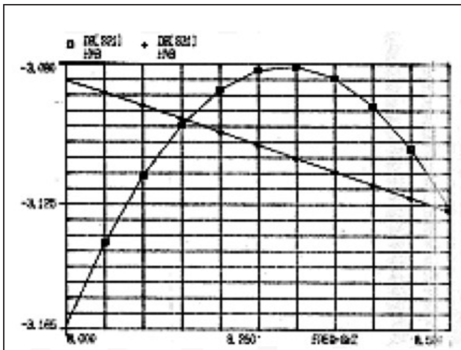

**Figure 3 • Magnitude plots.**

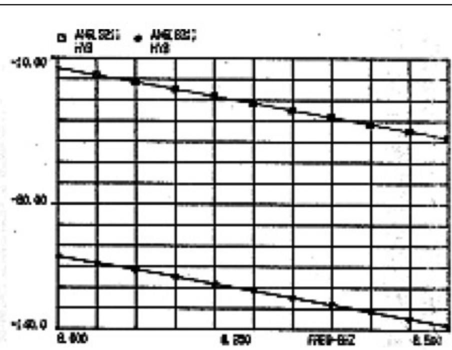

**Figure 4 • Phase plots.**

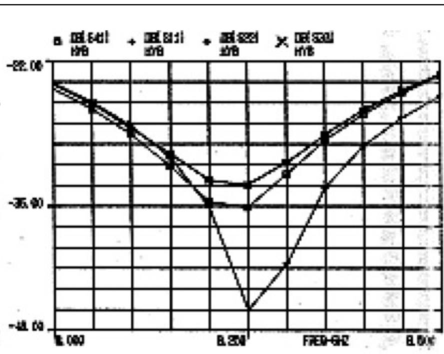

**Figure 5 • Return loss plots.**

| FREQ-GHZ | DB[S31] CC | DB[S32] CC | ANG[S31] CC | ANG[S32] CC | DB[S11] CC | DB[S22] CC | DB[S33] CC |
|---|---|---|---|---|---|---|---|
| 8.00000 | -3.065 | -3.065 | 18.476 | 18.476 | -23.264 | -23.264 | -33.073 |
| 8.05000 | -3.067 | -3.067 | 15.903 | 15.903 | -24.484 | -24.484 | -30.704 |
| 8.10000 | -3.069 | -3.069 | 13.330 | 13.330 | -25.867 | -25.867 | -28.967 |
| 8.15000 | -3.071 | -3.071 | 10.756 | 10.756 | -27.437 | -27.437 | -27.627 |
| 8.20000 | -3.073 | -3.073 | 8.182 | 8.182 | -29.184 | -29.184 | -26.561 |
| 8.25000 | -3.076 | -3.076 | 5.607 | 5.607 | -30.975 | -30.975 | -25.697 |
| 8.30000 | -3.078 | -3.078 | 3.029 | 3.029 | -32.334 | -32.334 | -24.992 |
| 8.35000 | -3.080 | -3.080 | 0.448 | 0.448 | -32.474 | -32.474 | -24.412 |
| 8.40000 | -3.083 | -3.083 | -2.136 | -2.136 | -31.266 | -31.266 | -23.936 |
| 8.45000 | -3.085 | -3.085 | -4.724 | -4.724 | -29.461 | -29.461 | -23.549 |
| 8.50000 | -3.086 | -3.086 | -7.317 | -7.317 | -27.632 | -27.632 | -23.236 |
| 8.55000 | -3.088 | -3.088 | -9.917 | -9.917 | -25.968 | -25.968 | -22.987 |

**Table 2**

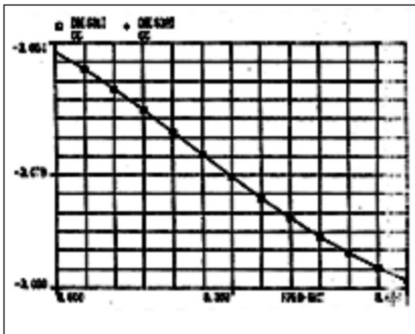

**Figure 6 • Magnitude plots.**

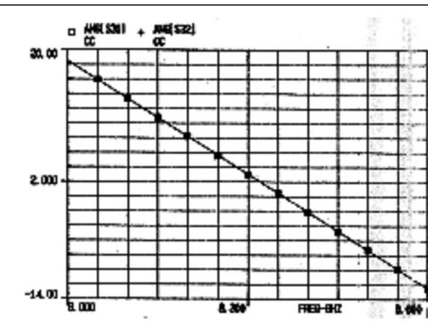

**Figure 7 • Phase plots.**

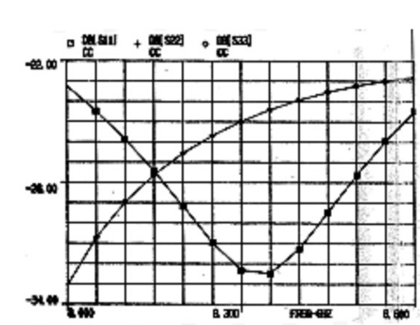

**Figure 8 • Return loss plots.**

divided equally into two with 90º phase difference between the output ports. The fourth port is terminated in a 50ohms load. Table 1 gives the simulated test results of the 3dB/ 90º hybrid coupler. Figs. 3 & 4 give the simulated magnitude and phase plots respectively for the S-parameters S21 and S31. The phase difference between two output ports is 90º. Fig.5 gives the return losses (S11, S22, S33 and S44) of all the four ports.

### Power Combiner

A two-way Wilkinson power combiner is a three port device which is used to divide the power into two equal magnitudes without any phase difference between the output ports. Table 2 gives the simulated test results of the power combiner. Figs. 6 & 7 give the simulated magnitude and phase plots respectively. It can be noted that the both ports magnitude is same (3dB) and phase difference is zero. Fig.8 gives the return losses of all the three ports and it is more than 20dB throughout the band.

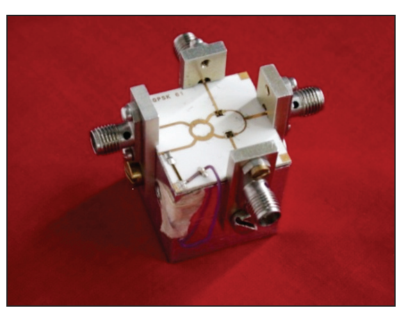

**Figure 9 • Miniaturized high data rate QPSK modulator.**

### Hardware Realization

A QPSK modulator was fabricated using 3dB hybrid, BPSK modulators and power combiner. The BPSK modulator was realized using bare dies. All the units were realized on a 1"x1" alumina substrate. The photograph of the modulator is shown in Fig.9. The substrate was mounted on a test jig and tested for its performance. The size can be reduced further by using a suitable package which may also improve the performance.

### Test Results

The individual test results of the 3dB hybrid coupler and power combiner are given in Tables 3 & 4 respectively. The QPSK modulator consisting of the 3dB hybrid, mixer dies and power combiner was realized on a single substrate and tested for its performance. The data rate requirement at X-band is only 320 Mbps per carrier. However, the modulator was tested up to 800Mbps. The spectrums for Pseudo Random Bit Sequence (PRBS) data pattern for 320Mbps and 800Mbps are shown in Figs.10 & 11 respectively.

The modulator was also tested for its four phases on a network analyzer. The output phase states are shown in the constellation diagrams in Fig.12. The amplitude and phase imbalance achieved are ±1.21 dB and ± 3.6º respectively.

| Freq GHz | db [S21] | db [S31] | Ang S21 | Ang S31 | db [S41] | db [S11] | db [S22] | db [S33] | db [S44] |
|---|---|---|---|---|---|---|---|---|---|
| 8.0 | -3.47 | -3.9 | 80.9 | 172.6 | -20.1 | -15.6 | -18.1 | -14.9 | -24.2 |
| 8.05 | -3.56 | -4.00 | 73.5 | 164.6 | -22.0 | -16.9 | -19.4 | -16.5 | -20.6 |
| 8.1 | -3.42 | -4.00 | 66.8 | 157.3 | -24.6 | -14.2 | -19.8 | -16.8 | -20.0 |
| 8.15 | -3.42 | -3.98 | 58.5 | 151.7 | -22.3 | -13.5 | -22.7 | -17.1 | -21.6 |
| 8.2 | -3.65 | -3.90 | 51.2 | 144.1 | -21.6 | -16.7 | -19.3 | -14.6 | -23.3 |
| 8.25 | -3.83 | -3.88 | 45.6 | 139.4 | -20.1 | -18.1 | -16.4 | -15.5 | -23.4 |
| 8.3 | -3.74 | -3.92 | 38.8 | 131.7 | -26.1 | -17.5 | -17.8 | -15.2 | -25.8 |
| 8.35 | -3.85 | -3.87 | 31.8 | 124.2 | -27.5 | -23.7 | -16.4 | -15.2 | -31.9 |
| 8.4 | -3.84 | -3.80 | 25.6 | 117.8 | -30.2 | -32.5 | -11.0 | -14.4 | -20.9 |
| 8.45 | -3.77 | -3.68 | 20.3 | 111.1 | -32.8 | -21.6 | -10.6 | -15.3 | -17.8 |
| 8.5 | -3.70 | -3.88 | 13.4 | 102.3 | -24.9 | -18.0 | -13.6 | -17.8 | -21.6 |
| 8.55 | -3.61 | -3.78 | 6.2 | 95.9 | -23.5 | -19.8 | -17.3 | -21.0 | -23.8 |
| 8.6 | -3.56 | -3.67 | 0.4 | 88.9 | -19.7 | -16.8 | -22.2 | -31.4 | -18.4 |

Table 3

| Freq | db [S31] | db [S32] | Ang S21 | Ang S31 | db [S11] | db [S22] | db [S33] |
|---|---|---|---|---|---|---|---|
| 8.0 | -3.8 | -4.01 | -107.86 | -108.37 | -18.9 | -25.5 | -14.6 |
| 8.05 | -3.8 | -4.0 | -113.09 | -113.54 | -18.0 | -24.4 | -12.3 |
| 8.1 | -3.8 | -3.9 | -119.74 | -120.66 | -19.1 | -26.6 | -13.5 |
| 8.15 | -3.8 | -3.9 | -125.63 | -126.76 | -17.5 | -22.6 | -16.5 |
| 8.2 | -3.8 | -3.9 | -129.85 | -130.31 | -13.7 | -16.5 | -15.6 |
| 8.25 | -3.9 | -4.0 | -137.36 | -138.43 | -13.1 | -15.9 | -13.4 |
| 8.3 | -3.9 | -3.9 | -142.33 | -143.31 | -15.2 | -19.5 | -14.6 |
| 8.35 | -3.9 | -3.9 | -148.68 | -149.95 | -16.6 | -21.9 | -13.4 |
| 8.4 | -4.0 | -4.1 | -153.82 | -154.75 | -14.7 | -19.8 | -10.0 |
| 8.45 | -4.4 | -4.37 | -159.46 | -160.63 | -14.8 | -19.7 | -9.71 |
| 8.5 | -4.3 | -4.2 | -165.88 | -167.56 | -19.8 | -36.0 | -11.3 |
| 8.55 | -4.2 | -4.1 | -170.59 | -171.56 | -22.4 | -35.2 | -11.6 |
| 8.6 | -4.28 | -4.12 | -175.32 | -176.41 | -22.1 | -30.7 | -13.9 |

Table 4

## Conclusion

A simple and compact QPSK modulator was designed at X-band using micro-strip line techniques for satellite data transmission. Simulated and hardware results are presented in the paper. It can support data rates up to 800Mbps. The modulator can be used directly at X-band by limiting the data to 375Mbps or the output can be up-converted to Ka-band to transmit higher data rates. The performance of the modulator is expected to improve if the test jig is replaced with proper RF package.

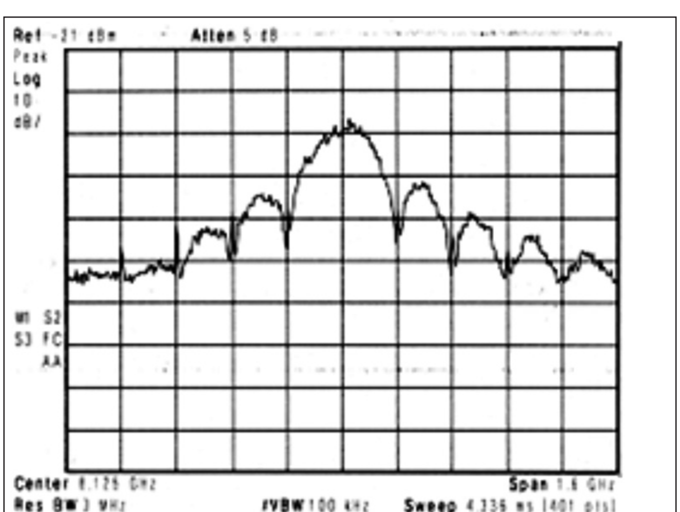

Figure 10 • PRBS spectrum for 320Mbps.

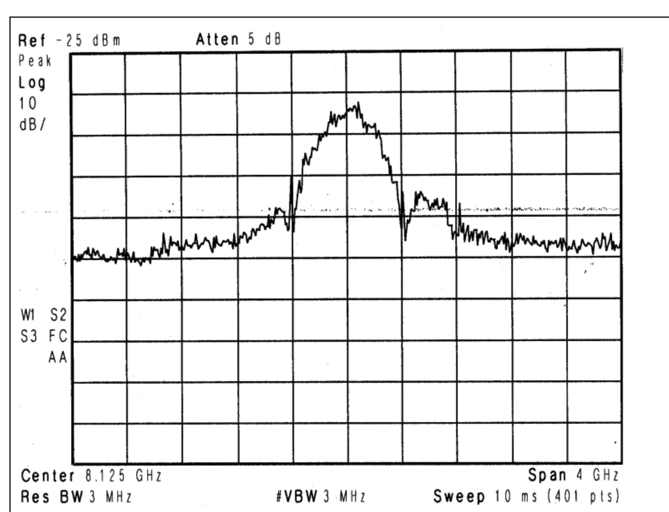

Figure 11 • PRBS spectrum for 800Mbps.

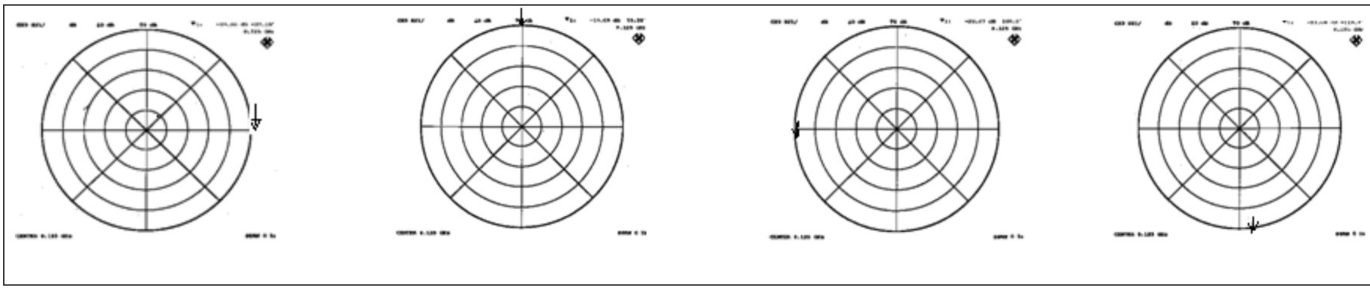

Figure 12 • Constellation Plots of QPSK Modulator.

**About the Authors:**

Dr. D. Venkata Ramana holds an M.Tech degree from National Institute of Technology, Surathkal and a Ph.D. from the Indian Institute of Science, Bangalore, India. He joined ISRO Satellite Centre, Bangalore in 1983 and has been associated with the Communication Systems Group. He is involved in the design and development of high bit rate data transmitters and advanced modulation schemes for various Indian Remote Sensing Satellites. He has published papers in various national and international journals. He is a Senior Member-IEEE; Fellow-IETE; Fellow-IE; LM-IMAPS.

Mrs. Jolie.R received her B.Tech from University of Kerala and M.Tech from Cochin University of Science and Technology. She joined the ISRO Satellite Centre, Bangalore in 2000 and is a design engineer for data transmitting systems for IRS satellites. Her work includes development of high bit rate modulators, data transmitters at X and Ka-band and investigations in the area of spectrally efficient data transmission system for space communication links. She is currently registered for her Ph.D. at VTU, Bangalore. She is a Life Member of IMAPS.

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