ON MEASURING POLARIZATION ELLIPTICITY WITH A NEW COMPACT BROADBAND ROTARY JOINT

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ABSTRACT

A simple, efficient and compact rotary joint has been designed, realized and measured. It has been used intensively to perform polarization ellipticity measurements on various circularly polarized (CP) antennas (e.g. helical antennas and CP horns, used either individually or feeding a lens antennas) operating in millimeter-wave band (around 30 GHz)

1. INTRODUCTION

When designing circularly-polarized antennas, an important figure of merit to be measured is the ellipticity of polarization. The most common measurement technique in this regard is the so-called "spinning dipole" or "spinning linear source" [1]. A linearly polarized (LP) range antenna (RA) is rotated around the axis defined by the line of view between the RA and the antenna under test (AUT). The amplitude of the ripple in the RA-AUT transfer function during the spinning of the RA amounts to the ellipticity of polarization of the AUT in the direction of the RA-AUT line of view.

To realize the transition between the spinning RA and the fixed instrumentation port, a rotary joint has to be used, most frequently of the coaxial type, to allow broad frequency coverage. The joint consists of a section of coaxial line made of two parts: the stationary and the rotating one. Both parts are mechanically aligned and electrically coupled to allow for stable operation of the joint with minimal insertion loss and matching while rotating at a few hundreds of revolutions per minute (RPM).

The rotary joint is driven by an electromotor integrated and shielded within the RA platform. This motor (with proper gears) determines the nominal RPM, which has to be compatible with the sampling rate of the measurement instrumentation (Network Analyzer) in order to provide an accurate measurement of the ellipticity of polarization of the AUT.

The accuracy of this measurement depends directly on the characteristics of the rotary joint used to spin the LP antenna, more precisely on its insertion loss (IL) which should be as constant as possible. In practice there are always small IL variations (called "**insertion loss wow**" or simply "**wow**") due to mechanical and electrical imperfections (misalignment, vibrations, bad contacts, etc.). These variations should be maintained to a minimum since they constitute a source of systematic errors. In fact, the wow of the rotary joint adds to the measured polarization ellipticity resulting in a pessimistic measurement of this parameter. The absolute value of the IL is less important since in a well designed antenna measurement facility the dynamic range is usually large (> 60 dB, and the effect of a 1 or 2 dB of IL introduced by the rotary joint is negligible).

Most commercially available coaxial rotary joints use galvanic coupling: the inner and outer conductors of the stationary and rotating part are respectively connected by electrical contacts, often made of elastic metallic strips (beryllium copper) pressing (and rubbing!) on the counterpart. This design has the advantage of being very broadband (from DC to 40 GHz or higher) with reasonable insertion loss (typically around 1 dB) and a typical wow around 0.1 to 0.2 dB at the highest frequency. The inconvenient are the mechanical wearing which degrades the rotary joint characteristics with aging; it also requires a relatively important mechanical torque to turn the rotary joint, with the need of an external power supply for the electromotor.

For the present application (measurements in the 26-40 GHz band) the LP antenna to be rotated (here a printed patch antenna) is very small (typically 10x10 to 20x20 mm) and lightweight, so that a small and compact rotary joint would be adequate. The electromotor should be powered by a couple of standard AA rechargeable batteries, to avoid the use of an external power supply. This requires a very low mechanical torque and thus a low friction rotary joint. The proposed solution is a contactless rotary joint with capacitive coupling.

2. CAPACITIVE COUPLING ROTARY JOINT

Such a device has important advantages: very low friction (no contacts subject to wearing) and consequently very high lifetime. But it suffers from a more limited bandwidth (it is evident that capacitive coupling is not adequate for low frequencies!). It might, perhaps, present a larger insertion loss than conventional rotary joints.

Our design goals in the 26-40 GHz band are as follows:

- insertion loss: 1 to 2 dB (not critical for our application, as shown above)
- reasonable matching: < -10 dB
- low wow: < 0.1 dB
- simple, small and low price design

- driven by a small battery powered electromotor

To keep realization simple and cost low, off the shelf parts were used:

- a pair of SMA connectors (adequately modified) for the coaxial RF part; these connectors are not designed to operate higher than 18 GHz, but in fact they will provide adequate performance as it will be shown
- a very cheap electromotor (miniature coreless type used in pager applications, with a 7 mm diameter and a length of 20 mm)
- plastic gears to couple the electromotor to the rotating part

The RF design was done using Ansoft HFSS [2] and the mechanical study using SolidWorks [3]. As no information is available concerning the internal details of SMA connectors, only simplified models have been implemented for its RF modeling.

3. FIRST ROTARY JOINT PROTOTYPE

The first prototype was designed within a few days and "hand-made". This joint consists of an aluminium cylinder supporting the fixed SMA section and the electromotor. The rotating SMA is supported by a ball bearing mounted inside the aluminium structure. Figure 1 shows a picture of the disassembled prototype:

Figure 1: disassembled first prototype

The fixed SMA (bottom left) comprises a small protruding pin (diameter 300 µm) which penetrates inside the inner conductor of the rotating SMA, forming the capacitive coupling for the inner conductor. The capacitive coupling for the outer conductor is provided by the two outer cylindrical parts of the SMAs, separated just by a small gap (about 50 to 100 µm, adjustable). The performance of this rotary joint has been measured with an Agilent E8361A Network Analyzer (10 MHz-67 GHz). The average S_{21} was around -1 dB from 26 to 40 GHz. The wow could not be measured under real dynamic conditions (at nominal rotating speed) for obvious reasons, but was deduced from the S_{22} measurement variations with the rotating SMA terminated with a matched load. The maximum wow within the band was estimated to be about 0.3 dB. These results can be considered very satisfactory for a first, simple prototype.

4. SECOND ROTARY JOINT PROTOTYPE

The first prototype was critically reviewed for its weak points, namely:

- mechanical instabilities, mainly due to the ball bearing
- possible misalignment between fixed and rotating parts
- RF design susceptible to be further optimized

The mechanics have been reworked to reduce potential instabilities and inaccuracies:

- the ball bearing was replaced with a polyoxymethylene* rotating part
- the single piece cylindrical aluminium structure was replaced by a two piece stainless steel assembly
- all parts have been manufactured on a CNC machine ensuring tight tolerances and optimum surface finish

Figure 2 shows an exploded view of the SolidWorks mechanical design:

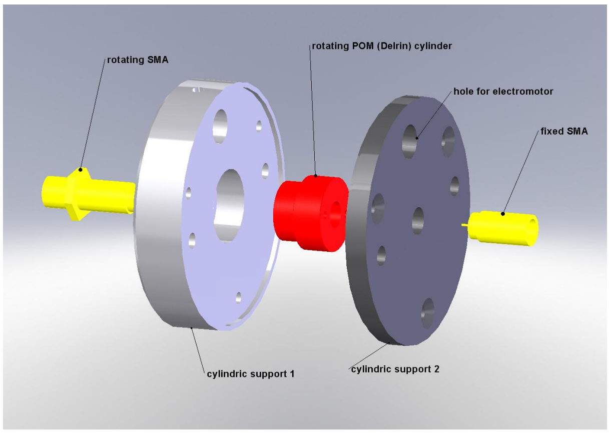

Figure 2: exploded view of the second prototype

The result was a greatly improved mechanical stability, and surprisingly a reduction of the friction, noticed by a 30% reduction in the current consumption by the electromotor.

The HFSS simulations showed that the air gap between the Teflon dielectric parts of the two SMA connectors created a discontinuity which degraded the RF behaviour of the rotary joint. To remedy to this, thin Teflon washers were manufactured and added. A fine adjustment of the gap between the two SMAs outer conductors brought further improvements.

*POM, also called Delrin, which is a *Dupont* trade name

Figure 3 is a picture of the disassembled prototype, which consists of a large plastic gear with the rotating SMA connector (1), the POM rotating part (2, the rotating SMA will be screwed inside it when mounted); the fixed SMA connector with its coupling pin (3), the miniature electromotor with its pinion (4) and the three screws for assembling the two-part stainless steel housing (5).

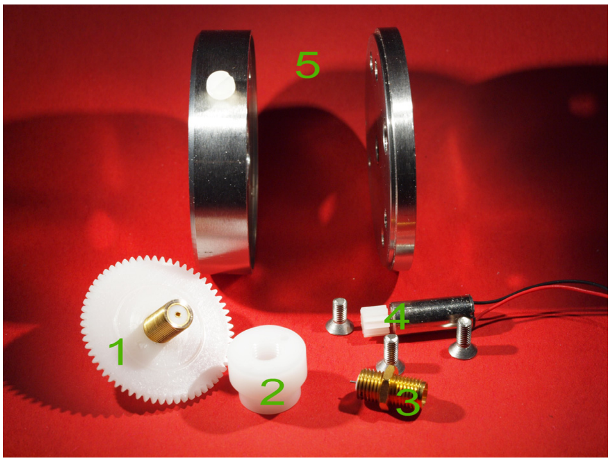

Figure 3: the disassembled rotary joint

The results within the initial 26-40 GHz band were so good that measurements outside this band were made, covering the 5-50 GHz band; again an Agilent E8361A Network Analyzer was used. The results can be seen on Figures 4 (S_{21}) and 5 (S_{22}). The simulations and measurements have been put on the same graphs.

It must be pointed out that the simulations only take into account the rotary joint itself (which is made of two SMA connectors), while for the measurements with the Network Analyzer 1.85mm/2.92mm transitions had to be attached on each side of the rotary joint.

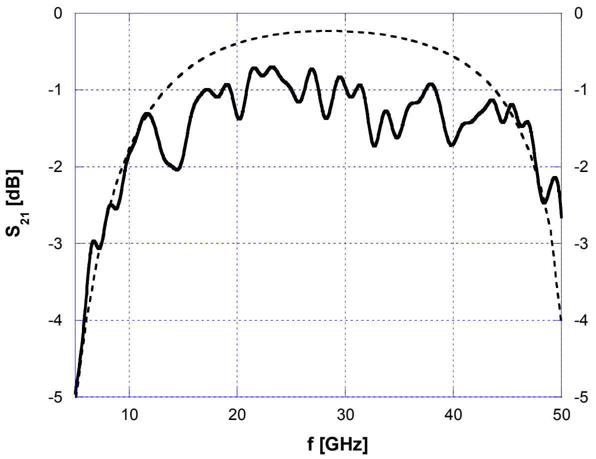

Figure 4: S_{21} (--- simulation, —— measurement)

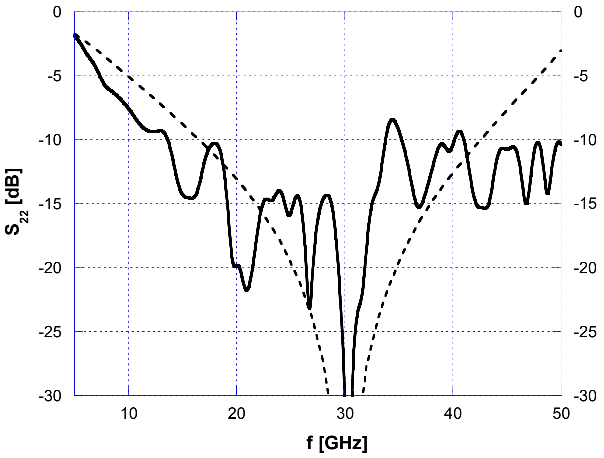

Figure 5: S_{22} (--- simulation, —— measurement)

This may well justify the differences between simulated and measured curves, which are however in quite reasonable agreement. To properly take into account the effect of the transitions in the simulation, a precise knowledge of their geometry would be required, but was not available.

With regard to the measured results, the S_{21} remains better than -3 dB from 6.5 to 50 GHz, and under 2 dB from about 10 to 45 GHz. Its best value is about 0.7 dB. Below 10 GHz the increase in insertion loss due to the capacitive coupling is clearly visible.

The S_{22} (matching seen from the fixed SMA) is better than -10 dB from 13.8 to 50 GHz, except at two points around 34.5 GHz (-8 dB) and 40.4 GHz (-9 dB).

As already mentioned, these measured results include two transitions, so that the performance of the rotary joint itself is certainly better.

As for the first prototype, the wow has been estimated from S_{11} measurements with the rotary joint terminated into a matched load, at nominal rotating speed. These measurements have been automated (Network Analyzer driven by computer, 1000 measurements per frequency). The measured results are summarized in Table 1:

frequency [GHz]	wow [dB]
10	0.065
20	0.016
30	0.023
40	0.057

Table 1: measured wow as a function of frequency

The rotary joint has been tested during an intensive measurement campaign on lens/horn combination antenna assemblies around 30 GHz. The linear source used is a rectangular patch antenna etched on RT/Duroid 5870 substrate (see Figure 6). It is observed to perform very well. With its current consumption of about 40 to 50 mA at 2.4V, the autonomy was about 30 hours (with two 1600 mAh NimH AA rechargeable batteries). No performance degradation could be detected after a few weeks of use.

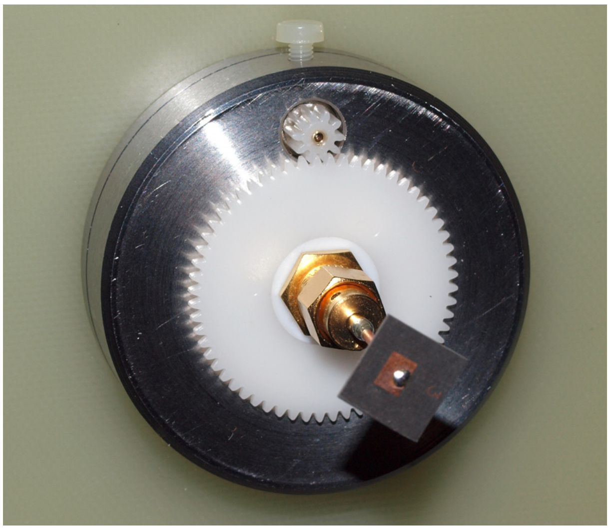

Figure 6: the second rotary joint with a 30 GHz patch (outer diameter of the device: 50 mm)

Figure 7 and 8 show examples of measured results around 30 GHz:

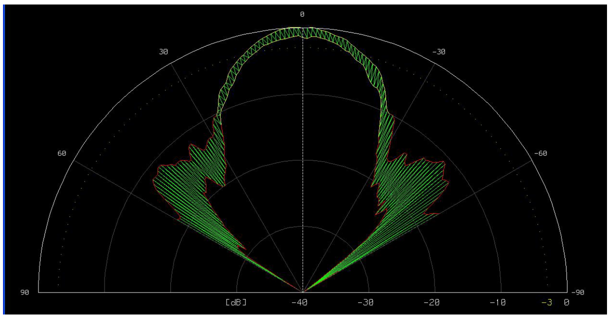

Figure 7: horn antenna with dielectric slab polarization converter

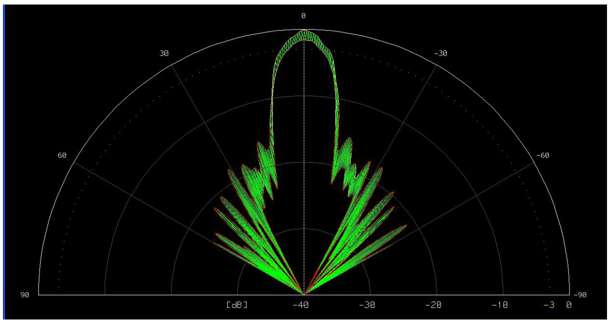

Figure 8: Teflon lens fed by a LP horn antenna, and fitted with a polarization converter grid

Figure 9 is a picture of the antenna whose radiation pattern is shown on Figure 8. This antenna assembly consists of a 60 mm diameter Teflon sphere fed by a LP waveguide horn and fitted with a LP/CP meander-line polarizer [4].

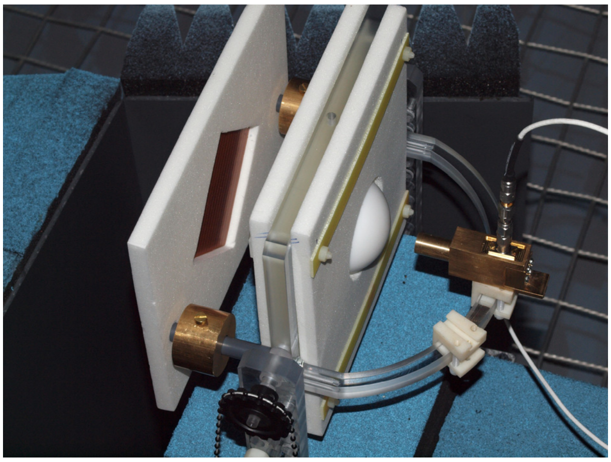

Figure 9: lens antenna with LP horn and polarizer

5. CONCLUSIONS

The design, realization and test results of a customized rotary joint have been illustrated. Two solutions are proposed, the second providing a substantial improvement in terms of bandwidth. In particular, the wow is well below 0.1 dB, the insertion loss is better than 2 dB from 10 to 48 GHz and the matching is better than -10 dB from 14 to 50 GHz, except above 34 GHz where a few points are around -8 dB.

If the matching and insertion loss are not too critical for the application, the total usable bandwidth ranges from 6.5 to 50 GHz with an insertion loss < 3 dB. The very low wow allows for an excellent accuracy in the measurement of the polarization ellipticity.

The proposed rotary joint is very convenient for polarization ellipticity measurements, being compact and requiring no external power supply. It is ideal to rotate small and lightweight LP antennas like those used for mm-wave measurements.

6. REFERENCES

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[2] Ansoft HFSS v. 12: *www.ansoft.com/products/hf/hfss/*

[3] SolidWorks 2009 SP5.0: *www.solidworks.com/*

[4] Young, L., Robinson, L. A. and Hacking, C. A., "Meander-Line Polarizer", IEEE Transactions on Antennas and Propagation, Vol. AP-21, May 1973, pp. 376-378.

[5] Zürcher, J-F., "A 6.5-50 GHz battery-powered compact rotary joint for polarization ellipticity measurements", submitted to Microwave and Optical Technology Letters (MOTL), currently under review