Pads (attenuators) in traditional telephone transmission systems

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INTRODUCTION

The setup of an interoffice telephone trunk implemented by a transmission system in the "traditional" telephone network typically included several "pads" (attenuators) used to control the transmission levels through the transmission channel and ultimately to control the overall transmission loss through the trunk.

These pads were given their intended loss (attenuation) for a particular trunk setup by plugging a small round module marked with a loss value (in dB) into a socket on an equipment unit. It is often (but incorrectly) thought that this module contained an actual pad (of that loss). In reality, it only contained three resistors, which collaborated with four fixed resistors located in the equipment unit itself to produce a rather complex attenuator having that loss. This article describes the how and why of this arrangement.

The emphasis is on the concepts and principles involved. However, some details of such things as the (often odd) terminal numbering used on the official Bell System documents for actual pads and their ingredients are included for the benefit of the reader who may encounter these pads "in the flesh" (perhaps while rehabilitating some historical equipment).

Considerable background is given for what is perhaps the most important application of such pads. The related matter of "TLP" notation is described.

1 CONTEXT

The descriptions here particularly relate to the practice in the Bell Telephone System, with Western Electric equipment and apparatus items. There was doubtless corresponding practices used by non-Bell telephone companies. But I have no details of that.

2 BACKGROUND

2.1 Attenuators and "pads"

In this context, an *attenuator* is a (usually passive) circuit element that reduces the power of a signal passing though it by a fixed ratio. That ratio, usually expressed in *decibels* (dB), is said to be the "loss" of the attenuator.

But another term for an attenuator (once considered colloquial) is "pad" [1], and this is the usual term most often used "officially" in the telephone field. I will mostly use that term here.

2.2 4-wire transmission

We note that the voice transmission to and from a telephone set ordinarily goes over the same pair of conductors

If we go back to the days where each interoffice or intercity trunk was carried directly by a pair of metallic conductors (perhaps on an open-wire basis, or as a pair in a cable), for operation over any considerable distance the inherent attenuation of the line became so great that communication was difficult if not impossible. The solution was to introduce amplifiers[2] into these lines at distances of perhaps every 50 miles.

But for reasons beyond the scope of this article, these repeaters each introduced "echo" into the transmission chain, and if many repeaters were invoked in he overall connection this accumulated to become a serious impairment to communication.

Eventually, in a bold step, AT&T decided that it should move to a transmission paradigm in which each direction of transmission was carried by a separate pair of conductors in the open wire line or cable. This completely eliminated the mechanism by which the enroute repeaters introduced "echo".

Not surprisingly, this new paradigm was called "4-wire transmission". Then. in contrast, the other paradigm (which originally had no name; it was just how telephone lines worked) came to be called "2-wire transmission".

As more modern transmission systems (especially multiplex systems) emerged, it was recognized that they intrinsically handled the two directions of transmission independently, and those two directional paths appeared on separate conductor pairs at the channel interface (just as for an actual "4-wire" metallic circuit). Thus such channels

[1] It is suspected that this usage comes from the notion that an attenuator is often used to "add loss" to some circuit to bring its overall loss up to some target value, much as we might add "padding" to a garment to increase one of its dimensions.

[2] For a fascinating historical reason (which is beyond the scope of this article) these amplifiers were actually called "repeaters".

came to be initially described as “equivalent 4-wire” transmission channels.

Eventually, it became the practice to just describe any transmission channel with independent transmission of speech in both directions (regardless of how achieved) as a “4-wire” channel.

2.3 Multiplex (“carrier”) transmission systems

An important development in telephone transmission was the multiplex transmission system, (In the industry, such systems were in fact called “carrier” systems.) These allowed the transmission of multiple telephone circuits over separate channels transmitted over perhaps two pairs of wires in cables (one pair for each direction of transmission. [3]

The most important early such system provided 12 (4-wire) channels transmitted over two pair of wires in cables. Later systems could carry up to several thousand channels over two coaxial “tubes”. For many years, these systems operated on an analog basis, using frequency-division multiplex. Later systems operated on a digital basis, using time-division multiplex.

In digital multiplex systems there are no “carrier frequencies”. Nonetheless, seemingly out of linguistic inertia, the digital multiplex systems were nomenclatured as “carrier systems”.

In any case, here I will speak of such systems as *multiplex transmission systems*.

2.4 Transmission level point (TLP) designation

2.4.1 *The transmission level (TL) of a point*

In traditional telephone transmission work, various points of interest in an overall transmission chain are assigned a *transmission level point* (TLP) value. We can consider it to be defined thus:

> A point in a transmission system where power of a signal passing through the chain is x dB different from the power of that signal at the end office (which serves the subscriber line) where that signal originates is said to be an “x TLP”

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[3] The moniker “carrier system” came from the fact that the frequency division systems used each voice signal to modulate a separate “carrier frequency”, a situation that was popularly compared with the operation of a number of radio stations. The result was that this technique became known as “carrier frequency telephony”, and the systems that implemented it were nomenclatured as “carrier systems”.

If the value is positive, the plus sign is shown (as, "+7 TLP").[4]

Although the reckoning is in terms of dB, that "unit" does not appear in the TLP designation (but see Section 2.4.2 for alternative forms).

The "end office" is considered to be a 0 TLP.

An important corollary is:

> The difference in the TLP values between two points in a transmission system is the gain (or loss) between those two points.

The TLP system can be thought of as a way to specify a "scaling" for the signals at various points in the overall transmission chain.

This designation is useful in setting up a trunk so that the range of powers of the speech signal at the sending port of the multiplex channel is appropriate. It is also useful in making the trunk setup give the desired end-to-end loss for the trunk.

2.4.2 *Alternative forms for the TLP designation*

The form "-16 TLP" was seemingly the most widely used in Bell Telephone System documents.

But in various places, TLP values are shown as "-16 dB TLP" or even as "-16 dBm TLP".

2.4.3 *Normalized signal power–dBm0 notation*

This actually doesn't directly figure in the story here, but I include it just for completeness of this area.

A signal with an actual power of

> -19 dBm at a -16 TLP

is "as potent" as a signal with an actual power of

> 4.0 dBm at a +7 TLP

or "as potent" as a signal with an actual power of

> -3 dBm at a 0 TLP
>
> (where everything is expected to be 16 dB "hotter" than at a -16 TLP.)

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[4] And it was the custom in the telephone industry to speak the *minus sign* as "neg" (for "negative"), the premise probably being that "minus" would refer to that sign as an indicator of subtraction, not an algebraic sign as it is here.

We describe the "potency" of a signal ("normalized power" is the more rigorous term), at any point, in terms of the power it would have at a 0 TLP. For the signal I just spoke of (wherever we might observe it), we would write that as:

-3 dBm0

That's a zero at the end, but is customarily spoken as "oh".

2.5 The standard 4-wire transmission channel interface

In order to facilitate the convenient deployment of transmission channels derived in various ways (notably via various multiplex systems), a standard transmission interface for 4-wire transmission channels was devised. At this interface, there are (not surprisingly) separate electrical circuits for the "sending" and "receiving" directions, always at a nominal 600 ohm impedance, and having standard TL values (which values I will discuss shortly).

3 ILLUSTRATIVE CONTEXT

3.1 Introduction

Although the type of pad (attenuator) described here has many applications in the traditional transmission systems of the telephone network, its perhaps most important use is in a trunk setup where the transmission for an intercity interoffice trunk is provided by a channel of a multiplex transmission system. I illustrate that in Figure 1. There is a lot to it, so be patient.

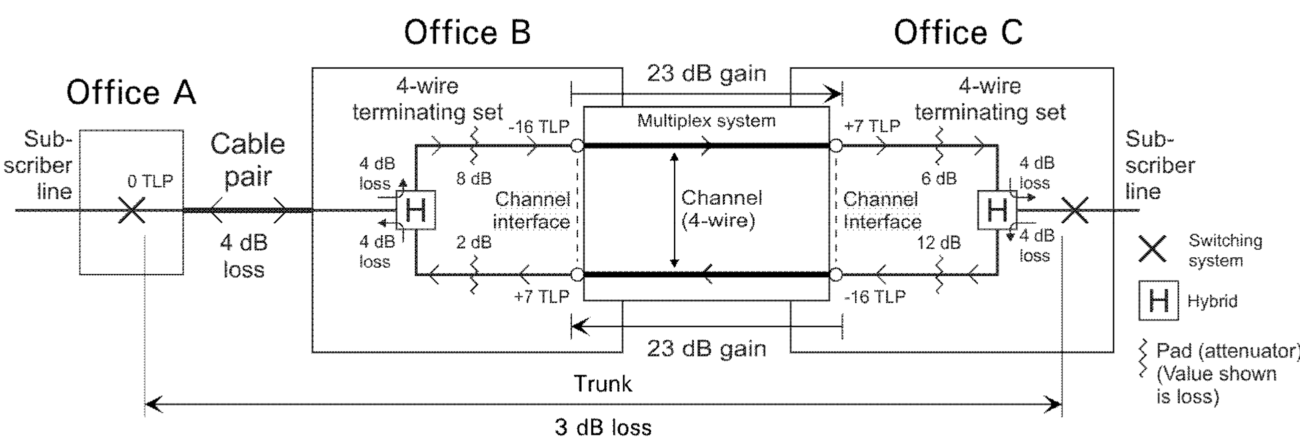

Figure 1. Illustrative trunk transmission layout

3.2 The transmission channel

In the example, the connection is between subscribers served by central offices "A" and "C", the latter of which may be in a suburb some distance from the city of office "A". We assume that there is direct dialing from office "A" to office "C". The connection uses a direct trunk from office "A" to office "C".

The transmission medium for this trunk is assumed to be, in part, a channel (4-wire) of a multiplex transmission system running from office “B” (perhaps the “downtown” office in the same city as office “A”) to office “C” itself. It is shown here in a generic form, as the details of its implementation do not enter into this story.

But the transmissions path between offices “A” and “B” is just a basic cable pair.

This multiplex channel is shown as being terminated at each end in the standard 4-wire transmission channel interface described earlier in section 2.5.

We see the hybrids at each end that mediate between the 4-wire multiplex channel and the 2-wire switching systems. Their assumed losses are shown.

3.3 The gain of the transmission channel

In relatively-modern times, the transmission levels (TL) at the standard transmission channel interface were established as -16 dB at the sending end and +7 dB[5] at the receiving end, implying (correctly) a gain of 23 dB for the ”raw” channel. Why was the interface designed that way? Certainly we would never want a trunk implemented via such a channel to have a gain of 23 dB, or anything close.

The reason is that there are often accessory units, or interposed local transmission lines, at each end of the trunk that have losses. (We see two of such in the illustration.) Rather than using separate “little amplifiers” to nullity part of those “ancillary” losses, we just use part of the intrinsic gain of the transmission channel.[6]

What do we do with the rest of that channel gain? We “burn it” with pads at each end. Aha!

3.4 The cable pair from office A” to office “B”

In this illustrative setup, which is for a trunk between the switching systems at offices “A” and “C”, the “4-wire” multiplex channel is “picked up” at office “B” (perhaps the “downtown” office of the city of office “A”).

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[5] Usually read as “plus seven, neg sixteen”.

[6] The incremental cost of increasing the gain of the sending and receiving circuits of the multiplex system to produce this amount of “channel gain” is much less that the cost of self-contained “little amplifiers”.

We see a common arrangement, in which the trunk goes from office "A" to office "B" over just a basic cable pair. We assume here that the loss of this pair is 2 dB.

3.5 The hybrid coil circuit

Here, the channel provided by the multiplex transmission system is intrinsically of the "4-wire" form.

But the switching systems of the day operated within a "2-wire" paradigm, and they expected the trunks they connected to to be of that form. So clearly we needed some circuit element that mediates between "4-wire" transmission channels and the "2-wire" paradigm that the switching systems expected to work with.

That circuit element is what is called a "hybrid coil circuit" (or just a "hybrid", for short). It is wholly passive. Conceptually, it takes the "outgoing" voice signal arriving over a 2-wire circuit from the switching system and sends it into the sending port of the 4-wire transmission system channel interface. (How it does that is a fascinating story, but that is for a different article.)

In the other direction, it takes the "incoming" voice signal arriving over the receiving port of the 4-wire transmission system channel interface and sends it over the 2-wire circuit to the switching system.

And magically, it does this in such a way that none (ideally) of the voice signal arriving from the receiving direction of the 4-wire channel would be sent back out over its sending direction (which of course would create the reviled "echo").

I note that an "ideal" passive hybrid coil circuit has a theoretical "loss" in each direction of 3.0 dB. But there are also losses in the transformers themselves that make up the hybrid coil circuit, usually adding perhaps another 0.4-0.6 dB of loss in each direction,

But "at the blackboard", to keep the numbers convenient, we often speak as if these additional losses were 1.0 dB, leading to an overall loss through the hybrid in each direction of 4.0 dB, as I assume on Figure 1

In the typical equipment arrangements that were used, this hybrid (and some other supporting stuff) was contained in a circuit unit called a "4-wire terminating set" (as we see in Figure 1).

3.6 Some loss arithmetic

Suppose that through some strategy that is beyond the scope of this article it had been decided that the overall end-to-end loss of the trunk in question should be 3.0 dB.

In introducing pads to "burn" the excess loss of the multiple channel. we have two major guidelines:

- The final end-to-end loss of the trunk (measured between its terminations on the two switching systems it interconnects connects) should be 3.0 dB.
- The expected loss from the interface of the typical subscriber's line with the serving switching system to the sending port of the multiplex channel interface should be 16 dB (so as to properly deal with the TL assigned at that point, -16 dB).

We see that, to fulfill these requirements in our example, we must have pads with the attenuation values shown on Figure 1 at the four locations seen.

4 NOW, FOR THE PADS

4.1 Introduction

We should guess by now that as each group of trunks is set up, the needed values of those pads might very over a large range. So we must gave some way to "adjust" their value for each group of trunks as the trunks are "commissioned".

4.2 Some requirements on the pads

There are of course many circuits that can be used to create a pad of a certain loss (attenuation).

But in this situation, there are a few pivotal requirements on the circuit to be used:

- Regardless of its loss value, the pad must exhibit "looking into" each end the nominal impedance of the circuit in which the pad is interposed. (The pads of interest here are almost invariably used in circuits whose nominal impedance is 600 ohms resistive.)
- The circuits in which the pads are used are balanced with respect to ground, and the pads must not compromise that.
- The attenuation should be able to be accurately set in the field on a fine basis, perhaps to a precision of 0.25 dB, with an accuracy commensurate with that.
- The pad must maintain its loss with negligible change over a period of many years, in the face of various environmental conditions (and perhaps taking into account occasional severe vibration of the equipment).

4.3 The obvious implementation

One obvious way to do that would be to have built into all the equipment units where such pads are located (in our example, the 4-wire terminating sets, “adjustable” pads. These would have a knob (probably operating on a multi-turn basis) that would be set to the needed loss value.

But such attenuators (especially if meeting the requirements enumerated above) are large and very costly.

4.4 Plug-in pads

An alternate approach, which studies showed would overall be much more economical, would use fixed-loss pads made as (fairly) small plug-in modules. Each module would have clearly marked on it its loss. Each pad location in an equipment unit would have a socket that would receive these modules.

At a central office where these pads were used, there would be a cabinet (well, maybe several cabinets) with bins that would each hold a number of plug-in pad modules of a given loss, over a wide range of values.

When a technician was setting up a trunk at one end of the multiplex channel, he would read the assigned pad loss values from the circuit order, fetch those modules from the cabinet, and plug them into the equipment unit.

4.5 Pad circuits.

Two circuits for balanced pads were well known The classical one, called for a fairly obvious reason the “H” pad circuit, is seen in Figure 2.

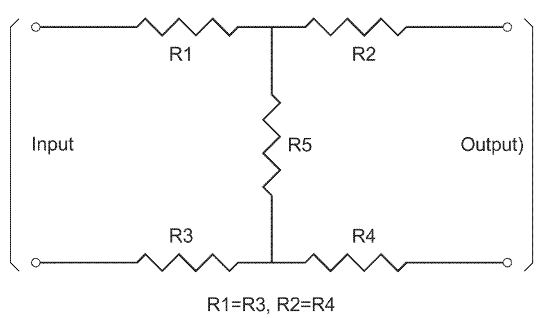

Figure 2. “H” pad circuit

If the pad is to be balanced, the equalities shown must be followed. If in fact the input and output impedances are to be equal (as is the case of interest here), then all four resistances, R1-R4, must be equal.

The interaction of these resistance values gives the desired loss while maintaining the impedance "looking into" the pad from either end at the nominal circuit impedance.

But a less costly circuit, suitable for most situations, called (again for a fairly obvious reason) the "square" pad, is seen in Figure 3.

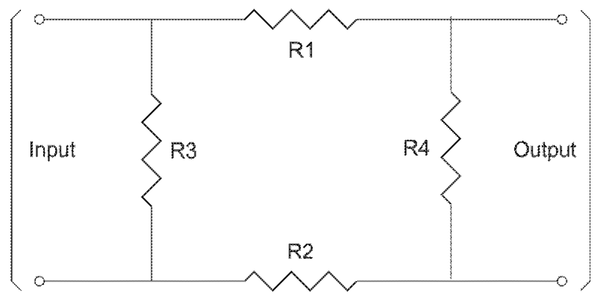

Figure 3. "Square" pad circuit

Here, if the pad is balanced and symmetrical as to input and output impedances, R1 = R2 and R3 = R4.

Again, the interaction of these resistance values gives the desired loss while maintaining the proper impedance "looking into" the pad from either end.

We note that this pad circuit uses only four resistors rather than the five resistors used in the "H" pad. So we might have suggested that the Bell System wonks would have chosen the "square" circuit for the plug-in pads (especially given that there would have been a zillion of them in those cabinets, so the cost saving from one less resistor in each would have been substantial).

But in fact neither of these was chosen.

4.6 The "bridged H" pad circuit

But the Bell System wonks did not actually go with having the entire pad proper in the plug in module. Instead they took a radically different approach, based on a classical (but rarely implemented) pad circuit called (again for a reason that will be obvious) the "bridged H" pad. We see it in Figure 4.

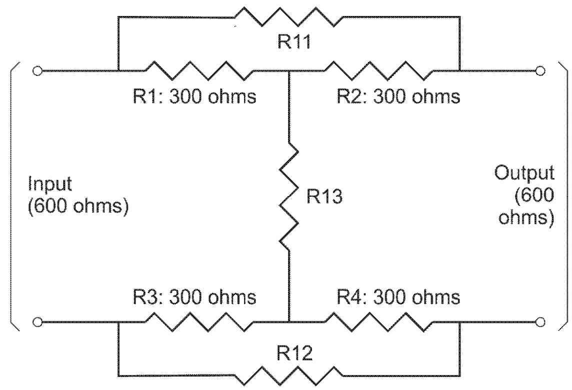

Figure 4. "Bridged H" pad circuit

Here, for convenience and clarity, I have shown an implementation for input and output impedances of 600 ohms. We see that R1-R4 have the same value (300 ohms) regardless of the loss of the pad. Resistors R11-R13 vary to give the desired loss. Their interaction with the four fixed resistors is such that the impedance "looking into" the input or output of the pad will be 600 ohms regardless of the loss for which the circuit is designed.

But why would anyone use such an elaborate circuit, requiring 7 resistors? In most situations, one wouldn't But in our situation, this is very attractive if executed in a certain clever way. Here is the plan:

- Resistors R1-R4 (always the same value) are put in the equipment unit for each pad position.
- Resistors R11-R13 are put in the plug-in module, chosen so that in combination with the fixed R1-R4 in the equipment the resulting "bridged H" circuit would have a loss of some certain value (marked on the plug-in module).

Economic studies showed that, since there would exist many more plug-in modules[7] than pad sites in equipment, then with only three resistors in each plug-in module (even with four resistors at each pad site) the overall cost would be less.

And that's what counted.

We see that concept in Figure 5.

[7] Most of which at any given time are reposing in bins in cabinets.

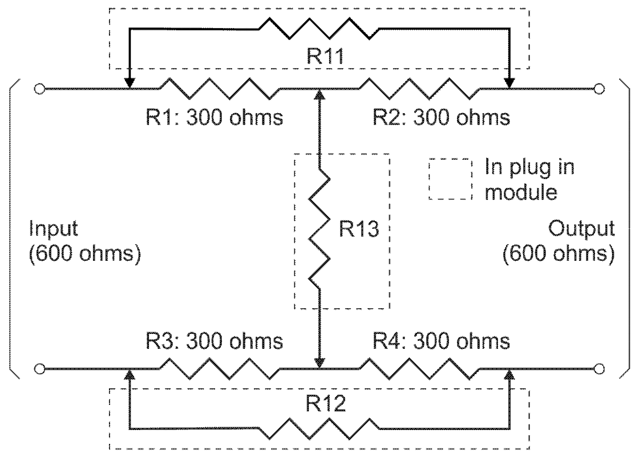

Figure 5. "Bridged H" pad circuit with plug-in module

5 IMPLEMENTATION

5.1 The connector

In a very uncharacteristic move, the Bell System wonks did not have a special plug-in connector designed for use with this pad system. Rather, they drew upon a connector then widely used in the "radio" field, the standard 6-pin vacuum tube base. This was widely used in consumer radios and the like for certain types of vacuum tube (this being prior to the introduction of the eventually nearly-ubiquitous "octal" vacuum tube base).

Of course the sockets were made (by Western Electric itself, or by some subcontractor) to stringent Bell System specifications.

5.2 The 89-type resistor

The plug in modules were nomenclatured as "resistors", with Western Electric apparatus codes in the 89 series (as, "89D resistor,"). They were housed in small aluminum cylinders as shown in Figure 66.

Eventually, standard modules were made that would produce losses of from 0.25 dB to about 23 dB in steps of 0.25 dB, plus a few greater values for special purposes, plus modules that produced "zero" and "infinite" loss, used mostly for testing purposes.

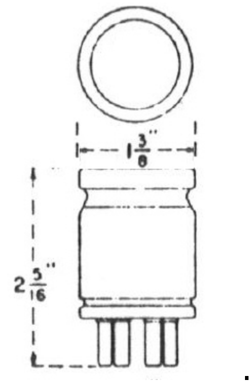

Figure 6. 89-type resistor–outline

The resistors used were a highly-stable and high-precision Western Electric type, and the enclosure was filled with a potting compound to block the ingress of moisture, harmful gases, and the like. (I'm sure the details of this advanced over the years.)

Notwithstanding the fact that there was a well-accepted industry convention for identifying the pins of vacuum pin bases (including the "6 pin") by number, the Bell System in its various drawings and such originally did not follow that but rather used their own scheme. Later they adopted the industry-standard scheme, but did not push that through into all documents, no doubt leading to many serious misunderstandings over the years.

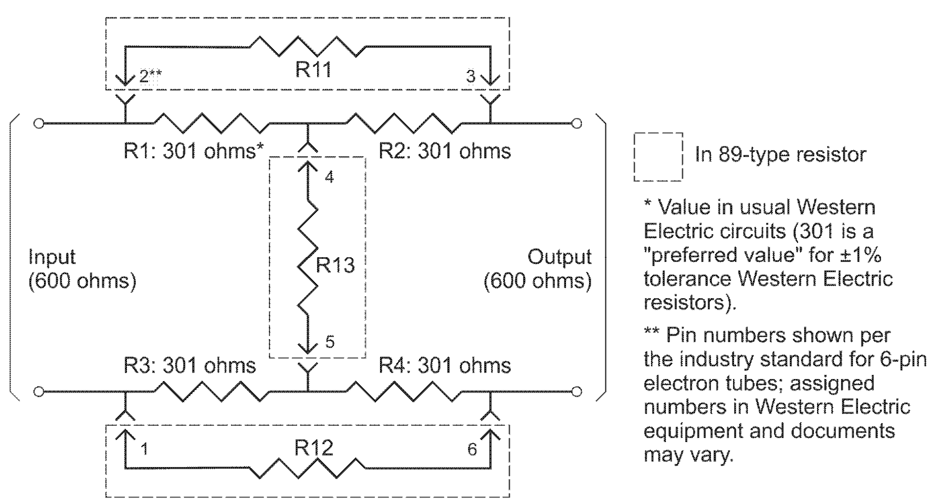

Figure 7. Pad circuit with 89-type resistor

In any case, the overall situation with the more modern pin number identification scheme (per the industry standard convention) is shown in Figure 7.

The resistor numbers are mine, arbitrarily assigned for reference here only. They are not the ones that might be found on official Bell System drawings.

I note that the resistance values 301 ohms (rather than the expected value of 300 ohms) is that 301 ohms was a "preferred value" for most types of Western Electric resistors of the 1% accuracy class.

The arrangement for the 89-type resistor (for both the "older" and "newer" numbering systems is shown in physical "pinout" drawing form in Figure 8.

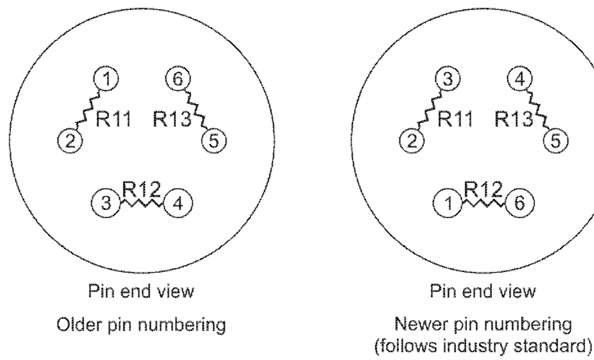

Figure 8. 89-type resistor–pinouts

5.3 144-type electron tube sockets

Two Western Electric 6-pin sockets that were often used in this situation are the 144A and 144B electron tube sockets. They differ only in that the numbers molded into them to identify the contacts follow the leftmost part of Figure 8 for the 144A and the rightmost part of Figure 8 for the 144B.

5.4 The 1C pad–not really a pad

A Western Electric 1C pad is a 6-pin electron tube socket with four 301-ohm resistors wired to its terminals (consistent with Figure 7, above). It is of course not a pad, but we get one when an 89-type resistor is plugged into it!

It is in effect a subassembly that might be included in an equipment unit at a site for a pad of the type discussed here.

In official documents discussing the operation of equipment that may include 1C pads (so that an 89-type resistor may be plugged in to set a certain loss value), this item is sometimes spoken of as a "1C pad socket".

The terminal numbering used in some places for this item differs from that used for the 89-type resistors themselves (or in fact from that used for the 144-type electron tube socket likely used as the base component of the 1C pad).

That minutiae is given in Appendix A.

6 IN MORE MODERN TIMES

6.1 Smaller implementation

Although the pad system I describe was very clever and proved effective over the years, in modern times the 89-type resistors seemed greatly out of date as to their size and construction.

As a consequence, various manufacturers of telephone transmission equipment developed their own pad systems, typically following the principles of the original Bell System scheme but with small plug-in modules using modern resistor types mounted on small circuit cards, with small sockets to match. Information on this is beyond the scope of this article.

6.2 Other ways of setting attenuation

Although earlier I somewhat denigrated the use of continuously-variable attenuators in telephone transmission systems, in modern times there were cases in which the gain of an amplifier (part of the transmission chain) was set with a continuous potentiometer with a knob operating on a scale marked in dB. This was equivalent to changing the loss of a pad as described above.

Other schemes were used to change th gain of an amplifier. In some cases, this done with a series of screws, which when “in” closed a circuit path and when “out” opened it. Those paths were branches of a multi-stage attenuator within the amplifier. A certain pattern of screw settings would produce a certain gain of the amplifier.

Sometimes the amplifier had a continuously-variable gain setting with a certain modest range (in dB), and there was a set of screws that would add certain fixed additional loss increments when they were “out”. In some cases small slide switches were provided for this purpose.

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Appendix A
The 1C pad–terminal numbers

The Western Electric 1C pad was a subassembly used to implement a "pad site" in transmission equipment. It comprises a 6-pin electron tube socket (possibly a Western Electric 144A or 144B electron tube socket) and the four fixed resistors I identify in the body of this article as R1-R4.

In the Western Electric Apparatus Card Catalog card for this item, the terminal numbers differ from that used (under two different systems) for the pins of the associated 89-type resistors or the contacts of the 144A or 144B electron tube socket that is probably the base component of this item.

The details of that are shown in Figure 9.

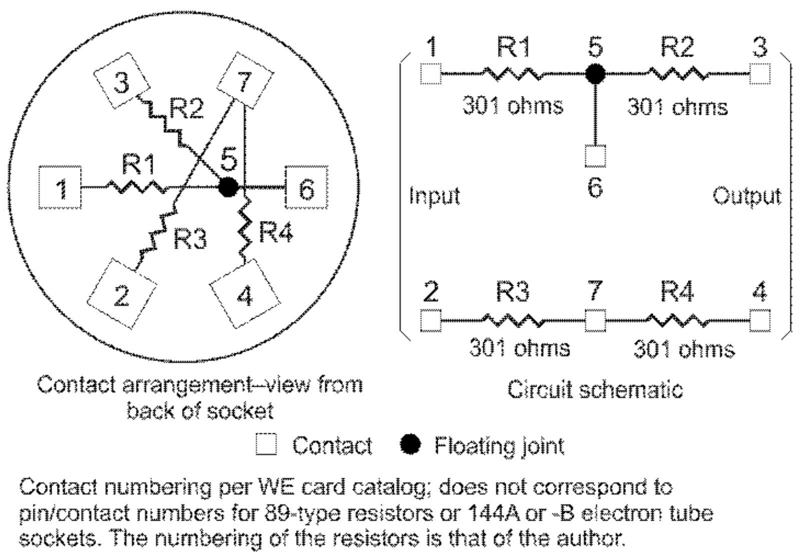

Figure 9. 1C pad–contact numbering

The numbering used for the socket contacts is inexplicable. Number "5" refers to a "floating joint" between two resistors, which is then strapped to contact "6".[8] The resistor numbers do not appear on the catalog card; they are the ones I (arbitrarily) use in the body of the article, and are shown here only for reference.

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[8] This floating joint ("5") is seemingly numbered only for consistency with a similar item (the 1D pad) in which the joint is not strapped to contact "6". I have to assume that where that item is used, an equipment wiring connection is actually made to that joint (ugh1). I imagine that this is so that some relay or key in the equipment can force the pad loss to zero for some special purpose.