The Signal Splitter for Laboratory GNSS Signal Distribution

Richard Linhart, Ivo Veřtát
Department of Applied Electronics and Telecommunications, University of West Bohemia
Pilsen, Czech Republic, rlinhart@kae.zcu.cz

***Abstract* – The paper presents a design of a four way signal splitter working in L frequency band, for standard GNSS (Global Navigation Satellite Systems) signals. These splitters are used when more than one receiver has to be connected to one signal source, like an antenna, a signal distribution socket or a test signal generator. The advantage of the solution is realization by a PCB structure, without need of any expensive or hard to find special components. The splitter is also integrated with a transformation from 75 Ω to 50 Ω. Then cheaper 75 Ω cable can be used for the signal distribution system. Final results from the splitter testing are also included in the paper.**

***Keywords*- Signal splitter, signal distribution GNSS, GPS, Galileo, GLONASS**

I. Introduction (Heading 1)

In the state of art technology, the role of the GNSS is very important. In civilian use, the GNSS is used in many applications in traffic, geodesy, emergency and safety as well as in sport and free time. Now the most used GNSS is still the GPS, developed for the US army and equipped with services released for civilian use. The GPS system is New European GNSS Galileo is still under deployment, sometimes it is taken as a competitor to GPS, sometimes as a cooperating or complementary system. There is also different Russian GNSS system GLONAS and more satellite navigation systems mainly for special or regional use.

Next to positioning, there is another use of GNSS, the determination of accurate time. Single frequency GNSS receivers provide a timing accuracy of about 30 ns (in 95% probability) with only one satellite in view. With more sophisticated techniques, the precision less than 1 ns is achievable. The GNSS accurate time or frequency receivers provide accurate 1 PPS or 10 MHz signal synchronous with the GNSS.

The main purpose of the signal splitter presented in this paper is distribution of the GNSS signal to multiple receivers. It can be used in test laboratory for the GNSS receiver evaluation and testing, for building systems when more stations process data from the GNSS in parallel or for systems with more accurate time receivers with the GNSS signal input.

II. GNSS Services in the L Band

The standard GNSS operate in the "L" microwave band, approximately from 1164 MHz to 1609 MHz. Segments of GNSS signals are in Fig. 1, graphically divided between three GNSS, the GPS, GLONAS and Galileo.

A. GPS Signals

Interesting frequencies of the GPS are L1 (1575.42 MHz) the most important frequency in civilian applications, then L2 (1227.6 MHz) and last, not fully supported option L5 (1176.45 MHz) [1]. Both L1 and L2 frequencies are modulated by a P(Y) code and modern M code both intended for military use. By using the L1 together with the L2, better resistance to ionosphere fluctuations is given. The most common free C/A code for civilian use is transmitted on the L1 only. Modern civilian codes are L1C code, transmitted on the L1 and the L2 CL with the L2 CM codes transmitted on the L2 [2]. The last L5 frequency contains signals L5I and L5Q for a special use [3].

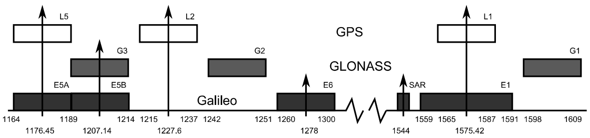

Figure 1. Main GNSS signals in the L band.

B. Other GNSS Signals

The GNSS system Galileo still in deployment these days is designed for frequencies E1 (1575.42 MHz), E6 (1278.75 MHz) and E5 (1191.795 MHz). The E1 is the same as the GPS L1 for compatibility, other frequencies are different. The signal spectrum E5 is overlapped partially with GPS signal on frequency L5 [1].

The last signal group in the L band belongs to the GLONASS, the Russian GNSS. There are three main frequencies G1 (1602.0 MHz), G2 (1246.0 MHz) and G3 (1204.704 MHz). The standard precision code C/A and high precision code P are transmitted around the G1 and the G2 frequencies using FDMA. Modern version of GLONASS will also transmit FDMA signals around the G3 frequency and CDMA around the G1 and the G2 [1].

III. Commercially Available Splitters

There are many GPS distribution blocks in the market now, including the power splitters. The number of outputs varies from 2 to 10 or more, there are passive power splitters as well as active ones. Three typical examples of GNSS signals were taken for parameters comparison, all four-way and passive. The main parameters of splitters selected are in Tab. 1.

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TABLE I. PASSIVE 4-WAY GNSS SIGNAL SPLITTERS COMMERCIALLY AVAILABLE WITH DOCUMENTED PARAMETERS

Manufacturer	**GPS Networking**
Type	LDCBS1X4
Frequency range	1.1 GHz – 1.7 GHz
Input/output impedance	50 Ω
Return loss at input	10.9 dB
Return loss at outputs	14 dB
Insertion loss	8.5 dB
Gain flatness between L1 and L2	0.5 dB
Amplitude imbalance of outputs	0.5 dB
Phase Imbalance of outputs	1°
Outputs isolation	15 dB
Group delay flatness	1 ns

Manufacturer	**GPS Source**
Type	S14
Frequency range	1.0 GHz – 2.0 GHz
Input/output impedance	50 Ω
Return loss at input	9.5 dB
Return loss at outputs	9.5 dB
Insertion loss	7.5 dB
Gain flatness between L1 and L2	1.0 dB
Amplitude imbalance of outputs	0.5 dB
Phase Imbalance of outputs	1°
Outputs isolation	13 dB
Group delay flatness	1 ns

Manufacturer	**INSTOCK Wireless**
Type	GPS400
Frequency range	1.0 GHz – 2.0 GHz
Input/output impedance	50 Ω
Return loss at input	17.7 dB
Return loss at outputs	20.8 dB
Insertion loss	6.6 dB
Gain flatness between L1 and L2	not documented
Amplitude imbalance of outputs	0.3 dB
Phase Imbalance of outputs	4°
Outputs isolation	22 dB
Group delay flatness	not documented

These examples were taken as a reference for the new design in the term of parameters importance and practical values [4], [5], [6].

IV. THE SPLITTER DESIGN

The GPS signals L1 (1575.42 MHz) and L2 (1227.6 MHz) are mandatory for our splitter design. All other signals have lower priority. If the splitter will operate also on other GNSS frequencies, it would be good if for future experiments. One can see the similar approach also at commercial splitter examples listed above, where the splitter is usable over the whole L band, but best parameters are defined at GPS frequencies only. These splitters can be best used for GPS signal, but they are still useable for other L band GNSS.

A. The Splitter Stucture

The most common low-loss power splitter is the Wilkinson power splitter based on quarter-wave transformers to match the split ports to the common port. There are many variants and modifications, but the basic one Fig. 2, (1) splits the signal from the common port into two equal branches [7].

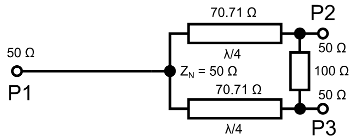

Figure 2. Basic three port Wilkinson power splitter.

The impedance Z_N (node) is converted to 50 Ω using 1/4 wave transformers with impedance Z_{0B} (1).

$$Z_{0B} = \sqrt{Z_{OUT} \cdot 2Z_N} = \sqrt{50 \cdot 100} = 70.71\Omega \quad (1)$$

The resistor between outputs is added for full matching of the three port network. In regular operation, there is no current through it and its loss is zero. The resistor helps to dissipate the reflected wave in the case of mismatched output port.

The main problem of the basic power splitter is the frequency response. The transfer ratio and the return loss have a peak on the central frequency. The solution is to make the Z_N lower in limits of PCB technology and its tolerances. The modified circuit is shown in Fig. 3 and (2).

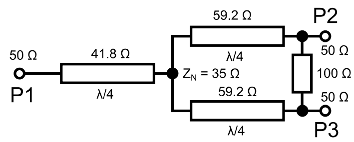

Figure 3. Modified three port splitter for needed bandwidth.

$$Z_{0A} = \sqrt{Z_{IN} \cdot Z_N} = \sqrt{50 \cdot 35} = 41.8\Omega$$
$$Z_{0B} = \sqrt{Z_{OUT} \cdot 2Z_N} = \sqrt{50 \cdot 70} = 59.2\Omega \quad (2)$$

The symbol Z_{0A} denotes the impedance of quarter wave transformer at the common port P1. Parameters of power splitters and modifications were obtained using RF circuit simulator and compared. The last version has the transfer characteristics flat over the interested bandwidth. It gives the transfer amplitude variation below 0.01 dB and the group delay variation 3 ps over bandwidth 1.1 GHz to 1.7 GHz. Return loss of the common port is greater than -28 dB over this bandwidth.

In the final design, the last structure is repeated three times to obtain four outputs. This approach was found best for a simple PCB technology.

V. IMPEDANCE TRANSFORMATION

Due to requirements in our laboratory setup, the common port of the power splitter has to be matched to 75 Ω distribution line. The transformer is made up of next two quarter wave lines. This solution gives better flat transfer response than with one transformation line. The middle point between two transformers has 60 Ω.

VI. THE FINAL REALIZATION

First tests were performed using the RF circuit simulator and transmission line models on real substrate and real resistor models, Fig. 4. Then structures of main blocks (the transformer and three splitters) were converted to the PCB form. After some corrections, electromagnetic models of transmission blocks were obtained, represented by S-parametric files. These models were imported back to the circuit simulator and used for obtaining of final parameters.

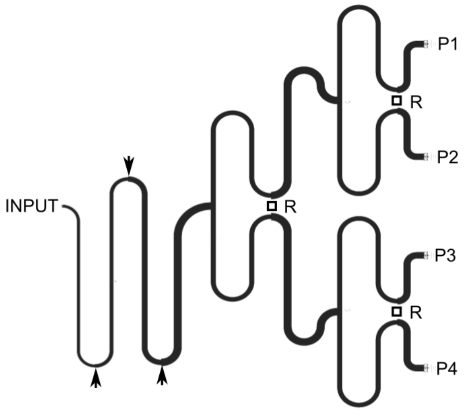

Figure 4. The final PCB structure of the power splitter. Transformation line steps are marked by arrows, resistors are denoted by squares and R.

As substrate, a cheap 0.5 mm thick FR4 was used, because the loss due to substrate parameters will be in order of 0.1 dB. The microstrip line width for the transformation and power splitter are listed in Tab. 2. The 8 mil is technology limit for the PCB trace and the technology tolerance is in 1 mil order.

TABLE II. MICROSTRIP LINE WIDTHS USED IN THE DESIGN

50 Ω	36 mil
54.3 Ω	30 mil
66.5 Ω	20 mil
75 Ω	16 mil
41.8 Ω	42 mil
59.2 Ω	26 mil

The final layout was transferred to the PCB editor and mechanically aligned. Two samples were made, assembled and prepared for measurement, Fig. 5.

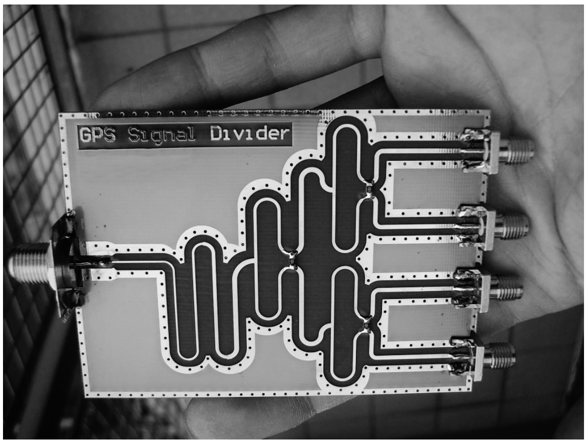

Figure 5. The photo of the power splitter first sample.

VII. MEASURED RESULTS

The first parameter discussed is the power splitter insertion loss, Fig. 6. Four traces belong to four outputs of the splitter. The mean value over both GPS frequencies, the L1 and the L2 (markers) and over all four outputs is 1.8 dB bigger than the minimal loss of the ideal splitter. The region between the L1 and the L2 maintains near flat. The maximal difference on both frequencies is 0.22 dB from the mean value. Both values are comparable well with the commercial products listed above.

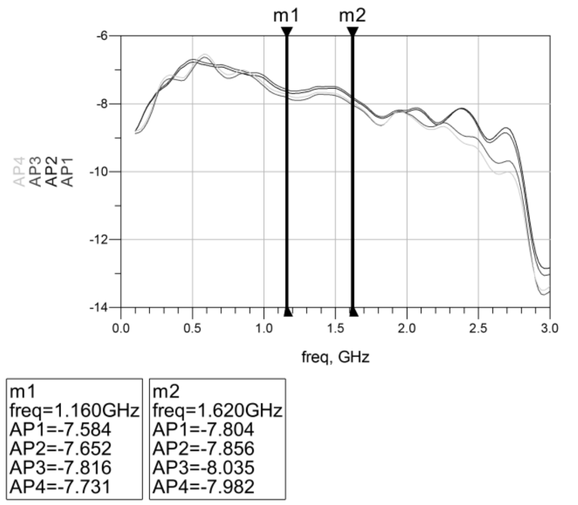

Figure 6. The insertion loss of the splitter. Four traces belong to four outputs. Markers are the GPS L1 and L2 main frequencies.

The next parameter is the return loss of the power splitter common port (input), Fig. 7. Markers have the same meaning as at the previous figure. The worst value is bigger than 11 dB. Tuning the circuit approximately 7 % lower will bring a better return loss about 15 dB.

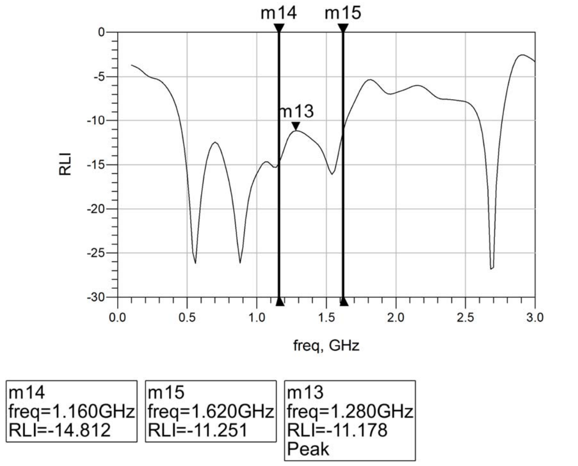

Figure 7. Fig. 9. The return loss at the common port (input). Markers are the GPS L1 and L2 main frequencies.

Next, the output ports return loss is discussed. The worst value on the L1 and the L2 frequencies as well as between them is bigger than 19 dB. Also here, when the circuit will be tuned approximately 7 % lower will improve the return loss near 25 dB. Regardless that, values of return loss at the input and at outputs are comparable with commercial splitters.

The phase distortion is very important parameter at GNSS applications. The phase difference of the four outputs on both L1 and L2 GPS frequencies is in Fig. 11. At the L1, there is worst phase difference between outputs 2.3°, at the L2, there is 2.9°.

The last tested parameter was a group delay Fig. 8. The mean value over all outputs and for GPS frequencies, the L1 and the L2 is 1.7 ns. The worst difference for all outputs and both frequencies is 72 ps.

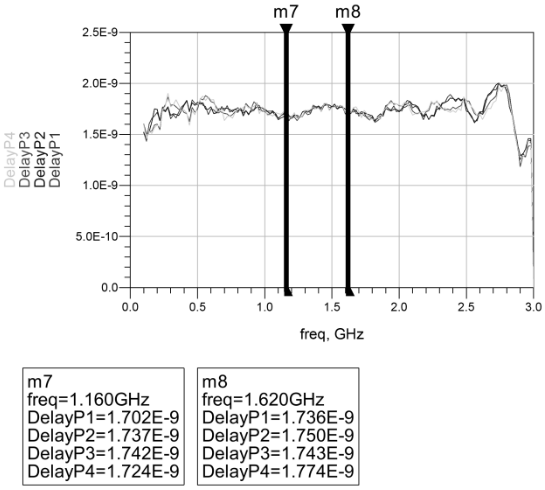

Figure 8. The group delay for all four output ports. Four traces belong to four outputs. Markers are the GPS L1 and L2 main frequencies.

VIII. CONCLUSIONS

The results of testing the power splitter on the vector network analyzer were compared with all three samples commercially available.

The insertion loss obtained is in the middle of range which is at commercial samples. The last sample GPS400, also based on the Wilkinson has very low insertion loss which may indicate a high quality substrate for the RF circuits used. Other LC based splitters have the same or bigger insertion loss than ours.

Next, the return loss at the power splitter input is smaller than at GPS400, but greater than other two samples. The PCB structure at GPS400 can be apparently matched better than lumped components at other two samples. It the next version will be tuned approximately 7 % to lower frequencies, it will bring better input return loss, near 14 dB. This frequency shift was caused by the different PCB permittivity, than used in the design. For the next version of the power splitter, the permittivity will be corrected in accordance to measurement results. The input port connector, a low-quality F type needed for our laboratory setup also may cause further return loss degradation.

The output return loss is near as at GPS400, other two samples are much worse. The current value of the return loss is greater than 19 dB and for modification of the structure approximately 7 % low in frequency can reach up to 25 dB. The problem and solution is the same as at input return loss discussed before.

Phase differences of all four outputs of the power splitter are between 2° to 3°, while at commercially available samples there are up to 1°. The values obtained will be studied in a future, if they are caused by an incorrect connector tightening or by the PCB topology. This parameter is very sensitive to the connector tightness. It will be measured again and the torque wrench will be used.

The last parameter is the group delay flatness, or difference between the GPS L1 and L2 frequencies. The measured value is 72 ps, which is under values of the commercially available samples.

The real test on GPS signal was not performed. This is the task for the future, as well as test of temperature stability of the parameters obtained.

At the conclusion, we can say that the first version of the GNSS power splitter gives comparable parameters to similar products commercially available. Modifications, needed for special requirements in the laboratory setup can be implemented easily and the final result is surprising. The parameters which have to be improved, will be easily corrected in the next version of power splitter.

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