SYSTEMS AND SERVICES
OF TELECOMMUNICATIONS

PRACTICE 3:

Cables and Connectors

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Course 2015-2016

Índice

1. Introduction.

This practice is intended to help students to be used to different types of RF cables and connectors used in the communication world. These components are basic in any communication system, and they are key for the quality of them.

They are part of different communication solutions such as:

- Analogue and digital televisión systems (terrestrial and satellite).
- Measurements devices (Network analyzers and Spectral analyzers).
- TV cable broadcast systems.
- Telephone Mobile Base Stations.
- Switching Telephone Systems.
- Computers communication networks (e.g. LAN 802.3, 802.5.....)

Considering the wide variety of possible applications, the use of coaxial cable is truly present in communication systems. As a result, itô s really fundamental a right selection and characterization of such cable.

The present practice is divided in two sections. The first one is theoretical and the basic of the cables and connectors are reviewed. The second one is intended to allow the students to apply such concepts in a practical way.

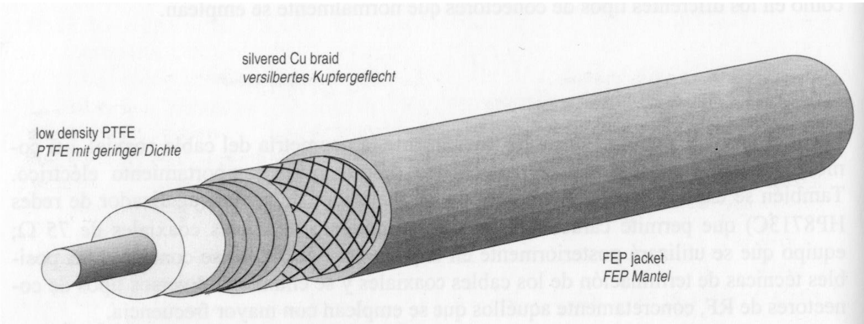
2. Theory

This section explains both the coaxial cable geometry and characteristic parameters which are involved in its electrical behavior. Additionally the twisted pair cable is also described as well as a set of typical connectors which are widely used for applications of telecommunication field.

2.1. Coaxial cable

2.1.1 Cable geometry

These are the more used cables in RF applications due to its low losses, easy use and good outer shield. This cable is a transmission line with two conductors isolated with a dielectric between them. The next figure shows the different parts of the coaxial cable.



The figure depicts the main next parts:

Inner Conductor: It is normally made of copper, with an either solid or twisted core. Itôs commonly chosen the solid core because the lower losses.

Dielectric: It is placed between both conductors and it is typically made of either solid polyetilene or polytetrafle. The dielectric defines several parameters of the cable such as losses, propagation speed, etc. The dielectric materials are characterized by its relative permittivity (ε_r) and the tangent of losses (δ_l). It is normally be in the range of 10^{-4}, and it can be related with the real and complex part of the permitivity in the following way:

$$\varepsilon = \varepsilon' - j\varepsilon'' = \varepsilon'\left(1 - j\frac{\varepsilon''}{\varepsilon'}\right) = \varepsilon'(1 - j\tan\delta_l) = \varepsilon_0\varepsilon_r(1 - j\tan\delta_l)$$

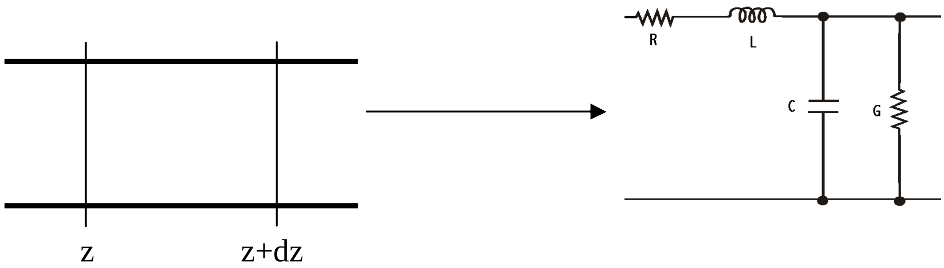
Inner shield: It is typically made of copper like the inner conductor, but in a twisted pair configuration. It plays the role of second conductor and fully covers the dielectric.

Outer shield: It is an optional layer which is usually built in copper and laid out twisted pair. It is used to reinforce the structure and increase the shielding.

Outer protection (Jacket): It is a dielectric material, normally made of *propileno etileno fluorinado*, *cloruro polivinílico* or any other material. It has the function to protect the whole inner structure.

2.1.2 Primary parameters

To carry out the study of the coax cable a differential length section of cable is analyzed as shown in the following figure:



In the figure above, the following elements are identified:

Resistance per length unit (R): It is the ohmical resistance (per length unit) for the two conductors of the cable, due to the skin effect. The resistance is defined by means of the following expressions:

$$R = \frac{R_s}{\pi}\left(\frac{1}{D} + \frac{1}{d}\right) \qquad (\Omega/\text{m})$$

Where R_s is the superfitial resistivity given by:

$$R_s = \frac{1}{\sigma\delta} \ (\Omega) \ \text{ y } \ \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \ (\text{m})$$

Where σ is the conductivity, f the frequency and $\mu=\mu_0$ the magnetic permeability (when $\mu_r=1$).

Inductance per Length unit (L): It is the self-inductance of two conductors when it is calculated in static mode (magneto static). The value of the self-inductance can be formulated as:

$$L = \frac{\mu_0}{2\pi}\ln\left(\frac{D}{d}\right) \qquad (\text{H/m})$$

Where μ_0 is the permeability in the void. The magnitude for this parameter is Henry per meter.

Capacitance per length unit (C): It provides the capacitance per length unit between two conductors in a cable. Such as happen in the calculation of the Inductance, the capacitance is calculated by means of the electrostatic. The expression is the following one:

$$C = \frac{2\pi\varepsilon_r\varepsilon_o}{\ln(\frac{D}{d})} \quad \text{(F/m)}$$

Where D and d are the outer and inner radius, and εr and εo are the relative and void permittivities.

Conductance per length unit (G): it is used for providing the conductance between two conductors caused by dielectric losses. It is directly related with capacitance, and it is defined as:

$$G = \frac{\sigma_l C}{\varepsilon_r \varepsilon_0} = \frac{2\pi\sigma_l}{\ln(\frac{D}{d})} \quad \text{(S/m)}$$

Where σ_1 is the equivalent conductivity of the dielectric material.

2.1.3 Secondary Parameters of the coaxial cable

The parameters defined in the paragraph 2.1.2 are the equivalent components of the circuital model, also called primary parameters. Based on these parameters other secondary parameters are derived which are described here below:

Characteristic Impedance (Z_0): It is calculated as the ratio of the voltaje and current in any point of the cable when it is matched (it is tos ay, it is finished with a load of impedance equal to the characteristic impedance). If low losses is assumed (R<<Lω y G<<Cω) the expression will be the following one:

$$Z_0 = \sqrt{\frac{L}{C}} = \frac{60}{\sqrt{\varepsilon_r}} \ln(\frac{D}{d}) \quad (\Omega)$$

This parameter is one of the more typical one, and it has to be taking into account when choosing the more suitable one for the considered application. The more common values for Z_0 with coaxial cables are 50, 75 y 95Ω.

Linear Exponent of Propagation (γ): This parameter describes the longitudinal propagation of the waves along the coaxial cable as well as the losses in such cable. This exponent is defined by a complex number as followed:

$$\gamma = \alpha + j\beta$$

Where α (real part) is called attenuation coefficient and β (complex part) provides the phase coefficient. The attenuation coefficient can be defined with the following expression:

$$\alpha = \alpha_c + \alpha_d = \frac{R}{2Z_0} + \frac{GZ_0}{2} = \frac{R_s\sqrt{\varepsilon_r}}{120\pi D}\frac{\left(1+\frac{D}{d}\right)}{\ln\left(\frac{D}{d}\right)} + \frac{60\pi\sigma_l}{\sqrt{\varepsilon_r}} \qquad \text{(Np/m)}$$

The losses caused by the cable are due to both the resistive phenomenon in the interior of the conductor and the skin effect in the outer conductor (αc). The second part is due to leakage lossess caused in the dielectric placed between the two conductors. (α_d).

Itôs important to take into account a factor of 8.686 to be applied when using dB/m instead of Np/m: .

$$\alpha(dB/m) = 8.686\alpha(Np/m)$$

This attenuation coefficient is an important characteristic parameter of any coaxial cable. It depends on, among other factors, environment temperature which it is present. The value must be modified with a correction factor depending on such temperature. This is due an increase in the resistive losses and the dielectric loss tangent as a function of the temperature.

Finally, we have to consider the phase coefficient (β). This is the imaginary part of the propagation constant (γ), and it provides the phase gradient of the voltaje and current per cable length unit. When the coaxial cable has low losses (R<<Lω y G<<Cω) the coefficient can be defined as:

$$\beta = \omega\sqrt{LC} = \omega\sqrt{\mu_0\varepsilon_r\varepsilon_0} \qquad \text{(rad/m)}$$

2.1.4 Cut off frequency.

Energy when propagating through a transmission line, such as a coaxial cable, is ruled by the Electromagnetic solutions called ñmodes of propagationò. There are three ways of modes:

- The TEM modes (Transversal Electric-Magnetic), where both electric and magnetic fields are perpendicular to the direction of propagation and they start from continuous frequency.

- The TE (Transversal Electric) mode, where the electrical component is perpendicular to the direction of propagation, but it is not required for magnetic field.

- The TM (Transversal Magnetic), where the magnetic component is perpendicular to the direction of propagation, but itôs not required for the electric field.

These last two modes are not propagated through all frequencies, but they are present from a specific frequency called cut off frequency. The first excited mode is the TE_{11} mode with a cut-off frequency of:

$$f_c = \frac{2c}{\pi(D+d)\sqrt{\varepsilon_r}} \qquad \text{(Hz)}$$

Normally, it is recommendable to work below such frequency value, because otherwise other modes could be excited and the characteristics of the cable could be degraded.

However, even exceeding the frequency figure defined here above the cable could still normally work without increasing the attenuation coefficient. On the other hand, sometimes these modes are even excited below the cut off frequency due to fabrication defects, but those are quickly attenuated.

2.1.5 Propagation speed

The propagation speed of the coaxial cable, considering that only the fundamental mode is present, TEM, will be the same than the phase speed, group speed and energy propagation speed.

The phase speed is defined as the speed which the both voltage and current waves are transmitted along the cable. Con esto se define la velocidad de propagación como:

$$v = v_{ph} = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\mu_0 \varepsilon_r \varepsilon_o}} = \frac{c}{\sqrt{\varepsilon_r}} \qquad \text{(m/s)}$$

As can be shown in the formula above, the selection of the dielectric will determine which propagation speed will be present.

2.1.6 Time Delay

It is defined as the derivative of the phase of the voltage and current waves with respect to the pulsation (w). Physically, it explains the temporal delay which the energy would suffer by length unit (it must not be confused with phase speed). Such time delay matches the group time delay for coaxial cables. Considering all of that, we can define the time delay as:

$$\tau = \frac{\partial \beta}{\partial \omega} = \sqrt{LC} = \sqrt{\mu_0 \varepsilon_r \varepsilon_0} = \frac{\sqrt{\varepsilon_r}}{c} \qquad \text{(s/m)}$$

Such as happened with the propagation speed, this parameter is only depending on the type of dielectric material.

2.1.7 Maximum voltage Level.

Cables canῶt withstand any level of voltage level. There is one value from this point on where cables will suffer an effect called as corona discharge. This effect is the responsible of the noise generation, damages in the dielectric and even the breakup. It must be selected a value in accordance with the type of application for such cable. The cable datasheets provide an effective voltage in AC, which must not be exceeded. For DC case, a conservative criterion is recommended stating that a three times the AC voltage must not be exceeded.

2.1.8 Structural Return Losses (SRL)

This parameter gives us an idea of the cable degradation during the fabrication. It is defined as the reflection coefficient module when the cable is ended with matching impedance. For this reason, the formulae will be given by:

$$SRL = 20\log\left|\rho_{IN}\right| = 20\log\left|\frac{Z_{IN} - Z_o}{Z_{IN} + Z_o}\right| \text{ (dB)}$$

In physical terms, this parameter provides the total reflection of the energy at the imput of the cable. These reflections are caused by tiny reflections, dents or single minor changes of the cable diameter. When these minor defects periodically happen, the energy levels could coherently add up and take place a peak level (with a length cable equals to $\lambda/2$ or 2π).

As a consequence, SRL value is thoroughly a key parameter in the sense that such parameter provides information about periodical important defects in the cable.

2.1.9 Shielding (isolation).

When the cable is shielded it is worthwhile to do it covering as much as possible the inner layer. Depending on the kind of shielding, we can distinguish the following one:

- Single Shield: Only one shield made of bared copper, tined or nickeled wires with silver. It provides a coverage of 85-90%.

- Double shield: A shield made of twisted pair without any isolation between them.

- Triaxial: shielding is made of two twisted pair with an isolating material (dielectric) between them.

- Braids of strips: Made of strips of flat braids of copper instead of wires. Its coverage is about 90%.

- Solid cover: with a shape of either aluminum or copper pipe.

A key parameter in communications is called as cross-talk which provides a parameter related to the energy coupling between cables placed together. A high figure of this parameter will guarantee a good isolation against cross-talk effect.

2.1.10 Temperature ranges

Itós essential to study the temperature which any cable will be functioning in any application, because the materials used for the building of the dielectric and cover of the cable are really sensible to the temperature effects. As an illustrative example, only materials like nickel are able to withstand temperatures higher than 80ºC.

2.1.11 Flexibility

Normally it is needed to bend the coaxial cable to match them to any specific application. If a twisted pair cable would be used it could allow more than 1000 times of bending with angles or 180º and bending radius of 20 times the outer diameter of the cable.
If a coaxial cable is selected and it is flexible, and it is a fixed installation, it is then recommended to not exceed a bending radius of 5 times the outer diameter (although it is a conservative value and it could sometimes be exceeded).

Coaxial cables using an outer conductor made of a pipe of aluminum are called semi-flexibles, and they cannot withstand more than 10 bending of 180º with a bending radius of 20 times. If it is a permanent installation the maximum bending radius is even decrease from 20 to 10 times (lower bending radius could provoke mechanical and/or electrical damage or degradation in the cable).

2.1.12 Types of coaxial cables.

At this point the most common coaxial cables used in RF applications are mentioned The identification of these coaxial cables are carried out either with RG code (traditional reference in engineering) or the present trend for their reference code using M17 specification:

- RG-58 (M17/28-RG58): the impedance is 50Ω and the cut-off frequency is 1GHz. It is used in Ethernet networks and audio applications

- RG-174 (M17/119-RG174): its impedance is 50Ω and the cut-off frequency is 1GHz. It has higher losses than the previous one, but thinner. It is used for lower quality applications than the first one.

- RG-223 (M17/84-RG223): Its impedance is 50Ω and the cut-off frequency of 12.4 GHz. It has very low power losses.

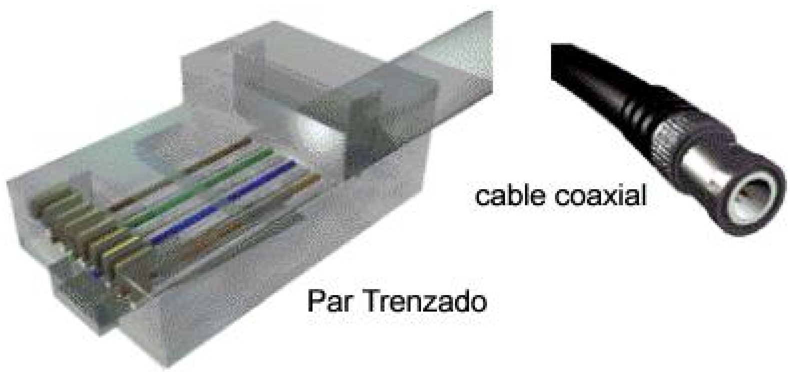
2.2. Twisted pair.

The twisted pair can be used both for digital and analogical transmission. Itös currently the most common mean used for the telephone systems due to its good performances and low cost. The maximum range without amplification for these kinds of cables is several kilometers; however repeaters are needed for longer ranges.

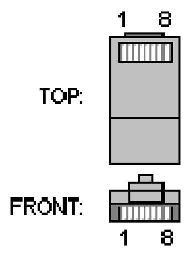
The attenuation and the crosstalk ratio of the twisted pair cables quickly increase with the frequency. Increasing the inductance of the line could help to reduce the effect of the attenuation of the voice frequencies which is also known as coil loading or pupinization.

Most twisted cables are balanced transmission lines. The reference between the two wires takes into account the voltage relative differences of each one, so it can be said that the circuit is well balanced with the ground. In this way more strength signals can be transmitted through the coaxial cable. Nevertheless, it is needed to isolate the twisted pair cable from other conductors, as well as to install isolators when they cross through other cable systems.

In the specific case of Ethernet networks, twisted pair cable is easier to be used. Coaxial cable was first used before twisted pair cables for the Ethernet networks. However, the coaxial cable cannot be used in the Fast Ethernet networks. In the following picture a coaxial cable and a twisted pair cable are shown. The second one is commonly used in PC networks.



If the twisted pair cable is selected, a cable with eight wires is selected. These are connected to the PC o HUB by means of a connector called RJ-45, as shown in the following figure:



Normally, when defining these kinds of networks, the already mentioned hubs are used for such networks (Straight through configuration). When just two PCs are required to be connected, a direct connection is usually chosen (Cross-over configuration) by means of this cable, taking care of crossing the wires belonging to the transmission and reception lines. When a hub is used, it carries out the function of a switching node, and it is not required to modify the cable. The next figure summarizes which is said before:

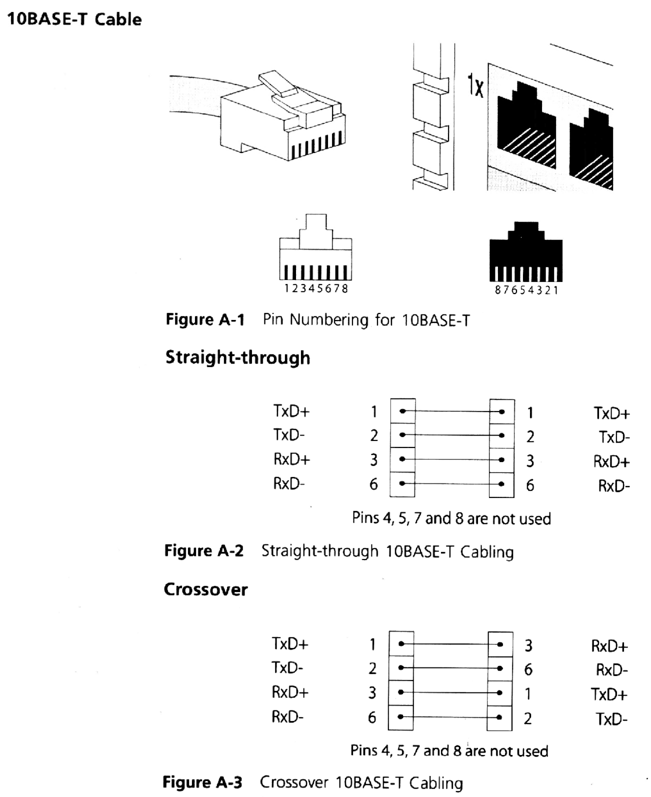


Figure A-1 Pin Numbering for 10BASE-T

Figure A-2 Straight-through 10BASE-T Cabling

Figure A-3 Crossover 10BASE-T Cabling

2.3. Connectors

Once the suitable cable is selected, it is required to connect it in a proper way to close the circuit.

2.3.1 General characteristics.

Regarding cable finishes the following classification can be considered:

- Clamp-Screw finish.
- Full stretch finish.
- Widening-Welding finish.

- Welding finish.

There are also connectors which are fitted on the printed circuits to allow the connection of these PCB to the coaxial cables. And, finally, there are others which are connected on the equipment itself such as RF instruments (scopes, spectral analyzersé), both on the front panel and at the back side. These last ones can be also classified as screwed panel or thread panel.

The characteristical parameters of the connectors are:

Impedance: It must be chosen a connector with the same impedance than the cable. It is usually 50 or 60 Ω.

Frequency Margin: It is the bandwidth within the connector can be used. Se debe seleccionar de tal forma que la respuesta en frecuencia sea lo más lineal posible.

Temperature Margin: Such as happen in cables, the temperatura affects the electrical performance of the connectors. This behavior is due to the thermical characteristics of the selected material as isolator.

Type of coupling: It is understood as the physical way the connectors are coupled. They usually are either threaded, clamp, ñbayonetò type or with slip connection.

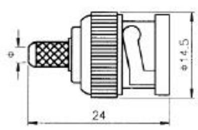
Electrical Specifications. As any component within a electrical circuit, it is going to have a frequency response. SWR (Standing Wave Ratio) and maximum voltage level are parameters to be considered.

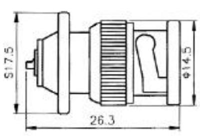
2.3.2 Basic Types of connectors.

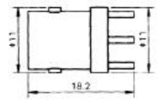
In this paragraph, the most common connectors are explained here below:

BNC: They are small and light, and they work up to 4 GHz. Coupling is carried out by means of ñbayonetò (BNC = Bayonet Nelly Concelman). These connectors have 50 Ω for the telecommunications industry and data communications (computer networks and local área network) and 75Ω for TV terrestrial broadcasting equipment and TV stations via satellite.

As an example, it is shown the BNC connectors placed on the front panel of the RF equipment which can be screwed or threaded.

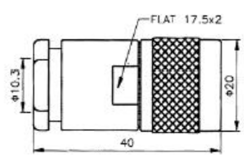


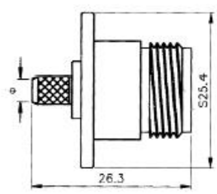
SMA connectors: They are smaller than the BNC connectors, and they work in a frequency margin from DC up to 18 GHz. They are normally threaded with an impedance of 50Ω. They are used in measurement tools, processing control applications, local area networks, base stations in mobile communications and for electrical components en microwave frequency band (power splitter, combiners, filters and amplifiers).

These connectors can be used either for flexible cables or for semi flexible, and thanks to be made with stainless Steel they provide a good accuracy and durability. However, there are other families of connectors made of brass which are also a cost effective solution when stainless steel is not required.

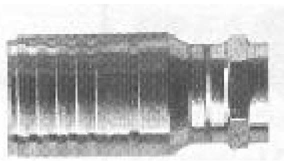
Connectors type N: They are connectors of median size with screwed coupling. They were the first one to work in the microwave frequency band. Its name is due to their inventor who is called Paul Nelly, from Bell Laboratories.

There are two different types, one of 50 Ω impedance, which can work up to 11GHz and another one of 75Ω which can reach up to 1.5 GHz. The first one is applied on antenna powering, base station equipments, microwave components (splitters, combiners, filters and duplexors) and instrumentation measurement equipment. The second one, with 75Ω impedance, are used in radio broadcasting and video.





Connectors type F: They have the same size than the BNC of 75Ω. They are selected for frequencies below than 3GHz. The coupling is threaded and they have an impedance of 75Ω, which is sitable for being used in Cable TV and Satellite applications.



TV Connectors: They are the typical one used at home for interconnections between the plug bases and the TV. Its impedance is 75Ω.

2.3.3 Transitions

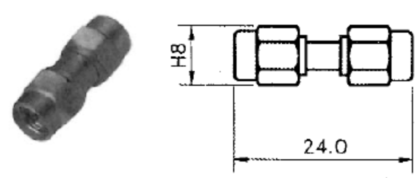
In many occasions is required the interconnection of electrical components, such as two coax cables or a cable to an equipment, fitted with connectors of different families, or even, from same family but with different shape (e.g. two male connectors). In such situations, itøs required the use of a transition between both connectors.

These connectors can be split in two main groups: those belonging to the same family and others connecting components from different families:

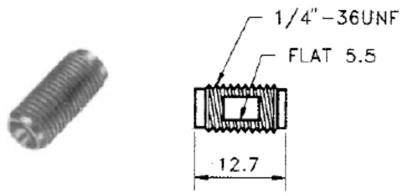
- **Transitions between BNC of 50Ω:** They usually are transitions from male to male, or female to female.

- **Transitions between SMAs:** They can be from male to male, or female to female, or male to female.

ADAPTADOR SMA MACHO A MACHO

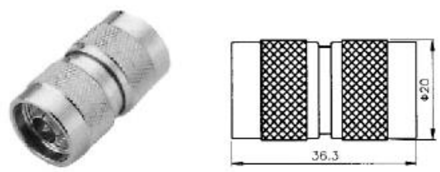


ADAPTADOR SMA HEMBRA A HEMBRA

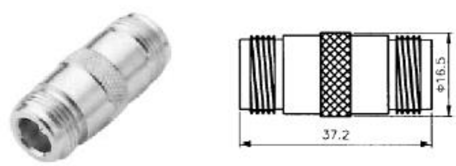


- **Transitions between Ns of 50Ω:** The more common ones are from male to male, and from female to female.

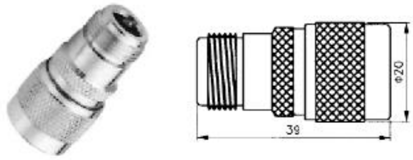
ADAPTADOR MACHO N A MACHO N



ADAPTADOR HEMBRA N A HEMBRA N

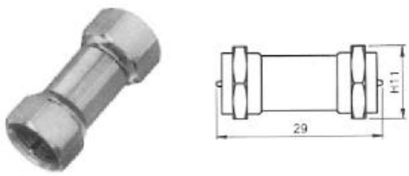


ADAPTADOR MACHO N A HEMBRA N

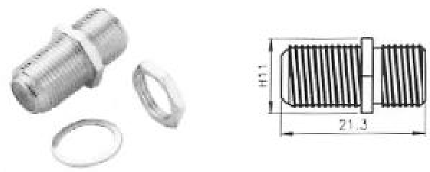


- **Transitions between Fs:** Available from female to female, and female to male.

ADAPTADOR F MACHO A MACHO

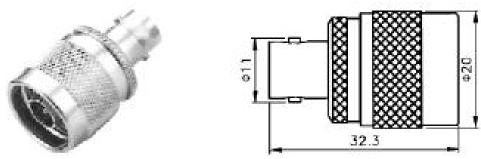


ADAPTADOR F HEMBRA - HEMBRA PARA PANEL



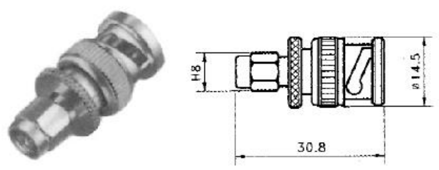
- **Transitions between BNCs and Ns:** BNC male to N male, BNC male to N female, BNC female to N female and BNC female to N male. They have a characteristic impedance of 50Ω.

ADAPTADOR MACHO N A HEMBRA BNC

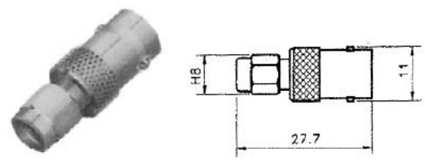


- **Transitions between BNCs and SMAs:** Here you will find the same combinations previously shown but changing N instead of SMA.

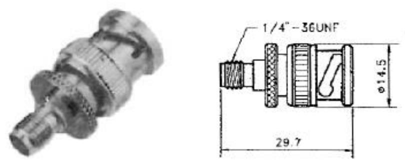
ADAPTADOR SMA MACHO A MACHO BNC



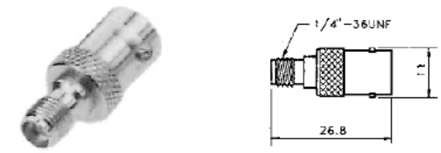
ADAPTADOR SMA MACHO A HEMBRA BNC



ADAPTADOR SMA HEMBRA A MACHO BNC

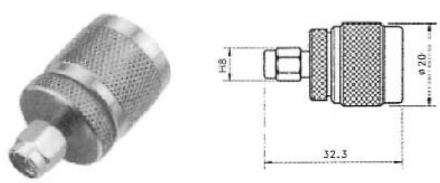


ADAPTADOR SMA HEMBRA A HEMBRA BNC



- **Transitions between SMAs and Ns:** The four posible combinations are also available between SMAs and N connectors.

ADAPTADOR SMA MACHO A MACHO N



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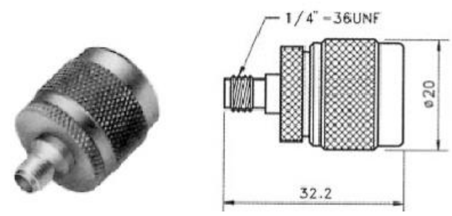

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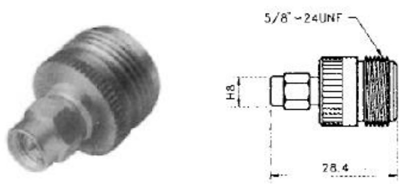
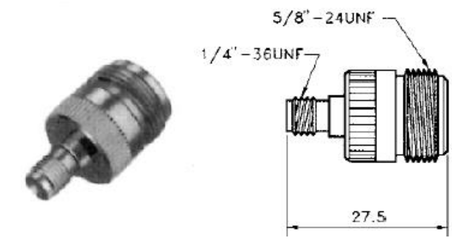


ADAPTADOR SMA HEMBRA A HEMBRA N



- **Transitions between F and N:** The four possible combinations are also available between F and N connectors.

- **Transitions between F and BNC:** The four posible combinations are also available between F and BNC.

3. Laboratory.

Once the theory has been read, itôs requested to the students to carry out the practical part in the laboratory. It is split in the following paragraphs:

3.1 Detailed study of two coaxial cables
3.2 To identify and be used to handle a section of twisted pair cable
3.3 To identify different type of connectors.

3.1. Study of a coaxial cable.

With this activity itôs intended to be used to with real coaxial cables by the student, being able to look for the needed parameters in a datasheet or catalogue and to estimate or calculate others by means of the theoretical approach seen in paragraph 2.

The selected cables for this study are RG-58 and RG-59. Their specific datasheets are provided during the practice. In any post of the laboratory samples of these two cables will be delivered. Such cables will be provided without jacket in order to allow the observation of their structure by the students.

So, the task will be to answer the following questions which will have to be delivered at the end of the practice. The questions will be answered for each of the chosen cables.

a) Please observe the cable of your bench. Which shield configuration has the cable? Please confirm the answer with the help of the datasheet, reviewing the column called **SHIELDING NUMBER: TYPE**. Please comment the type of material used to implement such configuration.
b) Is the cable either flexible or semi-flexible?

c) Please determine the material used to implement the inner conductor of the cable, as well as its inner diameter. This data will be found in the column **INNER CONDUCTOR.**
d) Please derive now the type of material used as a dielectric in the cable, together with the inner diameter of the outer conductor (D). This information is available from the columns called **DIELECTRIC MATERIAL** and **NOM. DOD.**
e) Please consult the catalog to get both Characteristic Impedance (Z_0) and Capacity (C) parameters of the cable (**NOMINAL IMPEDANCE Y NOMINAL CAPACITANCE).** Based on these figures, please derive the dielectric constant parameter (ε_r) from the material used as a dielectric. Check that the calculated figure matches the expected one for the said material in the list of isolating materials in the provided table. From such list, letôs record the loss dielectric tangent of the selected material.
f) Now, taking into account the ε_r derived figure, please calculate the propagation speed of the cable expressed in m/s as well as the temporal delay. Please also calculate the cut off frequency of the cable.
g) According to the cable catalog, please determine the isolation material used to protect the cable. This information can be found in the column **JACKET MATERIAL**.
h) Using the cable catalog, please identify the maximum alternate voltage level which can withstand (**MAX OPER VOLTAJE).** Considering that, please provide the maximum recommended value it is able to withstand in continuous.
i) Please take note of the recommended temperature range of functioning of the cable, and check that such range is within the temperature range of the material used as a dielectric.

3.2 To identify and become familiar with a sample of a twisted pair cable.

This second part of the practice is shorter than the two others and consists on analyzing the twisted pair sample provided in your laboratory desk. Each student will fulfil the following questions:

a) Which type of connector is used for this cable? Are all pins used for any purpose?
b) How many wires are there within the twisted pair cable?
c) Which is used for each wire?
d) Which cable connection configuration, from the two one described in theory, is being used in the laboratory?
e) Which cable connection configuration would be used to connect two PCôs?

3.3 To identify several connectors.

Now, to conclude with the practice, a set of connectors and transitions will be provided to any group of students in order to be observed and identified. In order to ease this task, each one is labelled with a number to be identified. So the student will properly identify all the connectors and transitions provided.

At the end of the practice the student will deliver the record sheets with the results of each section.