HIGH PERFORMANCE 30/20 GHz TRANSPONDER SYSTEM USING SUSPENDED SUBSTRATE MIC DOWN AND UPCONVERTERS

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In order to fully realize the operating potential of millimeter-wave communications systems, a 20/30 GHz spacecraft transponder system has been designed around the use of subharmonically pumped down and up converters. These converters, exhibiting the lowest commercially available system noise figures, provide a reliable nucleus for use in multichannel transponder architecture. SSB receiver noise temperatures of less than 1250°K including the 250°K contribution from an 8 GHz IF amplifier have been achieved for the subharmonically pumped downconverter operating between 30.2 and 31.2 GHz.

Introduction

This paper discusses the development of prototype down and upconverters for a 30/20 GHz satellite transponder system. The downconverter designed for 7-8 GHz IF output while subharmonically pumped, has attained a receiver noise figure of 7.2 dB SSB including a 250°K IF contribution. As a conerstone in the development of the transponder system, the downconverter specification is the result of various considerations which required an assessment of the desired channel characteristic, and the technology available for the time frame of implementation. A detailed frequency plan and hardware block diagram is then achieved through an iterative process. Finally the end-to-end available performance and the component specification are derived.

The 1.0 GHz of bandwidth available at 30/20 GHz for military satellite communications offers potential for two types of service which result in widely differing payload configurations.

1. High-data rate digital data.
2. Multi-channel spread spectrum low data rate.

In both cases narrower antenna beamwidths are available for the same apertures as used on the lower bands. The first year of a two year development program has resulted in demonstration hardware for the first of these two services including the down and upconverters described in this paper. The transponder design provides four maximum bandwidth channels along with two downlink beacons. Channel performance meets or exceeds that of existing X and Ku-Band transponders in order to maintain compatibility with existing ground modems.

One measure of the performance of a satellite transponder is the ratio of useable bandwidth to total frequency allocation. The necessity of guard bands between channels makes this ratio less than unity. DSCS II achieves 82% at X-Band, while ANIK-C and SBS, the newest satellites at Ku-Band are designed for 89-90%. In contrast the best achievement to date at 30 GHz has been 56% (Japanese CS Program). The channelization efficiency for a given requirement is a function of the quality of the channel and output filters. The design's channelization scheme is shown in Figure 1 and achieves 84% at 30/20 GHz. Four 210 MHz channels are provided, plus two beacons. The design provides high channel-to-channel isolation to prevent adjacent channel interference in a hard limiting mode and multipath induced phase ripple. In addition, the low-power beacons are protected from output intermodulation products and translated up-link signals.

Overall Transponder Design

Overall transponder design is the result of a technical assessment of the performance available from components in the time frame of implementation as well as tradeoffs of configurations. In this example, double conversion was chosen versus single conversion in order to have the design freedom of selecting an optimum frequency for the limiting amplifier. Amplifiers with low AM/PM conversion are not available at either 30 or 20 GHz which would be the only choice in a single conversion transponder. The selection of the intermediate frequency is based upon the performance available from limiters at the intermediate frequency, and an analysis of the location of the spurious frequencies generated by the double conversion process. When using a subharmonically pumped mixer, none of the local oscillator products or mixer images fall inside the design passbands if one selects an 8 GHz IF Frequency response for the first downconversion mixer. The subharmonically pumped mixer described in this paper with a 7.2-8.2 GHz IF output capability is therefore advantageous for use in this transponder architecture.

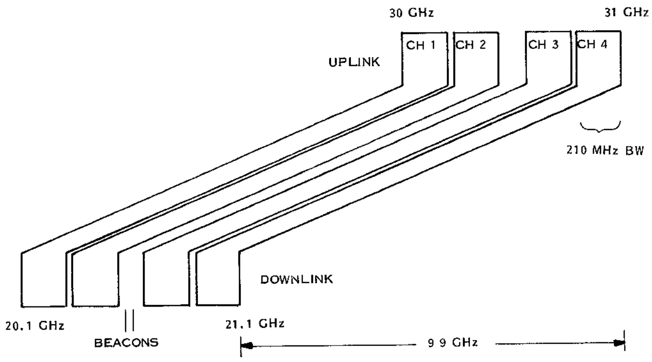

FIGURE 1 TRANSPONDER CHANNELIZATION SCHEME

The use of double conversion additionally allows the channelization filters to be implemented at X-Band rather than Ka-Band. Ten-section pseudo-elliptic dual mode TE_{111} waveguide filters are used. Figure 2 shows the unequalized response achieved. The double nulls at each side of the filters provides protection for the adjacent beacons in the case of channels 2 and 3.

The choice of output devices for the transponder are either a TWT or an IMPATT Amplifier. In the 20 GHz region, the TWT maintains a 4:1 efficiency ratio over the IMPATT and makes it a clear choice for a transponder of greater than 5 watts. Based upon Hughes EDD 250H results and other vendors' development plans, power outputs of up to 15 watts will be obtainable in long life TWTAs. The resulting overall transponder block diagram is shown in Figure 3, and is representative of the technology achievable in flight hardware by 1981. Figure 4 shows the one-channel test model of the transponder.

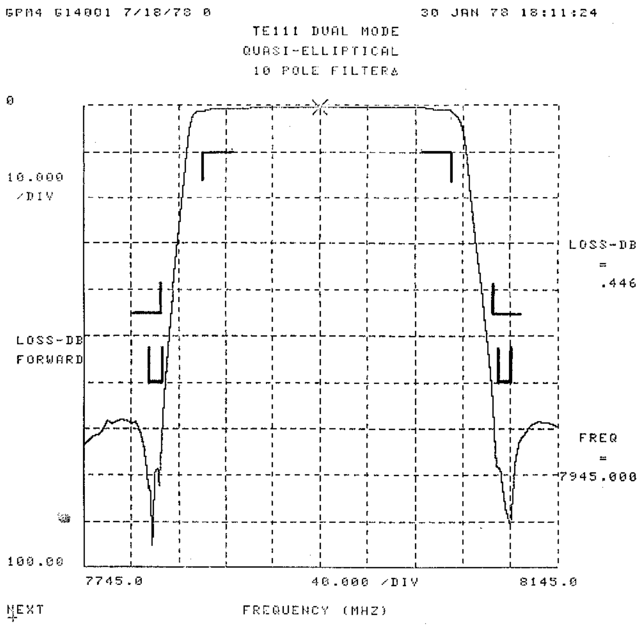

FIGURE 2 FREQUENCY RESPONSE OF CHANNELIZATION FILTER

Downconverter Design

The design of the downconverter utilizes the principle of subharmonic pumping[1,2] a two diode mixer with a quartz suspended stripline RF embedding network. A photograph of the substrate, in Figure 5, shows the various filters used in the design. The mixer is a true single sideband Image enhanced/Image reject mixer. The design goals for this mixer were:

Noise Figure SSB	6.5 dB SSB (Including 3 dB IF at 8 GHz)
RF Frequency	30.0-31.0 GHz
IF Frequency	7.2-8.2 GHz
LO Frequency	11.4 GHz
Image Rejection	60 dB

As is evident in Figure 5, the local oscillator is injected via a half-wave stripline resonator tuned for 11.4 GHz. This signal is applied to a shunt-configured diode pair located in the suspended stripline and just beyond the signal waveguide opening. The RF signal is terminated in a High Z-Low Z filter just beyond the diodes, while the image and the local oscillator response are controlled by the second 4 element filter which forms a bandpass response at the IF Frequency. Design of the mixer made use of a low frequency model in the 4-5 GHz region where scaled performance of the mixer was evaluated using low frequency beam lead diodes. The diodes used in this converter had C_{to} = 0.015 pfd and R_s = 4 ohms (dc), and have been described in a recent publication[3]. Image enhancement was optimized by varying the phase of the IF Bandpass filter with respect to the diode pair.

A typical conversion loss of 5.1 dB was obtained, with an associated noise figure of 7.2 dB SSB including a 2.5 dB IF Contribution from a 7-8 GHz FET amplifier. Measurements were made using both hot/cold loads and waveguide noise sources, and were in agreement at all times. The mixer, although optimized for a 7-8 GHz IF response, was capable of operation over a 2 GHz instantaneous bandwidth with slightly reduced performance. Using the definition of Carlson et al[4], the intrinsic mixer noise temperature T_m (defined by the relation $T_m = T_R(SSB) - (L_s T_{IF})$, was found to be 423°K ± 80°K SSB, which compares favorably with results quoted in the literature for many mixers with much lower IF output frequencies. An analysis of the measured noise figure data and noise calculations appear in Appendix I.

Because of the low intrinsic mixer noise temperature T_m, we plan to integrate a FET first stage directly into the mixer which will reduce the overall SSB noise figure of the unit to the range of 5.5-6.0 dB. Testing the mixer at a reduced ambient temperature is also planned. A photograph of the completed unit appears in Figure 6. Additionally, the frequency response of the mixer appears in Figure 7, where the conversion loss variation of approximately 0.5 dB over the range of interest is evident.

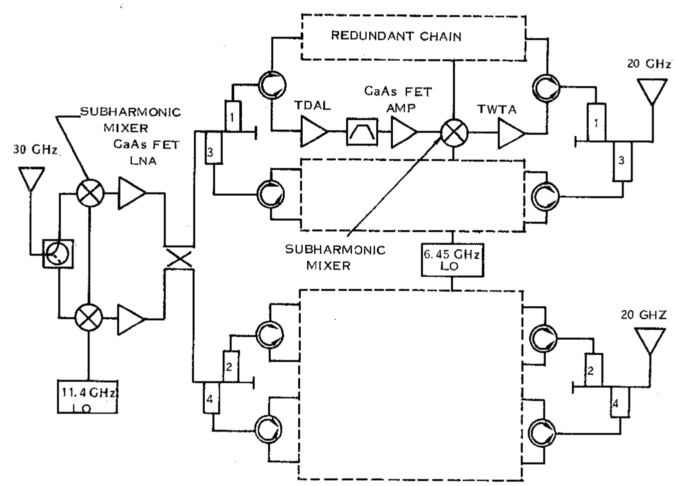

FIGURE 3 TRANSPONDER BLOCK DIAGRAM

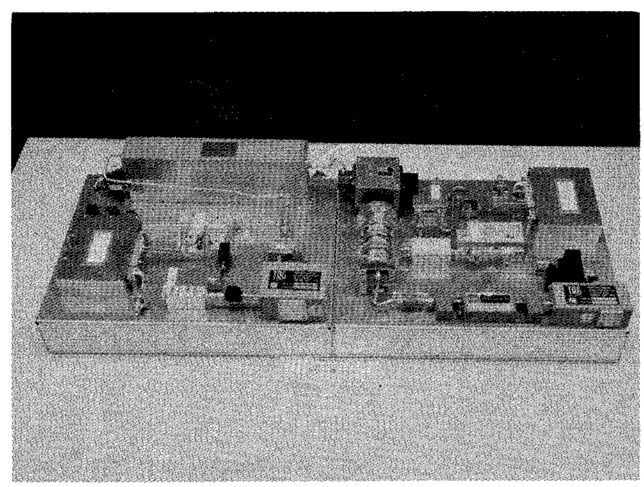

FIGURE 4 ONE CHANNEL TRANSPONDER TEST MODEL

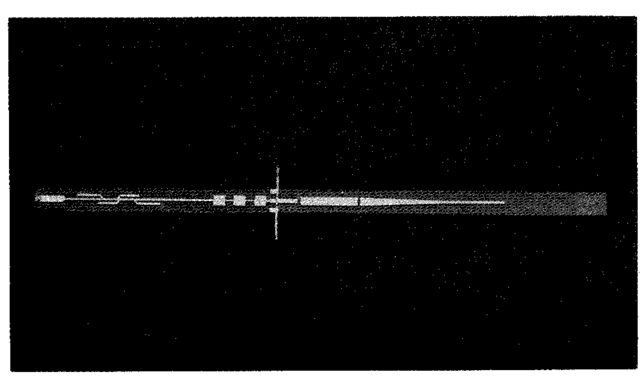

FIGURE 5 SUBSTRATE USED IN DOWNCONVERTER

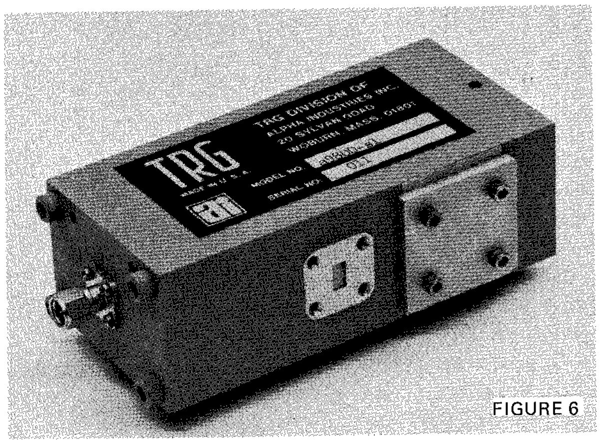

FIGURE 6

Downconverter Performance Summary

RF Freq. Range =	30.2-31.2 GHz
IF Output =	7.2-8.2 GHz
Local Osc. =	11.4 GHz +9 dBm
T_R (SSB) =	1231°K incl 250°K IF Contribution
T_m (SSB) =	423°K SSB ± 80°K
Signal Conversion Loss =	5.1 dB
Image Conversion Loss ⩾	60 dB
RF VSWR ⩽ 1.3:1	
IF Output = 50Ω	

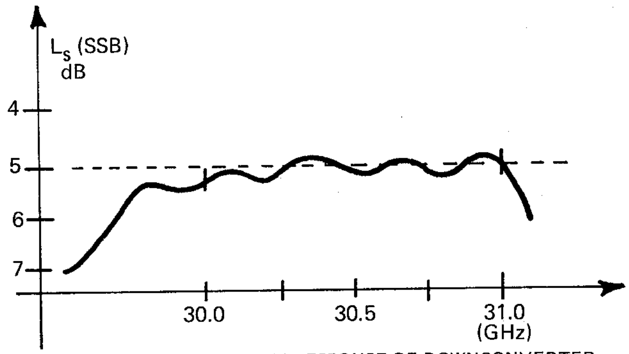

FIGURE 7 FREQUENCY RESPONSE OF DOWNCONVERTER

Upconverter

A subharmonically pumped upconverter was also developed. The converter, designed using a broadband configuration similar to that described in a recent article[5], where bandstop filters are used to separate the RF, IF, and pump circuits, has achieved -3 dBm output level ±0.5 dB over the range of interest. The measured specifications for this converter were:

RF Output:	20.2-21.2 GHz	-3 dBm nominal
IF Input:	7.2-8.2 GHz	+6 dBm nominal
Pump	6.4 GHz	+13 dBm

This converter is used to excite the TWTA amplifier in the modem final stage. No spurious responses could be detected 50 dB below the desired output for this converter.

Conclusion

Two key elements, the up and downconverters, have been developed for implementation of a 30/20 GHz transponder system designed for flight operation in the 1981 time frame. The use of advanced surface oriented diode technology and suspended stripline construction makes for a highly reliable and reproducable component of the highest quality.

Acknowledgement

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APPENDIX I: NOISE CALCULATIONS

Laboratory Measurements

9.6 dB Y factor using 16.3 dB ENR
AIL Noise Lamp
L_s = 5.1 dB Using HP Thermistor
$L_i = \infty$ Power meters at Signal, IF
T_{IF} = 250°K Using HP Calibrated noise lamp

Calculations based on above data

I. SSB Noise Figure

$$F_{dB} = ENR_{dB} - 10 \log_{10} (Y-1) \quad (1)$$

where Y is expressed as a ratio
Using egn (1) with 9.6 dB = Y ≡ 9.12 (ratio)

$$F_{dB} = 16.3 - 10 \log_{10} (9.12-1)$$
$$= 16.3 - 9.32$$
$$= 7.2 \text{ dB}$$

Now since $L_i = \infty$ F_{dB} = F(SSB)
and

$$\boxed{F(SSB) = 7.2 \text{ dB}}$$

II. Mixer Temperature (Intrinsic Mixer Temperature)

$$T_R (SSB) = (F_R(SSB) - 1)\, 290°K \quad (L_i = \infty) \quad (2)$$
$$T_R (SSB) = T_m (SSB) + L_s T_{IF} \quad (3)$$

Using (2) $\boxed{T_R (SSB) = 1231°K}$

Using (3) $T_m (SSB) = 1231 - (3.24)(250°K)$
$= 422°K$

So $\boxed{T_m (SSB) = 422°K}$

You are referred to Carlson et. al [4] for an explanation of formula (2) and (3). Formula (1) is courtesy of the AIL noise figure slide rule.

Conversion from Higher Order Sidebands

It was determined that conversion from sidebands near 60 GHz was down at least 15 dB below the conversion loss of 5.1 dB measured at 30 GHz. For this reason, errors in noise figure measurement due to noise at 60 GHz entering the mixer are insignificant. A 60 GHz Gunn Oscillator and calibrated IF and RF Thermistor mounts were used in this measurement.

References

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