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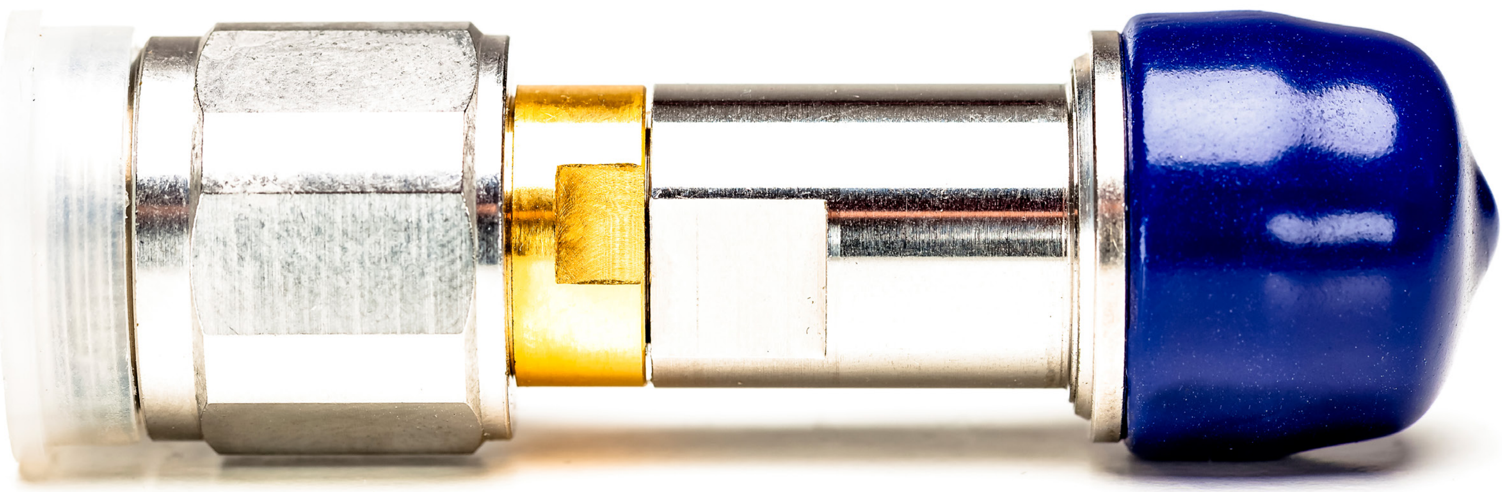

(Coaxial) Plug Connectors in High-Frequency Applications

Dipl. Ing. (FH) Stefan Burger | DeltaGamma RF-Expert

About the author

Stefan Burger received his engineering degree from the Offenburg University of Applied Science in 1986. He remained a research associate at the university until 1990. He then transferred to the research and development department of Endress + Hauser in Maulburg.

Until 2001, he was involved in the development of level measuring devices based on RADAR. Among other things, he was responsible for the support of the RADAR modules as well as the development of antennas and pressure-resistant RF components.

From 2001 to 2011, he worked on filters and duplexers for base stations as well as SAW filters at Panasonic Electronic Devices in Lüneburg. He was responsible for the "Lifetime and Power Durability" simulation.

In 2012, he founded his own company, Delta Gamma Consultant (www.delta-gamma.com), in Hampton, Australia. Since 2014, he has been working as an exclusive consultant in the area of RF and measurement technology for el-spec GmbH in Geretsried, Germany.

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Introduction

Coaxial lines lend themselves well to the wire-bound transmission of high-frequency signals. The have no lower frequency limit and thus are able to carry DC, as well. Moreover, the propagation velocity is constant across the whole useable frequency range as long as the cable is kept in the transversal electro-magnetic (TEM) mode. A disadvantage is the additional attenuation in the dielectric between outer and inner conductors. Compared to a WR-90 waveguide with 10.8 dB/100m at 10 GHz, a 1/2" Flexwell cable can merely offer 40.6 dB/100m. On the other hand, the waveguide is solid pipe and it is not easily bent which is no issue at all for a coax cable.

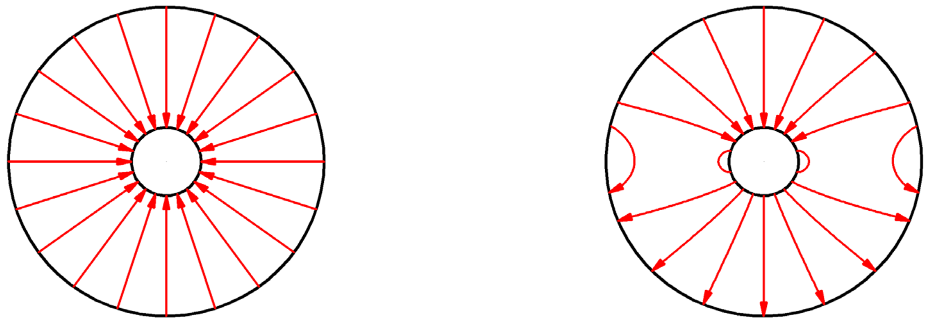
Even semi-rigid wires can be bent by hand using a tool which avoids deformation of the cross-section. To connect coax lines to devices or to other cables, various plug types were developed over time. Some of these have established themselves as a quasi-standard while others are not used anymore although they would have advantages over the existing systems.

Essential features are:

- useable frequency range
- maximum power-load
- matching
- maximum number of mating cycles
- passive intermodulation (PIM)

The largest frequency range in which a coaxial cable keeps to the TEM-mode can be calculated with the following formula. Above the cut-off frequency, propagation is also possible with the next upper mode, TE11. Since for this mode the propagation velocity is strongly frequency-dependent, impulse-distortions appear which were already observed in telegraph lines - these distortions are called „ringing".

Fig 1: Electrical field for the TEM und TE11 modes



(a) TEM-Mode *(b) TE11-Mode*

$$\Big(J_0(x \cdot A) - J_2(x \cdot A)\Big) \cdot \Big(Y_0(x) - Y_2(x)\Big) - \Big(Y_0(x \cdot A) - Y_2(x \cdot A)\Big) \cdot \Big(J_0(x) - J_2(x)\Big) = 0$$

$$A = \frac{R}{r}$$

In the above equation - taken from (3) - the first zero is the solution for x. It yields the cut-off frequency towards the TE11 mode.

The cut-off frequency results in:

$$f_c = \frac{x \cdot c_0 \cdot (A+1)}{(R+r) \cdot 2 \cdot \pi \cdot \sqrt{\epsilon_r}}$$

Jn: first-type Bessel function
Yn: second-type Bessel function
R: radius of the shield
r: radius des inner conductor

The relative propagation velocity of the higher modes is calculated as follows:

$$\frac{v}{c_0} = \sqrt{1 - \left(\frac{\lambda_0}{\lambda_c}\right)^2}$$

v: propagation velocity on the given mode
c_0: speed of light
λ_0: free space wavelength
λ_c: cut-off wavelength of the given mode

Below the cut-off frequency, the hight-oder mode cannot propagate and is strongly attenuated. Just above the cut-off frequency the propagation velocity is very low and rises with a root-function, i.e. the energy-content in the mode requires longer for the same distance and is the reason for signal distortions.

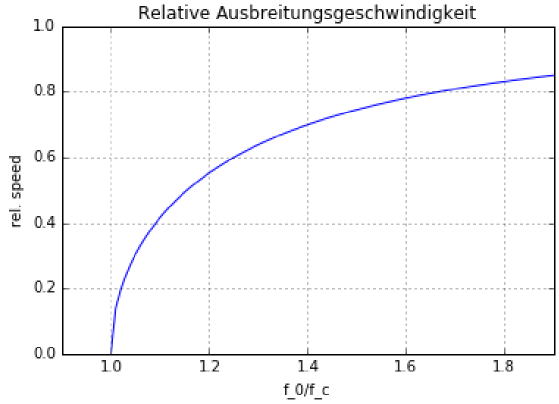
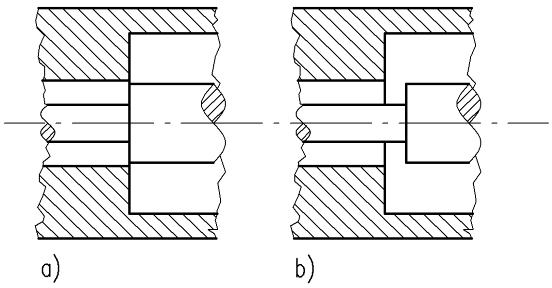


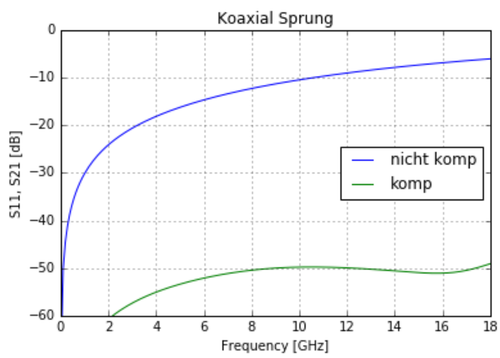
Fig 2: Relative propagation velocity in the mode

As long as the coax-cable is ideally concentric and straight there will be no field distributions, and thus higher modes will be present. However, normally the cable is neither ideal nor are diameter-jumps in connector-systems avoidable, for example to connect to the inner conductor with the pin or the outer conductor with the housing of the plug. At these locations the field is distorted and includes higher-mode-components. If the dimensions are such that these modes are not attenuated, they will spread through the system. Even if this is limited to a short distance, undesirable resonances can manifest themselves. Such resonance are to be avoided when designing plugs and when configuring coaxial cables. It is also beneficial to direct the design towards constant impedance. In the original connectors this recommendation was not observed, which led to considerable difficulties in the GHz-range.

Normally it is not possible to keep the diameter constant. In oder to still maintain a constant impedance, the inner and the outer conductors have to change at almost exactly the same location. Fig. 3 exemplifies such a jump, and Fig. aa.) depicts a non-compensated jump indicating a field concentration between the inner and the outer conductors. For Fig. ab.) this capacitive load was compensated with an inductive load: the smaller inner conductor protrudes a bit into the area with the larger outer diameter.



(a) coaxial jump



(b) reflection factor

Fig. 3: Uncompensated and compensated jump

When the N-type was developed in 1942, many things we take for granted today did notyet exist. In order to grasp the situation back then, here some more background info: the Smith diagram was published in 1939 by H. Smith for the first time with an expanded content following in a second article in 1944. To represent complex impedances and allow for graphical calculations with them, the common circle diagram for complex numbers was used.

This chart had the disadvantage that is was not possible to represent the whole range of passive impedances, and often results had to be re-normalized so that they could serve for further calculations. Network-analyzers had not arrived yet. Impedances were determined with elaborate processes involving slotted lines and measurements of the standing waves for each frequency individually, and then presented by hand-drawn curves. in 1947, Rohde & Schwarz issued the Zg-Diagraph 1947 which showed magnitude and phase as a light spot in a diagram, with a frequency range from 30 MHz to 300 MHz, and even up to 2400 MHz as of 1954. Wiltron (today the Anritsu company) and Hewlett-Packard (Agilent, Keysight) followed in 1965 and 1966, respectively, with the vector voltmeter which offered a direct complex measurement using external couplers and signal sources.

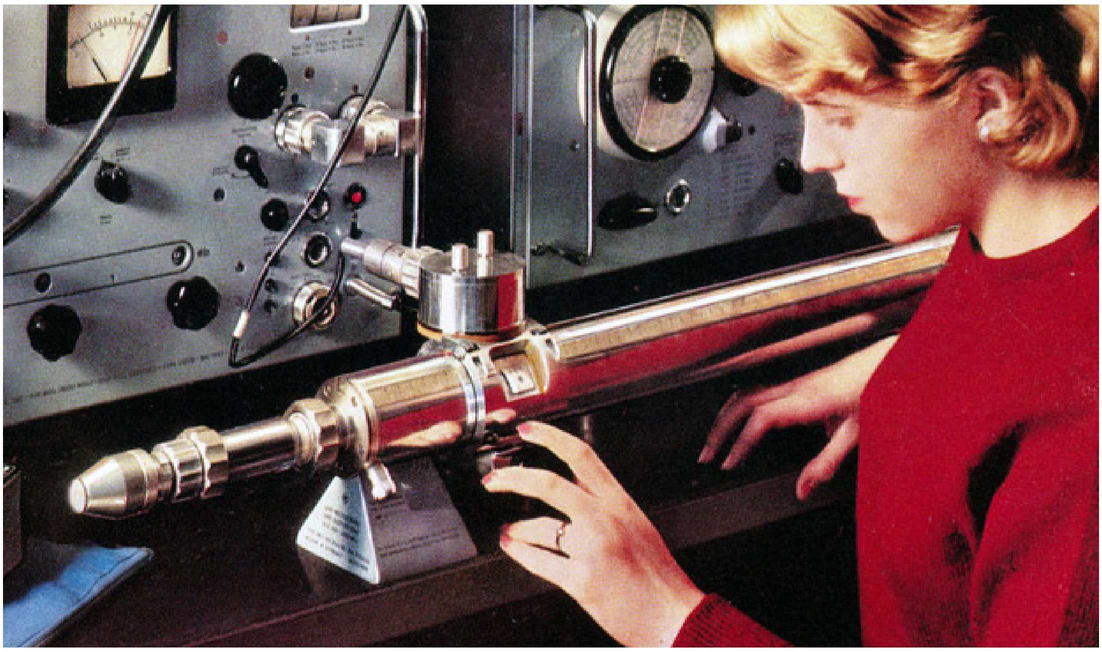


Fig 4: Measuring the impedance using a slitted coax-line

Computers were not available in general, and the pocked calculator would only arrive in 1969. Calculations were done with the aid of slide rules and tables for logarithms, and circular, hyperbolic, and exponential functions. Correspondingly, there were no simulation programs, and field patters were manually interpolated. Unfortunately, this generated also results which aber turned out to be completely wrong.

Until about 1945, waveguides were generally used for connections since they offered much lower attenuation and were not dependent on dielectrics. In addition, the bandwidth of the devices back in the day was sufficiently small so the waveguides could perform well - not considering that they were heavy and it was impossible bend them by hand.

There are two types of connectors: sexless and sexed. With the sexless variant the contact for both the inner and the outer conductors is achieved by a planar surfaces resting against each other. As a consequence there is only one sort of „plug". Today the 7mmm plug is still in use. All other customary connector versions are of the sexed species: N, BNC, SMA, 3.5mm, 2.92mm, 2.4mm 1.85mm, 1mm, SMB, SMC, etc

A connector reference plane is the defined via the outer conductor. Sexed connectors may be distinguished by whether the mechanical connection for the inner conductor coincides with he reference plane. The N-type, for example, does not have this feature, but e.g. the SMA and 3,5mm connectors do.

Fig. 5: Zg-Diagraph manufactured by Rohde und Schwarz

Connector quality

The quality of connectors is defined via three classes. „Production quality" is intended for general applications. Precision connectors are of „ instrument quality" while „metrology quality" connectors satisfy the most stringent requirements.

1.1 „Production quality"

Over the years, many manufacturers offering connecters of dubious quality have entered the market. In most cases they do feature gold-plating which is, however, too soft and rubs off quickly. The resulting metal dust on the one hand increases the wear but on the other hand can also be the reason for passive intermodulation (PIM). In case the dust settles on the dielectric (e.g. in an SMA-plug), additionally the dielectric strength is reduced.

Generally one should pay attention as to how many plug cycles the manufacturer specifies. If merely a few cycles are required for the given application, this kind of quality will be adequate. Care should also be taken regarding the environmental requirements for the connector, and the metallization should be selected correspondingly. The manufacturers should supply further information, as well.

1.2 „Instrument quality"

If a connector is required to be released and reconnected many times, „instrument quality" is necessary. On this level, the outer conductor is almost always made from stainless steel because this gives the required high stability and delivers continued quality for many (re-) connections. Moreover, the manufacturing tolerances are tighter to guarantee consistent connector characteristics. All this does reflect in the price. However, thinking in a cost-conscious manner will include the consideration of follow-up costs e.g. when a connection needs to be repaired. Usually, such corrections in the field are substantially more expensive compared to including high-quality parts from the get-go.

„Instrument quality" is also found in precision adapters of the same connector type or between types. Adapters produced by reputable manufacturers feature very good matching and should be preferred over low-cost products made in the Far East. Some cheap products do look like good adapters but have not been dimensioned to serve well given high-frequency environments. Accordingly, the electric characteristics are only moderator even bad.

1.3 „Metrology quality"

This quality is consistently used for instrumentation equipment which is referenced to national standards. The smallest manufacturing tolerances in dimensions and assembly apply. Special gauges are offered for the commonly used types to verify that individual connectors meet the requirements of the specification..

Utmost diligence should always be applied when working with „metrology quality" so as to avoid damaging the connectors. Replacements are very costly and can only be installed by the manufacturer, the latter having the additional consequence that equipment may not be available for weeks on end.

Maintenance of connectors

As already mentioned, the careful handling of connectors is essential to maintain their characteristics as long as possible. Any screw threads should only be tightened using matching tools and with the correct torque – otherwise they are highly likely to be damaged.

Storage

With many types the area representing the reference plane (see above) is openly accessible, and it is in particular this part that needs to be protected from damage. Normally, fitting clastic caps are available for this purpose, as far as they are not any way included with the connectors on delivery. Threads, as well, need to be in proper condition in oder to establish the correct electrical contact on the basis of the specified torque. A stiff action of the thread may make them jam which usually leads to a total loss for both parts involved. It is recommended to discard any damaged parts before something like this happens and they damage other parts. Any connectors not in use should be protected with the aforementioned protective cap.

If adapters are employed during a measurement and are not used at a given time, care should be taken to assure the contact plan does not touch anything. Unter no circumstances should adapters be kept without protective caps in a box since they could damage each other.

Cleaning

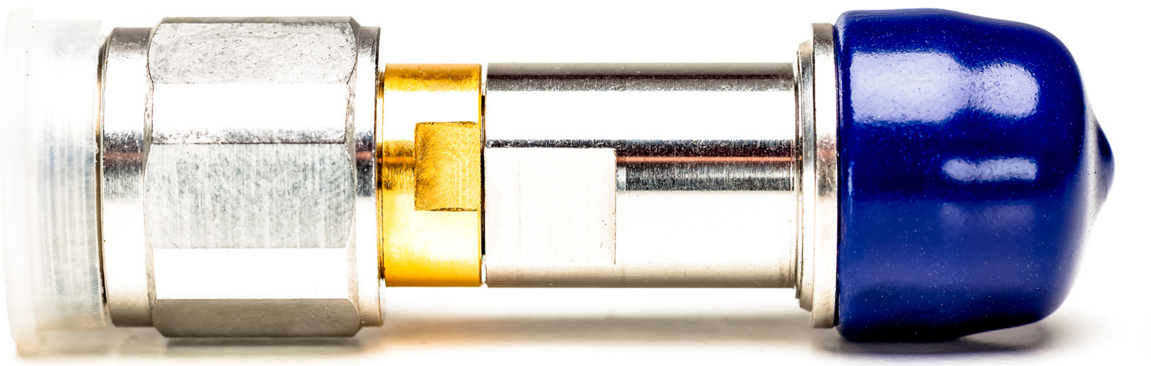
Isopropanol has proven itself to be exzellent for cleaning connectors; it is aided by cotton swabs and precision wiping cloth. The cloth moistened by the isopropanol is used to clean the outer parts. Dirt and abrasions can take root in the thread and as a worst case the thread can be blocked. As soon as the cloth discolors it should not be used anymore, i.e. it is recommended to always new cloths and only up to the point of discoloration. Using the approach prohibits any further spreading of the detached dirt and damaging the surface during cleaning.

Special care should be taken to keep the reference plane clean and without scratches and dents. For example, with the 7mm type these are the plane surfaces of the outer and inter conductors, and for the SMA socket it is the openly accessible end of the outer conductor. The inner section of the plug is carefully cleaned with the cotton swab dipped in isopropanol. In case of persistent deposits in the edges, very careful use of a wooden tooth-pick, a precision wiping cloth and a healthy dose of patience. A gentle and extended process is preferable to the risk of damaging the surface. In particular, connectors with an air dielectric need to be treated with sure instincts because the inner conductor or a part of the spring body can be bent out of shape easily. Ample time needs to be given so that the connector can air sufficiently before it is used. Any remaining fluff and dust is best removed using dry, oil-free compressed air with low pressure. Spray cans especially suited to this purpose are available..

Maintainance

Connectors are to be checked regularly for full integrity - best before every use. Plugs should be clean and without any scratches and dents, especially internally and on the reference planes. The inner conductor needs to be properly centre.

The individual elements of the spring body need to be oriented symmetrically, and no part of the spring body must be broken off or bent. If there is dirt, this must be removed first; if there is damage, there may be a possibility of limited use (with reduced requirements), but preferably the spring body should be discarded. If gauges are available, compliance to the tolerances should be checked from time to time. The time frame for this depends on how often the connector has been used: if the device is activated only once a month, an annual check is certainly sufficient, but in case of daily use, checks should be done monthly of even more often.



Types of connectors

N-type

Paul Neill developed the N-type at Bell Labs in 1942. At first it was not designed for higher frequente, since no corresponding instrumentation was available to Paul Neil at that time. He used what he had which were devices for telephone systems. Looking at the plug from the point of view of the HF-engineer, it is less than ideal because it was not designed for constant impedance along the system. However, it was only shown later that with keeping the impedance constant within the coax-system, one can extend the bandwidth almost up to the first higher TE11 modes.

This is achieved by placing (as described above) the jump in the inner and outer conductor at almost the same location. With correct design a matching of the jump of -50 dB is obtainable - this without considering manufacturing tolerances. In the course of time, the connector was optimized further and tolerances between plug and socket could be designed such that the connector is usable up to 11 GHz. Precision variants are now specified up to 18 GHz.A substantial contribution was made in 1946 by Julius Botka at Hewlett Packard (renamed first to Agilent and today operating under the name Keysight). The design was good for up to 12 GHz but no manufacturer saw the need for such high frequencies at the time. In 1962, Omni Spectra issued an improved series - mainly to promote their OSM (SMA) since at that time the N-type connector enjoyed the most widespread use.

The N-type is one of the oldest connector variants. It is still ofter used today. Plug-cycles between matching plus and sockets are specified by the manufacturers. To reach MIL-STD-348B, the connectors have to endure at least 10 000 plug cycles while maintaining the permissible mechanical and electrical limits.

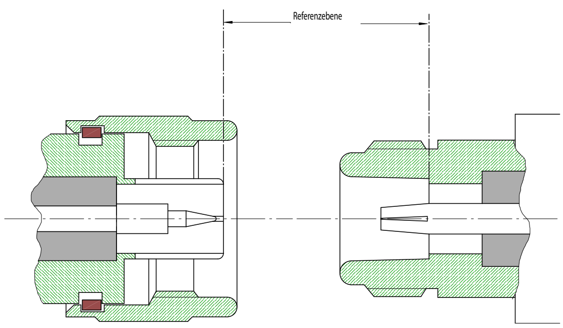
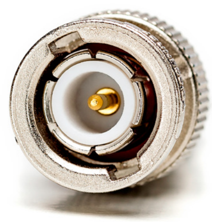


Fig. 6: Sectional drawing of an N-plug

BNC-type



The BNC was named after Paul Neil and Carl Councilman who cooperated in the design. The B stands for „baby", since it was supposed to be a smaller version of the N-type, and as such was not developed with HF aspects in mind, either. The „B" may also stand for „bayonet" - this feature allows for very quick connecting and decoupling.

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Just like with the N-connector, the separation point of the inner conductor does not lie within the reference plane. When plug and socked are connected, the clearance is filled with the dielectric which males the impedance dependent on the dielectric, as well. Losses are here accounted for, as well. The construction with interlacing parts enables the connector to have a higher proof voltage than designs with a radial cut point would yield. The bayonet catch does not deliver a sufficient good connection at higher frequencies such that the BNC-type is limited to about 4 GHz..

7/16-type

After the war, connectors with 60 Ω were mostly employed in Germany. In 1954, Dr. Spinner (Spinner GmbH) [7] designed the 6/17 for 60 Ω and high power applications. From this connector, he later derived the 7/16 as it is still in use today. The designation is connected to the dimensions of the inner conductor of 7 mm and the inner diameter of the shielding of 16 mm. With air as the dielectric the 7/16 has an impedance of 50 Ω..

The outer conductor is contacted via the front-surface of the shield. If the connector is employed outside, seal rings are inserted which makes it more difficult to attach the front-surface securely to its counterpart as it is required to avoid undesirable resonances and corresponding dips in the frequency range. Compared to other connectors, the 7/16 has a much higher locking torque.

In order to minimize these problems, the outer conductor received a slot. With it, the conductor could be electrically connected to its counterpart via the wall rather than via the thread of the union nut. A disadvantage is the higher PIM value. These days the precision versions of the 7/16 do not require a slotted outer conductor anymore, and, provided that they are properly fastened, connectors issued by well-known quality manufacturers can reach PIM (IM3) values lower than -155 dBc. The 7/16 has established itself as virtual standard especially in mobile telephony. At 1 GHz it can deal with a load of 1200 W, and at 2 GHz it can still withstand 850 W.

TNC-type

In 1956, J. R. Munro was working at Raytheon. He had been confronted with noise-problems caused by BNC connectors subjected to vibrations. To better secure the plug, he designed a connector with the same interface - but featuring a screw plug instead of the bayonet. The TNC was not meant to carry higher frequencies and had the same disadvantages as the BNC connector.

In todays designs the screw plug has advantages over the bayonet such that – with correct design of the interior build – it can be used up to 11 GHz.

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SMP-type

The SMP connector was developed by the Gilbert company (today Corning Gilbert) during the 1980s; today it is distributed under the brand name GPO (for „Gilbert push-on"). Many other manufacturers carry their own connector systems under the general SMP moniker..

The standard version is useable up to 26.5 GHz. Often, SMP-types are also specified up to 40 GHz, but only some versions achieve a better tolerance - this is the „precision version". The SMP type is advertised as as PCB-interconnector and as „blind-mate" i.e. the two opposing circuit boards are fitted with SMP-plugs in such a way that the connection between the boards is achieved simply by socket-to-socket adapters of corresponding length. Naturally, the plugs must be in opposing locations, as well. In this configuration, the SMP helps to achieve a certain tolerance against misalignment without compromising the electoral characteristics. Moreover, it is smaller than either of the SMA, the 3.5mm and the 2.92mm connectors which helps saving space especially if a high number of connections is required.

The SMP in addition has a simpler build leading to lower cost. Since there is a gap between the PTFE (Polytetrafluorethelene) insulator and the outer mantle, and since no specific data were available, the impedance and the cut-off frequency could not be calculated exactly. For the entries in the table purposeful values were assumed for the calculation.

The inner build of the SMP is not part of the specification and consequently there are differences between connectors especially in the angular version. The angular plug of the Rosenberger company can - given correct confectioning - reach a matching of better than 20 dB in the range between about 20 to 27 GHz. Connector from other manufacturers merely reach about 10 to 15 dB.

7mm-type

The 7mm connector was developed the labs of Hewlett-Packard in the mid-1960s; the finalization towards a precision connector happened at Amphenol (APC7). It features the best matching and was very often used in instrumentation, with a range of application specified up to 18 GHz. From the start, it was designed from an HF-engineering point-of-view; this led to outstanding characteristics.

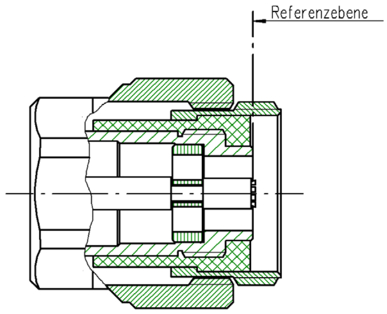


Fig. 7: Sectional drawing of a 7mm-plug

As already mentioned, this connector is sexless: contact is established by interacting planar surfaces for both the inner and the outer conductor. The cut point for both inner and outer conductors is in the reference plane, as well. These contact surfaces are elementary for the characteristics and need to be protected against damage. It is recommended to partially unscrew the thread such that it protrudes and can protect the surfaces. It should be mandatory to use a protective cap when the connector is not in use.

SMA-type

The precursor of the SMA connector was developed around 1960 at the Bendix Research Laboratories Division by mechanic Val Colossi under the supervision of James Ceal. The required a small connector for a pulse doppler radar system – the N-type which was typically used at the time was too large. The group was working on components which were far ahead of their time and did not think it to be necessary to deploy an HF-engineer for a part as trivial as a plug. From 1961, semi-rigid lines were offered increasingly, and the SMA-type was also developed in consideration of these special lines.

Ceal gave the diameter relationships and Clous was supposed to develop a connector as small, as short, and as mechanically stable as possible, with a standard thread. The result features 50Ω consistently, and a cut point between plug and socket in one plane for both inner and outer conductor which is at the same time the reference plane

The concept of the connector was kept and after some further developmental steps was distributed by Omni Spectra Inc. as OSM from 1962. Other companies entered the market with their own developments and „SMA" established itself as designation for this kind of connector.

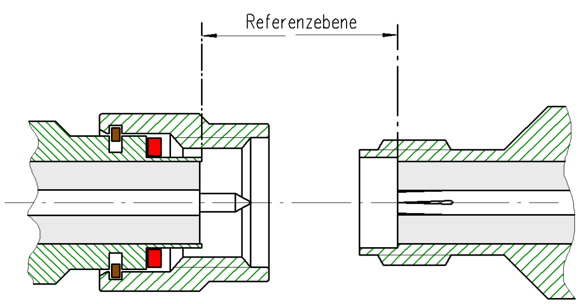


Fig 8: Sectional drawing of an SMA-plug

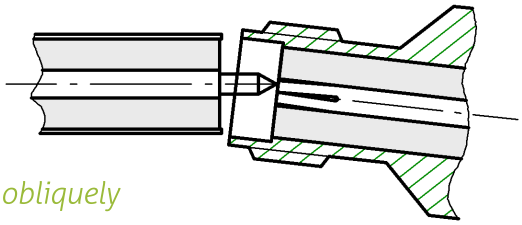


Fig 9: SMA plugged in obliquely

The SMA is mode-free up to TE11 cut-off (i.e. 25.22 GHz), dependent on the given tolerances. Designed with suitable dimensions and tolerances, some available versions are mode-free up to 26.5 GHz. One disadvantage is the danger that - as the plug is not plugged in - the pin next to the spring body is pressed into the PTFE if the plug is not in use. If this happens, it leads to the socket most often being damaged to such an extent that it should be discarded.

3.5mm-type

The 3.5mm connector was developed at Hewlett Packard and was later manufactured by Amphenol.

Larry Renihan reported on this connector at the IEEE MTT-S International Microwave Symposium 1976. It is a logical evolution of the SMA-type but using air as dielectric. While the SMA was intended to only work for a few plug-cycles and not for instrumentation, the developers of the 3.5mm-type received the specification for a connector holding up to many plug cycles, being a match to the SMAS interface and working up to 26.5 GHz.

During the design the problem of the SMA plug was considered, and the connector was constructed such that the spring body is not damaged in case the plug is inserted at an angle. This was accomplished by an early lead via the outer conductor which aligns the pin before it reaches the spring body..

Both the 3.5mm and the 2.92mm are compatible to the SMA [6]. All three can be used in combination without causing any damage.

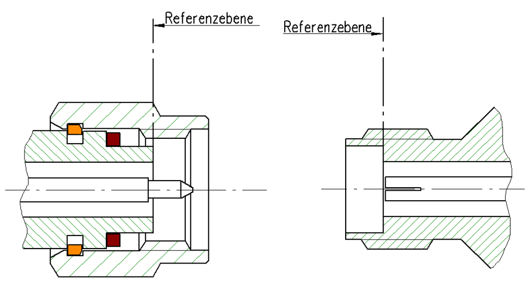


Fig. 10: Sectional drawing of a 3.5mm-plug

Moreover, it has been shown that better matching values at higher frequencies can be obtained. This is due to the fact that with the SMA being plugged in, a small air gap remains around the inner conductor. This region of course fails to maintain the 50-Ω-condition and deteriorates the matching. The 3.5mm, on the other hand, has air as dielectric to begin with and thus this effect is smaller. With the nominal dimensions, a mode-free use is calculated to reach up to 38.8 GHz. Some sources, however, give 34 GHz and it is recommended to limit the suet 34 GHz, unless the manufacturer gives other specifications.

2.92mm-type

Based on the geometry of the 2.92mm, Maury Microwave introduced the MPC3 in the middle of the 1970s. At the time there was rarely any need for a connector working up to 40 GHz and little attention was given to the new plug.

In 1983, Wiltron (today Anritsu) marketed the first devices working up to 40 GHz, and they were fitted wit the 2.92-type. They offered the connector under the brand K-plug, as well, with the K standing for K-band indicating that it reached up to the K-band (20 - 40 GHz). The design is based on the SMA and therefore connection to the SMA is possible. The manufacturers have constructed the connector such that that no damage occurs in this use as long as the connector is in the proper good condition.

2.4mm-type und 1.85mm-type

Both variants were developed in 1986 at Hewlett-Packard by Julius Botka and Paul Watson. There was no need for compatibility with the SMA, and any corres-ponding requirements could be left without consideration. The 2.4mm and 1,85mm types are available in all three quality standards for production, instrumentation, and metrology.

The union nut has a metric thread (M7 x 0.75) while the SMA, 3.5mm and 2.92mm sport the thread measured in inches. These connectors may seem kompatible at first glance but they are not.

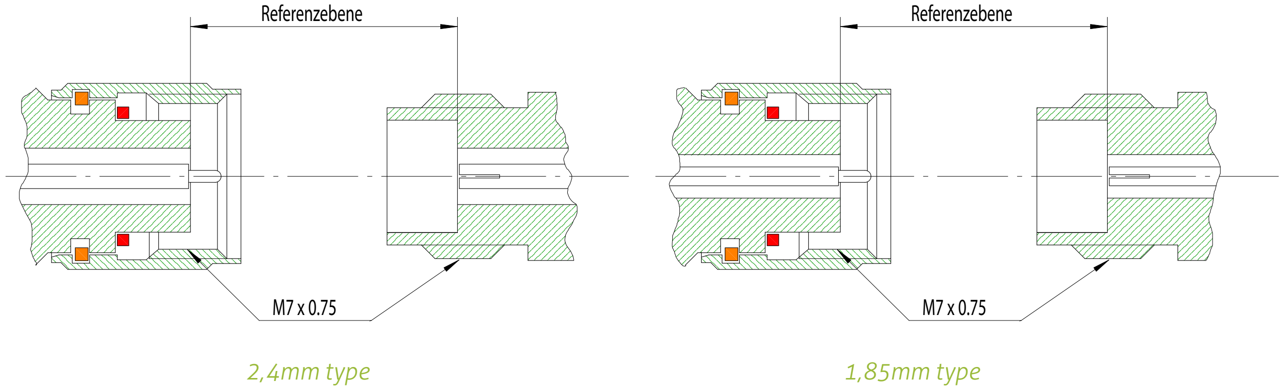


Fig 11: Sectional drawing of 2,4mm- and 1,85mm-plugs

Table 1: Overview of some specifications

type	D mm	d mm	Dielectric	Impedance Ω	Max Freq. GHz	Cut-off TE11 GHz
N	7.0	3.04	Air	49.8	11 (18)	19.4
BNC	7.0	2.06 - 2.21	PTFE	48.6 - 51.6	4.0	15.0
TNC	7.0	2.06 - 2.21	PTFE	48.6 - 51.6	11.0	15.0
7/16	15.85 - 16.25	7.0	Air	49.0 - 50.5	8.3	8.37
7mm	6.995 - 7.005	3.0397	Air	50.0	18	19.4
SMA	4.178	1.245 - 1.295	PTFE	49.4 - 51.1	18 (26.5)	25.2
3.5mm	3.5	1.519	Air	50.03	26.5	38.8
2.92mm	2.92	1.27	Air	49.9	40	46.5
SMP	~2.31	0.89	Air + PTFE	~50	40	~52
2.4mm	2.4	1.041	Air	50.0	50	56.6
1.85mm	1.85	0.803	Air	50.0	70	73.4
1.0mm	1.0	0.434	Air	50.0	110	135.8

If they are paired up nonetheless, they will be damaged. The 2.4mm however can be paired with the 1.85mm. Anritsu distributes the 1.85mm under the designation V-plug.

1.0mm-type

This connector was developed at Hewlett Packard in 1989 by Paul Watson. Corresponding to the small dimensions, the requirements for manufacturing are very tough. Even the smallest deviations translate noticeably into Performance, as is shown in the following exemplary values.

- Tolerance 0.005mm 49.05Ω - 51.03Ω
- Tolerance 0.010mm 48.07Ω - 52.03Ω

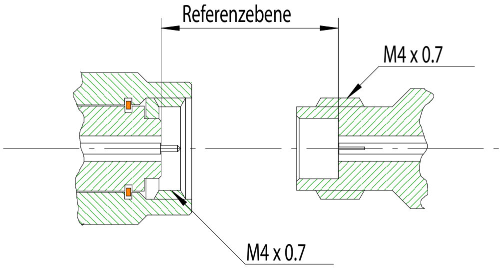
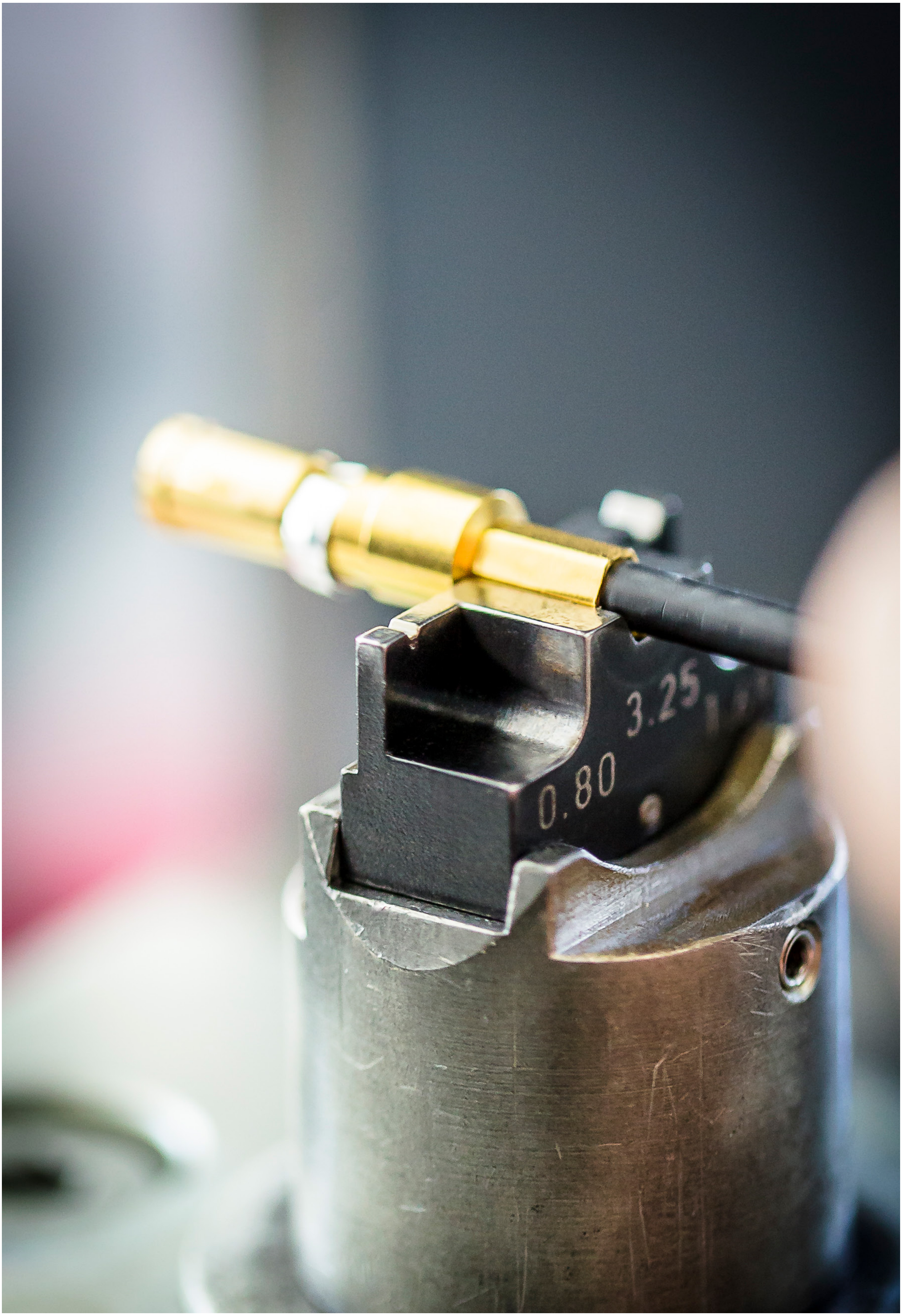


Fig. 12: Sectional drawing of a 1,0mm -plug

The union nut has a metric thread, as well (M4 x 0.7) but it is smaller the one used for the 2.4mm- and 1.85mm-types. This avoids any attempt to pair-up the 1.0mm with the 2.4mm oder 1.85mm.


3.25
0.80

Literature

[1] J. Bryant: Coaxial Transmission Lines, Related Two-Conductor Transmission Lines, Connectors, and Components: A U.S. Historical Perspective, IEEE Transaction MTT, Vol. MTT-32, No. 9, September 1984

[2] M. Maury, Jr.: Microwave Coaxial Connector Technology: A Continuing Evolution, Application Note 5A-021, Maury Microwave Corporation, 13 December 2005

[3] N. Marcuvitz: Waveguide Handbook, Isha Books, New Delhi, India, Reprinted 2013

[4] H. Meinke, F. Gundlach: Taschenbuch der Hochfrequenztechnik, Springer-Verlag Berlin Heidelberg New York Tokyo, 1982 14

[5] Rohde & Schwarz: A Test and Measurement Retrospective - 75 Years of Rohde & Schwarz, Microwave Journal, 10 July 2008

[6] P. Pino: Intermateability of SMA, 3.5-mm, and 2.92-mm Connectors, White Paper, W. L. Gore & Associates, Inc., Januar 2007

[7] SPINNER Communication Katalog, Spinner GmbH, 2011

[8] DJ6TA: 7-16-Stecker, Amateurfunk Wiki, http://www.amateurfunkwiki.de/index.php/7-16-Stecker

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